Chapter 13

Biodeterioration of Wood

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Contents

Under proper conditions, wood will give centuries of service. However, if conditions exist that permit the development of wood-degrading organisms, protection must be provided during processing, merchandising, and use.

The principal organisms that can degrade wood are fungi, insects, bacteria, and marine borers.

Molds, most sapwood stains, and decay are caused by fungi, which are microscopic, thread-like microorganisms that must have organic material to live. For some of them, wood offers the required food supply. The growth of fungi depends on suitably mild temperatures, moisture, and air (oxygen). Chemical stains, although they are not caused by organisms, are mentioned in this chapter because they resemble stains caused by fungi.

Insects also may damage wood, and in many situations must be considered in protective measures. Termites are the major insect enemy of wood, but on a national scale, they are a less serious threat than fungi.

Bacteria in wood ordinarily are of little consequence, but some may make the wood excessively absorptive. In addition, some may cause strength losses over long periods of exposure, particularly in forest soils.

Marine borers are a fourth general type of wood-degrading organism. They can attack susceptible wood rapidly in salt water harbors where they are the principal cause of damage to piles and other wood marine structures.

Wood degradation by organisms has been studied extensively, and many preventive measures are well known and widely practiced. By taking ordinary precautions with the finished product, the user can contribute substantially to ensuring a long service life.

Fungus Damage and Control

Fungus damage to wood may be traced to three general causes: (a) lack of suitable protective measures when storing

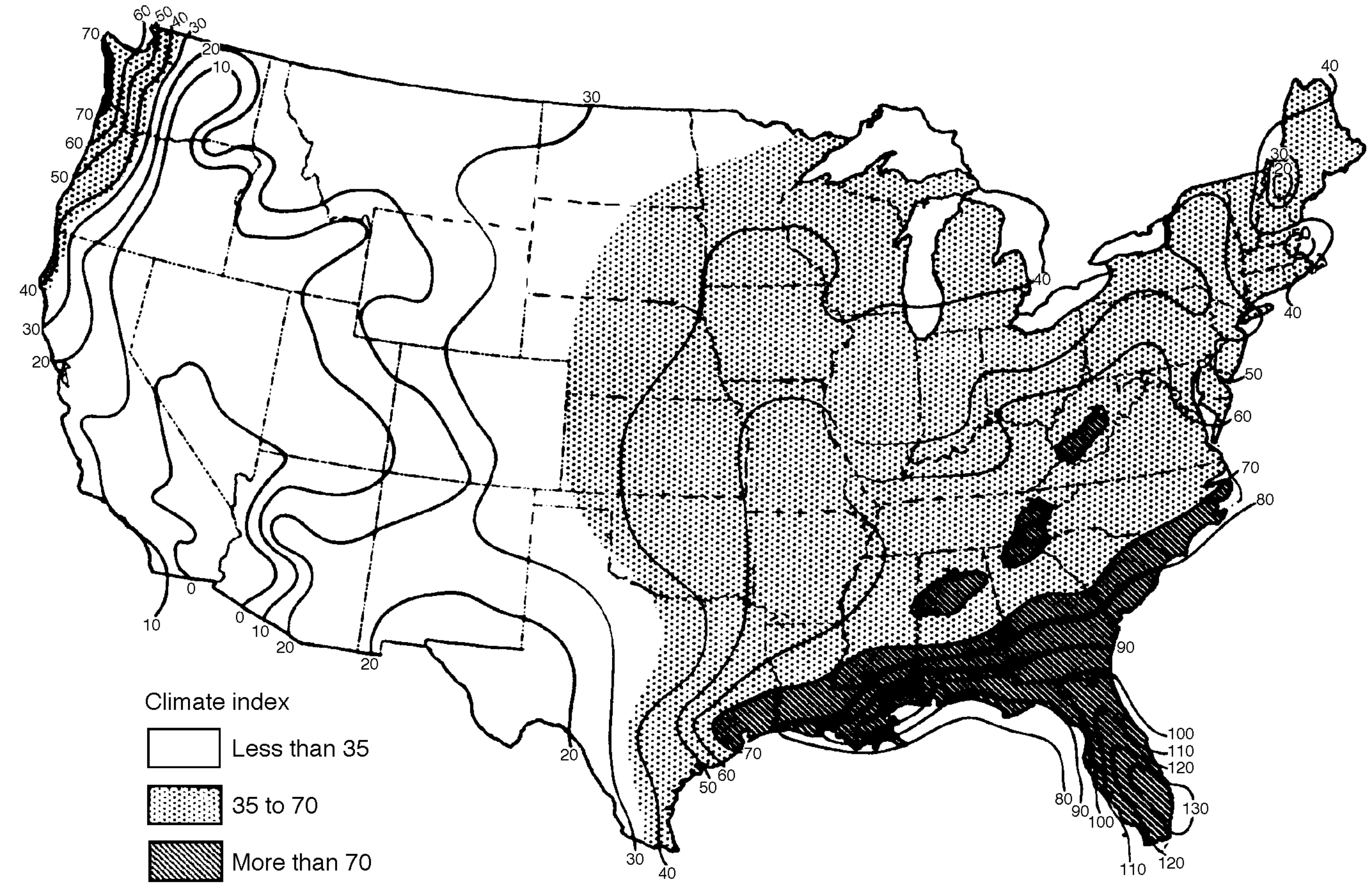

Figure 13–1. Climate index for decay hazard. Higher numbers indicate greater decay hazard.

logs or bolts; (b) improper seasoning, storing, or handling of the raw material produced from the log; and (c) failure to take ordinary simple precautions in using the final product. The incidence and development of molds, decay, and stains caused by fungi depend heavily on temperature and moisture conditions (Fig. 13–1).

Molds and Fungus Stains

Molds and fungus stains are confined to a great extent to sapwood and are of various colors. The principal fungus stains are usually referred to as sap stain or blue stain. The distinction between molding and staining is made primarily on the basis of the depth of discoloration. With some molds and the lesser fungus stains, there is no clear-cut differentiation. Typical sap stain or blue stain penetrates into the sapwood and cannot be removed by surfacing. Also, the discoloration as seen on a cross section of the wood often appears as pie-shaped wedges oriented radially, corresponding to the direction of the wood rays (Fig. 13–2). The discoloration may completely cover the sapwood or may occur as specks, spots, streaks, or patches of various intensities of color. The so-called blue stains, which vary from bluish to bluish black and gray to brown, are the most common, although various shades of yellow, orange, purple, and red are sometimes encountered. The exact color of the stain depends on the infecting organisms and the species and moisture condition of the wood. The fungal brown stain mentioned here should not be confused with chemical brown stain.

Mold discolorations usually become noticeable as fuzzy or powdery surface growths, with colors ranging from light shades to black. Among the brighter colors, green and yellowish hues are common. On softwoods, though the fungus may penetrate deeply, the discoloring surface growth often can easily be brushed or surfaced off. However, on large-pored hardwoods (for example, oaks), the wood beneath the surface growth is commonly stained too deeply to be surfaced off. The staining tends to occur in spots of varying concentration and size, depending on the kind and pattern of the superficial growth.

Under favorable moisture and temperature conditions, staining and molding fungi may become established and develop rapidly in the sapwood of logs shortly after they are cut. In addition, lumber and such products as veneer, furniture stock, and millwork may become infected at any stage of manufacture or use if they become sufficiently moist. Freshly cut or unseasoned stock that is piled during warm, humid weather may be noticeably discolored within 5 or 6 days. Recommended moisture control measures are given in Chapter 12.

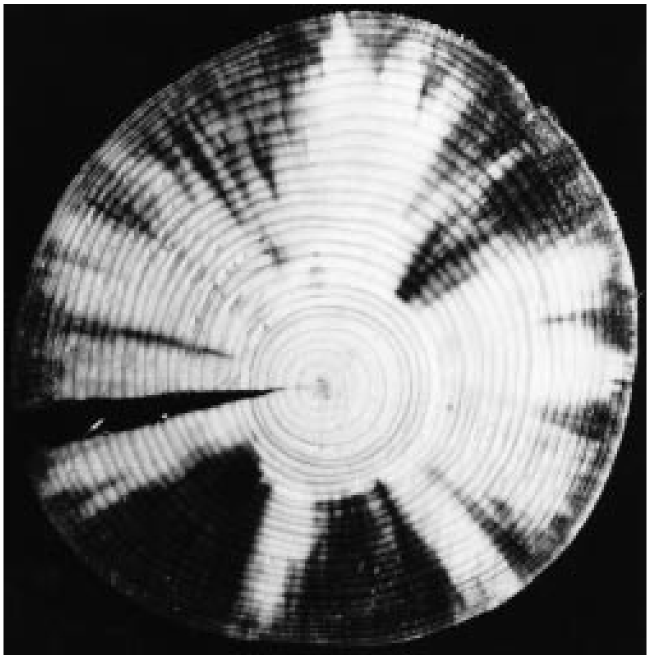

Figure 13–2. Typical radial penetration of log by stain. The pattern is a result of more rapid penetration by the fungus radially (through the ray) than tangentially.

Ordinarily, stain and mold fungi affect the strength of the wood only slightly; their greatest effect is usually confined to strength properties that determine shock resistance or toughness (Ch. 4). They increase the absorbency of wood, and this can cause over-absorption of glue, paint, or wood preservative during subsequent processing. Increased porosity also makes wood more wettable, which can lead to colonization by typical wood-decay fungi.

Stain- and mold-infected stock is practically unimpaired for many uses in which appearance is not a limiting factor, and a small amount of stain may be permitted by standard grading rules. Stock with stain and mold may not be entirely satisfactory for siding, trim, and other exterior millwork because of its greater water absorbency. Also, incipient decay may be present, though inconspicuous, in the discolored areas. Both of these factors increase the possibility of decay in wood that is rain-wetted unless the wood has been treated with a suitable preservative.

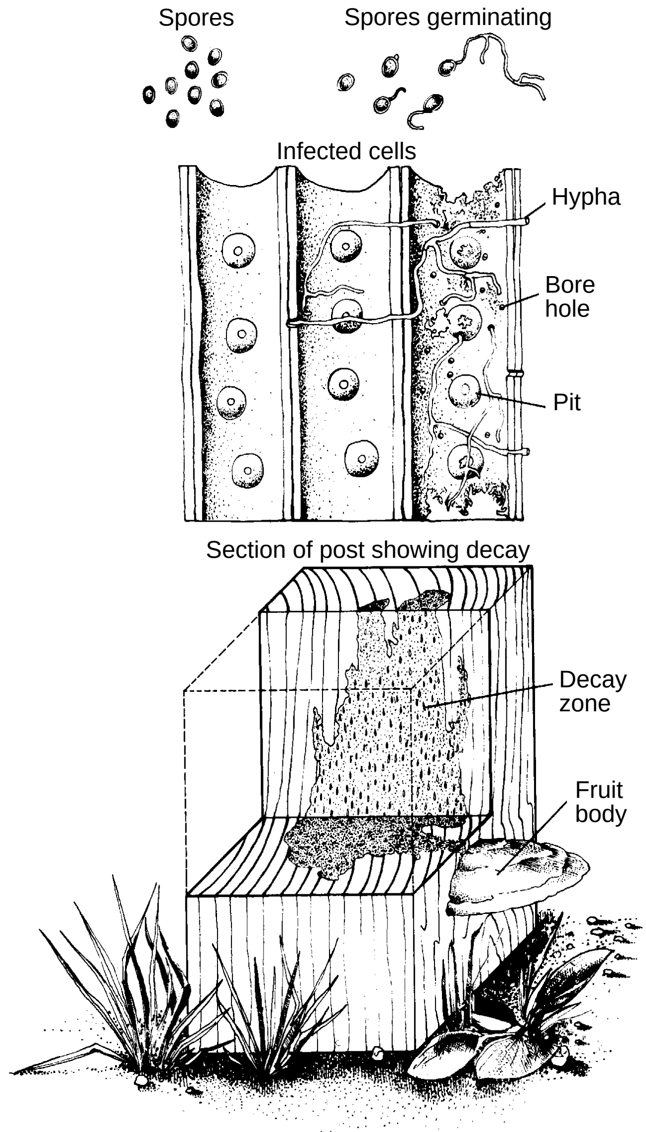

Figure 13–3. The decay cycle (top to bottom). Thousands of spores produced in a fruiting body are distributed by wind or insects. On contacting moist, susceptible wood, they germinate to create new infections in the wood cells. In time, serious decay develops that may be accompanied by formation of new fruiting bodies.

Chemical Stains

Nonmicrobial or chemical stains are difficult to control and represent substantial loss in wood quality. These stains include a variety of discolorations in wood that are often promoted by slow drying of lumber and warm to hot temperatures. Such conditions allow naturally occurring chemicals in wood to react with air (enzymatic oxidation) to form a new chemical that is typically dark in color. Common chemical stains include (a) interior sapwood graying, prevalent in oak, hackberry, ash, and maple; (b) brown stain in softwoods; and (c) pinking and browning in the interior of light-colored woods such as maple. Another common discoloration is caused by the interaction of iron with tannins in wood. Iron stain is more prevalent in hardwoods (for example, oak and many tropical hardwoods) and in some softwoods such as Douglas-fir. Control is achieved by eliminating the source of iron.

Decay

Decay-producing fungi may, under conditions that favor their growth, attack either heartwood or sapwood in most wood species (Fig. 13–3). The result is a condition designated as decay, rot, dote, or doze. Fresh surface growths of decay

Figure 13–4. Mycelial fans on a wood door.

fungi may appear as fan-shaped patches (Fig. 13–4), strands, or root-like structures, usually white or brown. Sometimes fruiting bodies are produced that take the form of mushrooms, brackets, or crusts. The fungus, in the form of microscopic, threadlike strands, permeates the wood and uses parts of it as food. Some fungi live largely on the cellulose; others use the lignin as well as the cellulose.

Certain decay fungi colonize the heartwood (causing heart rot) and rarely the sapwood of living trees, whereas others confine their activities to logs or manufactured products, such as sawn lumber, structural timbers, poles, and ties. Most fungi that attack trees cease their activities after the trees have been cut, as do the fungi causing brown pocket (peck) in baldcypress or white pocket in Douglas-fir and other conifers. Relatively few fungi continue their destruction after the trees have been cut and worked into products and then only if conditions remain favorable for their growth. Although heartwood is more susceptible to decay than is sapwood in living trees, for many species the sapwood of wood products is more susceptible to decay than is the heartwood.

Most decay can progress rapidly at temperatures that favor growth of plant life in general. For the most part, decay is relatively slow at temperatures below 10°C (50°F) and above 35°C (95°F). Decay essentially ceases when the temperature drops as low as 2°C (35°F) or rises as high as 38°C (100°F).

Serious decay occurs only when the moisture content of the wood is above the fiber saturation point (average 30%). Only when previously dried wood is contacted by water, such as provided by rain, condensation, or contact with wet ground, will the fiber saturation point be reached. By itself, the water vapor in humid air will not wet wood sufficiently to support significant decay, but it will permit development of some mold fungi. Fully air-dried wood usually will have a moisture content not exceeding 20% and should provide a reasonable margin of safety against fungus damage. Thus, wood will not decay if it is kept air dry, and decay already present from prior infection will not progress.

Wood can be too wet for decay as well as too dry. If the wood is water-soaked, the supply of air to the interior of a piece may not be adequate to support development of typical decay fungi. For this reason, foundation piles buried beneath the water table and logs stored in a pond or under a suitable system of water sprays are not subject to decay by typical wood-decay fungi.

The early or incipient stages of decay are often accompanied by a discoloration of the wood, which is more evident on freshly exposed surfaces of unseasoned wood than on dry wood. Abnormal mottling of the wood color, with either unnatural brown or bleached areas, is often evidence of decay infection. Many fungi that cause heart rot in the standing tree produce incipient decay that differs only slightly from the normal color of the wood or gives a somewhat water-soaked appearance to the wood.

Typical or late stages of decay are easily recognized, because the wood has undergone definite changes in color and properties, the character of the changes depending on the organism and the substances it removes.

Two kinds of major decay fungi are recognized: brown rot and white rot. With brown-rot fungi, only the cellulose is extensively removed, the wood takes on a browner color, and it can crack across the grain, shrink, collapse, and be crushed into powder (Fig. 13–5). With white-rot fungi, both lignin and cellulose usually are removed, the wood may lose color and appear "whiter" than normal, it does not crack across the grain, and until severely degraded, it retains its outward dimensions, does not shrink or collapse, and often feels spongy. Brown-rot fungi commonly colonize softwoods, and white-rot fungi commonly occur on hardwoods, but both brown- and white-rot fungi occasionally colonize both types of wood.

Brown, crumbly rot, in the dry condition, is sometimes called dry rot, but the term is incorrect because wood must be damp to decay, although it may become dry later.

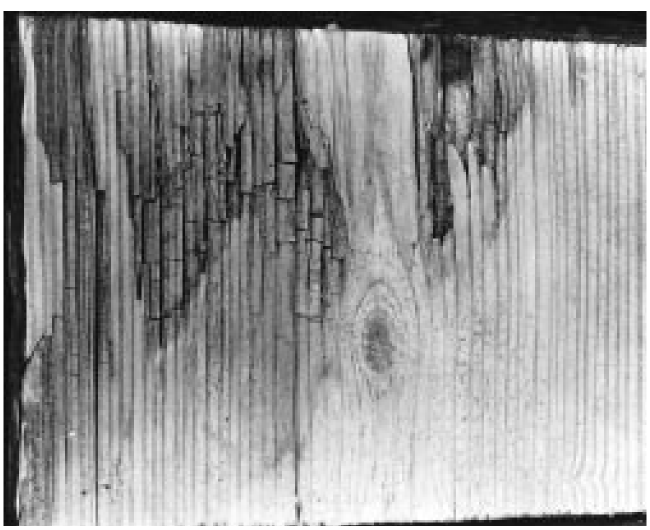

Figure 13–5. Brown rot in Southern Pine railroad tie. Note the darker color and the cubical checking in the wood.

A few fungi, however, have water-conducting strands; such fungi are capable of carrying water (usually from the soil) into buildings or lumber piles, where they moisten and rot wood that would otherwise be dry. They are sometimes referred to technically as dry-rot fungi or water-conducting fungi. The latter term better describes the true situation because these fungi, like the others, must have water.

A third and generally less important kind of decay is known as soft rot. Soft rot is caused by fungi related to the molds rather than those responsible for brown and white rot. Soft rot typically is relatively shallow; the affected wood is greatly degraded and often soft when wet, but immediately beneath the zone of rot, the wood may be firm (Fig. 13–6). Because soft rot usually is rather shallow, it is most likely to damage relatively thin pieces of wood such as slats in cooling towers. It is favored by wet situations but is also prevalent on surfaces that have been alternately wet and dry over a substantial period. Heavily fissured surfaces, familiar to many as weathered wood, generally have been quite degraded by soft-rot fungi.

Decay Resistance of Wood

Chapter 3 discusses the natural resistance of wood to fungi and ranks a grouping of species according to decay resistance. In decay-resistant domestic species, only the heartwood has significant resistance because the natural preservative chemicals in wood that retard the growth of fungi are essentially restricted to the heartwood. Natural resistance of species to fungi is important only where conditions conducive to decay exist or may develop. If wood is subjected to severe decay conditions, pressure-treated wood, rather than resistant heartwood, is generally recommended.

Effect of Decay on Strength of Wood

Decay initially affects toughness, or the ability of wood to withstand impacts. This is generally followed by reductions in strength values related to static bending. Eventually, all strength properties are seriously reduced.

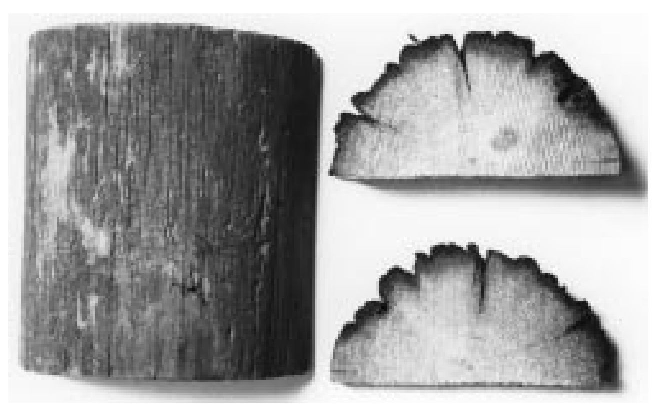

Figure 13–6. Soft-rotted preservative-treated pine utility pole. Note the shallow depth of decay.

Strength losses during early stages of decay can be considerable, depending to a great extent upon the fungi involved and, to a lesser extent, upon the type of wood undergoing decay. In laboratory tests, losses in toughness ranged from 6% to >50% by the time a 1% weight loss had occurred in the wood as a result of fungal attack. By the time weight losses resulting from decay have reached 10%, most strength losses may be expected to exceed 50%. At such weight losses, decay is detectable only microscopically. It may be assumed that wood with visually discernible decay has been greatly reduced in all strength values.

Prevention of Mold, Stain, and Decay

Logs, Poles, Piles, and Ties

The wood species, geographic region, and time of the year determine what precautions must be taken to avoid serious damage from fungi in logs, poles, piles, ties, and similar thick products during seasoning or storage. In dry climates, rapid surface seasoning of poles and piles will retard development of mold, stain, and decay. The bark is peeled from the pole and the peeled product is decked on high skids or piled on high, well-drained ground in the open to dry. In humid regions, such as the Gulf States, these products often do not air-dry fast enough to avoid losses from fungi. Preseasoning treatments with approved preservative solutions can be helpful in these circumstances.

For logs, rapid conversion into lumber or storage in water or under a water spray (Fig. 13–7) is the surest way to avoid fungal damage. Preservative sprays promptly applied to the wood will protect most timber species during storage for 2 to 3 months, except in severe decay hazard climates, such as in Mississippi (Fig. 13–1). For longer storage, an end coating is needed to prevent seasoning checks, through which infection can enter the log.

Lumber

Growth of decay fungi can be prevented in lumber and other wood products by rapidly drying them to a moisture content of 20% or less and keeping them dry. Standard air-drying practices will usually dry the wood fast enough to protect it, particularly if the protection afforded by drying is supplemented by dip or spray treatment of the stock with an EPA-approved fungicidal solution. Successful control by this method depends not only upon immediate and adequate treatment but also upon proper handling of the lumber after treatment. However, kiln drying is the most reliable method of rapidly reducing moisture content.

Figure 13–7. Spraying logs with water protects them against fungal stain and decay.

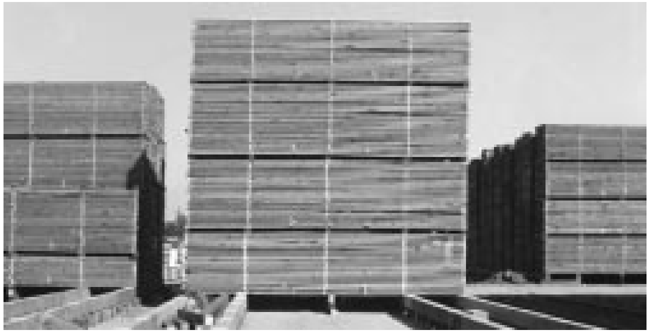

Figure 13–8. A sanitary, well-drained air-drying yard.

Air-drying yards should be kept as sanitary and as open as possible to air circulation (Fig. 13–8). Recommended practices include locating yards and sheds on well-drained ground; removing debris (which serves as a source of infection) and weeds (which reduce air circulation); and employing piling methods that permit rapid drying of the lumber and protect against wetting. Storage sheds should be constructed and maintained to prevent significant wetting of the stock. Ample roof overhang on open sheds is desirable. In areas where termites or water-conducting fungi may be troublesome, stock to be held for long periods should be set on foundations high enough so that the wood can be inspected from beneath.

The user's best assurance of receiving lumber free from decay other than light stain is to buy stock marked by a lumber association in a grade that eliminates or limits such quality-reducing features. Surface treatment for protection at the drying yard is only temporarily effective. Except for temporary structures, lumber to be used under conditions conducive to decay should be all heartwood of a naturally durable species or should be adequately treated with a wood preservative (Ch. 14).

Buildings

The lasting qualities of properly constructed wood buildings are apparent in all parts of the country. Serious decay problems are almost always a sign of faulty design or construction, lack of reasonable care in the handling of the wood, or improper maintenance of the structure.

Construction principles that ensure long service and avoid decay in buildings include (a) building with dry lumber, free of incipient decay and not exceeding the amounts of mold and blue stain permitted by standard grading rules; (b) using construction details and building designs that will keep exterior wood dry and accelerate runoff; (c) using wood treated with a preservative or heartwood of a decay-resistant species for parts exposed to aboveground decay hazards; and (d) using pressure-treated wood for the high hazard situation associated with ground contact.

A building site that is dry or for which drainage is provided will reduce the possibility of decay. Stumps, wood debris, stakes, or wood concrete forms are frequently subject to decay if left under or near a building.

Unseasoned or infected wood should not be enclosed until it is thoroughly dried. Unseasoned wood includes green lumber. Wood can become infected because of improper handling at the sawmill or retail yard or after delivery on the job.

Untreated wood parts of substructures should not be permitted to contact the soil. A minimum of 200 mm (8 in.) clearance between soil and framing and 150 mm (6 in.) between soil and siding is recommended. Where frequent hard rains occur, a foundation height above grade of 300 to 460 mm (12 to 18 in.) is advocated. An exception may be made for certain temporary constructions. If contact with soil is unavoidable, the wood should be pressure treated (Ch. 14).

Sill plates and other wood resting on a concrete slab foundation generally should be pressure treated and protected by installing a moisture-resistant membrane such as polyethylene beneath the slab. Girder and joist openings in masonry walls should be big enough to ensure an air space around the ends of these wood members. If the members are below the outside soil level, moisture proofing of the outer face of the wall is essential.

In buildings without basements but with crawl spaces, wetting of the wood by condensation during cold weather or by air-conditioning may result in serious decay damage. However, serious condensation leading to decay may be prevented by laying a barrier such as polyethylene on the soil. To facilitate inspection of the crawl space, a minimum 460-mm (18-in.) clearance should be left under wood joists.

Wood should also be protected from rain during construction. Protection from rainwater or condensation in walls and roofs will prevent the development of decay. A fairly wide roof overhang (0.6 m (2 ft)) with gutters and downspouts that are kept free of debris is desirable. Roofs must be kept tight, and cross ventilation in attics is recommended in cold climates. The use of sound, dry lumber is important in all parts of buildings.

Where service conditions in a building are such that the wood cannot be kept dry, the use of preservative-treated wood (Ch. 14) or heartwood of a durable species is advised. Examples include porches, exterior steps, and platforms and such places as textile mills, pulp and paper mills, and cold storage plants.

In making repairs necessitated by decay, every effort should be made to correct the moisture condition that led to the damage. If the condition cannot be corrected, all infected parts should be replaced with preservative-treated wood or with all-heartwood lumber of a naturally decay-resistant wood species. If the sources of moisture that caused the decay are entirely eliminated, it is necessary only to replace the weakened wood with dry lumber.

Other Structures and Products

In general, the principles underlying the prevention of mold, stain, or decay damage to veneer, plywood containers, boats, and other wood products and structures are similar to those described for buildings—dry the wood rapidly and keep it dry or treat it with approved protective and preservative solutions. Interior grades of plywood should not be used where the plywood will be exposed to moisture; the adhesives, as well as the wood, may be damaged by fungi and bacteria as well as degraded by moisture. With exterior-type panels, joint construction should be carefully designed to prevent the entrance of rainwater.

In treated bridge or wharf timbers, checking may occur and may expose untreated wood to fungal attack. Annual in-place treatment of these checks will provide protection from decay. Similarly, pile tops may be protected by treatment with a wood preservative followed by application of a suitable capping compound.

Wood boats present certain problems that are not encountered in other uses of wood. The parts especially subject to decay are the stem, knighthead, transom, and frameheads, which can be reached by rainwater from above or condensation from below. Frayed surfaces are more likely to decay than are exposed surfaces, and in salt water service, hull members just below the weather deck are more vulnerable than those below the waterline. Recommendations for avoiding decay include (a) using only heartwood of durable species, free of infection, and preferably below 20% moisture content; (b) providing and maintaining ventilation in the hull and all compartments; (c) keeping water out as much as is practicable, especially fresh water; and (d) where it is necessary to use sapwood or nondurable heartwood, impregnating the wood with an approved preservative and treating the fully cut, shaped, and bored wood before installation by soaking it for a short time in preservative solution. Where such mild soaking treatment is used, the wood most subject to decay should also be flooded with an approved preservative at intervals of 2 or 3 years. During this treatment, the wood should be dry so that joints are relatively loose.

Remedial Treatment of Internally Decayed Wood

Four fumigants, 32% sodium N-methyldithiocarbamate in water, methylisocyanate, Basamid (tetrahydro-3, 5-dimethyl-2-H-1,3,5, thiodazine-6-thione), and chloropicrin (trichloronitromethane), are registered for use to arrest internal decay in wood. All these fumigants produce volatile toxic gases when applied to wood and move several meters from the point of application. These chemicals are restricted-use preservatives, and applicators must be trained and pass a test on pesticide handling and safety before using the chemicals. Fumigant treating poses risks, and thus the chemicals cannot be used safely in some situations.

Water diffusible boron- and fluoride-based rods, pastes, or solutions can be applied to wood by flooding or as external coatings (for example, bandage wraps containing borate or fluoride paste applied to the groundline of poles).

Bacteria

Most wood that has been wet for a considerable length of time probably will contain bacteria. The sour smell of logs that have been held under water for several months, or of lumber cut from them, manifests bacterial action. Usually, bacteria have little effect on wood properties, except over long periods, but some may make the wood excessively absorptive. This can result in excessive pickup of moisture, adhesive, paint, or preservative during treatment or use. This effect has been a problem in the sapwood of millwork cut from pine logs that have been stored in ponds. There also is evidence that bacteria developing in pine veneer bolts held under water or sprayed with water may cause noticeable changes in the physical character of the veneer, including some strength loss. Additionally, a mixture of different bacteria, as well as fungi, was found capable of accelerating decay of treated cooling tower slats and mine timbers.

Insect Damage and Control

The more common types of damage caused by wood-attacking insects are shown in Table 13–1 and Figure 13–9. Methods of controlling and preventing insect attack of wood are described in the following paragraphs.

Beetles

Bark beetles may damage the surface of the components of logs and other rustic structures from which the bark has not been removed. These beetles are reddish brown to black and vary in length from approximately 1.5 to 6.5 mm (1/16 to 1/4 in.) They bore through the outer bark to the soft inner part, where they make tunnels in which they lay their eggs. In making tunnels, bark beetles push out fine brownish-white sawdust-like particles. If many beetles are present, their extensive tunneling will loosen the bark and permit it to fall off in large patches, making the structure unsightly.

To avoid bark beetle damage, logs may be debarked rapidly, sprayed with an approved insecticidal solution, stored in water or under a water spray, or cut during the dormant season (October or November, for instance). If cut during this period, logs should immediately be piled off the ground and arranged for good air movement, to promote rapid drying of the inner bark. This should occur before the beetles begin to fly in the spring. Drying the bark will almost always prevent damage by insects that prefer freshly cut wood.

Ambrosia beetles, roundheaded and flatheaded borers, and some powder-post beetles that get into freshly cut timber can cause considerable damage to wood in rustic structures and some manufactured products. Certain beetles may complete development and emerge several years after the wood is dry, often raising a question as to the origin of the infestation.

Table 13–1. Types of damage caused by wood-attacking insects

Type of damage	Description	Causal agent	Damage: Begins	Damage: Ends
Pin holes	0.25 to 6.4 mm (1/100 to 1/4 in.) in diameter, usually circular			
	Tunnels open:			
	Holes 0.5 to 3 mm (1/50 to 1/8 in.) in diameter, usually centered in dark streak or ring in surrounding wood	Ambrosia beetles	In living trees and unseasoned logs and lumber	During seasoning
	Holes variable sizes; surrounding wood rarely dark stained; tunnels lined with wood-colored substance	Timber worms	In living trees and unseasoned logs and lumber	Before seasoning
	Tunnels packed with usually fine sawdust:			
	Exit holes 0.8 to 1.6 mm (1/32 to 1/16 in.) in diameter; in sapwood of large-pored hardwoods; loose floury sawdust in tunnels	Lyctid powder-post beetles	During or after seasoning	Reinfestation continues until sapwood destroyed
	Exit holes 1.6 to 3 mm (1/16 to 1/8 in.) in diameter; primarily in sapwood, rarely in heartwood; tunnels loosely packed with fine sawdust and elongate pellets	Anobiid powder-post beetles	Usually after wood in use (in buildings)	Reinfestation continues; progress of damage very slow
	Exit holes 2.5 to 7 mm (3/32 to 9/32 in.) in diameter; primarily sapwood of hard woods, minor in softwoods; sawdust in tunnels fine to coarse and tightly packed	Bostrichid powder-post beetles	Before seasoning or if wood is rewetted	During seasoning or redrying
	Exit holes 1.6 to 2 mm (1/16 to 1/12 in.) in diameter; in slightly damp or decayed wood; very fine sawdust or pellets tightly packed in tunnels	Wood-boring weevils	In slightly damp wood in use	Reinfestation continues while wood is damp
Grub holes	3 to 13 mm (1/8 to 1/2 in.) in diameter, circular or oval			
	Exit holes 3 to 13 mm (1/8 to 1/2 in.) in diameter; circular; mostly in sapwood; tunnels with coarse to fibrous sawdust or it may be absent	Roundheaded borers (beetles)	In living trees and unseasoned logs and lumber	When adults emerge from seasoned wood or when wood is dried
	Exit holes 3 to 13 mm (1/8 to 1/2 in.) in diameter; mostly oval; in sapwood and heartwood; sawdust tightly packed in tunnels	Flatheaded borers (beetles)	In living trees and unseasoned logs and lumber	When adults emerge from seasoned wood or when wood is dried
	Exit holes ~6 mm (~1/4 in.) in diameter; circular; in sapwood of softwoods, primarily pine; tunnels packed with very fine sawdust	Old house borers (a roundheaded borer)	During or after seasoning	Reinfestation continues in seasoned wood in use
	Exit holes perfectly circular, 4 to 6 mm (1/6 to 1/4 in.) in diameter; primarily in softwoods; tunnels tightly packed with coarse sawdust, often in decay softened wood	Woodwasps	In dying trees or fresh logs	When adults emerge from seasoned wood, usually in use, or when kiln dried
	Nest entry hole and tunnel perfectly circular ~13 mm (~1/2 in.) in diameter; in soft softwoods in structures	Carpenter bees	In structural timbers, siding	Nesting reoccurs annually in spring at same and nearby locations
Network of galleries	Systems of interconnected tunnels and chambers	Social insects with colonies		
	Walls look polished; spaces completely clean of debris	Carpenter ants	Usually in damp partly decayed, or soft-textured wood in use	Colony persists unless prolonged drying of wood occurs
	Walls usually speckled with mud spots; some chambers may be filled with "clay"	Subterranean termites	In wood structures	Colony persists
	Chambers contain pellets; areas may be walled-off by dark membrane	Dry-wood termites (occasionally damp wood termites)	In wood structures	Colony persists
Pitch pocket	Openings between growth rings containing pitch	Various insects	In living trees	In tree
Black check	Small packets in outer layer of wood	Grubs of various insects	In living trees	In tree
Pith fleck	Narrow, brownish streaks	Fly maggots or adult weevils	In living trees	In tree
Gum spot	Small patches or streaks of gum-like substances	Grubs of various insects	In living trees	In tree
Ring distortion	Double growth rings or incomplete annual layers of growth	Larvae of defoliating insects or flatheaded cambium borers	In living trees	In tree
	Stained area more than 25.4 mm (1 in.) long introduced by insects in trees or recently felled logs	Staining fungi	With insect wounds	With seasoning

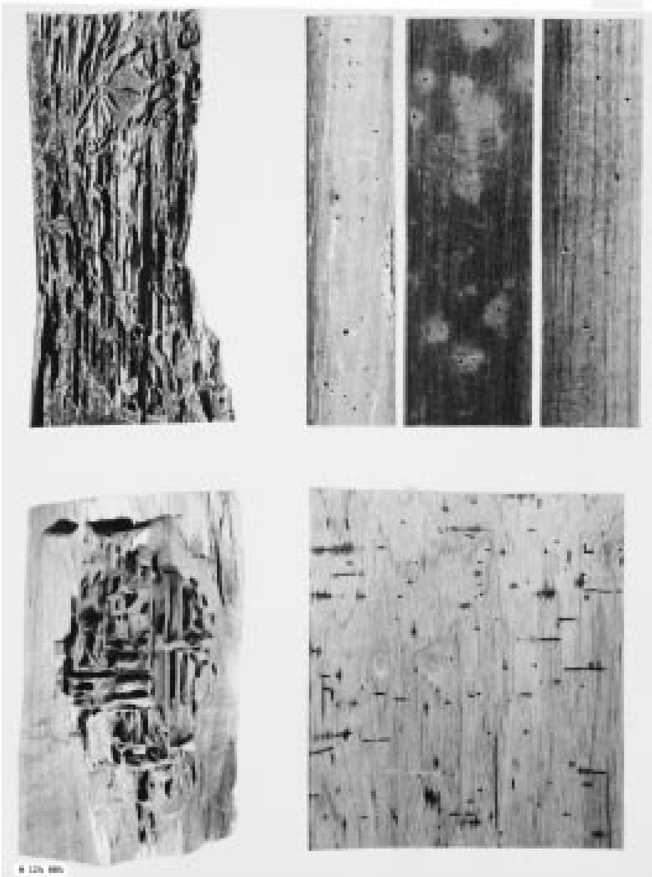

Figure 13–9. Types of insect damage most likely to occur in a building. Upper left—Termite attack; feeding galleries (often parallel to the grain) contain excrement and soil. Upper right—Powder-post beetle attack; exit holes usually filled with wood flour and not associated with discolored wood. Lower left—Carpenter ant attack; nesting galleries usually cut across grain and are free of residue. Lower right—Beetle attack; feeding galleries (made in the wood while green) free of residue and surrounding wood darkly stained.

Proper cutting practices, rapid debarking, storing under water, and spraying the material with an approved chemical solution, as recommended for bark beetles, will control these insects. Damage by ambrosia beetles can be prevented in freshly sawn lumber by dipping the product in a chemical solution. The addition of one of the sap-stain preventives approved for controlling molds, stains, and decay will keep the lumber bright. Powder-post beetles attack both hardwoods and softwoods and both freshly cut and seasoned lumber and timber. Powder-post damage is indicated by holes made in the surface of the wood by the winged adults as they emerge and by the fine powder that may fall from the wood. The powder-post beetles that cause most of the damage to dry hardwood lumber belong to the genus *Lyctus*. They attack the sapwood of ash, hickory, oak, and other large-pored hardwoods as it begins to season. Eggs are laid in pores of the wood, and the larvae burrow through the wood, making tunnels from 1.5 to 2 mm (1/16 to 1/12 in.) in diameter, which they leave packed with a fine powder. Species of anobiid beetles colonize coniferous materials.

Susceptible hardwood lumber used for manufacturing purposes should be protected from powder-post beetle attack as soon as it is sawn and when it arrives at the plant. An approved insecticide applied in water emulsion to the green lumber will provide protection. Such treatment may be effective even after the lumber is kiln dried, until it is surfaced.

Good plant sanitation is extremely important in alleviating the problem of infestation. Proper sanitation measures can often eliminate the necessity for other preventative steps. Damage to manufactured items frequently is traceable to infestation that occurred before the products were placed on the market, particularly if a finish is not applied to the surface of the items until they are sold. Once wood is infested, the larvae will continue to develop, even though the surface is subsequently painted, oiled, waxed, or varnished.

When selecting hardwood lumber for building or manufacturing purposes, any evidence of powder-post infestation should not be overlooked, because the beetles may continue to be active long after the wood is put to use. For standard 19-mm (nominal 1-in.) lumber, sterilization of green wood with steam at 54°C (130°F) or sterilization of wood with a lower moisture content at 82°C (180°F) under controlled conditions of relative humidity for about 2 h is effective for checking infestation or preventing attack. Thicker material requires a longer time. A 3-min soaking in a petroleum oil solution containing an insecticide is also effective for checking infestation or preventing attack on lumber up to standard 19 mm (nominal 1 in.) thick. Small dimension stock also can be protected by brushing or spraying with approved chemicals. For infested furniture or finished woodwork in a building, the same insecticides may be used, but they should be dissolved in a refined petroleum oil, like mineral spirits. Because the *Lyctus* beetles lay their eggs in the open pores of wood, infestation can be prevented by covering the entire surface of each piece of wood with a suitable finish.

Powder-post beetles in the family Anobiidae, depending on the species, infest hardwoods and softwoods. Their life cycle takes 2 to 3 years and they require a wood moisture content around 15% or greater for viable infestation. Therefore, in most modern buildings, the wood moisture content is generally too low for anobiids. When ventilation is inadequate or in more humid regions of the United States, wood components of a building can reach the favorable moisture conditions for anobiids. This is especially a problem in air-conditioned buildings where water condenses on cooled exterior surfaces. Susceptibility to anobiid infestation can be alleviated by lowering the moisture content of wood through improved ventilation and the judicious use of insulation and vapor barriers. Insecticides registered for use against these beetles are generally restricted for exterior applications to avoid potential safety hazards indoors. Wood being reused or recycled from older structures often has lyctid or anobiid larvae in it. Such wood should be fumigated or kiln dried before use in another structure.

Beetles in the family Bostrichidae and weevils in the family Curculionidae are associated with wood moisture contents favorable for wood-infesting fungi because they may benefit nutritionally from the fungi. Thus, protection against these insects consists of the same procedures as for protection against wood-decay fungi.

A roundheaded beetle, commonly known as the old house borer, causes damage to seasoned coniferous building materials. The larvae reduce the sapwood to a powdery or granular consistency and make a ticking sound while at work. When mature, the beetles make an oval hole approximately 6.5 mm (1/4 in.) in diameter in the surface of the wood and emerge. Anobiid powder-post beetles, which make holes 1.6 to 3.2 mm (1/16 to 1/8 in.) in diameter, also cause damage to pine joists. Infested wood should be drenched with a solution of one of the currently recommended insecticides in a highly penetrating solvent. Beetles nesting in wood behind plastered or paneled walls can be eliminated through fumigation of the building by a licensed operator.

Termites

Termites superficially resemble ants in size, general appearance, and habit of living in colonies. About 56 species are known in the United States. From the standpoint of their methods of attack on wood, termites can be grouped into two main classes: (a) ground-inhabiting or subterranean termites and (b) wood-inhabiting or nonsubterranean termites.

Subterranean Termites

Subterranean termites are responsible for most of the termite damage done to wood structures in the United States. This damage can be prevented. Subterranean termites are more prevalent in the southern than in the northern states, where low temperatures do not favor their development (Fig. 13–10). The hazard of infestation is greatest (a) beneath buildings without basements that were erected on a concrete slab foundation or were built over a crawl space that is poorly drained and ventilated and (b) in any substructure wood component close to the ground or an earth fill (for example, an earth-filled porch).

The subterranean termites develop their colonies and maintain their headquarters in the ground. They build their tunnels through earth and around obstructions to reach the wood they need for food. They also must have a constant source of moisture, whether from the wood on which they are feeding or the soil where they nest. The worker members of the colony cause destruction of wood. At certain seasons of the year, usually spring, male and female winged forms swarm from the colony, fly a short time, lose their wings, mate, and if successful in locating a suitable home, start new colonies. The appearance of “flying ants” or their shed wings is an indication that a termite colony may be near and causing serious damage. Not all “flying ants” are termites; therefore, suspicious insects should be identified before investing in eradication (Fig. 13–11).

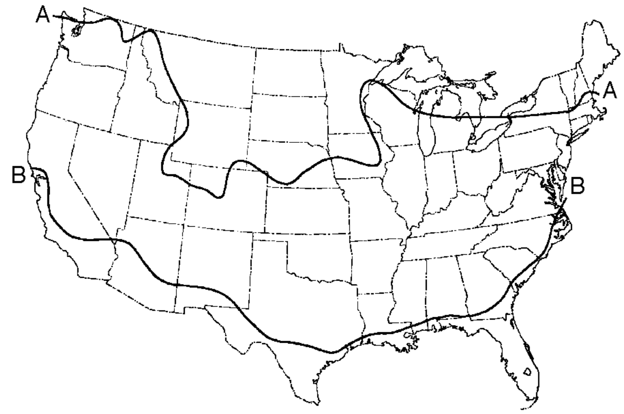

Figure 13–10. A, the northern limit of recorded damage done by subterranean termites in the United States; B, the northern limit of damage done by dry-wood termites.

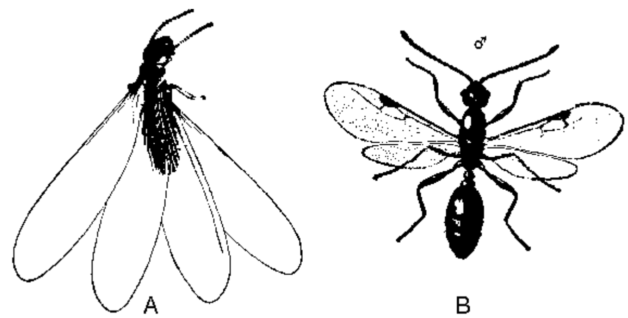

Figure 13–11. A, winged termite; B, winged ant (both greatly enlarged). The wasp waist of the ant and the long wings of the termite are distinguishing characteristics.

Subterranean termites normally do not establish themselves in buildings by being carried there in lumber; they primarily enter from ground nests after the building has been constructed. An introduced species, the Formosan termite, is adept at initiating aboveground infestations and nests in structures where wood remains wet for prolonged periods, such as from roof leaks. Telltale signs of subterranean termite presence are the earthen tubes or runways built by these insects over the surfaces of the foundation or other exposed areas to reach the wood above. Another sign is the swarming of winged adults early in the spring or fall. In the wood itself, the termites make galleries that generally follow the grain, leaving a shell of sound wood to conceal their activities. Because the galleries seldom show on the wood surfaces, probing with a pick or knife is advisable if the presence of termites is suspected.

The best protection for wood in areas where subterranean termites are prevalent is to prevent the termites from gaining hidden access to a building. The foundations should be of concrete, pressure-treated wood, or other material through which the termites cannot penetrate. With brick, stone, or concrete block, cement mortar should be used because termites can work through some other kinds of mortar. Also, it is a good precaution to cap the foundation with 100 mm (4 in.) of reinforced concrete. Posts supporting floor girders should, if they bear directly on the ground, be of concrete. If there is a basement, it should be floored with concrete. Untreated posts in such a basement should rest on concrete piers extending a few inches above the basement floor. However, pressure-treated posts can rest directly on the basement floor. With the crawl-space type of foundation, wood floor joists should be kept at least 460 mm (18 in.) and girders 300 mm (12 in.) from the earth and good ventilation should be provided beneath the floor. A rule of thumb is to have a minimum of 1 unit area of ventilation for every 150 units of crawlspace (for example, 1 ft^2 of ventilated area for 150 ft^2 of crawlspace).

Moisture condensation on the floor joists and subflooring, which may cause conditions favorable to decay and contribute to infestation by termites, can be avoided by covering the soil below with a moisture barrier, maintaining adequate ventilation, and assuming proper drainage of rainwater away from all sides of a structure. All concrete forms, stakes, stumps, and wastewood should be removed from the building site because they are possible sources of infestation. Generally, the precautions effective against subterranean termites are also helpful against decay.

The principal method of protecting buildings in high termite areas is to thoroughly treat the soil adjacent to the foundation walls and piers beneath the building with a soil insecticide. When concrete slab floors are laid directly on the ground, all soil under the slab should be treated with an approved insecticide before the concrete is poured. Furthermore, insulation containing cellulose that is used as a filler in expansion joints should be impregnated with an approved chemical toxic to termites. Sealing the top 13 mm (1/2 in.) of the expansion joint with roofing-grade coal-tar pitch also provides effective protection from ground-nesting termites. New modifications in soil treatment and an insecticidal bait control method are currently under investigation and appear promising. Current references (available from national pest control operator associations) should be consulted to take advantage of the new developments in termite control.

To control termites already in a building, contact between the termite colony in the soil and the woodwork must be broken. This can be done by blocking the runways from soil to wood, treating the soil, repairing leaks that keep wood within the structure wet (for example, plumbing leaks), or some combination of these techniques. Possible reinfestations can be guarded against by frequent inspections for signs of termites.

Nonsubterranean Termites

In the United States, nonsubterranean termites have been found only in a narrow strip of territory extending from central California around the southern edge of the continental United States to Virginia (Fig. 13–10) and in the West Indies and Hawaii. Their principal damage is confined to an area in southern California, to parts of southern Florida, notably Key West, and to the islands of Hawaii. They also are a localized problem in Arizona and New Mexico.

The nonsubterranean termites, especially the dry-wood type, do not multiply as rapidly as the subterranean termites and have somewhat different colony life and habits. The total amount of destruction they cause in the United States is much less than that caused by the subterranean termites. The ability of dry-wood termites to live in dry wood without outside moisture or contact with the ground, however, makes them a definite menace in the regions where they occur. Their depredations are not rapid, but they can thoroughly riddle timbers with their tunnelings if allowed to work undisturbed for many years. Nonsubterranean termites are often moved from structure to structure in infested items such as furniture.

In constructing a building in localities where the dry-wood type of nonsubterranean termite is prevalent, it is good practice to inspect the lumber carefully to see that it was not infested before arrival at the building site. If the building is constructed during the swarming season, the lumber should be watched during the course of construction, because infestation by colonizing pairs can easily take place. Because paint is a good protection against the entrance of dry-wood termites, exposed wood (except that which is preservative treated) should be kept covered with a paint film. Fine screen should be placed over any openings to the interior unpainted parts of the building. As in the case of ground-nesting termites, dead trees, old stumps, posts, or wood debris of any kind that could serve as sources of infestation should be removed from the premises.

If a building is infested with dry-wood termites, badly damaged wood should be replaced. If the wood is only slightly damaged or is difficult to replace, further termite activity can be arrested by injecting a small amount of an approved pesticidal dust or liquid formulation into each nest. Current recommendations for such formulations can be found from state pest control associations. Buildings heavily infested with nonsubterranean termites can be successfully fumigated. This method is quicker than the use of poisonous liquids and dusts and does not require finding all of the colonies. However, it does not prevent the termites from returning because no poisonous residue is left in the tunnels. Fumigation is very dangerous and should be conducted only by licensed professional fumigators. Infested pieces of furniture, picture frames, and other small pieces can be individually fumigated, heated, or placed in a freezer for a short time. In localities where dry-wood termites do serious damage to posts and poles, the best protection for these and similar forms of outdoor timbers is full-length pressure treatment with a preservative.

Naturally Termite-Resistant Woods

Only a limited number of woods grown in the United States offer any marked degree of natural resistance to termite attack. The close-grained heartwood of California redwood has some resistance, especially when used above ground. Very resinous heartwood of Southern Pine is practically immune to attack, but it is not available in large quantities and is seldom used.

Carpenter Ants

Carpenter ants are black or brown. They usually occur in stumps, trees, or logs but sometimes damage poles, structural timbers, or buildings. One form is easily recognized by its giant size relative to other ants. Carpenter ants use wood for shelter rather than for food, usually preferring wood that is naturally soft or has been made soft by decay. They may enter a building directly by crawling or may be carried there in fuelwood. If left undisturbed, they can, in a few years, enlarge their tunnels to the point where replacement or extensive repairs are necessary. The parts of dwellings they frequent most often are porch columns, porch roofs, window sills, and sometimes the wood plates in foundation walls. They often nest in hollow-core doors. The logs of rustic cabins are also attacked.

Precautions that prevent attack by decay and termites are usually effective against carpenter ants. Decaying or infested wood, such as logs, stumps, or retaining walls, should be removed from the premises, and crevices present in the foundation or woodwork of the building should be sealed. Particularly, leaks in porch roofs should be repaired because the decay that may result makes the wood more desirable to the ants.

When carpenter ants are found in a structure, any badly damaged timbers should be replaced. Because the carpenter ant needs high humidity in its immature stages, alterations in the construction may also be required to eliminate moisture from rain or condensation. In wood not sufficiently damaged to require replacement, the ants can be killed by injection of approved insecticide into the nest galleries. Carpenter ant nests are relatively easy to find because they keep their internal nest sites very clean and free of debris. As particles of wood are removed to create galleries or as pieces of insects that have been fed upon accumulate, the debris is removed from the nest and then accumulates below the nest opening.

Carpenter Bees

Carpenter bees resemble large bumblebees, but the top of their abdomen is hairless, causing their abdomens to shine, unlike bumblebees. The females make large (13-mm- (1/2-in.-) diameter) tunnels into unfinished soft wood for nests. They partition the hole into cells; each cell is provided with pollen and nectar for a single egg. Because carpenter bees reuse nesting sites for many years, a nesting tunnel into a structural timber may be extended several feet and have multiple branches. In thin wood, such as siding, the holes may extend the full thickness of the wood. They nest in stained wood and wood with thin paint films or light preservative salt treatments as well as in bare wood. A favorite nesting site is in unfinished exterior wood not directly exposed to sunlight (for example, the undersides of porch roofs, and grape arbors).

Control is aimed at discouraging the use of nesting sites in and near buildings. The tunnel may be injected with an insecticide labeled for bee control and plugged with caulk. Treating the surface around the entry hole will discourage reuse of the tunnel during the spring nesting period. A good paint film or pressure preservative treatment protects exterior wood surfaces from nesting damage. Bare interior wood surfaces, such as in garages, can be protected by screens and tight-fitting doors.

Marine Borer Damage and Control

Damage by marine-boring organisms to wood structures in salt or brackish waters is practically a worldwide problem. Evidence of attack is sometimes found in rivers even above the region of brackishness. The rapidity of attack depends upon local conditions and the kinds of borers present. Along the Pacific, Gulf, and South Atlantic Coasts of the United States, attack is rapid, and untreated pilings may be completely destroyed in a year or less. Along the coast of the New England States, the rate of attack is slower because of cold water temperatures but is still sufficiently rapid to require protection of wood where long life is desired. The principal marine borers from the standpoint of wood damage in the United States are described in this section. Control measures discussed in this section are those in use at the time this handbook was revised. Regulations should be reviewed at the time control treatments are being considered so that approved practices will be followed.

Shipworms

Shipworms are the most destructive of the marine borers. They are mollusks of various species that superficially are worm-like in form. The group includes several species of *Teredo* and several species of *Bankia*, which are especially damaging. These mollusks are readily distinguishable on close observation but are all very similar in several respects. In the early stages of their life, they are minute, free-swimming organisms. Upon finding suitable lodgment on wood, they quickly develop into a new form and bury themselves in the wood. A pair of boring shells on the head grows rapidly in size as the boring progresses, while the tail part or siphon remains at the original entrance. Thus, the animal grows in length and diameter within the wood but remains a prisoner in its burrow, which it lines with a shell-like deposit. It lives on the wood borings and the organic matter extracted from the sea water that is continuously being pumped through its system. The entrance holes never grow large, and the interior of wood may be completely honeycombed and ruined while the surface shows only slight perforations. When present in great numbers, shipworms grow only a few centimeters before the wood is so completely occupied that growth is stopped. However, when not crowded, they can grow to lengths of 0.3 to 1.2 m (1 to 4 ft) depending on the species.

Pholads

Another group of wood-boring mollusks is the pholads, which clearly resemble clams and therefore are not included with the shipworms. They are entirely encased in their double shells. The *Martesia* are the best-known species, but another well-known group is the *Xylophaga*. Like the shipworms, the *Martesia* enter the wood when they are very small, leaving a small entrance hole, and grow larger as they burrow into the wood. They generally do not exceed 64 mm (2-1/2 in.) long and 25 mm (1 in.) in diameter but are capable of doing considerable damage. Their activities in the United States appear to be confined to the Gulf Coast, San Diego, and Hawaii.

Limnoria and *Sphaeroma*

Another distinct group of marine borers are crustaceans, which are related to lobsters and shrimp. The principal borers in this group are species of *Limnoria* and *Sphaeroma*. Their attack differs from that of the shipworms and the *Martesia* in that the bore hole is quite shallow; the result is that the wood gradually is thinned from the surface inward through erosion by the combined action of the borers and water erosion. Also, the *Limnoria* and *Sphaeroma* do not become imprisoned in the wood but may move freely from place to place.

Limnoria are small, 3 to 4 mm (1/8 to 1/6 in.) long, and bore small burrows in the surface of wood. Although they can change their location, they usually continue to bore in one place. When great numbers of *Limnoria* are present, their burrows are separated by very thin walls of wood that are easily eroded by the motion of the water or damaged by objects floating upon it. This erosion causes the *Limnoria* to burrow continually deeper; otherwise, the burrows would probably not become greater than 51 mm (2 in.) long or 13 mm (1/2 in.) deep. Because erosion is greatest between tide levels, piles heavily attacked by *Limnoria* characteristically wear within this zone to an hourglass shape. In heavily infested harbors, untreated piling can be destroyed by *Limnoria* within a year.

Sphaeroma are somewhat larger, sometimes reaching a length of 13 mm (1/2 in.) and a width of 6 mm (1/4 in.). In general appearance and size, they resemble the common sow bug or pill bug that inhabits damp places. *Sphaeroma* are widely distributed but are not as plentiful as *Limnoria* and cause much less damage. Nevertheless, piles in some structures have been ruined by them. Occasionally, they have been found working in fresh water. In types of damage, *Sphaeroma* action resembles that of *Limnoria*. It has been reported that *Sphaeroma* attack salt-treated wood in Florida.

The average life of well-creosoted structures is many times the average life obtained from untreated structures. However, even thorough creosote treatment will not always stop *Martesia, Sphaeroma*, and especially *Limnoria*; shallow or erratic creosote penetration affords only slight protection. The spots with poor protection are attacked first, and from there, the borers spread inward and destroy the untreated interior of the pile.

When wood is to be used in salt water, avoidance of cutting or injuring the surface after treatment is even more important than when wood is to be used on land. No cutting or injury of any kind for any purpose should be permitted in the underwater part of the pile. Where piles are cut to grade above the waterline, the exposed surfaces should be protected from decay. This may be accomplished by in-place application of a wood preservative followed by a suitable capping compound.

Natural Resistance to Marine Borers

No wood is immune to marine-borer attack, and no commercially important wood of the United States has sufficient marine-borer resistance to justify its use untreated in any important structure in areas where borers are active. The heartwood of several foreign species, such as greenheart, jarrah, azobe, and manbarklak, has shown resistance to marine-borer attack. Service records on these woods, however, do not always show uniform results and are affected by local conditions.

Protection of Permanent Structures

The best practical protection for piles in sea water with shipworms and moderate *Limnoria* hazard is heavy treatment with coal-tar creosote or creosote coal-tar solution. Where severe *Limnoria* hazard exists, dual treatment (copper-arsenate-containing waterborne preservatives followed by coal-tar creosote) is recommended. The treatment must be thorough, the penetration as deep as possible, and the retention high to give satisfactory results in heavily infested waters. It is best to treat such piles by the full-cell process to refusal; that is, to force in all the preservative the piles can hold without using treatments that cause serious damage to the wood. For highest retentions, it is necessary to air- or kiln-dry the piling before treatment. Details of treatments are discussed in Chapter 14.

The life of treated piles is influenced by the thoroughness of the treatment, the care and diligence used in avoiding damage to the treated shell during handling and installation, and the severity of borer attack. Differences in exposure conditions, such as water temperature, salinity, dissolved oxygen, water depth, and currents, tend to cause wide variations in the severity of borer attack even within limited areas. Service records show average-life figures of 22 to 48 years on well-treated Douglas-fir piles in San Francisco Bay waters. In South Atlantic and Gulf of Mexico waters, creosoted piles are estimated to last 10 to 12 years and frequently much longer. On the North Atlantic Coast, where exposure conditions are less severe, piles can last even longer than the 22- to 48-year life recorded in the San Francisco Bay.

Metal armor and concrete or plastic jacketing have been used with varying degrees of success for the protection of marine piles. The metal armor may be in the form of sheets, wire, or nails. Sheathing of piles with copper or muntz metal has been only partially successful, owing to difficulty in maintaining a continuous armor. Theft, damage in driving, damage by storm or driftwood, and corrosion of sheathing have sooner or later let in the borers, and in only a few cases has long pile life been reported. Attempts during World War II to electroplate wood piles with copper were not successful. Concrete casings are now in greater use than is metal armor, and they appear to provide better protection when high-quality materials are used and carefully applied. Unfortunately, they are readily damaged by ship impact. For this reason, concrete casings are less practical for fender piles than for foundation piles that are protected from mechanical damage.

Jacketing piles by wrapping them with heavy polyvinyl plastic is one recent form of supplementary protection. If properly applied, the jacketing will kill any borers that may have already become established by creating stagnant water, thereby decreasing oxygen levels in the water that is in contact with the piles. Like other materials, the plastic jacket is subject to mechanical damage.

Protection of Boats

Wood barges have been constructed with planking or sheathing pressure-treated with creosote to protect the hull from marine borers, and the results have been favorable. Although coal-tar creosote is an effective preservative for protecting wood against marine borers in areas of moderate borer hazard, it has disadvantages in many types of boats. Creosote adds considerably to the weight of the boat hull, and its odor is objectionable to boat crews. In addition, antifouling paints are difficult to apply over creosoted wood.

Some copper bottom paints protect boat hulls against marine-borer attack, but the protection continues only while the coating remains unbroken. Because it is difficult to maintain an unbroken coating of antifouling paint, the U.S. Navy has found it desirable to impregnate the hull planking of some wood boats with certain copper-containing preservatives. Such preservatives, when applied with high retentions (24 to 32 kg/m^3 (1.5 to 2.0 lb/ft^3)), have some effectiveness against marine borers and should help to protect the hull of a boat during intervals between renewals of the antifouling coating. These copper preservatives do not provide protection equivalent to that furnished by coal-tar creosote; their effectiveness in protecting boats is therefore best assured if the boats are dry docked at regular and frequent intervals and the antifouling coating maintained. However, the leach-resistant wood preservatives containing copper arsenates have shown superior performance (at a retention of 40 kg/m^3 (2.5 lb/ft^3)) to creosote in tests conducted in areas of severe borer hazard.

Plywood as well as plank hulls can be protected against marine borers by preservative treatment. The plywood hull presents a surface that can be covered successfully with a protective membrane of reinforced plastic laminate. Such coverings should not be attempted on wood that has been treated with a preservative carried in oil, because the bond will be unsatisfactory.

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Chapter 14

Wood Preservation

Rebecca E. Ibach

Contents

When left untreated in many outdoor applications, wood becomes subject to degradation by a variety of natural causes. Although some trees possess naturally occurring resistance to decay (Ch. 3, Decay Resistance), many are in short supply or are not grown in ready proximity to markets. Because most commonly used wood species, such as Southern Pine, ponderosa pine, and Douglas-fir, possess little decay resistance, extra protection is needed when they are exposed to adverse environments. Wood can be protected from the attack of decay fungi, harmful insects, or marine borers by applying chemical preservatives. The degree of protection achieved depends on the preservative used and the proper penetration and retention of the chemicals. Some preservatives are more effective than others, and some are more adaptable to certain use requirements. Not only are different methods of treating wood available, but treatability varies among wood species—particularly their heartwood, which generally resists preservative treatment more than does sapwood. To obtain long-term effectiveness, adequate penetration and retention are needed for each wood species, chemical preservative, and treatment method.

Wood preservatives that are applied at recommended retention levels and achieve satisfactory penetration can greatly increase the life of wood structures. Thus, the annual replacement cost of treated wood in service is much less than that of wood without treatment. In considering preservative treatment processes and wood species, the combination must provide the required protection for the conditions of exposure and life of the structure. All these factors are considered by the consensus technical committees in setting reference levels required by the American Wood-Preservers' Association (AWPA), the American Society for Testing and Materials (ASTM), and the Federal Specification Standards. Details are discussed later in this chapter.

Note that mention of a chemical in this chapter does not constitute a recommendation; only those chemicals registered by the U.S. Environmental Protection Agency (EPA) may be recommended. Registration of preservatives is under constant review by EPA and the U.S. Department of Agriculture. Use only preservatives that bear an EPA registration number and carry directions for home and farm use. Preservatives, such as creosote and pentachlorophenol, should not be applied to the interior of dwellings that are occupied by humans.

Because all preservatives are under constant review by EPA, a responsible State or Federal agency should be consulted as to the current status of any preservative.

Wood Preservatives

The EPA regulates pesticides, and wood preservatives are one type of pesticide. Preservatives that are not restricted by EPA are available to the general consumer for nonpressure treatments, and the sale of others is restricted to certified pesticide applicators. These preservatives can be used only in certain applications and are referred to as “restricted use.” Restricted use refers to the chemical preservative and not to the treated wood product. The general consumer may buy and use wood products treated with restricted-use pesticides; EPA does not consider treated wood a toxic substance nor is it regulated as a pesticide.

Consumer Information Sheets (EPA-approved) are available from retailers of treated-wood products. The sheets provide information about the preservative and the use and disposal of treated-wood products. Consumer information sheets are available for three major groups of wood preservatives (Table 14–1):

- Creosote pressure-treated wood
- Pentachlorophenol pressure-treated wood
- Inorganic arsenical pressure-treated wood

Wood preservatives can be divided into two general classes: (1) oilborne preservatives, such as creosote and petroleum solutions of pentachlorophenol and (2) waterborne preservatives that are applied as water solutions. Many different chemicals are in each of these classes, and each has differing effectiveness in various exposure conditions. The three exposure categories for preservatives are (1) ground contact (high decay hazard that needs a heavy-duty preservative), (2) aboveground contact (low decay hazard that does not usually require pressure treatment), and (3) marine exposure (high decay hazard that needs a heavy-duty preservative or possibly dual treatment). In this chapter, both oilborne and waterborne preservative chemicals are described as to their potential and uses. See Table 14–2 for a summary of preservatives and their retention levels for various wood products. Some active ingredients can be used in both oilborne and waterborne preservatives.

Oilborne Preservatives

Wood does not swell from treatment with preservative oils, but it may shrink if it loses moisture during the treating process. Creosote and solutions with heavy, less volatile petroleum oils often help protect wood from weathering, but may adversely influence its cleanliness, odor, color, paintability, and fire performance. Volatile oils or solvents with oilborne preservatives, if removed after treatment, leave the wood cleaner than do the heavy oils but may not provide as much protection. Wood treated with some preservative oils can be glued satisfactorily, although special processing or cleaning may be required to remove surplus oils from surfaces before spreading the adhesive.

Coal-Tar Creosote

Coal-tar creosote (creosote) is a black or brownish oil made by distilling coal tar that is obtained after high temperature carbonization of coal. Advantages of creosote are (a) high toxicity to wood-destroying organisms; (b) relative insolubility in water and low volatility, which impart to it a great degree of permanence under the most varied use conditions; (c) ease of application; (d) ease with which its depth of penetration can be determined; (e) relative low cost (when purchased in wholesale quantities); and (f) lengthy record of satisfactory use.

The character of the tar used, the method of distillation, and the temperature range in which the creosote fraction is collected all influence the composition of the creosote. Therefore, the composition of the various coal-tar creosotes available may vary considerably. However, small differences in composition do not prevent creosotes from giving good service. Satisfactory results in preventing decay may generally be expected from any coal-tar creosote that complies with the requirements of standard specifications.

Several standards prepared by different organizations are available for creosote oils of different kinds. Although the oil obtained under most of these standards will probably be effective in preventing decay, the requirements of some organizations are more exacting than others. The American Society for Testing and Materials Standard D390 for coal-tar creosote has been approved for use by U.S. Department of Defense agencies. This standard covers new coal-tar creosote and creosote in use for the preservative treatment of piles, poles, and timber for marine, land, and fresh water use. Under normal conditions, requirements of this standard can be met without difficulty by most creosote producers. The requirements of this specification are similar to those of the AWPA standard P1/P13 for creosote, which is equally acceptable to the user.

Although coal-tar creosote (AWPA P1/P13) or creosote solutions (AWPA P2) are well-suited for general outdoor service in structural timbers, this creosote has properties that are undesirable for some purposes. The color of creosote and the fact that creosote-treated wood usually cannot be painted satisfactorily make this preservative unsuitable where appearance and paintability are important. Creosote is commonly used for heavy timbers, poles, piles, and railroad ties.

The odor of creosote-treated wood is unpleasant to some people. Also, creosote vapors are harmful to growing plants, and foodstuffs that are sensitive to odors should not be stored where creosote odors are present. Workers sometimes object to creosote-treated wood because it soils their clothes, and creosote vapor photosensitizes exposed skin. With normal precautions to avoid direct skin contact with creosote, there appears to be no danger to the health of workers handling or working near the treated wood. The EPA or the treater should be contacted for specific information on this subject.

Table 14–1. EPA-approved consumer information sheets for three major groups of preservative pressure-treated wood

Preservative treatment	Inorganic arsenicals	Pentachlorophenol	Creosote
Consumer information	This wood has been preserved by pressure-treatment with an EPA-registered pesticide containing inorganic arsenic to protect it from insect attack and decay. Wood treated with inorganic arsenic should be used only where such protection is important. Inorganic arsenic penetrates deeply into and remains in the pressure-treated wood for a long time. Exposure to inorganic arsenic may present certain hazards. Therefore, the following precautions should be taken both when handling the treated wood and in determining where to use or dispose of the treated wood.	This wood has been preserved by pressure-treatment with an EPA-registered pesticide containing pentachlorophenol to protect it from insect attack and decay. Wood treated with pentachlorophenol should be used only where such protection is important. Pentachlorophenol penetrates deeply into and remains in the pressure-treated wood for a long time. Exposure to pentachlorophenol may present certain hazards. Therefore, the following precautions should be taken both when handling the treated wood and in determining where to use and dispose of the treated wood.	This wood has been preserved by pressure treatment with an EPA-registered pesticide containing creosote to protect it from insect attack and decay. Wood treated with creosote should be used only where such protection is important. Creosote penetrates deeply into and remains in the pressure-treated wood for a long time. Exposure to creosote may present certain hazards. Therefore, the following precautions should be taken both when handling the treated wood and in determining where to use the treated wood.
Handling precautions	Dispose of treated wood by ordinary trash collection or burial. Treated wood should not be burned in open fires or in stoves, fireplaces, or residential boilers because toxic chemicals may be produced as part of the smoke and ashes. Treated wood from commercial or industrial use (e.g., construction sites) may be burned only in commercial or industrial incinerators or boilers in accordance with state and Federal regulations. Avoid frequent or prolonged inhalation of sawdust from treated wood. When sawing and machining treated wood, wear a dust mask. Whenever possible, these operations should be performed outdoors to avoid indoor accumulations of airborne sawdust from treated wood. When power-sawing and machining, wear goggles to protect eyes from flying particles. After working with the wood, and before eating, drinking, and using tobacco products, wash exposed areas thoroughly. If preservatives or sawdust accumulate on clothes, launder before reuse. Wash work clothes separately from other household clothing.	Dispose of treated wood by ordinary trash collection or burial. Treated wood should not be burned in open fires or in stoves, fireplaces, or residential boilers because toxic chemicals may be produced as part of the smoke and ashes. Treated wood from commercial or industrial use (e.g., construction sites) may be burned only in commercial or industrial incinerators or boilers rated at 20 million BTU/hour or greater heat input or its equivalent in accordance with state and Federal regulations. Avoid frequent or prolonged inhalation of sawdust from treated wood. When sawing and machining treated wood, wear a dust mask. Whenever possible, these operations should be performed outdoors to avoid indoor accumulations of airborne sawdust from treated wood. Avoid frequent or prolonged skin contact with pentachlorophenol-treated wood. When handling the treated wood, wear long-sleeved shirts and long pants and use gloves impervious to the chemicals (for example, gloves that are vinyl-coated). When power-sawing and machining, wear goggles to protect eyes from flying particles. After working with the wood, and before eating, drinking, and using tobacco products, wash exposed areas thoroughly. If oily preservatives or sawdust accumulate on clothes, launder before reuse. Wash work clothes separately from other household clothing.	Dispose of treated wood by ordinary trash collection or burial. Treated wood should not be burned in open fires or in stoves, fireplaces, or residential boilers, because toxic chemicals may be produced as part of the smoke and ashes. Treated wood from commercial or industrial use (e.g., construction sites) may be burned only in commercial or industrial incinerators or boilers in accordance with state and Federal regulations. Avoid frequent or prolonged inhalations of sawdust from treated wood. When sawing and machining treated wood, wear a dust mask. Whenever possible these operations should be performed outdoors to avoid indoor accumulations of airborne sawdust from treated wood. Avoid frequent or prolonged skin contact with creosote-treated wood; when handling the treated wood, wear long-sleeved shirts and long pants and use gloves impervious to the chemicals (for example, gloves that are vinyl-coated). When power-sawing and machining, wear goggles to protect eyes from flying particles. After working with the wood and before eating, drinking, and using tobacco products, wash exposed areas thoroughly. If oily preservative or sawdust accumulate on clothes, launder before reuse. Wash work clothes separately from other household clothing.

Table 14–1. EPA-approved consumer information sheets for three major groups of preservative pressure-treated wood—con.

Preservative treatment	Inorganic arsenicals	Pentachlorophenol	Creosote
Use site precautions	Wood pressure-treated with waterborne arsenical preservatives may be used inside residences as long as all sawdust and construction debris are cleaned up and disposed of after construction. Do not use treated wood under circumstances where the preservative may become a component of food or animal feed. Examples of such sites would be structures or containers for storing silage or food. Do not use treated wood for cutting boards or countertops. Only treated wood that is visibly clean and free of surface residue should be used for patios, decks, and walkways. Do not use treated wood for construction of those portions of beehives that may come into contact with the honey. Treated wood should not be used where it may come into direct or indirect contact with public drinking water, except for uses involving incidental contact such as docks and bridges.	Logs treated with pentachlorophenol should not be used for log homes. Wood treated with pentachlorophenol should not be used where it will be in frequent or prolonged contact with bare skin (for example, chairs and other outdoor furniture), unless an effective sealer has been applied. Pentachlorophenol-treated wood should not be used in residential, industrial, or commercial interiors except for laminated beams or building components that are in ground contact and are subject to decay or insect infestation and where two coats of an appropriate sealer are applied. Sealers may be applied at the installation site. Urethane, shellac, latex epoxy enamel, and varnish are acceptable sealers for pentachlorophenol-treated wood. Wood treated with pentachlorophenol should not be used in the interiors of farm buildings where there may be direct contact with domestic animals or livestock that may crib (bite) or lick the wood. In interiors of farm buildings where domestic animals or livestock are unlikely to crib (bite) or lick the wood, pentachlorophenol-treated wood may be used for building components which are in ground contact and are subject to decay or insect infestation and where two coats of an appropriate sealer are applied. Sealers may be applied at the installation site. Do not use pentachlorophenol-treated wood for farrowing or brooding facilities. Do not use treated wood under circumstances where the preservative may become a component of food or animal feed. Examples of such sites would be structures or containers for storing silage or food. Do not use treated wood for cutting boards or countertops. Only treated wood that is visibly clean and free of surface residue should be used for patios, decks, and walkways. Do not use treated wood for construction of those portions of beehives that may come into contact with the honey. Pentachlorophenol-treated wood should not be used where it may come into direct or indirect contact with public drinking water, except for uses involving incidental contact such as docks and bridges. Do not use pentachlorophenol-treated wood where it may come into direct or indirect contact with drinking water for domestic animals or livestock, except for uses involving incidental contact such as docks and bridges.	Wood treated with creosote should not be used where it will be in frequent or prolonged contact with bare skin (for example, chairs and other outdoor furniture) unless an effective sealer has been applied. Creosote-treated wood should not be used in residential interiors. Creosote-treated wood in interiors of industrial buildings should be used only for industrial building components that are in ground contact and are subject to decay or insect infestation and for wood-block flooring. For such uses, two coats of an appropriate sealer must be applied. Sealers may be applied at the installation site. Wood treated with creosote should not be used in the interiors of farm buildings where there may be direct contact with domestic animals or livestock that may crib (bite) or lick the wood. In interiors of farm buildings where domestic animals or livestock are unlikely to crib (bite) or lick the wood, creosote-treated wood may be used for building components that are in ground contact and are subject to decay or insect infestation if two coats of an effective sealer are applied. Sealers may be applied at the installation site. Coal-tar pitch and coal-tar pitch emulsion are effective sealers for creosote-treated wood-block flooring. Urethane, epoxy, and shellac are acceptable sealers for all creosote-treated wood. Do not use creosote-treated wood for farrowing or brooding facilities. Do not use treated wood under circumstances where the preservative may become a component of food or animal feed. Examples of such use would be structures or containers for storing silage or food. Do not use treated wood for cutting boards or countertops. Only treated wood that is visibly clean and free of surface residues should be used for patios, decks, and walkways. Do not use treated wood for construction of those portions of beehives that may come into contact with the honey. Creosote-treated wood should not be used where it may come into direct or indirect contact with public drinking water, except for uses involving incidental contact such as docks and bridges. Do not use creosote-treated wood where it may come into direct or indirect contact with drinking water for domestic animals or livestock, except for uses involving incidental contact such as docks and bridges.

Table 14–2. Creosote, oilborne, and waterborne preservatives and retention levels for various wood products[a]

Form of product and service condition	Creosote and oilborne preservative retention (kg/m^3 (lb/ft^3)) Creosote	Creosote solutions	Creosote-petroleum	Pentachlorophenol, P9, Type A	Pentachlorophenol, P9, Type E	Copper naphthenate	Oxine copper	AWPA standard
A. Ties (crossties and switch ties)	96–128 (6–8)	112–128 (7–8)	112–128 (7–8)	5.6–6.4 (0.35–0.4)	NR	NR	NR	C2/C6
B. Lumber, timber, plywood; bridge and mine ties								
(1) Salt water[b]	400 (25)	400 (25)	NR	NR	NR	NR	NR	C2/C9
(2) Soil and fresh water	160 (10)	160 (10)	160 (10)	8 (0.50)	NR	0.96 (0.06)	NR	C2/C9
(3) Above ground	128 (8)	128 (8)	128 (8)	6.41 (0.40)	6.4 (0.40)	0.64 (0.04)	0.32 (0.02)	C2/C9
C. Piles								
(1) Salt water[b]								C3/C14/C18
Borer hazard, moderate	320 (20)	320 (20)	NR	NR	NR	NR	NR	
Borer hazard, severe	NR	NR	NR	NR	NR	NR	NR	
Dual treatment	320 (20)	320 (20)	NR	NR	NR	NR	NR	
(2) Soil, fresh water, or foundation	96–272 (6–17)	96–272 (6–17)	96–272 (6–17)	4.8–13.6 (0.30–0.85)	NR	1.60 (0.10)	NR	C3/C14/C24
D. Poles (length >5 m (>16 ft))								
(1) Utility	120–256 (7.5–16)	120–256 (7.5–16)	120–256 (7.5–16)	4.8–12.8 (0.30–0.80)	NR	1.2–2.4 (0.075–0.15)	NR	C4
(2) Building, round and sawn	144–216 (9–13.5)	NR	NR	7.2–10.9 (0.45–0.68)	NR	NR	NR	C4/C23/C24
(3) Agricultural, round and sawn	120–256 (7.5–16)	120–256 (7.5–16)	NR, round (sawn, 192 (12))	6.1–9.6 (0.38–0.60)	NR	NR, round (sawn, 1.2 (0.075))	NR	C4/C16
E. Posts (length <5 m (<16 ft))								
(1) Agricultural, round and sawn, fence	128–160 (8–10)	128–160 (8–10)	128–160 (8–10)	6.4–8.0 (0.40–0.50)	NR	sawn, 0.96 (0.060)	round, 0.88 (0.055)	C2/C5/C16
(2) Commercial–residential construction, round and sawn	128–192 (8–12)	128–192 (8–12)	128–192 (8–12)	8–9.6 (0.50–0.60)	NR	NR	NR	C2/C5/C15/C23
(3) Highway construction								
Fence, guide, sign, and sight	128–160 (8–10)	128–160 (8–10)	128–160 (8–10)	6.4–8.1 (0.40–0.50)	NR	sawn four sides, 0.96 (0.06)	NR	C2/C5/C14
Guardrail and spacer blocks	160–192 (10–12)	160–192 (10–12)	160–192 (10–12)	8–9.6 (0.50–0.60)	NR	sawn four sides, 1.2 (0.075)	NR	C2/C5/C14
F. Glued-laminated timbers/laminates								
(1) Soil and fresh water	160 (10)	160 (10)	160 (10)	9.6 (0.60)	NR	9.6 (0.60)	NR	C28
(2) Above ground	128 (8)	128 (8)	128 (8)	4.8 (0.30)	NR	6.4 (0.40)	3.2 (0.20)	C28

Table 14–2. Creosote, oilborne, and waterborne preservatives and retention levels for various wood products[a]—con.

Form of product and service condition	Waterborne preservative retention (kg/m³ (lb/ft³)) ACC	ACZA or ACA	CCA Types I, II, or III	ACQ Type B	ACQ Type D	CDDC as Cu	CC	CBA Type A	AWPA standard
A. Ties (crossties and switch ties)	NR	NR	NR	NR	NR	NR	NR	NR	C2/C6
B. Lumber, timber, plywood; bridge and mine ties									
(1) Salt water[b]	NR	40 (2.50)	40 (2.50)	NR	NR	NR	40 (2.50)	NR	C2/C9
(2) Soil and fresh water	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	3.2 (0.20)	6.4 (0.40)	NR	C2/C9
(3) Above ground[c]	4.0 (0.25)	4.0 (0.25)	4.0 (0.25)	4.0 (0.25)	4.0 (0.25)	1.6 (0.10)	4.0 (0.25)	3.27 (0.20)	C2/C9
C. Piles									
(1) Salt water[b]									C3/C14/ C18
Borer hazard, moderate	NR	24 (1.5)	24.1 (1.5)	NR	NR	NR	NR	NR	
Borer hazard, severe	NR	40 (2.50)	40 (2.50)	NR	NR	NR	NR	NR	
Dual treatment	NR	16 (1.00)	16 (1.00)	NR	NR	NR	NR	NR	
(2) Soil, fresh water or foundation	NR	12–16 (0.80–1.0)	12–16 (0.80–1.0)	NR	NR	NR	NR	NR	C3/C14/ C24
D. Poles (length >5 m (>16 ft))									
(1) Utility	NR	9.6 (0.60)	9.6 (0.60)	9.6 (0.60)	NR	NR	NR	NR	C4
(2) Building, round and sawn timber	NR	9.6–12.8 (0.60–0.80)	9.6–12.8 (0.60–0.80)	9.6 (0.60)	9.6 (0.60)	3.2 (0.2)	NR	NR	C4/C23/ C24
(3) Agricultural, round and sawn	NR	9.6 (0.60)	9.6 (0.60)	9.6 (0.60)	NR	NR	NR	NR	C4/C16
E. Posts (length < 5 m (<16 ft))									
(1) Agricultural, round and sawn, fence	NR	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	NR	NR	NR	NR	C2/C5/ C16
(2) Commercial–residential construction, round and sawn	8 (0.50), (NR, sawn structural members)	6.4–9.6 (0.40–0.60)	6.4–9.6 (0.40–0.60)	6.4–9.6 (0.40–0.60)	6.4–9.6 (0.40–0.6)	3.2 (0.20)	6.4 (0.4), (NR, sawn structural members)	NR	C2/C5/ C15/ C23
(3) Highway construction									
Fence, guide, sign, and sight	8–9.9 (0.50–0.62)	6.4 (0.40)	6.4 (0.40)	6.4 (0.40)	NR	NR	NR	NR	C2/C5/ C14
Guardrail and spacer blocks	NR	8 (0.50)	8 (0.50)	8 (0.50)	NR	NR	NR	NR	C2/C5/ C14
F. Glued- laminated timbers/laminates									
(1) Soil and fresh water	8 (0.50)[d]	6.4 (0.40)[d]	6.4 (0.40)[d]	NR	NR	NR	NR	NR	C28
(2) Above ground	3.2 (0.20)	4 (0.25)	4 (0.25)	NR	NR	NR	NR	NR	C28

[a]Retention levels are those included in Federal Specification TT–W–571 and Commodity Standards of the American Wood Preservers' Association. Refer to the current issues of these specifications for up-to-date recommendations and other details. In many cases, the retention is different depending on species and assay zone. Retentions for lumber, timber, plywood, piles, poles, and fence posts are determined by assay of borings of a number and location as specified in Federal Specification TT–W–571 or in the Standards of the American Wood Preservers' Association referenced in last column. Unless noted, all waterborne preservative retention levels are specified on an oxide basis. NR is not recommended.
[b]Dual treatments are recommended when marine borer activity is known to be high (see AWPA C2, C3, C14, and C18 for details).
[c]For use when laminations are treated prior to bonding.

In 1986, creosote became a restricted-use pesticide and is available only to certified pesticide applicators. For use and handling of creosote-treated wood, refer to the EPA-approved Consumer Information Sheet (Table 14–1).

Freshly creosoted timber can be ignited and burns readily, producing a dense smoke. However, after the timber has seasoned for some months, the more volatile parts of the oil disappear from near the surface and the creosoted wood usually is little, if any, easier to ignite than untreated wood. Until this volatile oil has evaporated, ordinary precautions should be taken to prevent fires. Creosote adds fuel value, but it does not sustain ignition.

Coal-Tar Creosotes for Nonpressure Treatments

Special coal-tar creosotes are available for nonpressure treatments, although these creosotes can only be purchased by licensed pesticide applicators. Special coal-tar creosotes differ somewhat from regular commercial coal-tar creosote in (a) being crystal-free to flow freely at ordinary temperatures and (b) having low-boiling distillation fractions removed to reduce evaporation in thermal (hot and cold) treatments in open tanks. Consensus standards do not exist for coal-tar creosote applied by brush, spray, or open-tank treatments.

Other Creosotes

Creosotes distilled from tars other than coal tar are used to some extent for wood preservation, although they are not included in current Federal or AWPA specifications. These include wood-tar creosote, oil-tar creosote, and water–gas-tar creosote. These creosotes protect wood from decay and insect attack but are generally less effective than coal-tar creosote.

Creosote Solution

For many years, either coal tar or petroleum oil has been mixed with coal-tar creosote, in various proportions, to lower preservative costs. These creosote solutions have a satisfactory record of performance, particularly for railroad ties and posts where surface appearance of the treated wood is of minor importance.

The ASTM D391 "Creosote–Coal-Tar Solution" standard covers creosote–coal-tar solution for use in the preservative treatment of wood. This standard has been approved for use by agencies of the U.S. Department of Defense. This specification contains four grades of creosote solutions:

- A (land and fresh water), contains no less than 80% coal-tar distillate (creosote) by volume
- B (land and fresh water), contains no less than 70% coal-tar distillate (creosote) by volume
- C (land and fresh water), contains no less than 60% coal-tar distillate (creosote) by volume
- Marine

The AWPA standard P2 similarly describes the requirements for creosote solutions. The AWPA standard P3 (for creosote–petroleum oil solution) stipulates that creosote–petroleum oil solution shall consist solely of specified proportions of 50% coal-tar creosote by volume (which meets AWPA standard P1/P13) and 50% petroleum oil by volume (which meets AWPA standard P4). However, because no analytical standards exist to verify the compliance of P3 solutions after they have been mixed, the consumer assumes the risk of using these solutions.

Compared with straight creosote, creosote solutions tend to reduce weathering and checking of the treated wood. These solutions have a greater tendency to accumulate on the surface of the treated wood (bleed) and penetrate the wood with greater difficulty because they are generally more viscous than is straight creosote. High temperatures and pressures during treatment, when they can be safely used, will often improve penetration of high viscosity solutions.

Even though petroleum oil and coal tar are less toxic to wood-destroying organisms and mixtures of the two are also less toxic in laboratory tests than is straight creosote, a reduction in toxicity does not necessarily imply less preservative protection. Creosote–petroleum and creosote–coal-tar solutions help reduce checking and weathering of the treated wood. Posts and ties treated with standard formulations of these solutions have frequently shown better service than those similarly treated with straight coal-tar creosote.

Pentachlorophenol Solutions

Water-repellent solutions containing chlorinated phenols, principally pentachlorophenol (penta), in solvents of the mineral spirits type, were first used in commercial dip treatments of wood by the millwork industry about 1931. Commercial pressure treatment with pentachlorophenol in heavy petroleum oils on poles started about 1941, and considerable quantities of various products soon were pressure treated. The standard AWPA P8 defines the properties of pentachlorophenol preservative. Pentachlorophenol solutions for wood preservation shall contain not less than 95% chlorinated phenols, as determined by titration of hydroxyl and calculated as pentachlorophenol. The performance of pentachlorophenol and the properties of the treated wood are influenced by the properties of the solvent used.

The AWPA P9 standard defines solvents and formulations for organic preservative systems. A commercial process using pentachlorophenol dissolved in liquid petroleum gas (LPG) was introduced in 1961, but later research showed that field performance of penta/LPG systems was inferior to penta/P9 systems. Thus, penta/LPG systems are no longer used.

The heavy petroleum solvent included in AWPA P9 Type A is preferable for maximum protection, particularly when wood treated with pentachlorophenol is used in contact with the ground. The heavy oils remain in the wood for a long time and do not usually provide a clean or paintable surface.

Pentachlorophenol in AWPA P9, Type E solvent (dispersion in water), is only approved for aboveground use in lumber, timber, bridge ties, mine ties, and plywood for southern pines, coastal Douglas-fir, and redwood (Table 14–2; AWPA C2 and C9).

Because of the toxicity of pentachlorophenol, care is necessary when handling and using it to avoid excessive personal contact with the solution or vapor. Do not use indoors or where human, plant, or animal contact is likely. Pentachlorophenol became a restricted-use pesticide in November 1986 and is only available to certified applicators. For use and handling precautions, refer to the EPA-approved Consumer Information Sheet (Table 14–1).

The results of pole service and field tests on wood treated with 5% pentachlorophenol in a heavy petroleum oil are similar to those with coal-tar creosote. This similarity has been recognized in the preservative retention requirements of treatment specifications. Pentachlorophenol is effective against many organisms, such as decay fungi, molds, stains, and insects. Because pentachlorophenol is ineffective against marine borers, it is not recommended for the treatment of marine piles or timbers used in coastal waters.

Copper Naphthenate

Copper naphthenate is an organometalic compound that is a dark-green liquid and imparts this color to the wood. Weathering turns the color of the treated wood to light brown after several months of exposure. The wood may vary from light brown to chocolate-brown if heat is used in the treating process. The AWPA P8 standard defines the properties of copper naphthenate, and AWPA P9 covers the solvents and formulations for organic preservative systems.

Copper naphthenate is effective against wood-destroying fungi and insects. It has been used commercially since the 1940s for many wood products (Table 14–2). It is a reaction product of copper salts and naphthenic acids that are usually obtained as byproducts in petroleum refining. Copper naphthenate is not a restricted-use pesticide but should be handled as an industrial pesticide. It may be used for superficial treatment, such as by brushing with solutions with a copper content of 1% to 2% (approximately 10% to 20% copper naphthenate).

Chlorothalonil

Chlorothalonil (CTL) [tetrachloroisophthalonitrile] is an organic biocide that is used to a limited extent for mold control in CCA-treated wood (AWPA P8). It is effective against wood decay fungi and wood-destroying insects. The CTL has limited solubility in organic solvents and very low solubility in water, but it exhibits good stability and leach resistance in wood. This preservative is being evaluated for both aboveground and ground contact applications. The solvent used in the formulation of the preservative is AWPA P9 Type A.

Chlorothalonil/Chlorpyrifos

Chlorothalonil/chlorpyrifos (CTL/CPF) is a preservative system composed of two active ingredients (AWPA P8). The ratio of the two components depends upon the retention specified. CTL is an effective fungicide, and CPF is very effective against insect attack. The solvent used for formulation of this preservative is specified in AWPA P9.

Oxine Copper (copper-8-quinolinolate)

Oxine copper (copper-8-quinolinolate) is an organometalic compound, and the formulation consists of at least 10% copper-8-quinolinolate, 10% nickel-2-ethylhexanoate, and 80% inert ingredients (AWPA P8). It is accepted as a stand-alone preservative for aboveground use for sapstain and mold control and is also used for pressure treating (Table 14–2). A water-soluble form can be made with dodecylbenzene sulfonic acid, but the solution is corrosive to metals.

Oxine copper solutions are greenish brown, odorless, toxic to both wood decay fungi and insects, and have a low toxicity to humans and animals. Because of its low toxicity to humans and animals, oxine copper is the only EPA-registered preservative permitted by the U.S. Food and Drug Administration for treatment of wood used in direct contact with food. Some examples of its uses in wood are commercial refrigeration units, fruit and vegetable baskets and boxes, and water tanks. Oxine copper solutions have also been used on nonwood materials, such as webbing, cordage, cloth, leather, and plastics.

Zinc Naphthenate

Zinc naphthenate is similar to copper naphthenate but is less effective in preventing decay from wood-destroying fungi and mildew. It is light colored and does not impart the characteristic greenish color of copper naphthenate, but it does impart an odor. Waterborne and solventborne formulations are available. Zinc naphthenate is not used for pressure treating and is not intended as a stand-alone preservative.

Bis(tri-n-butyltin) Oxide

Bis(tri-n-butyltin) oxide, commonly called TBTO, is a colorless to slightly yellow organotin compound that is soluble in many organic solvents but insoluble in water. It is not used for pressure treating or as a stand-alone preservative for in-ground use. TBTO concentrate contains at least 95% bis(tri-n-butyltin) oxide by weight and from 38.2% to 40.1% tin (AWPA P8). This preservative has lower mammalian toxicity, causes less skin irritation, and has better paintability than does pentachlorophenol, but it is not effective against decay when used in ground contact. Therefore, TBTO is recommended only for aboveground use, such as millwork. It has been used as a marine antifoulant, but this use has been almost eliminated because of the environmental impact of tin on shellfish.

3-Iodo-2-Propynyl Butyl Carbamate

3-Iodo-2-propynyl butyl carbamate (IPBC) is a preservative that is intended for nonstructural, aboveground use only (for example, millwork). It is not used for pressure treating applications such as decks. The IPBC preservative is included as the primary fungicide in several water-repellent-preservative formulations under the trade name Polyphase and marketed by retail stores. However, it is not an effective insecticide. Waterborne and solventborne formulations are available. Some formulations yield an odorless, treated product that can be painted if dried after treatment. IPBC is also being used in combination with didecyldimethylammonium chloride in a sapstain–mold formulation (NP–1). IPBC contains 97% 3-iodo-2-propynyl butyl carbamate, with a minimum of 43.4% iodine (AWPA P8).

Alkyl Ammonium Compound

Alkyl ammonium compound (AAC) or didecyldimethylammonium chloride (DDAC) is a compound that is effective against wood decay fungi and insects. It is soluble in both organic solvents and water and is stable in wood as a result of chemical fixation reactions. It is currently being used as a component of ammoniacal copper quat (ACQ) (see section on Waterborne Preservatives) for aboveground and ground contact and is a component of NP–1 for sapstain and mold control.

Propiconazole

Propiconazole is an organic triazole biocide that is effective against wood decay fungi but not against insects (AWPA P8). It is soluble in some organic solvents, but it has low solubility in water and is stable and leach resistant in wood. It is currently being used commercially for aboveground and sapstain control application in Europe and Canada. Solvents used in the formulation of the preservative are specified in either AWPA P9 Type C or Type F.

4,5-Dichloro-2-N-Octyl-4-Isothiazolin-3-One

4,5-dichloro-2-N-octyl-4-isothiazolin-3-one is a biocide that is effective against wood decay fungi and insects. It is soluble in organic solvents, but not in water, and is stable and leach resistant in wood. This biocide is not currently being used as a wood preservative. The solvent used in the formulation of the preservative is specified in AWPA P9 Type C.

Tebuconazole

Tebuconazole (TEB) is an organic triazole biocide that is effective against wood decay fungi, but its efficacy against insects has not yet been evaluated. It is soluble in organic solvents but not in water, and it is stable and leach resistant in wood. Currently, TEB has no commercial application. The solvents used in the formulation of this preservative are specified in either AWPA P9 Type C or Type F.

Chlorpyrifos

Chlorpyrifos (CPF) is a preservative recently put into standard (AWPA P8). It is very effective against insect attack but not fungal attack. If fungal attack is a concern, then CPF should be combined with an appropriate fungicide, such as chlorothalonil/chlorpyrifos or IPBC/chlorpyrifos.

Water-Repellent and Nonpressure Treatments

Effective water-repellent preservatives will retard the ingress of water when wood is exposed above ground. Therefore, these preservatives help reduce dimensional changes in the wood as a result of moisture changes when the wood is exposed to rainwater or dampness for short periods. As with any wood preservative, the effectiveness in protecting wood against decay and insects depends upon the retention and penetration obtained in application. These preservatives are most often applied using nonpressure treatments like brushing, soaking, or dipping.

Preservative systems containing water-repellent components are sold under various trade names, principally for the dip or equivalent treatment of window sash and other millwork. Many are sold to consumers for household and farm use. Federal specification TT–W–572 stipulates that such preservatives (a) be dissolved in volatile solvents, such as mineral spirits, (b) do not cause appreciable swelling of the wood, and (c) produce a treated wood product that meets a performance test on water repellency.

The preservative chemicals in Federal specification TT–W–572 may be one of the following:

- Not less than 5% pentachlorophenol
- Not less than 1% copper in the form of copper naphthenate
- Not less than 2% copper in the form of copper naphthenate for tropical conditions
- Not less than 0.045% copper in the form of oxine copper for uses when foodstuffs will be in contact with the treated wood

The National Wood Window and Door Association (NWWDA) standard for water-repellent preservative nonpressure treatment for millwork, IS 4–94, permits other preservatives, provided the wood preservative is registered for use by the EPA under the latest revision of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and that all water-repellent preservative formulations are tested for effectiveness against decay according to the soil block test (NWWDA TM1).

The AWPA Standard N1 for nonpressure treatment of millwork components also states that any water-repellent preservative formulation must be registered for use by the EPA under the latest revision of FIFRA. The preservative must also meet the *Guidelines for Evaluating New Wood Preservatives for Consideration by the AWPA* for nonpressure treatment.

Water-repellent preservatives containing oxine copper are used in nonpressure treatment of wood containers, pallets, and other products for use in contact with foods. When combined with volatile solvents, oxine copper is used to pressure-treat lumber intended for use in decking of trucks and cars or related uses involving harvesting, storage, and transportation of foods (AWPA P8).

Waterborne Preservatives

Waterborne preservatives are often used when cleanliness and paintability of the treated wood are required. Several formulations involving combinations of copper, chromium, and arsenic have shown high resistance to leaching and very good performance in service. Waterborne preservatives are included in specifications for items such as lumber, timber, posts, building foundations, poles, and piling.

Test results based on sea water exposure have shown that dual treatment (waterborne copper-containing salt preservatives followed by creosote) is possibly the most effective method of protecting wood against all types of marine borers. The AWPA standards have recognized this process as well as the treatment of marine piles with high retention levels of ammoniacal copper arsenate (ACA), ammoniacal copper zinc arsenate (ACZA), or chromated copper arsenate (CCA). The recommended treatment and retention in kilograms per cubic meter (pounds per cubic foot) for round timber piles exposed to severe marine borer hazard are given in Table 14–3. Poorly treated or untreated heartwood faces of wood species containing "high sapwood" that do not require heartwood penetration (for example, southern pines, ponderosa pine, and red pine) have been found to perform inadequately in marine exposure. In marine applications, only sapwood faces should be allowed for waterborne-preservative-treated pine in direct sea water exposure.

Waterborne preservatives leave the wood surface comparatively clean, paintable, and free from objectionable odor. CCA and acid copper chromate (ACC) must be used at low treating temperatures (38ºC to 66ºC (100ºF to 150ºF)) because they are unstable at higher temperatures. This restriction may involve some difficulty when higher temperatures are needed to obtain good treating results in woods such as Douglas-fir. Because water is added to the wood in the treatment process, the wood must be dried after treatment to the moisture content required for the end use intended.

Inorganic arsenicals are a restricted-use pesticide. For use and handling precautions of pressure-treated wood containing inorganic arsenicals, refer to the EPA-approved Consumer Information Sheet (Table 14–1).

Standard wood preservatives used in water solution include ACC, ACZA, and CCA (Types A and C). Other preservatives in AWPA P5 include alkyl ammonium compound (AAC) and inorganic boron. Waterborne wood preservatives, without arsenic or chromium, include ammoniacal copper quat (ACQ) (Types B and D), copper bis(dimethyldithiocarbamate) (CDDC), ammoniacal copper citrate (CC), and copper azole–Type A (CBA–A), for aboveground use only.

Acid Copper Chromate

Acid copper chromate (ACC) contains 31.8% copper oxide and 68.2% chromium trioxide (AWPA P5). The solid, paste, liquid concentrate, or treating solution can be made of copper sulfate, potassium dichromate, or sodium dichromate. Tests on stakes and posts exposed to decay and termite attack indicate that wood well-impregnated with ACC gives acceptable service, but it is more prone to leaching than are most other waterborne preservatives. Use of ACC is generally limited to cooling towers that cannot allow arsenic leachate in cooling water.

Ammoniacal Copper Zinc Arsenate

Ammoniacal copper zinc arsenate (ACZA) is used in the United States but not in Canada. It is commonly used on the West Coast for the treatment of Douglas-fir. The penetration

Table 14–3. Preservative treatment and retention necessary to protect round timber piles from severe marine borer attack

Treatment	Retention (kg/m³ (lb/ft³)) Southern Pine, red pine	Retention (kg/m³ (lb/ft³)) Coastal Douglas-fir	AWPA standard
Limnoria tripunctata only			
Ammoniacal copper arsenate	40 (2.50), (24 (1.5))[a]	40 (2.50)	C3, C18
Ammoniacal copper zinc arsenate	40 (2.50), (24 (1.5))[a]	40 (2.50)	C3, C18
Chromated copper arsenate	40 (2.50) (24 (1.5))[a]	Not recommended	C3, C18
Creosote	320 (20), (256 (16))[a]	320 (20)	C3, C18
Limnoria tripunctata and Pholads (dual treatment)			
First treatment			
Ammoniacal copper arsenate	16 (1.0)	16 (1.0)	C3, C18
Ammoniacal copper zinc arsenate	16 (1.0)	16 (1.0)	C3, C18
Chromated copper arsenate	16 (1.0)	16 (1.0)	C3, C18
Second treatment			
Creosote	320 (20.0)	320 (20.0)	C3, C18
Creosote solution	320 (20.0)	Not recommended	C3, C18

[a]Lower retention levels are for marine piling used in areas from New Jersey northward on the East Coast and north of San Francisco on the West Coast in the United States.

of Douglas-fir heartwood is improved with ACZA because of the chemical composition and stability of treating at elevated temperatures. Wood treated with ACZA performs and has characteristics similar to those of wood treated with CCA (Table 14–2).

ACZA should contain approximately 50% copper oxide, 25% zinc oxide, and 25% arsenic pentoxide dissolved in a solution of ammonia in water (AWPA P5). The weight of ammonia is at least 1.38 times the weight of copper oxide. To aid in solution, ammonium bicarbonate is added (at least equal to 0.92 times the weight of copper oxide).

A similar formulation, ammoniacal copper arsenate (ACA), is used in Canada. This preservative is used most commonly to treat refractory species, such as Douglas-fir. Service records on structures treated with ACA show that this preservative provides protection against decay and termites. High retention levels of preservative will provide extended service life to wood exposed to the marine environment, provided pholad-type borers are not present. ACZA replaced ACA in the United States because ACZA has less arsenic and is less expensive than ACA.

Chromated Copper Arsenate

Three types of chromated copper arsenate (CCA)—Types A, B, C—are covered in AWPA P5, but Type C is by far the most commonly used formulation. The compositions of the three types are given in Table 14–4. Standard P5 permits substitution of potassium or sodium dichromate for chromium trioxide; copper sulfate, basic copper carbonate, or copper hydroxide for copper oxide; and arsenic acid, sodium arsenate, or pyroarsenate for arsenic pentoxide.

1. CCA Type A (Greensalt)—Currently, CCA Type A is only being used by a few treaters in California. CCA Type A is high in chromium. Service data on treated poles, posts, and stakes installed in the United States since 1938 have shown that CCA Type A provides excellent protection against decay fungi and termites.

2. CCA Type B (K–33) —Commercial use of this preservative in the United States started in 1964, but it is no longer used in significant quantities. CCA Type B is high in arsenic and has been commercially used in Sweden since 1950. It was included in stake tests in the United States in 1949 and has been providing excellent protection.

3. CCA Type C (Wolman)—Currently, Type C is by far the most common formulation of CCA being used because it has the best leach resistance and field efficacy of the three CCA formulations. CCA Type C composition was selected by AWPA technical committees to encourage a single standard for CCA preservatives. Commercial preservatives of similar composition have been tested and used in England since 1954, then in Australia, New Zealand, Malaysia, and in various countries of Africa and Central Europe; they are performing very well.

High retention levels (40 kg/m^3 (2.5 lb/ft^3)) of the three types of CCA preservative will provide good resistance to *Limnoria* and *Teredo* marine borer attack. In general, Douglas-fir heartwood is very resistant to treatment with CCA.

Ammoniacal Copper Quat

There are basically two types of ammoniacal copper quat (ACQ) preservatives (AWPA P5):

- Type B (ACQ–B) [ammoniacal]
- Type D (ACQ–D) [amine-based]

The compositions of these two types are given in Table 14–5. ACQ is used for many of the same applications as are ACZA and CCA, but it is not recommended for use in salt water. ACQ–B, the ammoniacal formulation, is better able to penetrate difficult to treat species such as Douglas-fir; ACQ–D provides a more uniform surface appearance. Wood products treated with ACQ Type B and D are included in the AWPA Commodity Standards (Table 14–2).

Copper bis(dimethyldithiocarbamate)

Copper bis(dimethyldithiocarbamate) (CDDC) is a reaction product formed in wood as a result of the dual treatment of two separate treating solutions. The first treating solution contains a maximum of 5% bivalent copper–ethanolamine (2-aminoethanol), and the second treating solution contains a minimum of 2.5% sodium dimethyldithiocarbamate

Table 14–4. Composition of the three types of chromated copper arsenate[a]

	Chromated copper arsenate (parts by weight)		
Component	Type A	Type B	Type C
Chromium trioxide	65.5	35.3	47.5
Copper oxide	18.1	19.6	18.5
Arsenic pentoxide	16.4	45.1	34.0

[a]As covered in AWPA P5.

Table 14–5. Composition of two types of ammoniacal copper quat[a]

	Ammoniacal cooper quat (parts by weight)	
Component	Type B	Type D
Copper oxide	66.7	66.7
Quat as DDAC[b]	33.3	33.3
Formulation	ammoniacal	amine

[a]As covered in AWPA P5.
[b]DDAC is didecyldimethylammonium chloride.

(AWPA P5). CDDC-treated wood products are included in the AWPA Commodity Standards (Table 14–2) for uses such as residential construction. Like CCA and ACQ–D, CDDC is not recommended for treatment of refractory species such as Douglas-fir.

Ammoniacal Copper Citrate

Ammoniacal copper citrate (CC) has 62.3% copper as copper oxide and 35.8% citric acid dissolved in a solution of ammonia in water (AWPA P5). CC-treated wood products are included in the AWPA Commodity Standards (Table 14–2). Like other ammonia-based preservatives, CC can be used to treat refractory species such as Douglas-fir.

Copper Azole–Type A

Copper azole–Type A (CBA–A) has 49% copper as Cu, 49% boron as boric acid, and 2% azole as tebuconazole dissolved in a solution of ethanolamine in water (AWPA P5). Wood products treated with CBA–A are included in the AWPA Commodity Standards for aboveground use only (Table 14–2).

Inorganic Boron (Borax/Boric Acid)

Borate preservatives are readily soluble in water, are highly leachable, and should only be used above ground where the wood is protected from wetting. When used above ground and protected from wetting, this preservative is very effective against decay, termites, beetles, and carpenter ants. Borates are odorless and can be sprayed, brushed, or injected. They will diffuse into wood that is wet; therefore, these preservatives are often used as a remedial treatment. Borates are widely used for log homes, natural wood finishes, and hardwood pallets.

The solid or treating solution for borate preservatives (borates) should be greater than 98% pure, on an anhydrous basis (AWPA P5). Acceptable borate compounds are sodium octaborate, sodium tetraborate, sodium pentaborate, and boric acid. These compounds are derived from the mineral sodium borate, which is the same material used in laundry additives.

Preservative Effectiveness

Preservative effectiveness is influenced not only by the protective value of the preservative chemical, but also by the method of application and extent of penetration and retention of the preservative in the treated wood. Even with an effective preservative, good protection cannot be expected with poor penetration or substandard retention levels. The species of wood, proportion of heartwood and sapwood, heartwood penetrability, and moisture content are among the important variables that influence the results of treatment. For various wood products, the preservatives and retention levels listed in Federal Specification TT–W–571 and the AWPA Commodity Standards are given in Table 14–2.

Few service tests include a variety of preservatives under comparable conditions of exposure. Furthermore, service tests may not show a good comparison between different preservatives as a result of the difficulty in controlling the previously mentioned variables. Such comparative data under similar exposure conditions, with various preservatives and retention levels, are included in the USDA Forest Service, Forest Products Laboratory, stake test study on Southern Pine sapwood (Gutzmer and Crawford 1995). A summary of these test results is included in Table 14–6.

In the same manner, a comparison of preservative treatments in marine exposure (Key West, Florida) of small wood panels is included in Johnson and Gutzmer (1990). These preservatives and treatments include creosotes with and without supplements, waterborne preservatives, waterborne preservative and creosote dual treatments, chemical modifications of wood, and various chemically modified polymers. In this study, untreated panels were badly damaged by marine borers after 6 to 18 months of exposure while some treated panels have remained free of attack after 19 years in the sea.

Effect of Species on Penetration

The effectiveness of preservative treatment is influenced by the penetration and distribution of the preservative in the wood. For maximum protection, it is desirable to select species for which good penetration is best assured.

The heartwood of some species is difficult to treat. There may be variations in the resistance to preservative penetration of different wood species. Table 14–7 gives the relative resistance of the heartwood to treatment of various softwood and hardwood species (MacLean 1952).

In general, the sapwood of most softwood species is not difficult to treat under pressure. Examples of species with sapwood that is easily penetrated when it is well dried and pressure treated are the pines, coastal Douglas-fir, western larch, Sitka spruce, western hemlock, western redcedar, northern white-cedar, and white fir (*A. concolor*). Examples of species with sapwood and heartwood somewhat resistant to penetration are the red and white spruces and Rocky Mountain Douglas-fir. Cedar poles are commonly incised to obtain satisfactory preservative penetration. With round members, such as poles, posts, and piles, the penetration of the sapwood is important in achieving a protective outer zone around the heartwood.

The heartwood of most species resists penetration of preservatives, but well-dried white fir, western hemlock, northern red oak, the ashes, and tupelo are examples of species with heartwood that is reasonably easy to penetrate. The southern pines, ponderosa pine, redwood, Sitka spruce, coastal Douglas-fir, beech, maples, and birches are examples of species with heartwood that is moderately resistant to penetration.

Table 14–6. Results of Forest Products Laboratory studies on 5- by 10- by 46-cm (2- by 4- by 18-in.) Southern Pine sapwood stakes, pressure-treated with commonly used wood preservatives, installed at Harrison Experimental Forest, Mississippi

Preservative	Average retention (kg/m^3 (lb/ft^3))[a]	Average life (year) or condition at last inspection
Control (untreated stakes)		1.8 to 3.6 years
Acid copper chromate	2.08 (0.13)	11.6 years
	2.24 (0.14)	6.1 years
	4.01 (0.25)	70% failed after 24 years
	4.17 (0.26)	60% failed after 46 years
	4.65 (0.29)	4.6 years
	5.93 (0.37)	50% failed after 46 years
	8.01 (0.50)	40% failed after 24 years
	12.18 (0.76)	20% failed after 24 years
Ammoniacal copper borate	2.72 (0.17)	65% failed after 16 years
	3.52 (0.22)	30% failed after 16 years
	5.29 (0.33)	10% failed after 16 years
	7.21 (0.45)	5% failed after 16 years
	.41 (0.65)	5% failed after 16 years
	21.31 (1.33)	No failures after 16 years
Ammoniacal copper arsenate	2.56 (0.16)	60% failed after 16 years
	3.52 (0.22)	10% failed after 16 years
	3.84 (0.24)	67% failed after 47 years
	4.01 (0.25)	20% failed after 24 years
	7.37 (0.46)	10% failed after 24 years
	8.17 (0.51)	10% failed after 47 years
	15.54 (0.97)	No failures after 47 years
	20.02 (1.25)	No failures after 47 years
Chromated copper arsenate	2.40 (0.15)	70% failed after 46 years
Type I	3.52 (0.22)	30% failed after 24 years
	4.65 (0.29)	30% failed after 46 years
	7.05 (0.44)	10% failed after 24 years
	7.05 (0.44)	10% failed after 46 years
Type II	3.68 (0.23)	30% failed after 24 years
	4.17 (0.26)	10% failed after 42 years
	5.93 (0.37)	No failures after 42 years
	8.33 (0.52)	No failures after 42 years
	12.66 (0.79)	No failures after 42 years
	16.66 (1.04)	No failures after 42 years
Type III	2.24 (0.14)	No failures after 12-1/2 years
	3.20 (0.20)	No failures after 20 years
	4.01 (0.25)	No failures after 14 years
	4.33 (0.27)	No failures after 12-1/2 years
	6.41 (0.40)	No failures after 20 years
	6.41 (0.40)	No failures after 14 years
	6.41 (0.40)	No failures after 12-1/2 years
	9.61 (0.60)	No failures after 20 years
	9.93 (0.62)	No failures after 12-1/2 years
	12.34 (0.77)	No failures after 14 years
	12.66 (0.79)	No failures after 12-1/2 years
Chromated zinc arsenate	1.76 (0.11)	22.1 years
	3.52 (0.22)	33.0 years
	4.65 (0.29)	89% failed after 51-1/2 years
	3.20 (0.20)	10% failed after 40 years
	6.41 (0.40)	No failures after 40 years
	8.49 (0.53)	No failures after 40 years
	6.09 (0.38)	40% failed after 51-1/2 years
	8.33 (0.52)	10% failed after 51-1/2 years
	11.21 (0.70)	No failures after 51-1/2 years

Table 14–6. Results of Forest Products Laboratory studies on 5- by 10- by 46-cm (2- by 4- by 18-in.) Southern Pine sapwood stakes, pressure-treated with commonly used wood preservatives, installed at Harrison Experimental Forest, Mississippi—con.

Preservative	Average retention (kg/m^3 (lb/ft^3))[a]	Average life (year) or condition at last inspection
Chromated zinc chloride	4.81 (0.30)	14.2 years
	7.53 (0.47)	20.2 years
	7.37 (0.46)	13.7 years
	10.09 (0.63)	20.1 years
	9.93 (0.62)	14.9 years
	14.74 (0.92)	23.4 years
	15.38 (0.96	90% failed after 24 years
	28.52 (1.78)	32.7 years
		90% failed after 38 years
	58.79 (3.67)	No failures after 38 years
Oxine copper	0.16 (0.01)	5.3 years
(Copper-8-quinolinoate)	0.32 (0.02)	4.2 years
Stoddard solvent	0.96 (0.06)	5.6 years
	1.92 (0.12)	7.8 years
Oxine copper	0.22 (0.014)	80% failed after 28 years
(Copper-8-quinolinolate)	0.48 (0.03)	70% failed after 28 years
AWPA P9 heavy petroleum	0.95 (0.059)	20% failed after 28 years
	1.99 (0.124)	No failures after 28 years
Copper naphthenate		
0.11% copper in No. 2 fuel oil	0.19 (0.012)	15.9 years
0.29% copper in No. 2 fuel oil	0.46 (0.029)	21.8 years
0.57% copper in No. 2 fuel oil	0.98 (0.061)	27.2 years
0.86% copper in No. 2 fuel oil	1.31 (0.082)	29.6 years
Creosote, coal-tar	52.87 (3.3)	24.9 years
	65.68 (4.1)	14.2 years
	67.28 (4.2)	17.8 years
	73.69 (4.6)	21.3 years
	124.96 (7.8)	70% failed after 49-1/2 years
	128.24 (8.0)	80% failed after 51-1/2 years
	132.97 (8.3)	40% failed after 42 years
	160.2 (10.0)	90% failed after 51 years
	189.04 (11.8)	30% failed after 51-1/2 years
	211.46 (13.2)	20% failed after 49-1/2 years
	232.29 (14.5)	No failures after 51 years
	264.33 (16.5)	No failures after 51-1/2 years
Low residue, straight run	128.16 (8.0)	17.8 years
Medium residue, straight run	128.16 (8.0)	18.8 years
High residue, straight run	124.96 (7.8)	20.3 years
Medium residue, low in tar acids	129.76 (8.1)	19.4 years
Low in naphthalene	131.36 (8.2)	21.3 years
Low in tar acids and naphthalene	128.16 (8.0)	18.9 years
Low residue, low in tar acids and naphthalene	128.16 (8.0)	19.2 years
High residue, low in tar acids and naphthalene	131.36 (8.2)	20.0 years
English vertical retort	84.91 (5.3)	80% failed after 44 years
	128.16 (8.0)	18.9 years
	161.80 (10.1)	80% failed after 44 years
	240.30 (15.0)	No failures after 44 years
English coke oven	75.29 (4.7)	16.3 years
	126.56 (7.9)	13.6 years
	161.80 (10.1)	70% failed after 44 years
	237.10 (14.8)	70% failed after 44 years

Table 14–6. Results of Forest Products Laboratory studies on 5- by 10- by 46-cm (2- by 4- by 18-in.) Southern Pine sapwood stakes, pressure-treated with commonly used wood preservatives, installed at Harrison Experimental Forest, Mississippi—con.

Preservative	Average retention (kg/m^3 (lb/ft^3))[a]	Average life (year) or condition at last inspection
Fluor chrome arsenate phenol type A	1.92 (0.12)	10.2 years
	3.04 (0.19)	18.0 years
	3.52 (0.22)	18.3 years
	4.97 (0.31)	18.5 years
	6.09 (0.38)	24.1 years
Pentachlorophenol (various solvents)		
Liquefied petroleum gas	2.24 (0.14)	90% failed after 30-1/2 years
	3.04 (0.19)	15.9 years
	5.45 (0.34)	No failures after 30-1/2 years
	5.45 (0.34)	70% failed after 28 years
	7.85 (0.49)	No failures after 28 years
	9.29 (0.58)	No failures after 30-1/2 years
	10.41 (0.65)	No failures after 28 years
Stoddard solvent (mineral spirits)	2.24 (0.14)	13.7 years
	2.88 (0.18)	15.9 years
	3.20 (0.20)	9.5 years
	3.20 (0.20)	13.7 years
	6.09 (0.38)	40% failed after 30-1/2 years
	6.41 (0.40)	15.5 years
	10.73 (0.67)	No failures after 30-1/2 years
Heavy gas oil (Mid-United States)	3.20 (0.20)	67% failed after 44-1/2 years
	6.41 (0.40)	60% failed after 44-1/2 years
	9.61 (0.60)	10% failed after 44-1/2 years
No. 4 aromatic oil (West Coast)	3.36 (0.21)	21.0 years
	6.57 (0.41)	50% failed after 42 years
AWPA P9 (heavy petroleum)	1.76 (0.11)	80% failed after 30-1/2 years
	3.04 (0.19)	No failures after 30-1/2 years
	4.65 (0.29)	No failures after 30-1/2 years
	8.49 (0.53)	No failures after 28 years
	10.73 (0.67)	No failures after 30-1/2 years
Tributyltin oxide		
Stoddard solvent	0.24 (0.015)	6.3 years
	0.40 (0.025)	4.5 years
	0.48 (0.030)	7.2 years
	0.72 (0.045)	7.4 years
	0.75 (0.047)	7.0 years
AWPA P9 (heavy petroleum)	0.38 (0.024)	20.8 years
	0.77 (0.048)	24.0 years
Petroleum solvent controls	64.08 (4.0)	7.6 years
	65.68 (4.1)	4.4 years
	75.29 (4.7)	12.9 years
	123.35 (7.7)	14.6 years
	126.56 (7.9)	90% failed after 44-1/2 years
	128.16 (8.0)	19.7 years
	128.16 (8.0)	23.3 years
	128.16 (8.0)	14.6 years
	129.76 (8.1)	3.4 years
	136.17 (8.5)	90% failed after 28 years
	157.00 (9.8)	6.3 years
	192.24 (12.0)	17.1 years
	193.84 (12.1)	20% failed after 44-1/2 years
	310.79 (19.4)	9.1 years

[a]Retention values are based on preservative oxides or copper metal.

Table 14–7. Penetration of the heartwood of various softwood and hardwood species[a]

Ease of treatment	Softwoods	Hardwoods
Least difficult	Bristlecone pine (*Pinus aristata*)	American basswood (*Tilia americana*)
	Pinyon (*P. edulis*)	Beech (white heartwood) (*Fagus grandifolia*)
	Pondersosa pine (*P. pondersosa*)	Black tupelo (blackgum) (*Nyssa sylvatica*)
	Redwood (*Sequoia sempervirens*)	Green ash (*Fraxinus pennsylvanica* var. *lanceolata*)
		Pin cherry (*Prunus pensylvanica*)
		River birch (*Betula nigra*)
		Red oaks (*Quercus* spp.)
		Slippery elm (*Ulmus fulva*)
		Sweet birch (*Betula lenia*)
		Water tupelo (*Nyssa aquatica*)
		White ash (*Fraxinus americana*)
Moderately difficult	Baldcypress (*Taxodium distichum*)	Black willow (*Salix nigra*)
	California red fir (*Abies magnifica*)	Chestnut oak (*Quercus montana*)
	Douglas-fir (coast) *(Pseudotsuga taxifolia)*)	Cottonwood (*Populus* sp.)
	Eastern white pine (*Pinus strobus*)	Bigtooth aspen (*P. grandidentata*)
	Jack pine (*P. banksiana*)	Mockernut hickory (*Carya tomentosa*)
	Loblolly pine (*P. taeda*)	Silver maple (*Acer saccharinum*)
	Longleaf pine (*P. palustris*)	Sugar maple (*A. saccharum*)
	Red pine (*P. resinosa*)	Yellow birch (*Betula lutea*)
	Shortleaf pine (*P. echinata*)	
	Sugar pine (*P. lambertiana*)	
	Western hemlock (*Tsuga heterophylla*)	
Difficult	Eastern hemlock (*Tsuga canadensis*)	American sycamore (*Platanus occidentalis*)
	Engelmann spruce (*Picea engelmanni*)	Hackberry (*Celtis occidentalis*)
	Grand fir (*Abies grandis*)	Rock elm (*Ulmus thomoasi*)
	Lodgepole pine (*Pinus contorta* var. *latifolia*)	Yellow-poplar (*Liriodendron tulipifera*)
	Noble fir (*Abies procera*)	
	Sitka spruce (*Picea sitchensis*)	
	Western larch (*Larix occidentalis*)	
	White fir (*Abies concolor*)	
	White spruce (*Picea glauca*)	
Very difficult	Alpine fir (*Abies lasiocarpa*)	American beech (red heartwood) (*Fagus grandifolia*)
	Corkbark fir (*A. lasiocarpa* var. *arizonica*)	American chestnut (*Castanea dentata*)
	Douglas-fir (Rocky Mountain) (*Pseudotsuga taxifolia*)	Black locust (*Robinia pseudoacacia*)
	Northern white-cedar (*Thuja occidentalis*)	Blackjack oak (*Quercus marilandica*)
	Tamarack (*Larix laricina*)	Sweetgum (redgum) (*Liquidambar styraciflua*)
	Western redcedar (*Thuja plicata*)	White oaks (*Quercus* spp.)

[a]As covered in MacLean (1952).

Preparation of Timber for Treatment

For satisfactory treatment and good performance, the timber must be sound and suitably prepared. Except in specialized treating methods involving unpeeled or green material, the wood should be well peeled and either seasoned or conditioned in the cylinder before treatment. It is also highly desirable that all machining be completed before treatment. Machining may include incising to improve the preservative penetration in woods that are resistant to treatment, as well as the operations of cutting or boring of holes.

Peeling

Peeling round or slabbed products is necessary to enable the wood to dry quickly enough to avoid decay and insect damage and to permit the preservative to penetrate satisfactorily. Even strips of the thin inner bark may prevent penetration. Patches of bark left on during treatment usually fall off in time and expose untreated wood, thus permitting decay to reach the interior of the member.

Careful peeling is especially important for wood that is to be treated by a nonpressure method. In the more thorough processes, some penetration may take place both longitudinally and tangentially in the wood; consequently, small strips of bark are tolerated in some specifications. Processes in which a preservative is forced or permitted to diffuse through green wood lengthwise do not require peeling of the timber. Machines of various types have been developed for peeling round timbers, such as poles, piles, and posts (Fig. 14–1).

Drying

Drying of wood before treatment is necessary to prevent decay and stain and to obtain preservative penetration. However, for treatment with waterborne preservatives by certain diffusion methods, high moisture content levels may be permitted. For treatment by other methods, however, drying before treatment is essential. Drying before treatment opens up the checks before the preservative is applied, thus increasing penetration, and reduces the risk of checks opening after treatment and exposing unpenetrated wood. Good penetration of heated organic-based preservatives may be possible in wood with a moisture content as high as 40% to 60%, but severe checking while drying after treatment can expose untreated wood.

For large timbers and railroad ties, air drying is a widely used method of conditioning. Despite the increased time, labor, and storage space required, air drying is generally the most inexpensive and effective method, even for pressure treatment. However, wet, warm climatic conditions make it difficult to air dry wood adequately without objectionable infection by stain, mold, and decay fungi. Such infected wood is often highly permeable; in rainy weather, infected wood can absorb a large quantity of water, which prevents satisfactory treatment.

Figure 14–1. Machine peeling of poles. The outer bark has been removed by hand, and the inner bark is being peeled by machine. Frequently, all the bark is removed by machine.

How long the timber must be air dried before treatment depends on the climate, location, and condition of the seasoning yard, methods of piling, season of the year, timber size, and species. The most satisfactory seasoning practice for any specific case will depend on the individual drying conditions and the preservative treatment to be used. Therefore, treating specifications are not always specific as to moisture content requirements.

To prevent decay and other forms of fungal infection during air drying, the wood should be cut and dried when conditions are less favorable for fungus development (Ch. 13). If this is impossible, chances for infection can be minimized by prompt conditioning of the green material, careful piling and roofing during air drying, and pretreating the green wood with preservatives to protect it during air drying.

Lumber of all species, including Southern Pine poles, is often kiln dried before treatment, particularly in the southern United States where proper air seasoning is difficult. Kiln drying has the important added advantage of quickly reducing moisture content, thereby reducing transportation charges on poles.

Conditioning of Green Products

Plants that treat wood by pressure processes can condition green material by means other than air and kiln drying. Thus, they avoid a long delay and possible deterioration of the timber before treatment.

When green wood is to be treated under pressure, one of several methods for conditioning may be selected. The steaming-and-vacuum process is used mainly for southern pines, and the Boulton or boiling-under-vacuum process is used for Douglas-fir and sometimes hardwoods.

In the steaming process, the green wood is steamed in the treating cylinder for several hours, usually at a maximum of 118ºC (245ºF). When steaming is completed, a vacuum is immediately applied. During the steaming period, the outer part of the wood is heated to a temperature approaching that of the steam; the subsequent vacuum lowers the boiling point so that part of the water is evaporated or forced out of the wood by the steam produced when the vacuum is applied. The steaming and vacuum periods used depend upon the wood size, species, and moisture content. Steaming and vacuum usually reduce the moisture content of green wood slightly, and the heating assists greatly in getting the preservative to penetrate. A sufficiently long steaming period will also sterilize the wood.

In the Boulton or boiling-under-vacuum method of partial seasoning, the wood is heated in the oil preservative under vacuum, usually at about 82ºC to 104ºC (180ºF to 220ºF). This temperature range, lower than that of the steaming process, is a considerable advantage in treating woods that are especially susceptible to injury from high temperatures. The Boulton method removes much less moisture from heartwood than from sapwood.

Incising

Wood that is resistant to penetration by preservatives may be incised before treatment to permit deeper and more uniform penetration. To incise, lumber and timbers are passed through rollers equipped with teeth that sink into the wood to a predetermined depth, usually 13 to 19 mm (1/2 to 3/4 in.). The teeth are spaced to give the desired distribution of preservative with the minimum number of incisions. A machine of different design is required for deeply incising the butts of poles, usually to a depth of 64 mm (2.5 in.) (Fig. 14–2).

The effectiveness of incising depends on the fact that preservatives usually penetrate into wood much farther in the longitudinal direction than in a direction perpendicular to the faces of the timber. The incisions open cell lumens along the grain, which greatly enhances penetration. Incising is especially effective in improving penetration in the heartwood areas of sawn surfaces.

Incising is practiced primarily on Douglas-fir, western hemlock, and western larch ties and timbers for pressure treatment and on cedar and Douglas-fir poles. Incising can result in significant reductions in strength (Ch. 4).

Cutting and Framing

All cutting and boring of holes should be done prior to preservative treatment. Cutting into the wood in any way after treatment will frequently expose the untreated interior of the timber and permit ready access to decay fungi or insects.

Figure 14–2. Deep incising permits better penetration of preservative.

In some cases, wood structures can be designed so that all cutting and framing is done before treatment. Railroad companies have followed this practice and have found it not only practical but economical. Many wood-preserving plants are equipped to carry on such operations as the adzing and boring of crossties; gaining, roofing, and boring of poles; and framing of material for bridges and specialized structures, such as water tanks and barges.

Treatment of the wood with preservative oils results in little or no dimensional change. With waterborne preservatives, however, some change in the size and shape of the wood may occur even though the wood is redried to the moisture content it had before treatment. If precision fitting is necessary, the wood is cut and framed before treatment to its approximate final dimensions to allow for slight surfacing, trimming, and reaming of bolt holes. Grooves and bolt holes for timber connectors are cut before treatment and can be reamed out if necessary after treatment.

Application of Preservatives

Wood-preserving methods are of two general types: (a) pressure processes, in which the wood is impregnated in closed vessels under pressures considerably above atmospheric, and (b) nonpressure processes, which vary widely in the procedures and equipment used.

Pressure Processes

In commercial practice, wood is most often treated by immersing it in a preservative in a high pressure apparatus and applying pressure to drive the preservative into the wood. Pressure processes differ in details, but the general principle is the same. The wood, on cars or trams, is run into a long steel cylinder (Fig. 14–3), which is then closed and filled with preservative. Pressure forces the preservative into the wood until the desired amount has been absorbed. Considerable preservative is absorbed, with relatively deep penetration. Three pressure processes are commonly used: full-cell, modified full-cell, and empty-cell.

Full-Cell

The full-cell (Bethel) process is used when the retention of a maximum quantity of preservative is desired. It is a standard procedure for timbers to be treated full-cell with creosote when protection against marine borers is required. Waterborne preservatives are generally applied by the full-cell process, and control over preservative retention is obtained by regulating the concentration of the treating solution. Steps in the full-cell process are essentially the following:

1. The charge of wood is sealed in the treating cylinder, and a preliminary vacuum is applied for a half-hour or more to remove the air from the cylinder and as much as possible from the wood.
2. The preservative, at ambient or elevated temperature depending on the system, is admitted to the cylinder without breaking the vacuum.
3. After the cylinder is filled, pressure is applied until the wood will take no more preservative or until the required retention of preservative is obtained.
4. When the pressure period is completed, the preservative is withdrawn from the cylinder.
5. A short final vacuum may be applied to free the charge from dripping preservative.

When the wood is steamed before treatment, the preservative is admitted at the end of the vacuum period that follows steaming. When the timber has received preliminary conditioning by the Boulton or boiling-under-vacuum process, the cylinder can be filled and the pressure applied as soon as the conditioning period is completed.

Modified Full-Cell

The modified full-cell process is basically the same as the full-cell process except for the amount of initial vacuum and the occasional use of an extended final vacuum. The modified full-cell process uses lower levels of initial vacuum; the actual amount is determined by the wood species, material size, and final retention desired.

Empty-Cell

The objective of the empty-cell process is to obtain deep penetration with a relatively low net retention of preservative. For treatment with oil preservatives, the empty-cell process should always be used if it will provide the desired retention. Two empty-cell processes, the Rueping and the Lowry, are commonly employed; both use the expansive force of compressed air to drive out part of the preservative absorbed during the pressure period.

The Rueping empty-cell process, often called the empty-cell process with initial air, has been widely used for many years in Europe and the United States. The following general procedure is employed:

1. Air under pressure is forced into the treating cylinder, which contains the charge of wood. The air penetrates some species easily, requiring but a few minutes application of pressure. In treating the more resistant species, common practice is to maintain air pressure from 1/2 to 1 h before admitting the preservative, but the necessity for lengthy air-pressure periods does not seem fully established. The air pressures employed generally range between 172 to 689 kPa (25 to 100 lb/in^2), depending on the net retention of preservative desired and the resistance of the wood.
2. After the period of preliminary air pressure, preservative is forced into the cylinder. As the preservative is pumped in, the air escapes from the treating cylinder into an equalizing or Rueping tank, at a rate that keeps the pressure constant within the cylinder. When the treating cylinder is filled with preservative, the treating pressure is increased above that of the initial air and is maintained until the wood will absorb no more preservative, or until enough has been absorbed to leave the required retention of preservative in the wood after the treatment.

Figure 14–3. Interior view of treating cylinder at wood-preserving plant, with a load about to come in.

3. At the end of the pressure period, the preservative is drained from the cylinder, and surplus preservative is removed from the wood with a final vacuum. The amount of preservative recovered can be from 20% to 60% of the gross amount injected.

The Lowry is often called the empty-cell process without initial air pressure. Preservative is admitted to the cylinder without either an initial air pressure or a vacuum, and the air originally in the wood at atmospheric pressure is imprisoned during the filling period. After the cylinder is filled with the preservative, pressure is applied, and the remainder of the treatment is the same as described for the Rueping treatment.

The Lowry process has the advantage that equipment for the full-cell process can be used without other accessories that the Rueping process usually requires, such as an air compressor, an extra cylinder or Rueping tank for the preservative, or a suitable pump to force the preservative into the cylinder against the air pressure. However, both processes have advantages and are widely and successfully used.

With poles and other products where bleeding of preservative oil is objectionable, the empty-cell process is followed by either heating in the preservative (expansion bath) at a maximum of 104ºC (220ºF) or a final steaming for a specified time limit at a maximum of 116ºC (240ºF) prior to the final vacuum.

Treating Pressures and Preservative Temperatures

The pressures used in treatments vary from about 345 to 1,723 kPa (50 to 250 lb/in^2), depending on the species and the ease with which the wood takes the treatment; most commonly, pressures range from about 862 to 1,207 kPa (125 to 175 lb/in^2). Many woods are sensitive to high treating pressures, especially when hot. For example, AWPA standards permit a maximum pressure of 1,034 kPa (150 lb/in^2) in the treatment of Douglas-fir, 862 kPa (125 lb/in^2) for redwood, and 1,723 kPa (250 lb/in^2) for oak. In commercial practice, even lower pressures are frequently used on such woods.

The AWPA C1 standard requires that the temperature of creosote and creosote solutions, as well as that of the oilborne preservatives, during the pressure period shall not be greater than 93ºC (200ºF) for Western redcedar and 99ºC (210ºF) for all other species. With a number of waterborne preservatives, especially those containing chromium salts, maximum temperatures are limited to avoid premature precipitation of the preservative. The AWPA specifications require that the temperature of the preservative during the entire pressure period not exceed the maximum of 49ºC (120ºF) for ACC and CCA and 60ºC (150ºF) for ACA, CC, ACQ Type B, ACQ Type D, ACZA, CBA–A, and CDDC. The limit for inorganic boron is 93ºC (200ºF).

Penetration and Retention

Penetration and retention requirements are equally important in determining the quality of preservative treatment. Penetration levels vary widely, even in pressure-treated material. In most species, heartwood is more difficult to penetrate than sapwood. In addition, species differ greatly in the degree to which their heartwood may be penetrated. Incising tends to improve penetration of preservative in many refractory species, but those highly resistant to penetration will not have deep or uniform penetration even when incised. Penetration in unincised heart faces of these species may occasionally be as deep as 6 mm (1/4 in.) but is often not more than 1.6 mm (1/16 in.).

Experience has shown that even slight penetration has some value, although deeper penetration is highly desirable to avoid exposing untreated wood when checks occur, particularly for important members that are costly to replace. The heartwood of coastal Douglas-fir, southern pines, and various hardwoods, although resistant, will frequently show transverse penetrations of 6 to 12 mm (1/4 to 1/2 in.) and sometimes considerably more.

Complete penetration of the sapwood should be the ideal in all pressure treatments. It can often be accomplished in small-size timbers of various commercial woods, and with skillful treatment, it may often be obtained in piles, ties, and structural timbers. Practically, however, the operator cannot always ensure complete penetration of sapwood in every piece when treating large pieces of round material with thick sapwood, for example, poles and piles. Therefore, specifications permit some tolerance. For instance, AWPA C4 for Southern Pine poles requires that 63 mm (2-1/2 in.) or 85% of the sapwood thickness be penetrated for 96 kg/m^3 (6 lb/ft^3) retention of creosote. This applies only to the smaller class of poles. The requirements vary, depending on the species, size, class, and specified retention levels.

At one time, all preservative retention levels were specified in terms of the weight of preservative per cubic foot (0.028 m^3) of wood treated, based on total weight of preservative retained and the total volume of wood treated in a charge. This is commonly called gauge retention. However, specifications for most products now stipulate a minimum retention of preservative as determined from chemical analysis of borings from specified zones of the treated wood, known as a "assay-retention" or results-type specification.

The preservatives and retention levels listed in Federal Specification TT–W–571 and the AWPA Commodity Standards are shown in Table 14–2. The retention levels are often a range. The current issues of these specifications should be referenced for up-to-date recommendations and other details. In many cases, the retention level is different depending on species and assay zone. Higher preservative retention levels are justified in products to be installed under severe climatic or exposure conditions. Heavy-duty transmission poles and items with a high replacement cost, such as structural timbers and house foundations, are required to be treated to higher retention levels. Correspondingly, deeper penetration or heartwood limitations are also necessary for the same reasons.

It may be necessary to increase retention levels to ensure satisfactory penetration, particularly when the sapwood is either unusually thick or is somewhat resistant to treatment. To reduce bleeding of the preservative, however, it may be desirable to use preservative-oil retention levels less than the stipulated minimum. Treatment to refusal is usually specified for woods that are resistant to treatment and will not absorb sufficient preservative to meet the minimum retention requirements. However, such a requirement does not ensure adequate penetration of preservative, should be avoided, and must not be considered as a substitute for results-type specification in treatment.

Nonpressure Processes

The numerous nonpressure processes differ widely in the penetration and retention levels of preservative attained, and consequently in the degree of protection they provide to the treated wood. When similar retention and penetration levels are achieved, wood treated by a nonpressure method should have a service life comparable to that of wood treated by pressure. Nevertheless, results of nonpressure treatments, particularly those involving surface applications, are not generally as satisfactory as those of pressure treatment. The superficial processes do serve a useful purpose when more thorough treatments are impractical or exposure conditions are such that little preservative protection is required.

Nonpressure methods, in general, consist of (a) surface application of preservatives by brushing or brief dipping,

(b) soaking in preservative oils or steeping in solutions of waterborne preservatives, (c) diffusion processes with waterborne preservatives, (d) vacuum treatment, and (e) a variety of miscellaneous processes.

Surface Applications

The simplest treatment is to apply the preservative to the wood with a brush or by dipping. Preservatives that are thoroughly liquid when cold should be selected, unless it is possible to heat the preservative. The preservative should be flooded over the wood rather than merely painted. Every check and depression in the wood should be thoroughly filled with the preservative, because any untreated wood left exposed provides ready access for fungi. Rough lumber may require as much as 40 L of oil per 100 m^2 (10 gallons of oil per 1,000 ft^2) of surface, but surfaced lumber requires considerably less. The transverse penetration obtained will usually be less than 2.5 mm (1/10 in.), although in easily penetrated species, end-grain (longitudinal) penetration is considerably greater. The additional life obtained by such treatments over that of untreated wood will be affected greatly by the conditions of service. For wood in contact with the ground, service life may be from 1 to 5 years.

Compared with brushing, dipping for a few seconds to several minutes in a preservative gives greater assurance that all surfaces and checks are thoroughly coated with the preservative; it usually results in slightly greater penetration. It is a common practice to treat window sash, frames, and other millwork, either before or after assembly, by dipping the item in a water-repellent preservative. Such treatment is covered by NWWDA IS 4–94, which also provides for equivalent treatment by the vacuum process. AWPA also has a new nonpressure standard, N1, that includes preservative treatments by nonpressure processes for all millwork products.

In some cases, preservative oil penetrates the end surfaces of ponderosa pine sapwood as much as 25 to 76 mm (1 to 3 in.). However, end penetration in such woods as the heartwood of Southern Pines and Douglas-fir is much less. Transverse penetration of the preservative applied by brief dipping is very shallow, usually only less than a millimeter (a few hundredths of an inch). The exposed end surfaces at joints are the most vulnerable to decay in millwork products; therefore, good end penetration is especially advantageous. Dip applications provide very limited protection to wood used in contact with the ground or under very moist conditions, and they provide very limited protection against attack by termites. However, they do have value for exterior woodwork and millwork that is painted, not in contact with the ground, and exposed to moisture only for brief periods.

Cold Soaking and Steeping

Cold soaking well-seasoned wood for several hours or days in low viscosity preservative oils or steeping green or seasoned wood for several days in waterborne preservatives has provided varying success on fence posts, lumber, and timbers.

Pine posts treated by cold soaking for 24 to 48 h or longer in a solution containing 5% of pentachlorophenol in No. 2 fuel oil have shown an average life of 16 to 20 years or longer. The sapwood in these posts was well penetrated, and preservative solution retention levels ranged from 32 to 96 kg/m^3 (2 to 6 lb/ft^3). Most species do not treat as satisfactorily as do the pines by cold soaking, and test posts of such woods as birch, aspen, and sweetgum treated by this method have failed in much shorter times.

Preservative penetration and retention levels obtained by cold soaking lumber for several hours are considerably better than those obtained by brief dipping of similar species. However, preservative retention levels seldom equal those obtained in pressure treatment except in cases such as sapwood of pines that has become highly absorptive through mold and stain infection.

Steeping with waterborne preservatives has very limited use in the United States but it has been used for many years in Europe. In treating seasoned wood, both the water and the preservative salt in the solution soak into the wood. With green wood, the preservative enters the water-saturated wood by diffusion. Preservative retention and penetration levels vary over a wide range, and the process is not generally recommended when more reliable treatments are practical.

Diffusion Processes

In addition to the steeping process, diffusion processes are used with green or wet wood. These processes employ waterborne preservatives that will diffuse out of the water of the treating solution or paste into the water of the wood.

The double-diffusion process developed by the Forest Products Laboratory has shown very good results in fence post tests and standard 38- by 89-mm (nominal 2- by 4-in.) stake tests, particularly for full-length immersion treatments. This process consists of steeping green or partially seasoned wood first in one chemical solution, then in another (Fig. 14–4). The two chemicals diffuse into the wood, then react to precipitate an effective preservative with high resistance to leaching. The process has had commercial application in cooling towers and fence posts where preservative protection is needed to avoid early replacement of the wood.

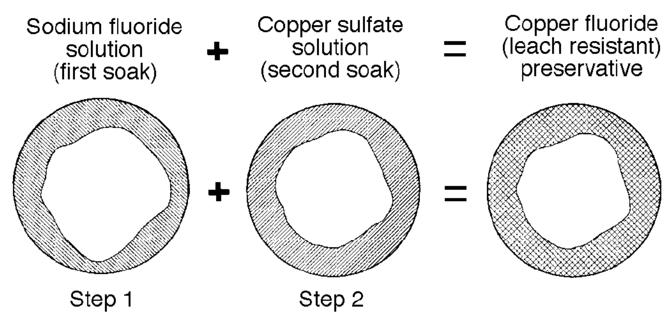


Figure 14–4. Double-diffusion steps for applying preservatives.

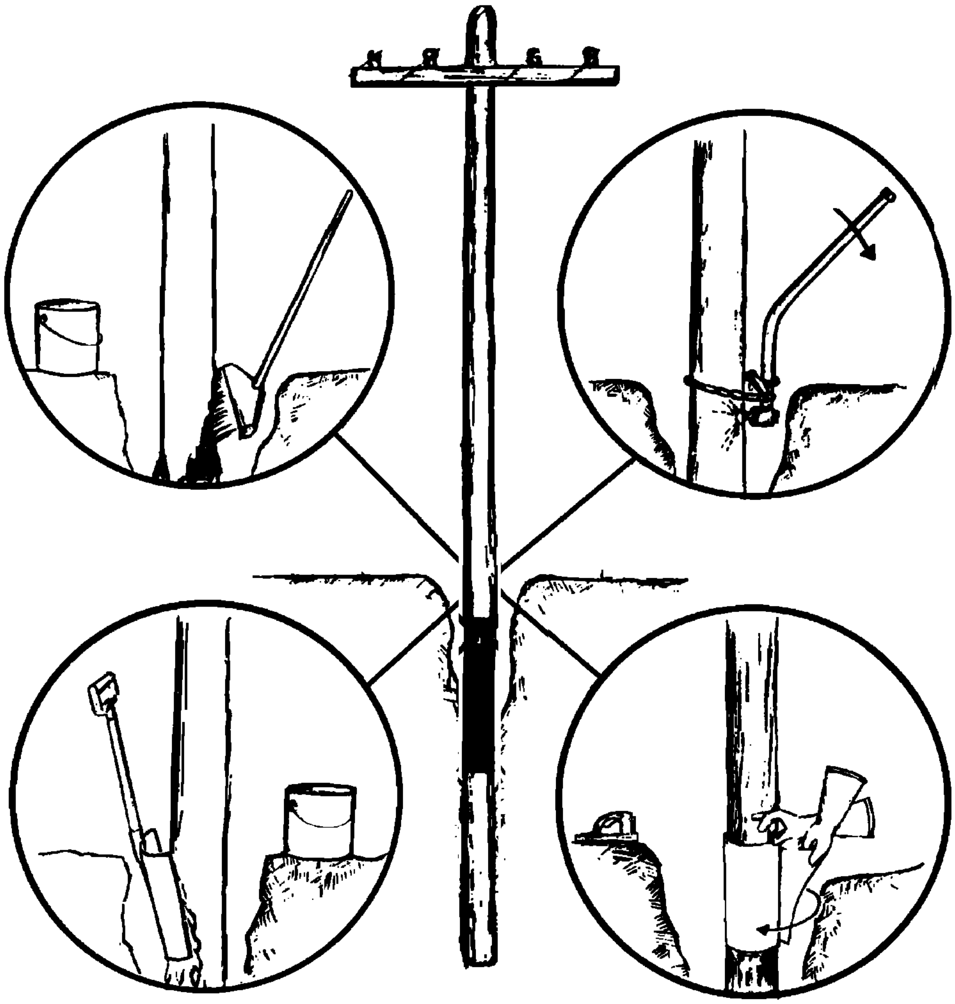


Figure 14–5. Methods of applying groundline treatment to utility poles. Preservative is injected into the pole at the groundline with a special tool or applied on the pole surface as a paste or bandage.

Other diffusion processes involve applying preservatives to the butt or around the groundline of posts or poles. In treatments of standing poles, the preservative can be injected into the pole at groundline with a special tool, applied on the pole surface as a paste or bandage (Fig. 14–5), or poured into holes bored in the pole at the groundline. These treatments have recognized value for application to untreated standing poles and treated poles where preservative retention levels are determined to be inadequate.

Vacuum Process

The vacuum process, or "VAC–VAC" as referred to in Europe, has been used to treat millwork with water-repellent preservatives and construction lumber with waterborne and water-repellent preservatives.

In treating millwork, the objective is to use a limited quantity of water-repellent preservative and obtain retention and penetration levels similar to those obtained by dipping for 3 min. The vacuum process treatment is included in NWWDA IS–94 for "Water-Repellent Preservative Nonpressure Treatment for Millwork." In this treatment, a quick, low initial vacuum is followed by filling the cylinder under vacuum, releasing the vacuum and soaking, followed by a final vacuum. The treatment is better than the 3-min dip treatment because of better penetration and retention, and the surface of the wood is quickly dried, thus expediting glazing, priming, and painting. The vacuum treatment is also reported to be less likely than dip treatment to leave objectionably high retention levels in bacteria-infected wood referred to as "sinker stock."

Lumber intended for buildings has been treated by the vacuum process, either with a waterborne preservative or a water-repellent pentachlorophenol solution, with preservative retention levels usually less than those required for pressure treatment. The process differs from that used in treating millwork in employing a higher initial vacuum and a longer immersion or soaking period.

In a study by the Forest Products Laboratory, an initial vacuum of −93 kPa (27.5 inHg) was applied for 30 min, followed by a soaking for 8 h, and a final or recovery vacuum of −93 kPa (27.5 inHg) for 2 h. Results of the study showed good penetration of preservative in the sapwood of dry lumber of easily penetrated species such as the pines. However, in heartwood and unseasoned sapwood of pine and heartwood of seasoned and unseasoned coastal Douglas-fir, penetration was much less than that obtained by pressure treatment. Preservative retention was less controllable in vacuum than in empty-cell pressure treatment. Good control over retention levels is possible in vacuum treatment with a waterborne preservative by adjusting concentration of the treating solution.

Miscellaneous Nonpressure Processes

Several other nonpressure methods of various types have been used to a limited extent. Many of these involve the application of waterborne preservatives to living trees. The Boucherie process for the treatment of green, unpeeled poles has been used for many years in Europe. This process involves attaching liquid-tight caps to the butt ends of the poles. Then, through a pipeline or hose leading to the cap, a waterborne preservative is forced under hydrostatic pressure into the pole.

A tire-tube process is a simple adaptation of the Boucherie process used for treating green, unpeeled fence posts. In this treatment, a section of used inner tube is fastened tight around the butt end of the post to make a bag that holds a solution of waterborne preservative. There are limitations for application of this process in the United States because of the loss of preservative to the soil around the treatment site.

Effect on Mechanical Properties

Coal-tar creosote, creosote solutions, and pentachlorophenol dissolved in petroleum oils are practically inert to wood and have no chemical influence that would affect its strength. Chemicals commonly used in waterborne salt preservatives, including chromium, copper, arsenic, and ammonia, are reactive with wood. Thus, these chemicals are potentially damaging to mechanical properties and may also promote corrosion of mechanical fasteners.

Significant reductions in mechanical properties may be observed if the treating and subsequent drying processes are not controlled within acceptable limits. Factors that influence the effect of the treating process on strength include (a) species of wood, (b) size and moisture content of the timbers treated, (c) type and temperature of heating medium, (d) length of the heating period in conditioning the wood for treatment and time the wood is in the hot preservative, (e) post-treatment drying temperatures, and (f) amount of pressure used. Most important of those factors are the severity and duration of the in-retort heating or post-treatment redrying conditions used. The effect of wood preservatives on the mechanical properties of wood is covered in Chapter 4.

Handling and Seasoning of Timber After Treatment

Treated timber should be handled with sufficient care to avoid breaking through the treated areas. The use of pikes, cant hooks, picks, tongs, or other pointed tools that dig deeply into the wood should be prohibited. Handling heavy loads of lumber or sawn timber in rope or cable slings can crush the corners or edges of the outside pieces. Breakage or deep abrasions can also result from throwing or dropping the lumber. If damage results, the exposed places should be retreated, if possible.

Wood treated with preservative oils should generally be installed as soon as practicable after treatment to minimize lateral movement of the preservative, but sometimes cleanliness of the surface can be improved by exposing the treated wood to the weather for a limited time before installation. Waterborne preservatives or pentachlorophenol in a volatile solvent are best suited to uses where cleanliness or paintability is of great importance.

Lengthy, unsheltered exterior storage of treated wood before installation should be avoided because such storage encourages deep and detrimental checking and can also result in significant loss of some preservatives. Treated wood that must be stored before use should be covered for protection from the sun and weather.

Although cutting wood after treatment is highly undesirable, it cannot always be avoided. When cutting is necessary, the damage can be partly overcome in timber for land or freshwater use by a thorough application of copper naphthenate (2% copper) to the cut surface. This provides a protective coating of preservative on the surface that may slowly migrate into the end grain of the wood. A special device is available for pressure treating bolt holes that are bored after treatment. For wood treated with waterborne preservatives, a 2% (as copper) solution of copper naphthenate should be used. Thoroughly brushing cut surfaces with two coats of hot creosote (applicator license required) is also helpful, although brush coating of cut surfaces provides little protection against marine borers.

For treating the end surfaces of piles where they are cut off after driving, at least two generous coats of creosote should be applied. A coat of asphalt or similar material may be thoroughly applied over the creosote, followed by some protective sheet material, such as metal, roofing felt, or saturated fabric, fitted over the pile head and brought down the sides far enough to protect against damage to the treatment and against the entrance of storm water. AWPA M4 contains instructions for the care of pressure-treated wood after treatment.

With waterborne preservatives, seasoning after treatment is important for wood that will be used in buildings or other places where shrinkage after placement in the structure would be undesirable. Injecting waterborne preservatives puts large amounts of water into the wood, and considerable shrinkage is to be expected as subsequent seasoning takes place. For best results, the wood should be dried to approximately the moisture content it will ultimately reach in service. During drying, the wood should be carefully piled and, whenever possible, restrained by sufficient weight on the top of the pile to prevent warping.

With some waterborne preservatives, seasoning after treatment is recommended. During this seasoning period, volatile chemicals can escape and chemical reactions are completed within the wood. Thus, the resistance of the preservative to leaching by water is increased. This physical or chemical process whereby a wood preservative system is rendered leach resistant in both water and soil application is called "fixation." In this process, the active ingredient or ingredients maintain fungal or insecticidal efficacy.

The Western Wood Preservers' Institute and the Canadian Institute of Treated Wood (1996) have developed a publication to address best management practices (BMPs) for the use of treated wood in aquatic environments. Their purpose is to protect the quality of the water and diversity of the various life forms found in the lakes, streams, estuaries, bays, and wetlands of North America. The document is continually updated as better methods for risk assessment and research are developed.

Quality Assurance for Treated Wood

Treating Conditions and Specifications

Specifications on the treatment of various wood products by pressure processes have been developed by AWPA. These specifications limit pressures, temperatures, and time of conditioning and treatment to avoid conditions that will cause serious injury to the wood. The specifications also contain minimum requirements for preservative penetration and retention levels and recommendations for handling wood after treatment to provide a quality product.

Specifications are broad in some respects, allowing the purchaser some latitude in specifying the details of individual requirements. However, the purchaser should exercise great care so as not to hinder the treating plant operator from doing a good treating job and not to require treating conditions so severe that they will damage the wood. Federal Specification TT–W–571 lists treatment practices for use on U.S. Government orders for treated wood products; other purchasers have specifications similar to those of AWPA.

The AWPA is working on the development of a Use Category System (UCS), which is a new way to organize the Commodity Standards. The system utilizes seven different exposure categories for treated-wood products, with each exposure category representing a different degree of biodeterioration hazard and/or product expectation. Product users will be able to specify treated-wood products based on the biodeterioration risk to which the product will be exposed. The UCS is expected to appear in the 1998 AWPA Book of Standards for information only and with standardization parallel to the current C-Standards in 1999.

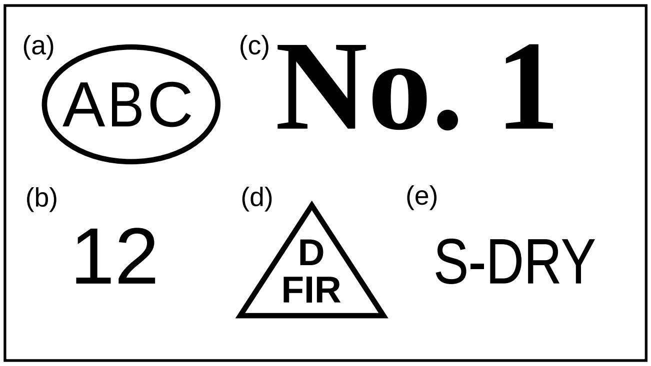
Inspection

There are two important factors to consider depending upon the intended end use of preservative-treated wood: (a) the grade or appearance of the lumber and (b) the quality of the preservative treatment in the lumber. The U.S. Department of Commerce American Lumber Standard Committee (ALSC), an accrediting agency for treatment quality assurance, has an ink stamp or end tag for each grade stamp (Fig. 14–6) and quality mark (Fig. 14–7). These marks indicate that the producer of the treated-wood product subscribes to an independent inspection agency. However, there are non-ALSC end tags or ink stamps that are similar to ALSC tags. Only end tags or ink stamps with the logo of an accredited ALSC–QA agency are acceptable. (A current list is available from ALSC.)

Quality control overview by ALSC is preferable to simple treating plant certificates or other claims of conformance made by the producer without inspection by an independent agency. These third-party agencies verify for customers that the wood was properly treated in accordance with AWPA standards. Thus, the purchaser may either accept the stamps as their quality assurance or have an independent inspector inspect and analyze the treated products to ensure compliance with the specifications. The latter is recommended for treated-wood products used for critical structures. Railroad companies and other corporations that purchase large quantities of treated timber usually maintain their own inspection services.

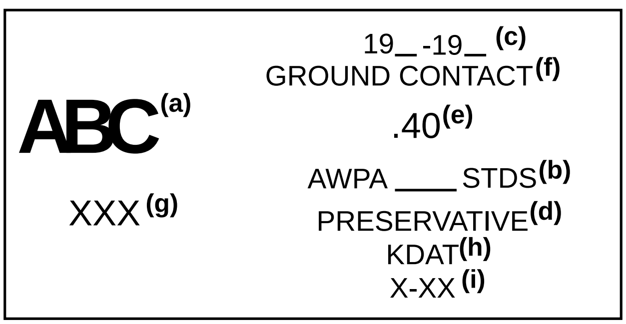
Purchase of Treated Wood

To obtain a treated-wood product of high quality, the purchaser should use the appropriate specifications. Specifications and standards of importance here are Federal Specification TT–W–571, "Wood Preservation—Treating Practices;" Federal Specification TT–W–572, "Fungicide: Pentachlorophenol;" and the *AWPA Book of Standards*. The inspection of material for conformity to the minimum requirements listed in these specifications should be in accordance with the American Wood Preservers' M2, "Standard for Inspection of Treated Timber Products."



a Trademark indicates agency quality supervision.
b Mill Identification—firm name, brand, or assigned mill number
c Grade Designation—grade name, number, or abbreviation
d Species Identification—indicates species individually or in combination
e Condition of Seasoning at time of surfacing
    S-DRY — 19% max. moisture content
    MC 15 — 15% max. moisture content
    S-GRN — over 19% moisture content (unseasoned)

Figure 14–6. Typical lumber grade stamp as approved by ALSC and its interpretation for Douglas Fir lumber.



a Identifying symbol, logo, or name of the accredited agency.
b Applicable American Wood Preservers' Association (AWPA) commodity standard.
c Year of treatment, if required by AWPA standard.
d Preservative used, which may be abbreviated.
e Preservative retention.
f Exposure category (e.g. Above Ground, Ground Contact, etc.).
g Plant name and location, plant name and number, or plant number.
h If applicable, moisture content after treatment.
i If applicable, length, and/or class.

Figure 14–7. Typical quality mark for preservative-treated lumber to conform to the ALSC accreditation program.

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Chapter 15

Finishing of Wood

R. Sam Williams

Contents

The primary function of any wood finish (paint, varnish, and stain, for example) is to protect the wood surface, help maintain a certain appearance, and provide a cleanable surface. Although wood can be used both outdoors and indoors without finishing, unfinished wood surfaces exposed to the weather change color, are roughened by photodegradation and surface checking, and erode slowly. Unfinished wood surfaces exposed indoors may also change color; moreover, unfinished wood is more difficult to clean than is finished wood.

Wood and wood-based products in a variety of species, grain patterns, textures, and colors can be finished effectively by many different methods. Selection of a finish will depend on the appearance and degree of protection desired and on the substrates used. Because different finishes give varying degrees of protection, the type of finish, its quality and quantity, and the method used to apply the finish must be considered when finishing or refinishing wood and wood products.

Factors Affecting Finish Performance

Satisfactory performance of wood finishes is achieved when the many factors that affect these finishes are given full consideration. These factors include the effect of the wood substrate, properties of the finishing material, details of application, and severity of exposure. Some important considerations are reviewed in this chapter. Sources of more detailed information are provided in a list of references at the end of this chapter.

Wood Properties

Wood surfaces that have the least tendency to shrink and swell are best for painting. For this reason, vertical- or edge-grain surfaces are far better than flat-grain surfaces (Fig. 15–1), especially when the wood is used outside where wide ranges of relative humidity and periodic wetting can produce wide ranges of swelling and shrinking. In addition, because the swelling of wood is directly proportional to specific gravity, species with low specific gravity are preferred to those with high specific gravity. Vertical-grain heartwood

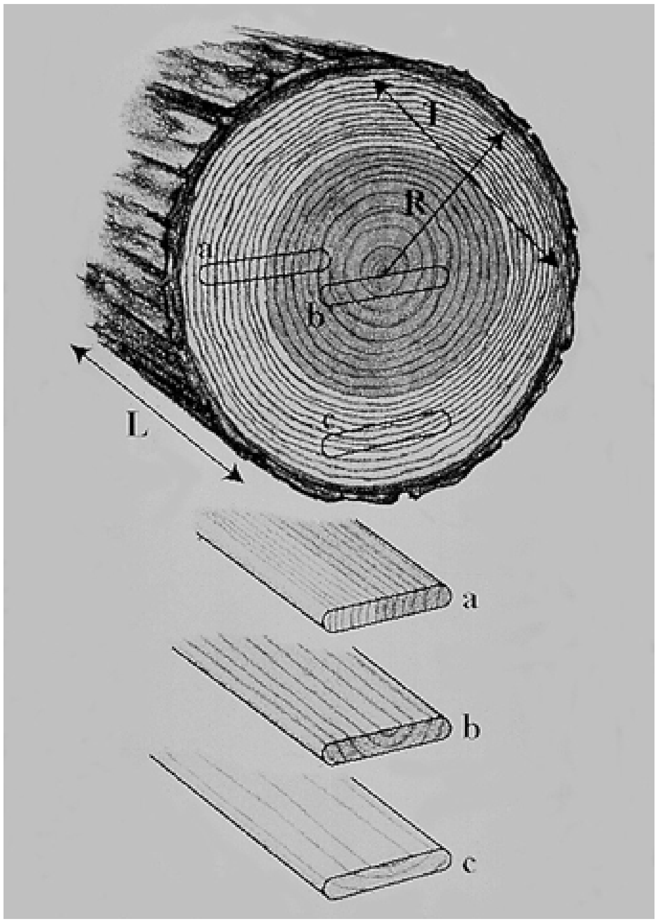

Figure 15–1. Lumber grain affects finish performance: (a) edge-grain (vertical-grain or quartersawn) board; (b) edge-grain board containing pith; (c) flat-grain (slash-grain or plainsawn) board. Arrows show radial (R), tangential (T), and longitudinal (L) orientation of wood grain.

of western redcedar and redwood are the species usually recommended for use as exterior siding and trim when painting is desired. These species are classified in Group I, woods with the best paint-holding characteristics (Table 15–1). Although vertical-grain surfaces of most species are considered excellent for painting, most species are generally available only as flat-grain lumber.

Very few wood species are graded according to vertical- or flat-grain specifications. Without a grade for marketing the lumber, there is no incentive for a mill to either cut to maximize the yield of vertical-grain lumber or to select vertical-grain lumber from the mill run. Exceptions are redwood and western redcedar, which are marketed in a range of grades, including vertical grain. The premium grade is all-heartwood and vertical-grain. This grade is usually sold as resawn bevel siding and it demands a high price; it is worthwhile for a mill to cut to maximize the yield of this grade. Most often, cutting is only practical with fairly large-diameter logs. For those species that are primarily available in small-diameter logs, the yield of vertical-grain lumber is small. It is not practical to cut the log to maximize the vertical grain because such cutting would substantially decrease overall yield from the log.

Species normally cut as flat-grain lumber that are high in specific gravity and swelling, or have defects such as knots or pitch, are classified in Groups II through V, depending upon their general paint-holding characteristics. Many species in Groups II through IV are commonly painted, particularly the pines, Douglas-fir, and spruce; however, these species generally require more careful surface preparation than do the vertical-grain (also called edge-grain) surfaces of Group I. Exterior paint will be more durable on vertical-grain boards than on flat-grain boards for any species with marked differences in specific gravity between earlywood and latewood, even if the species are rated in Group I (Fig. 15–2). Flat-grain lumber will hold paint reasonably well if it is used in areas protected from rain and sun, particularly if the wood is rough sawn or scuff sanded.

Other wood properties that affect wood finishing are defects such as knots and colored materials (extractives) in the wood. These colored materials include a wide range of chemicals with different solubilities in water, organic solvents, and paint polymers. Their effects on wood finishing are covered in detail later in this chapter. See Chapters 1 to 3 for more detailed information on wood properties.

Wood Extractives

Water-soluble colored extractives occur naturally in the heartwood of such species as western redcedar, cypress, and redwood. These substances give the heartwood of some species their attractive color, water repellency, and natural decay resistance. However, discoloration of paint may occur when the extractives are dissolved and leached from the wood by water. The water carries the extractives to the painted surface, then evaporates, leaving the extractives as a yellow to reddish brown stain on the paint. The water that gets behind the paint and causes moisture blisters also causes migration of extractives.

Wood also contains resins and oils that are insoluble in water. The type and amount of these compounds in lumber depend on the wood species. For example, many pines contain pitch and the knots of almost all wood species contain sufficient oils and resins to cause discoloration of light-colored paint. Since these oils and resins are organic in nature, they are similar chemically to oil-based and/or alkyd paints; therefore, they cannot be blocked by typical oilborne stain-blocking primers as can the water-soluble extractives. Latex-based formulations are also ineffective. Knots can be sealed prior to priming with shellac or similar finishes specifically formulated to block oils and resins. Because shellac is sensitive to moisture, it is essential to use it only over the knots and to seal it into the knots with a good paint system. In many species, bleeding of oils and resins from knots is a difficult problem. At present, there is no easy fix other than the extra step of sealing knots before priming.

Table 15–1. Characteristics of selected woods for painting

Wood species	Specific gravity[a] green/dry	Shrinkage (%)[b]		Paint-holding characteristic (I, best; V, worst)[c]		Weathering		Color of heartwood
		Flat grain	Vertical grain	Oil-based paint	Latex paint	Resistance to cupping (1, most; 4, least)	Conspicuousness of checking (1, least; 2, most)	
Softwoods								
Baldcypress	0.42/0.46	6.2	3.8	I	I	1	1	Light brown
Cedars								
Incense	0.35/0.37	5.2	3.3	I	I	—	—	Brown
Northern white	0.29/0.31	4.9	2.2	I	I	—	—	Light brown
Port-Orford	0.39/0.43	6.9	4.6	I	I	—	1	Cream
Western red	0.31/0.32	5	2.4	I	I	1	1	Brown
Yellow	0.42/0.44	6	2.8	I	I	1	1	Yellow
Douglas-fir[d]	0.45/0.48[e]	7.6	4.8	IV	II	2	2	Pale red
Larch, western	0.48/0.52	9.1	4.5	IV	II	2	2	Brown
Pine								
Eastern white	0.34/0.35	6.1	2.1	II	II	2	2	Cream
Ponderosa	0.38/0.42	6.2	3.9	III	II	2	2	Cream
Southern[d]	0.47/0.51[f]	8	5	IV	III	2	2	Light brown
Sugar	0.34/0.36	5.6	2.9	II	II	2	2	Cream
Western white	0.36/0.38	7.4	4.1	II	II	2	2	Cream
Redwood, old growth	0.38/0.40	4.4	2.6	I	I	1	1	Dark brown
Spruce, Engelmann	0.33/0.35	7.1	3.8	III	II	2	2	White
Tamarack	0.49/0.53	7.4	3.7	IV	—	2	2	Brown
White fir	0.37/0.39	7.0	3.3	III	—	2	2	White
Western hemlock	0.42/0.45	7.8	4.2	III	II	2	2	Pale brown
Hardwoods								
Alder	0.37/0.41	7.3	4.4	III	—	—	—	Pale brown
Ash, white	0.55/0.60	8	5	V or III	—	4	2	Light brown
Aspen, bigtooth	0.36/0.39	7	3.5	III	II	2	1	Pale brown
Basswood	0.32/0.37	9.3	6.6	III	—	2	2	Cream
Beech	0.56/0.64	11.9	5.5	IV	—	4	2	Pale brown
Birch, yellow	0.55/0.62	9.5	7.3	IV	—	4	2	Light brown
Butternut	0.36/0.38	6.4	3.4	V or III	—	—	—	Light brown
Cherry	0.47/0.50	7.1	3.7	IV	—	—	—	Brown
Chestnut	0.40/0.43	6.7	3.4	V or III	—	3	2	Light brown
Cottonwood, eastern	0.37/0.40	9.2	3.9	III	II	4	2	White
Elm, American	0.46/0.50	9.5	4.2	V or III	—	4	2	Brown
Hickory, shagbark	0.64/0.72	11	7	V or IV	—	4	2	Light brown
Lauan plywood	—[g]	8	4	IV	—	2	2	Brown
Magnolia, southern	0.46/0.50	6.6	5.4	III	—	2	—	Pale brown
Maple, sugar	0.56/0.63	9.9	4.8	IV	—	4	2	Light brown
Oak								
White	0.60/0.68	8.8	4.4	V or IV	—	4	2	Brown
Northern red	0.56/0.63	8.6	4.0	V or IV	—	4	2	Brown
Sweetgum	0.46/0.52	10.2	5.3	IV	III	4	2	Brown
Sycamore	0.46/0.49	8.4	5	IV	—	—	—	Pale brown
Walnut	0.51/0.55	7.8	5.5	V or III	—	3	2	Dark brown
Yellow-poplar	0.40/0.42	8.2	4.6	III	II	2	1	Pale brown

[a]Specific gravity based on weight ovendry and volume at green or 12% moisture content.
[b]Value obtained by drying from green to ovendry.
[c]Woods ranked in Group V have large pores that require wood filler for durable painting. When pores are properly filled before painting, Group II applies. Vertical-grain lumber was used for cedars and redwood. Other species were primarily flat-grain. Decrease in paintability is caused by a combination of species characteristics, grain orientation, and greater dimensional change of flat-grain lumber. Flat-grain lumber causes at least 1 unit decrease in paintability.
[d]Lumber and plywood.
[e]Coastal Douglas-fir.
[f]Loblolly, shortleaf, specific gravity of 0.54/0.59 for longleaf and slash.
[g]Specific gravity of different species varies from 0.33 to 0.55.

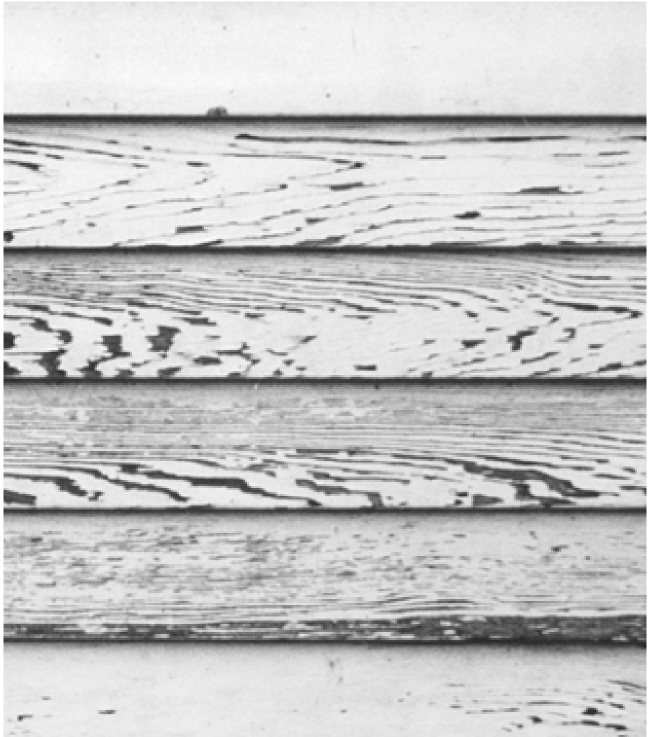

Figure 15–2. Paint applied over edge-grain boards (top and bottom) performs better than that applied to flat-grain boards (middle).

Wood Product Characteristics

Five general categories of wood products are commonly used in exterior construction: (a) lumber, (b) plywood, (c) finger-jointed wood, (d) reconstituted wood products (such as hardboard, oriented strandboard (OSB), and particleboard), and (e) preservative–fire-retardant-treated wood. Each product has unique characteristics that affect the application and performance of finishes.

Lumber

Although several alternative materials are being used for siding (such as vinyl, aluminum, OSB, and hardboard), lumber is still the preferred choice for siding in many areas of the country and for a variety of architectural designs. Many older homes have wood siding. The ability of lumber to retain and hold a finish is affected by species, grain orientation, and surface texture.

The specific gravity of wood varies tremendously among wood species (Table 15–1). The specific gravity of wood is important because denser woods generally shrink and swell more than less dense woods. In lumber, this dimensional change occurs as the wood gains or loses moisture. Excessive dimensional change in wood constantly stresses a paint film and may cause early paint failure. If two species have the same specific gravity but shrink and swell differently, their paintability will be greatly affected by dimensional changes. For example, redwood and western white pine have about the same specific gravity (0.38), but their shrinkage values for flat- and vertical-grain wood are different (4.4% and 2.6% for redwood and 7.4% and 4.1% for western white pine, respectively) (Table 15–1). Redwood has a paintability rating of I and western white pine, a rating of II. The greater dimensional instability of the flat-grain western white pine results in lower paintability compared with that of the vertical-grain redwood.

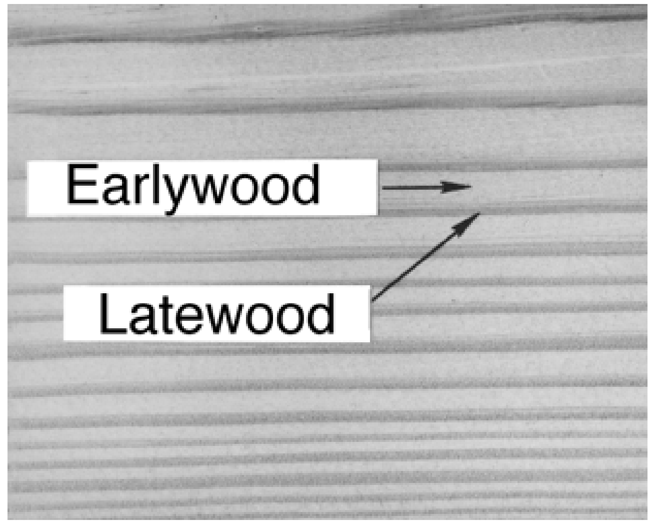

Figure 15–3. Earlywood and latewood bands in Southern Pine.

The shrinkage values given in Table 15–1 were obtained from drying wood from its green state to ovendry. The swelling rates would be about the same. The paintability values for western redcedar and redwood were obtained from vertical-grain lumber; other species were primarily flat-grain. Note that the shrinkage values for vertical-grain lumber are about half that of flat-grain lumber. The paintability rating for flat-grain lumber is probably at least one unit lower than that for vertical-grain lumber. The values given in Table 15–1 for oil-based paints were obtained from research conducted in the 1930s and 1940s using lumber from large-diameter logs. It is not known how the properties of lumber from small-diameter logs and new paint formulations would affect these ratings. Therefore, the ratings given in Table 15–1 should be used to rank paintability rather than obtain absolute paintability values.

Some species have wide bands of earlywood and latewood (Fig. 15–3). These distinct bands often lead to early paint failure. Wide, prominent bands of latewood are characteristic of the southern pines and Douglas-fir, and paint will not hold well on these species. In contrast, redwood and cedar do not have wide latewood bands, and these species are preferred for painting.

Grain orientation also affects paint-holding characteristics and is determined by the way lumber is cut from a log (Fig. 15–1). Most standard grades of lumber contain a high percentage of flat-grain lumber. Lumber used for board and batten, drop, or shiplap siding is frequently flat-grain. Bevel siding is commonly produced in several grades. The highest grade of redwood and western redcedar bevel siding is vertical-grain all-heartwood. Other grades of redwood and western redcedar may be flat, vertical, or mixed grain and may not be required to be all-heartwood.

The texture (roughness or smoothness) of the wood surface has an important effect on the selection, application, and service life of finishes. Until recently, a general rule of thumb for matching substrates to finishes was to paint smooth wood and stain rough-sawn wood. This easy rule of thumb no longer applies. Although it is true that penetrating finishes such as semitransparent stains give much better service life on rough-sawn wood compared with smooth wood, many film-forming finishes such as opaque stains and paints also give much better service life on rough-sawn wood. The paint adheres better, the film buildup is better, and the service life is longer on a roughened than a smooth (planed) surface, particularly when flat-grain lumber or siding is used. Surface texture is discussed in more detail in later sections of this chapter.

Plywood

As with lumber, species, grain orientation, and surface texture are important variables that affect the finishing of plywood. In addition, plywood contains small checks (face checks) that are caused by the lathe when the veneer is cut during plywood manufacture. Cycles of wetting and drying with subsequent swelling and shrinking tend to worsen face-checking of plywood veneer. Face checking sometimes extends through paint coatings to detract from the appearance and durability of the paint. Face checks can lead to early paint failure, particularly with oil or alkyd paint systems (Fig. 15–4). Latex primer and top coat paint systems generally perform better than oil or alkyd systems. For use as exterior siding, plywood is often overlaid with resin-treated paper (medium-density overlay (MDO)); MDO eliminates cracks caused by lathe checking and provides plywood with excellent paintability (equal to or better than that of Group I vertical-grain lumber).

Plywood for exterior use nearly always has a flat-grain surface, and if it is used for exterior wood siding, the surface is rough sawn. Smooth-sanded plywood is not recommended for siding, although it is often used for soffits. The flat-grain pattern in nearly all plywood can contribute to early paint failure. Therefore, if plywood is to be painted, take special care to prepare the surface and use high quality latex paint. Rough-sawn plywood holds paint much better than does smooth plywood. Smooth plywood should be scuff-sanded with 50-grit sandpaper prior to priming, and both smooth and rough plywood should be edge-treated with a water-repellent preservative. Penetrating stains are often more appropriate for rough-sawn than smooth-sawn exterior plywood surfaces.

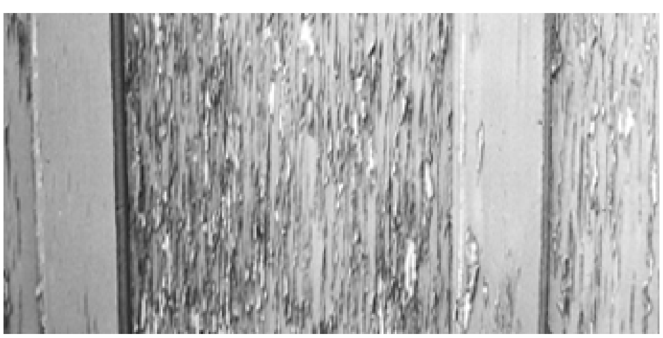

Figure 15–4. Early paint failure on plywood caused by penetration of moisture into surface face-checks.

Fingerjointed Lumber

In recent years, many mills have been producing lumber that consists of many small pieces of wood that are glued together and have fingerjoints to improve strength (Chs. 9 and 11). This process is done to eliminate knots and other defects from the lumber. The lumber is commonly used for fascia boards, interior and exterior trim, windows and doors, and siding. Although fingerjointed lumber contains no knots or other defects, the wood pieces are generally not sorted in regard to heartwood or sapwood or to grain orientation prior to gluing. However, with some suppliers, care is taken to decrease variability in fingerjointed lumber. For example, fingerjointed redwood siding is available in Clear All Heart vertical grain and Clear flat grain. Fingerjointed lumber is usually sold as a particular species, although this is not always the case. Because a particular board may contain pieces from many trees and in many grain orientations, the finishing requirements are determined by the worst piece of wood in a single board. It is quite common for paint failure to occur in a “patchwork” manner according to the paintability of the particular piece of wood in the board (Fig. 15–5). The finishing of fingerjointed lumber requires special care to ensure that the finish will adhere to the whole board. Rough-sawn lumber should hold paint better than will planed lumber. Planed wood should be scuff-sanded with 50-grit sandpaper prior to priming.

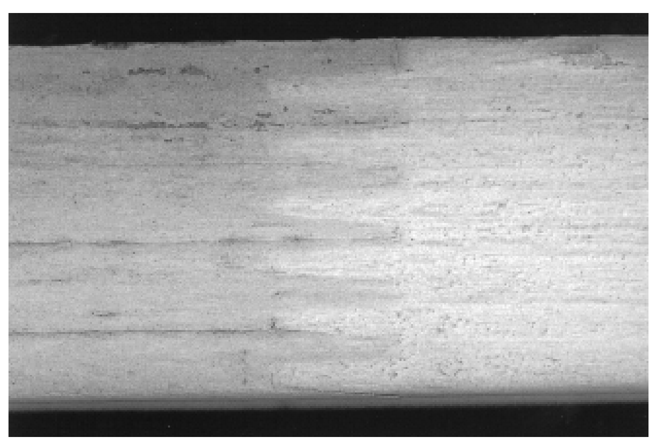

Figure 15–5. Differences in stain from extractives on fingerjointed yellow pine (probably ponderosa pine) painted with acrylic solid-color stain.

Particleboard and Similar Reconstituted Wood Products

Reconstituted wood products are those made by forming small pieces of wood into large sheets, usually 1.2 by 2.4 m (4 by 8 ft) or as required for a specialized use such as clapboard siding. These products may be classified as fiberboard or particleboard, depending upon the nature of the basic wood component (see Ch. 10).

Although wood characteristics such as grain orientation, specific gravity of earlywood and latewood, warping, and splitting are not considerations with reconstituted wood products, other characteristics must be addressed when finishing these products. The surface of fiberboard accepts and holds paint very well, and it can be improved with the addition of a resin-treated paper overlay. Film-forming finishes such as paints and solid-color stains will provide the most protection to reconstituted wood products. Some reconstituted wood products may be factory primed with paint, and factory-applied top-coats are becoming more common. The edges of these products are sensitive to moisture, and extra care should be used to assure that edges get a good coat of paint. Better yet, edges can be sealed with a paintable water-repellent preservative. Reconstituted wood products should not be finished with semitransparent stain or other penetrating finishes.

Fiberboard is produced from wood that is pulped by mechanical means. Hardboard is a relatively heavy type of fiberboard. The tempered or treated form of hardboard is designed for outdoor exposure and is used for exterior siding. Hardboard is often sold in 1.2- by 2.4-m (4- by 8-ft) sheets and in 152- to 203-mm (6- to 8-in.) widths as a substitute for solid-wood beveled siding.

Particleboard is manufactured from whole wood in the form of splinters, chips, flakes, strands, or shavings. Flakeboard is a type of particleboard made from relatively large flakes or shavings. Oriented strandboard (OSB) is a refinement of flakeboard in that the flakes have a large length-to-width aspect ratio and are laid down in layers, with the flakes in each layer oriented 90° to each other as are veneers in plywood (Ch. 10). Particleboard that is to be used outdoors must be overlaid with either wood veneer or resin-treated paper; exterior particleboard can be finished in the same way as are other paper over-laid products. As with fiberboard, special care must taken to assure a good paint film on the edges of particleboard.

Treated Wood

Wood used in severe outdoor exposures requires special treatment for proper protection and best service. The most common hazard in such exposures is decay (rot) and insect attack, particularly by termites. Marine exposure also requires wood to be protected with special treatment. Many building codes require fire-retardant treatment of wood for some uses.

When wood is used in situations with high decay and termite hazards, it is usually treated with a wood preservative. The three main types of preservatives are (a) preservative oils (such as coal–tar creosote), (b) organic solvent solution (such as pentachlorophenol), and (c) waterborne salts (such as chromated copper arsenate (CCA)) (Ch. 14). These preservatives can be applied in several ways, but pressure treatment generally provides the greatest protection against decay. Wood preservatives may also improve the wood's resistance to weathering, particularly if the preservative contains chromium salts. Chromium-containing preservatives protect wood against ultraviolet degradation, an important factor in the weathering process.

Wood treated with waterborne preservatives, such as CCA, can be painted or stained if the wood is clean and dry. Wood treated with a water-repellent preservative, by vacuum-pressure or dipping, is paintable. Wood treated with coal–tar creosote or other dark oily preservatives is not paintable; even if the paint adheres to the treated wood, the dark oils tend to discolor the paint, especially light-colored paint.

Fire-retardant treatment of wood does not generally interfere with adhesion of paint coatings, unless the treated wood has extremely high moisture content because of its increased hygroscopicity. Fire-retardant-treated wood is generally painted according to the manufacturer's recommendations rather than left unfinished because the treatment and subsequent drying often darken and discolor the wood. It is critical that wood to be used outside be treated with only those fire-retardant treatments that are specifically recommended for outdoor exposure.

Weathering

Weathering is the general term used to describe the degradation of materials exposed outdoors. This degradation occurs on the surface of all organic materials, including wood and finishes used on wood such as paints and stains. The process occurs through photo-oxidation of the surface catalyzed by ultraviolet (UV) radiation in sunlight, and it is augmented by other processes such as washing by rain, changes in temperature, changes in moisture content, and abrasion by windblown particles. The weathering process can take many forms depending on the exposed material; in general, the process begins with a color change, followed by slow erosion (loss of material) from the surface. The surface initially develops slight checking; with some materials, deep cracks may ultimately develop. Weathering is dependent on the chemical makeup of the affected material. Because the surface of a material may be composed of many different chemicals, not all materials on the surface may erode at the same rate.

Effect on Wood

The surface of wood consists of four types of organic materials: cellulose, hemicellulose, lignin, and extractives. Each of these materials is affected by the weathering process in a different way. The extractives (that is, the material in the wood that gives each species its distinctive color) undergo changes upon exposure to sunlight and lighten or darken in color. With some wood species, this color change can take place within minutes of exposure. Changes in the color of the surface are accompanied by other changes that affect the wettability and surface chemistry of the wood. The mechanism of these early changes is not very well understood, but these changes can have a drastic effect on the surface chemistry of wood and thus the interaction of the wood with other chemicals, such as paint and other finishes.

From 20% to 30% of the wood surface is composed of lignin, a polymeric substance that is the adhesive that holds wood celluloses together. Because lignin is affected by photodegradation more than are celluloses, lignin degrades and cellulose fibers remain loosely attached to the wood surface. Further weathering causes fibers to be lost from the surface (a process called erosion); but this process is so slow that on the average only about 6 mm (1/4 in.) of wood is lost in a century (Fig. 15–6). This erosion rate is slower for most hardwoods and faster for certain softwoods. Other factors like growth rate, degree of exposure, grain orientation, temperature, and wetting and drying cycles are important in determining the rate of erosion. Table 15–2 shows erosion rates for several wood species that were measured over a 16-year period.

Water and the swelling and shrinking stresses set up by fluctuations in moisture content accelerate erosion. Cyclic wetting and drying roughen the surface, raise the grain, cause differential swelling of earlywood and latewood bands, and result in many small, parallel checks and cracks. Larger and deeper cracks may also develop. Fewer checks develop in woods with moderate to low specific gravity than in those with high specific gravity, and vertical-grain boards have fewer checks than do flat-grain boards. Flat-grain lumber frequently warps as well.

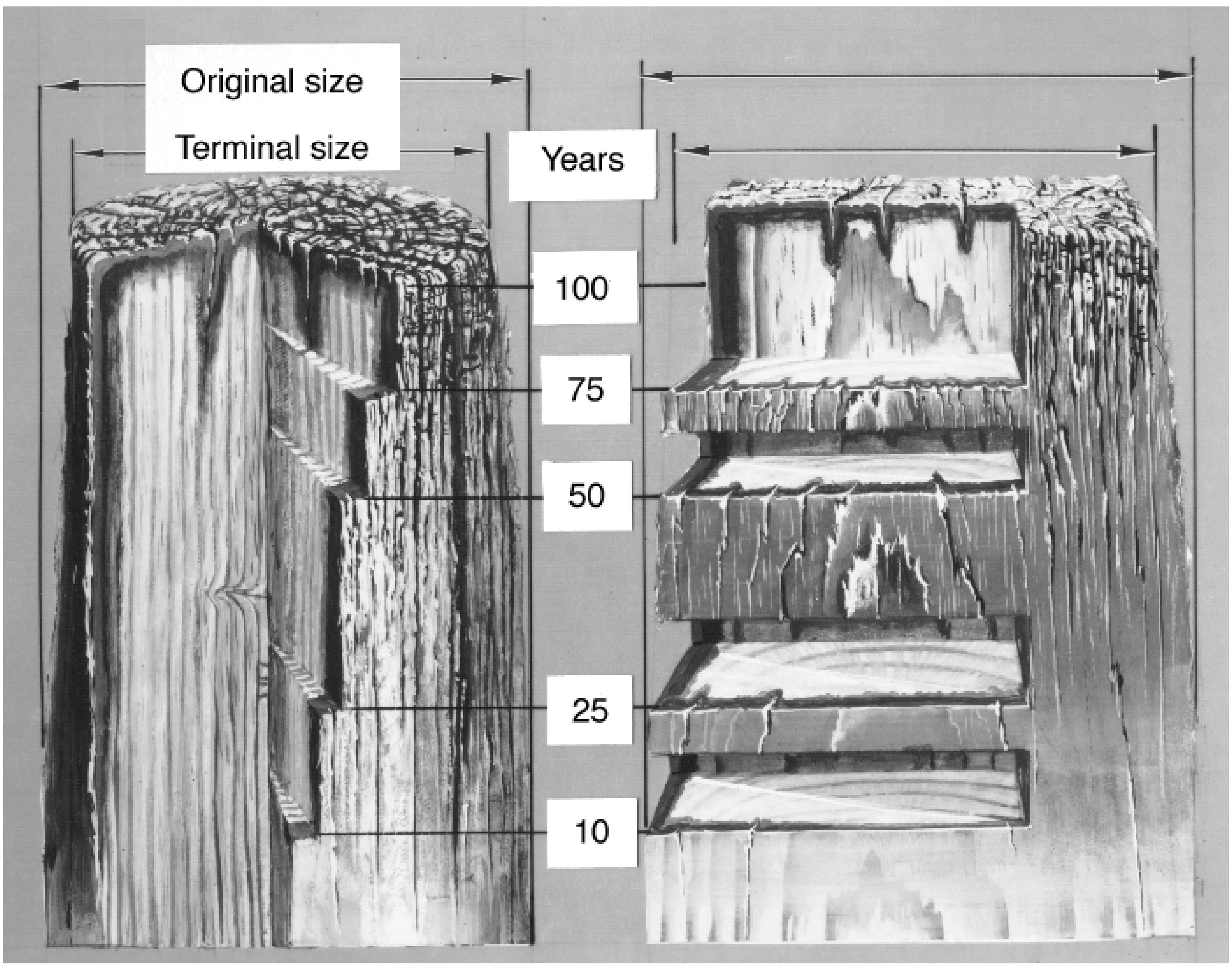

Figure 15–6. Artist's rendition of weathering process of round and square timbers. As cutaway shows, interior wood below surface is relatively unchanged.

Table 15–2. Erosion of earlywood and latewood on smooth planed surfaces of various wood species after outdoor exposure[a]

Wood species	Avg SG[b]	Erosion (µm) after various exposure times[c] 4 years LW	4 years EW	8 years LW	8 years EW	10 years LW	10 years EW	12 years LW	12 years EW	14 years LW	14 years EW	16 years LW	16 years EW
Western redcedar plywood	—	170	580	290	920	455	1,095	615	1,165	805	1,355	910	1,475
Redwood plywood	—	125	440	295	670	475	800	575	965	695	1,070	845	1,250
Douglas-fir plywood	—	110	270	190	390	255	500	345	555	425	770	515	905
Douglas-fir	0.46	105	270	210	720	285	905	380	980	520	1,300	500	1,405
Southern Pine	0.45	135	320	275	605	315	710	335	710	445	1,180	525	1,355
Western redcedar	0.31	200	500	595	1,090	765	1,325	970	1,565	1,160	1,800	1,380	1,945
Redwood	0.36	165	405	315	650	440	835	555	965	670	1,180	835	1,385
Loblolly pine	0.66	80	205	160	345	220	490	—	—	—	—	—	—
Western redcedar	0.35	115	495	240	1,010	370	1,225	—	—	—	—	—	—
Southern Pine	0.57	95	330	180	640	195	670	—	—	—	—	—	—
Yellow-poplar	0.47	—	220	—	530	—	640	—	—	—	—	—	—
Douglas-fir	0.48	75	255	175	605	225	590	—	—	—	—	—	—
Red oak	0.57	180	245	340	555	440	750	—	—	—	—	—	—
Ponderosa pine	0.35	130	270	315	445	430	570	Decay	Decay	Decay	Decay	—	—
Lodgepole pine	0.38	105	255	265	465	320	580	475	745	560	810	—	—
Engelmann spruce	0.36	125	320	310	545	390	650	505	795	590	950	—	—
Western hemlock	0.34	145	320	310	575	415	680	515	1,255	600	1,470	—	—
Red alder	0.39	—	295	—	545	—	620	—	920	—	955	—	—

[a]Data from three studies are shown. Specimens were exposed vertically facing south. Radial surfaces were exposed with the grain vertical.
[b]SG is specific gravity.
[c]All erosion values are averages of nine observations (three measurements of three specimens). EW denotes earlywood; LW, latewood.

The time required for wood to become fully weathered depends on the severity of the exposure. Once weathered, and in the absence of decay, stain, and mildew, wood remains nearly unaltered in appearance (Fig. 15–7). As a result of weathering, boards tend to warp (particularly cup) and fasteners are loosened. The tendency to cup varies with the specific gravity, width, and thickness of the board. The greater the specific gravity and the greater the width in proportion to thickness, the greater the tendency to cup. For best resistance to cup, the width of a board should not exceed eight times its thickness. Warping also is more pronounced in flat-grain boards than in vertical-grain boards.

Biological attack of a wood surface by microorganisms is recognized as a contributing factor to color change or graying of wood. This biological attack, commonly called mildew, does not cause erosion of the surface, but it may cause initial graying or an unsightly dark gray and blotchy appearance. These color changes are caused by dark-colored fungal spores and mycelia on the wood surface. In advanced stages of weathering, when the surface has been enriched by cellulose, it may develop a silvery-gray sheen. This formation of a bright, light gray, silvery sheen on weathered wood occurs most frequently where micro-organism growth is inhibited by a hot, arid climate or a salty atmosphere in coastal regions. The microorganisms primarily responsible for gray discoloration of wood are commonly found on weathered wood (see subsection on mildew under Finish Failure or Discoloration).

Effect on Paint Adhesion

Although the erosion of the wood surface through weathering is a slow process, the chemical changes that occur within a few weeks of outdoor exposure can drastically decrease the adhesion of paints subsequently applied to the weathered surface. It is fairly obvious that a badly weathered, powdery wood surface cannot hold paint very well. This fact is not so obvious for wood that has weathered for only 2 to 3 weeks. The wood appears sound and much the same as when it was installed. The extent of damage to the wood surface after such a short exposure has yet to be determined. However,

Figure 15–7. Weathered surfaces of softwood after 15 years of exposure in Madison, Wisconsin.

long-term outdoor exposure of panels that had been preweathered for 1, 2, 4, 8, or 16 weeks before being painted showed a direct relationship between preweathering time and the time when the paint started to peel. For panels that had been preweathered for 16 weeks, the paint peeled within 3 years; for panels preweathered for only 1 week, the paint peeled after 13 years. Panels that were not preweathered showed no sign of peeling after 13 years. The paint system was a commercial oil–alkyd primer with two acrylic latex top-coats over planed all-heartwood vertical-grain western redcedar.

Several other wood species were tested in addition to western redcedar. In general, there was a direct relationship between wood specific gravity and amount of time the wood could be exposed without a deleterious effect on paint performance. More dense wood species such as Douglas-fir and the southern pines showed no preweathering effect until they had been preweathered for 3 to 4 weeks. For species with low specific gravity, it is essential to finish the wood as soon as possible after installation, or better yet, to preprime it before installation. The wood could be back-primed at the same time (see section on back-priming).

The best remedy for restoring a weathered wood surface is to sand it with 50- to 80-grit sandpaper. Sanding can easily be done by hand using a sheet rock sander. This tool consists of a sanding pad attached to a pole with a swivel connection. Large areas of siding can be quickly scuff-sanded to remove the weathered surface. Even if wood has not been weathered, scuff sanding provides a much better surface for painting, increases the service life of the paint, and improves the paint bond.

Effect on Wood Finishes

Finishes used on wood also undergo surface photodegradation because the primary ingredient that holds a paint film together or seals the wood surface is an organic polymer and thus is susceptible to photo-oxidative degradation. The UV radiation in sunlight breaks down the polymer in paint, causing a slow erosion similar to that which occurs on wood. The pigments in paint are not usually affected by UV radiation. Therefore, as film-forming finishes such as paints or solid-color stains weather, they do so by the slow breakdown of the polymer, which loosens the pigments. The surface becomes chalky because of the loose pigments. Eventually, these pigments and the degraded polymer erode from the surface. The rate of weathering primarily depends on the resistance of the polymer to UV radiation. Paints and stains based on acrylic polymers are more UV-resistant than those based on oil and oil–alkyds. Weathering is strictly a surface phenomenon on the finish, and as with wood, a painted surface can be attacked by mildew.

Control of Water or Moisture in Wood

Moisture Content

The moisture content of wood is the amount of water contained in the wood (see Ch. 3). Moisture content includes both water absorbed into the wood cell wall and free water within the hollow center of the cell, and it is expressed as a weight percentage. The amount of water that wood can absorb (that is, that can be bound in the cell wall) depends on the wood species; most species can absorb about 30% water. This limit to the amount of water that can be bound in the wood cell wall is called the fiber saturation point. Wood can reach the fiber saturation point by absorbing either liquid water or water vapor.

The amount of water vapor that can be absorbed primarily depends on the relative humidity (RH) of the surrounding air. If wood is stored at zero RH, the moisture content will eventually reach 0%. If wood is stored at 100% RH, it will eventually reach fiber saturation (about 30% water). Of course, if kept at a constant RH between these two extremes, the wood will reach a moisture content between 0 and 30%. The moisture content is controlled by the RH, and when the moisture content is in balance with the RH, the wood is at its equilibrium moisture content. This rarely happens because as the RH changes so does the moisture content of the wood, and atmospheric RH is almost always changing. It varies through daily and seasonal cycles, thus driving the moisture content of wood through daily and seasonal cycles. See Chapter 3 for a more detailed discussion of moisture content and equilibrium moisture content.

Equilibrium moisture content cannot be changed through the application of finishes. The only way that finishes can affect absorption of water or water vapor is to affect the rate at which absorption occurs. Finishes can decrease daily and seasonal moisture absorption and desorption, but they do not change the equilibrium moisture content. See the section on moisture-excluding effectiveness of finishes for discussion of this topic.

Wood exposed outdoors cycles around a moisture content of about 12% in most areas of the United States. In the Southeast, average moisture content can be slightly higher and in the Southwest, the average can be lower (9%) (Ch. 12, Table 12–1). Daily and annual moisture content will vary from these average values. In general, for wood exposed outdoors, moisture content decreases during the summer and increases during the winter. (For wood in interior use in northern climates, moisture content increases during the summer and decreases during the winter.) Even in very humid areas, the RH is rarely high enough for long enough to bring the moisture content of wood above 20%. Wood that is warmed by the sun experiences a virtual RH far below the ambient RH. Wood will dry faster and become drier than expected given the ambient RH. This is why checking often occurs on decking boards; the surface is much drier than the rest of the board. Shrinkage of the top portion of the board commensurate with this dryness goes beyond the elastic limit of the wood at the surface and checks form parallel to the grain.

As mentioned, fiber saturation is the greatest amount of water that can be absorbed by wood via water vapor absorption. This absorption is rather slow compared with the moisture changes that can occur through absorption of liquid water. Liquid water can quickly cause the wood to reach fiber saturation, and it is the only way to bring the moisture content of wood above fiber saturation. Liquid water must be present. Liquid water can reach wood through windblown rain, leaks, condensation, dew, melting ice and snow, and other ways. As wood continues to absorb water above its fiber saturation point, the water is stored in the hollow center of the wood cell; when all the air in the hollow center has been replaced by water, the wood is waterlogged and moisture content can be as high as 200%. The sources and ways by which wood can get wet sometimes seem endless. The result is always the same—poor performance, both of the wood and of the finish.

Wood decay (rot) cannot occur unless the moisture content of the wood is near fiber saturation. This requires water. Water also causes peeling of paint. Even if other factors are involved, water accelerates paint degradation. Fortunately, the moisture content of lumber can be controlled. But all too often, this critical factor is neglected during the construction and finishing processes. It is best to paint wood when its average moisture content is about that expected to prevail during its service life. Painting at this time can prevent a drastic change in wood dimension, which occurs as wood equilibrates to ambient conditions. The moisture content and thus the dimensions of the piece will still fluctuate somewhat, depending on the cyclic changes in atmospheric RH, but the dimensional change will not be excessive. Therefore, film-forming finishes (such as paints) will not be stressed unnecessarily, and service life should be better.

The recommended moisture content for wood used in exterior applications varies somewhat depending on climatic conditions. These conditions include, but are not limited to, coastal exposure, rainfall, elevation, and wind. However, problems associated with changes in moisture content should be minimized if the moisture content is between 9% and 14%. Most lumber is kiln dried to less than 20% moisture content before shipment. Material that has been kept dry during shipment and storage at the construction site should be close to the desired moisture content.

Lumber is often marketed for construction purposes in the kiln-dried condition, but it is sometimes exposed to moisture later during shipping, storage, and/or at the construction site. Wood that is obviously wet and sometimes discolored may not give optimum performance. If wet wood is used, it will dry in service, but shrinkage and accompanying warping, twisting, and checking can occur. If the moisture content of the wood exceeds 20% when the wood is painted, the risk of blistering and peeling is increased. Moreover, dark water-soluble extractives in woods like redwood and western redcedar may discolor the paint shortly after it is applied.

Plywood, particleboard, hardboard, and other wood composites undergo a significant change in moisture content during manufacture. Frequently, the moisture content of these materials is not known and may vary depending on the manufacturing process. To improve the service life of the finish, wood composites should be conditioned prior to finishing, as are other wood products.

Water Repellents

The control of water and/or water vapor requires different types of finishes. Water repellent is a generic name for a wide variety of sealers and wood treatments that change the surface properties of wood so that the wood sheds liquid water. Water repellents have almost no effect on the transmission of water vapor; that is, they have little effect on the change in wood moisture content caused by changes in RH. Water repellents work exceptionally well to retard the absorption of water into the end grain of wood, the most absorptive of the wood surfaces. Although water repellents do not stop all water absorption, they are an excellent treatment for wood used outdoors because they inhibit the absorption of liquid water during rain, yet allow the wood to dry after rain. Water-repellent formulations usually include a mildewcide or a wood preservative and are then referred to as water-repellent preservatives. These finishes are discussed in greater detail in later sections of this chapter.

Finish Moisture-Excluding Effectiveness

The moisture-excluding effectiveness of a finish is a measure of its resistance to the transmission of water vapor to the finished wood. It is basically a measure of the permeability of a coating to water vapor. It is not a measure of water repellency. Moisture-excluding effectiveness is determined by comparing the moisture pickup of a coated specimen with that of a matched uncoated control. A coating that blocks all moisture would be 100% effective; however, no coating is entirely moisture proof. There is as yet no way of completely keeping moisture out of wood that is exposed to prolonged periods of high RH. As wood is exposed to varying RH conditions, it absorbs or desorbs moisture depending on the RH. A coating that is effective at excluding moisture merely slows absorption or desorption of moisture; it cannot change the equilibrium moisture content (Ch. 3).

To achieve a high degree of moisture-excluding effectiveness, it is necessary to form a moisture barrier on the wood surface. In addition to repelling liquid water, this film will slow the diffusion of water vapor into or out of the wood. Water-repellent treatments differ from moisture-excluding coatings in that they do not slow the absorption–desorption of water vapor. They repel liquid water only. For example, a water-repellent treatment, which may have no moisture-excluding effectiveness against water vapor, might have more than 60% water repellency when tested using standard immersion tests. The high degree of protection provided by water repellents and water-repellent preservatives to short periods of wetting by liquid water is the major reason they are recommended for exterior finishing.

The protection afforded by coatings in excluding moisture from wood depends on a great number of variables. Among them are coating film thickness, defects and voids in the film, type of pigment, chemical composition of the oil or polymer, volume ratio of pigment to vehicle (pigment volume concentration), vapor-pressure gradient across the film, and length of exposure. Values in Table 15–3 indicate the range in protection against moisture in vapor form for some conventional finish systems when exposed to continuous high humidity. The degree of protection provided also depends on the kind of exposure.

Porous paints, such as latex paints and low-luster (flat) or breather-type oil-based paints formulated at a pigment volume concentration usually above 40%, afford little protection against moisture. These paints permit rapid entry of water vapor and water from dew and rain unless applied over a nonporous primer or pretreated with a paintable water-repellent preservative. In addition to being porous, latex finishes contain surfactants that can encourage absorption of water into the coating and wood, particularly just after the coating has been applied. It is thought that these surfactants wash out of the coating after a short time, but detailed information on this is not available.

The moisture-excluding effectiveness of coatings changes only slightly with age. As long as the original appearance and integrity of the coatings are retained, most effectiveness remains. Paint that is slowly fading or chalking will remain effective at excluding moisture; the paint is still effective if there is a glossy film underneath the chalk (which can be removed by rubbing). Deep chalking, checking, or cracking indicates serious impairment of moisture-excluding effectiveness.

The numerical values for percentage of effectiveness in Table 15–3 should be considered relative rather than absolute because the percentage of effectiveness varies substantially with exposure to moisture conditions. The values for effective coatings (≥60%) are reliable in the sense that they can be reproduced closely on repeating the test; values for ineffective coatings (<20%) must be regarded as rough approximations only. These percentages are based on average amounts of moisture absorbed per unit surface area by newly coated and uncoated wood panels. In addition, the values were determined from specimens coated on all sides. Since wood used in normal construction is seldom coated on all sides, the actual absorption–desorption will differ from the values listed in Table 15–3.

Effect of Finish on Liquid Water and Water Vapor Absorption

The various dimensions of wood and wood-based building materials are constantly changing because of changes in moisture content, which in turn are caused by fluctuations in atmospheric RH as well as the periodic presence of free moisture such as rain or dew. Water repellents provide protection against liquid water but are ineffective against water vapor (humidity). Film-forming finishes such as paint and varnish shed liquid water and retard the absorption of water vapor, provided the films are thick enough. Because film-forming wood finishes like paint will last longer on stable wood, it is desirable to stabilize the wood by finishing it with a water-repellent preservative as the first step in the finish system. As mentioned previously, there is no way to completely eliminate the changing moisture content of wood in response to changing RH. The coating simply slows down the rate at which the wood changes moisture content.

Film-forming finishes slow both the absorption of water vapor and drying of wood (Fig. 15–8). Aluminum flake paint is a laboratory formulation designed to block water vapor movement into wood. It is about 80% effective at blocking water vapor absorption compared with water vapor absorption in an unpainted control. Almost all common wood finishes, both oil and latex, are less effective than aluminum flake paint at blocking water vapor absorption. However, oil-based formulations are more effective than latex formulations. The coating slows the rate of drying. In cyclic high and low RH, the moisture content of the wood increases with time (Fig. 15–9).

The moisture-excluding effectiveness described in the previous section was obtained from specimens consisting of single pieces of wood that were painted on all sides. In normal construction, wood is seldom coated on all sides. In addition to absorbing water vapor, paint coatings usually crack at the joint between two pieces of wood, particularly if they have different grain orientations (and thus different dimensional stability). Water enters the wood through these cracks and is trapped by the coating, thus causing an increase in moisture content much higher than that shown in Figure 15–9.

Table 15–3. Moisture-excluding effectiveness of various finishes on ponderosa pine[a]

Finish	No. of coats	Moisture-excluding effectiveness (%) 1 day	7 days	14 days	Finish	No. of coats	Moisture-excluding effectiveness (%) 1 day	7 days	14 days
Linseed oil sealer (50%)	1	7	0	0	Alkyd house primer paint	1	85	46	24
	2	15	1	0	(tall maleic alkyd resin)	2	93	70	49
	3	18	2	0		3	95	78	60
Linseed oil	1	12	0	0	Enamel paint, satin	1	93	69	50
	2	22	0	0	(soya/tung/alkyd;	2	96	83	70
	3	33	2	0	interior/exterior)	3	97	86	80
Tung oil	1	34	0	0		4	98	92	85
	2	46	2	0		5	98	93	88
	3	52	6	2		6	98	94	89
Paste furniture wax	1	6	0	0	Floor and deck enamel	1	80	31	18
	2	11	0	0	(phenolic alkyd)	2	89	53	35
	3	17	0	0		3	92	63	46
Water repellent	1	12	0	0	Shellac	1	65	10	3
	2	46	2	0		2	84	43	20
	3	78	27	11		3	91	64	42
Latex flat wall paint	1	5	0	0		4	93	75	58
(vinyl acrylic resin)	2	11	0	0		5	94	81	67
	3	22	0	0		6	95	85	73
Latex primer wall paint	1	78	37	20	Nitrocellulose lacquer	1	40	4	1
(butadiene–styrene resin)	2	86	47	27		2	70	22	8
	3	88	55	33		3	79	37	19
Alkyd flat wall paint	1	9	1	0	Floor seal	1	31	1	0
(soya alkyd)	2	21	2	0	(phenolic resin/tung oil)	2	80	37	18
	3	37	5	0		3	88	56	35
Acrylic latex house	1	43	6	1	Spar varnish	1	48	6	0
primer paint	2	66	14	2	(soya alkyd)	2	80	36	15
	3	72	20	4		3	87	53	30
Acrylic latex flat	1	52	12	5	Urethane varnish	1	55	10	2
house paint	2	77	28	11	(oil-modified)	2	83	43	23
	3	84	39	16		3	90	64	44
Solid-color latex stain	1	5	0	0		4	91	68	51
(acrylic resin)	2	38	4	0		5	93	72	57
	3	50	6	0		6	93	76	62
Solid-color oil-based stain	1	45	7	1	Aluminum flake pigmented	1	90	61	41
(linseed oil)	2	84	48	26	urethane varnish	2	97	87	77
	3	90	64	42	(oil-modified)	3	98	91	84
FPL natural finish (linseed-	1	62	14	3		4	98	93	87
oil-based semitransparent	2	70	21	6		5	98	94	89
stain)	3	76	30	11		6	99	95	90
Semitransparent oil-based	1	7	0	0	Polyurethane finish, clear	1	48	6	0
stain (commercial)	2	13	0	0	(two components)	2	90	66	46
	3	21	1	0		3	94	81	66
Marine enamel, gloss (soya	1	79	38	18	Polyurethane paint, gloss (two	1	91	66	44
alkyd)	2	91	66	46	components)	2	94	79	62
	3	93	74	57		3	96	86	74
					Paraffin wax, brushed	1	97	82	69
					Paraffin wax, dipped	1	100	97	95

[a]Sapwood was initially finished and conditioned to 26°C (80°F) and 30% RH, then exposed to the same temperature and 90% RH.

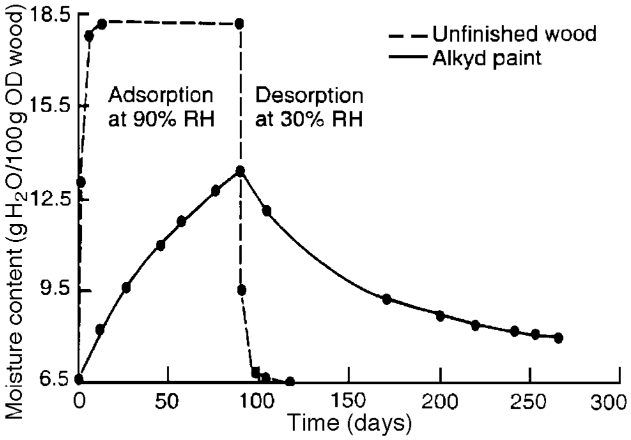

Figure 15–8. Change in moisture content of ponderosa pine sapwood finished with three coats of aluminum pigmented alkyd paint and exposed to 90% and 30% RH at 26˚C (80˚F), compared with moisture content of unfinished wood.

Figure 15–10. Decay in wood railing fully exposed to weather.

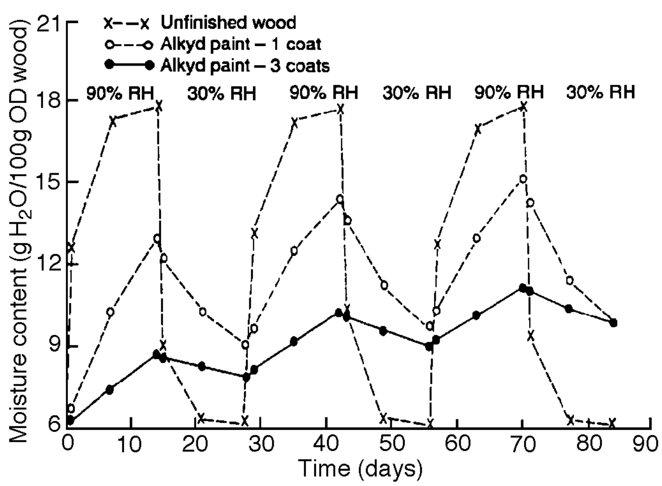

Figure 15–9. Change in moisture content of ponderosa pine sapwood finished with three coats of aluminum pigmented alkyd paint and exposed to alternating cycles of 90% and 30% RH at 26˚C (80˚F), compared with moisture content of unfinished wood.

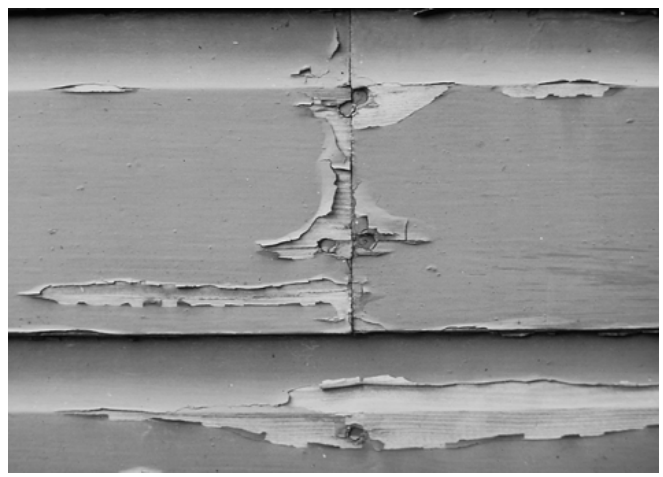

Figure 15–11. Paint failure at ends of boards.

The paint film inhibits drying, as shown. This retardation of drying can have a drastic effect on the durability of painted wood fully exposed to the weather. The moisture content of the wood can approach the range where decay fungi can become active. This type of wood paint failure usually occurs on painted fences and porch railings that are fully exposed to the weather (Fig. 15–10). Applying a water-repellent preservative or priming the end grain of wood used in these applications inhibits the absorption of water at the end grain and thus works in concert with the coating to keep the wood dry.

For a coating to be effective in minimizing moisture content changes in the wood, it must be applied to all surfaces, particularly the end grain. The end grain of wood absorbs moisture much faster than does the face grain, and finishes generally fail in the end grain first (Fig. 15–11). Coatings with good moisture-excluding effectiveness that are applied to only one side of the wood will cause unequal sorption of moisture, increasing the likelihood that the wood will cup (warp). When finishing siding, it is important to allow the back side of the wood to dry, particularly if it is finished with paint with high moisture-excluding effectiveness. Applying a water-repellent preservative or primer to the end grain and back of siding (see section on back-priming) prior to installing the siding improves resistance to water yet allows the siding to dry. Cupping can be minimized by using vertical-grain lumber and by minimizing the aspect ratio.

In those houses where moisture moves from the living quarters to the outside wall because of the lack of a vapor barrier (or a poor vapor barrier), the application of moisture-excluding finishes to the outside will not prevent paint peeling. In fact, finishes with higher moisture-excluding effectiveness are more prone to fail by peeling because they trap moisture.

Types of Exterior Wood Finishes

The types of exterior finishes for wood are separated into two groups, those that penetrate wood and those that form a film. As a general rule, penetrating finishes tend to give a more "natural" look to the wood. That is, they allow some of the character of the wood to show through the finish. Also, in general, the more natural a finish, the less durable it is. Natural finishes may be penetrating finishes such as semi-transparent stains or film-forming finishes such as varnish. The penetrating natural finishes generally give better performance and are easier to refinish. This section also addresses weathered wood as a "finish."

The properties, treatment, and maintenance of exterior finishes are summarized in Table 15–4. The suitability and expected life of the most commonly used exterior finishes on several wood and wood-based products are summarized in Table 15–5. The information in these tables should be considered as a general guideline only. Many factors affect the performance and lifetime of wood finishes.

Table 15–4. Initial application and maintenance of exterior wood finishes[a]

	Initial application			Maintenance		
Finish	Process	Cost	Appearance of wood	Process	Cost	Service life[b]
Water-repellent preservative	Brushing	Low	Grain visible; wood brown to black, fades slightly with age	Brush to remove surface dirt; remove mildew	Low	1–3 years
Waterborne preservative[c]	Pressure (factory applied)	Medium	Grain visible; wood greenish or brownish, fades with age	Brush to remove surface dirt; remove mildew	Nil, unless stained or painted	None, unless stained, or painted
Organic solvent preservative[d]	Pressure, steeping, dipping, and brushing	Low to medium	Grain visible; color as desired	Brush and reapply	Medium	2–3 years or when preferred
Water repellent[e]	One or two brush coats of clear material or, preferably, dip application	Low	Grain and natural color visible, becoming darker and rougher textured with age	Clean and reapply	Low to medium	1–3 years or when preferred
Semitransparent stain	One or two brush coats	Low to medium	Grain visible; color as desired	Clean and reapply	Low to medium	3–6 years or when preferred
Clear varnish	Three coats (minimum)	High	Grain and natural color unchanged if adequately maintained	Clean, sand, and stain bleached areas; apply two more coats	High	2 years or at breakdown
Paint and solid-color stain	Brushing: water repellent, prime, and two top-coats	Medium to high	Grain and natural color obscured	Clean and apply top coat, or re-move and repeat initial treatment if damaged	Medium	7–10 years for paint;[f] 3–7 years for solid-color stain

[a]Compilation of data from observations of many researchers.
[b]For vertical exposure.
[c]Although wood treated with waterborne preservative may be left unfinished, it is best to finish it with water-repellent preservative or semitransparent stain. See maintenance of water repellent and semitransparent stain.
[d]Pentachlorophenol, bis(tri-n-butyltin oxide), copper naphthenate, copper-8-quinolinolate, and similar materials.
[e]With or without added preservatives. Addition of preservative helps control mildew growth.
[f]If top-quality acrylic latex top-coats are used.

Table 15–5. Suitability and expected service life of finishes for exterior wood surfaces[a]

Type of exterior wood surface	Water-repellent preservative and oil: Suitability	Water-repellent preservative and oil: Expected life[b] (years)	Semitransparent stain: Suitability	Semitransparent stain: Expected life[c] (years)	Paint and solid-color stain: Suitability	Paint and solid-color stain: Expected life[d] (years): Paint	Paint and solid-color stain: Expected life[d] (years): Solid-color stain
Siding							
Cedar and redwood							
Smooth (vertical grain)	High	1–2	Moderate	2–4	High	4–6	3–5
Rough-sawn	High	2–3	High	5–8	Moderate	5–7	4–6
Pine, fir, spruce							
Smooth (flat grain)	High	1–2	Low	2–3	Moderate	3–5	3–4
Rough (flat grain)	High	2–3	High	4–7	Moderate	4–6	4–5
Shingles							
Sawn	High	2–3	High	4–8	Moderate	3–5	3–4
Split	High	1–2	High	4–8	—	3–5	3–4
Plywood (Douglas-fir and Southern Pine)							
Sanded	Low	1–2	Moderate	2–4	Moderate	2–4	2–3
Textured (smooth-sawn)	Low	1–2	Moderate	2–4	Moderate	3–4	2–3
Textured (rough-sawn)	Low	2–3	High	4–8	Moderate	4–6	3–5
MDO plywood, cedar and redwood[e]	—	—	—	—	Excellent	6–8	5–7
Sanded	Low	1–2	Moderate	2–4	Moderate	2–4	2–3
Textured (smooth-sawn)	Low	1–2	Moderate	2–4	Moderate	3–4	2–3
Textured (rough-sawn)	Low	2–3	High	5–8	Moderate	4–6	3–5
Hardboard, medium density[f]							
Smooth-sawn							
Unfinished	—	—	—	—	High	4–6	3–5
Preprimed	—	—	—	—	High	4–6	3–5
Textured							
Unfinished	—	—	—	—	High	4–6	3–5
Preprimed	—	—	—	—	High	4–6	3–5
Millwork (usually pine)[g]	High[h]	—	Moderate	2–3	High	3–6	3–4
Decking							
New (smooth-sawn)	High	1–2	Moderate	2–3	Low	2–3	1–2
Weathered (rough-sawn)	High	2–3	High	3–6	Low	2–3	1–2
Glued-laminated members							
Smooth-sawn	High	1–2	Moderate	3–4	Moderate	3–4	2–3
Rough-sawn	High	2–3	High	6–8	Moderate	3–5	3–4
Oriented strandboard	—	—	Low	1–3	Moderate	2–4	2–3

[a]Data were compiled from observations of many researchers. Expected life predictions are for average location in continental United States; expected life will vary in extreme climates or exposure (such as desert, seashore, and deep woods).
[b]Development of mildew on surface indicates need for refinishing.
[c]Smooth, unweathered surfaces are generally finished with only one coat of stain. Rough-sawn or weathered surfaces, which are more adsorptive, can be finished with two coats; second coat is applied while first coat is still wet.
[d]Expected life of two coats, one primer and one top-coat. Applying second top-coat (three-coat job) will approximately double the life. Top-quality acrylic latex paints have the best durability.
[e]Medium-density overlay (MDO) is generally painted.
[f]Semitransparent stains are not suitable for hardboard. Solid-color stains (acrylic latex) will perform like paints. Paints are preferred.
[g]Windows, shutters, doors, exterior trim.
[h]Exterior millwork, such as windows, should be factory treated according to Industry Standard IS4–99 of the Window and Door Manufacturer's Association. Other trim should be liberally treated by brushing before painting.

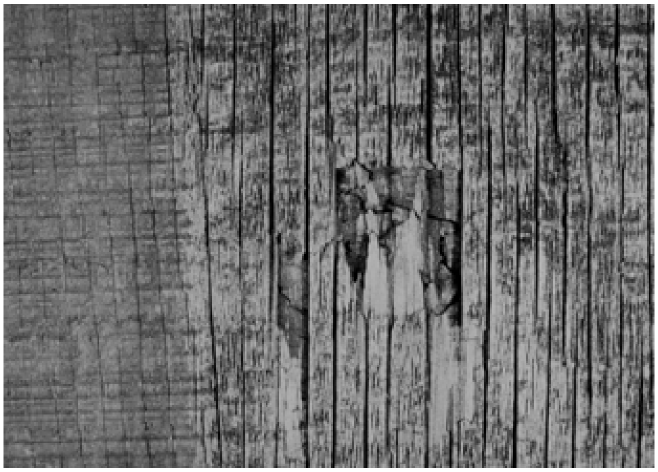

Figure 15–12. Front view of exterior grade of plywood siding after 10 years of exposure.

Weathered Wood as Natural Finish

The simplest finish for wood is that created by the weathering process. Without paint or treatment of any kind, wood surfaces gradually change in color and texture, and they may stay almost unaltered for a long time if the wood does not decay. Generally, dark-colored woods become lighter and light-colored woods become darker. As weathering continues, all woods become gray because of the loss of colored components from the wood surface and the growth of mildew. As the surface erodes, it becomes uneven because of the different erosion rates of earlywood and latewood. (Fig. 15–6).

Although leaving wood to weather to a natural finish may seem like an inexpensive low-maintenance alternative to finishing, there are many problems to this approach. To avoid decay, wood must be all heartwood from a decay-resistant species such as redwood or western redcedar. Wood should have vertical grain to decrease the potential for splitting, grain raising, and cupping. Composite wood products, such as plywood, must never be left unprotected to weather. The surface veneer of plywood can be completely destroyed within 10 years if not protected from weathering. Figure 15–12 shows weathering of unfinished plywood; the intact portion of the plywood (left) had been covered with a board to give a board-and-batten appearance.

To allow a wood structure to weather to a natural finish, the structure must be designed to keep the wood from getting wet from wind-driven rain (for example, wide roof overhangs). In most climates in the United States, exterior wood develops blotchy mildew growth and there is no protection against surface erosion or decay. It is very difficult to obtain the silvery-gray weathered patina that weathering can give. The climate along the coastal regions of New England and in some high mountains seems to encourage the development of this finish. Even when the climatic conditions favor the development of a weathered finish, it takes several years to achieve an even silvery-gray appearance.

Penetrating Wood Finishes

Penetrating finishes constitute a broad classification of natural wood finishes that do not form a film on the wood surface. Penetrating finishes are classified as (a) transparent or clear systems, (b) lightly colored systems, (c) pigmented or semi-transparent systems, and (d) oils.

Transparent or Clear Finishes

Penetrating transparent or clear finishes are generally a type of water repellent or water-repellent preservative. Water-repellent preservatives may be used as a natural finish. They differ from water repellents in that they contain a fungicide such as 3-iodo-2-propynyl butyl carbamate. As with water repellents, water-repellent preservatives contain a small amount of wax, a resin, or a drying oil. They were traditionally formulated using a solvent such as turpentine or mineral spirits, but they are presently available in a wide range of other solvent systems, including waterborne formulations.

Penetrating finishes that use paraffin oil as the solvent system are also available. These formulations penetrate wood like solventborne formulations do and the oil helps improve water repellency. Since penetrating finishes with paraffin oil are usually formulated without any volatile solvents, they meet air quality requirements. (See section on VOC-compliant finishes.) They are usually a good value because virtually all of what comes in the can ends up in the wood.

Water-repellent preservatives maintain the original appearance of the wood, but they are not very durable. Treating wood surfaces with a water-repellent preservative will protect wood exposed outdoors with little initial change in appearance. A bright, golden-tan color can be achieved with most wood species. The treatment decreases warping and cracking, prevents water staining at edges and ends of wood siding, and helps control mildew growth. The first application of a water-repellent preservative may protect exposed wood surfaces for only l to 2 years, but subsequent reapplications may last 2 to 4 years because the weathered boards absorb more finish. When a surface starts to show blotchy discoloration caused by extractives or mildew, it should be cleaned with a commercial cleaner or liquid household bleach and detergent solution, allowed to dry, and retreated.

> **Caution**: Because of the toxicity of some fungicides in water-repellent preservative solutions and some semitransparent stains, care should be exercised to avoid excessive contact with the solution or its vapor. Shrubs and plants should also be protected from accidental contamination.

Paintable water-repellent preservatives may also be used as a treatment for bare wood before priming and painting or in areas where old paint has peeled and the bare wood is exposed, particularly around butt joints or in corners. This treatment keeps rain or dew from penetrating into the wood, especially at joints and end grain, and thus decreases shrinking and swelling of the wood. As a result, less stress is placed on the paint film and its service life is extended

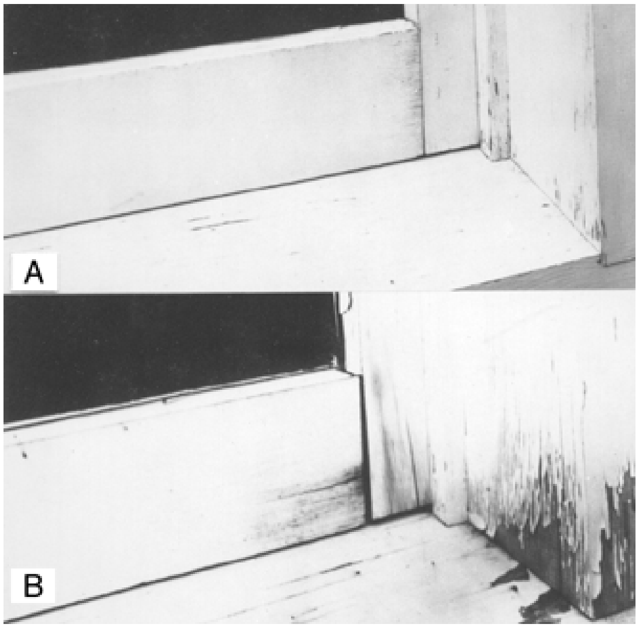

Figure 15–13. Effect of water-repellent preservative treatment. A, Window sash and frame treated with a water-repellent preservative and then painted; B, window sash and frame not treated before painting. Both window sash–frame sets were weathered for 5 years.

(Fig. 15–13). This stability is achieved by the small amount of wax present in water-repellent preservatives. The wax decreases the capillary movement or wicking of water up the back side of lap or drop siding. The fungicide inhibits decay.

A large number and variety of waterborne penetrating clear finishes are available for use on wood. The formulations of these finishes are generally proprietary, and it is difficult to determine the nature of these finishes. These formulations are usually water emulsions of synthetic polymers. The polymers do not penetrate the lateral surface of the wood very well, but they can change the surface properties. The polymer helps seal the surface and provides some water repellency. The formulations may include additional additives such as UV stabilizers, additional water repellents, mildewcides, and colorants.

Lightly Colored Finishes

Traditional solventborne formulations of water-repellent preservatives did not contain any coloring pigments. Therefore, the resulting finish varied little from the original color of the wood. Many of the newer formulations are slightly colored and have other additives such as UV stabilizers. As with traditional formulations, the preservative also prevents wood from darkening (graying) through mildew growth.

These lightly colored finishes may be water- or solventborne formulations. The color may be obtained from dyes or finely ground pigment. Although they are still classified as a penetrating finish or sealer for wood, many of the newer formulations form a slight film on the wood surface. This is particularly true for the waterborne formulations. As with the uncolored clear finishes, the durability of lightly colored finishes is somewhat limited. Although their durability is improved by the inclusion of UV stabilizers and finely ground pigment, lightly colored finishes still lack sufficient pigment to stop UV degradation of the wood.

Semitransparent Stains

Inorganic pigments can also be added to water-repellent preservative solutions to provide special color effects, and the mixture is then classified as a semitransparent stain. A semitransparent stain is a pigmented penetrating stain. Colors that match the natural color of the wood and extractives are usually preferred. The addition of pigment to the finish helps stabilize the color and increase the durability of the finish, but they give a less natural appearance because the pigment partially hides the original grain and color of the wood. Semitransparent stains are generally much more durable than are water-repellent preservatives and provide more protection against weathering. These stains slow weathering by retarding the alternate wetting and drying of wood, and the pigment particles on the wood surface minimize the degrading effects of sunlight. The amount of pigment in semitransparent stains can vary considerably, thus providing different degrees of protection against UV degradation and masking of the original wood surface. Higher pigment concentration yields greater protection against weathering, but it also hides the natural color of the wood.

Solventborne oil-based semitransparent penetrating stains penetrate the wood surface, are porous, and do not form a surface film like paints. As a result, they will not blister or peel even if moisture moves through the wood. Semitransparent penetrating stains are only moderately pigmented and do not totally hide the wood grain. Penetrating stains are alkyd or oil based, and some may contain a fungicide as well as a water repellent. Moderately pigmented latex-based (waterborne) stains are also available, but they do not penetrate the wood surface as well as the oil-based stains. Some latex-based formulations are oil modified. These formulations give better penetration than do the unmodified formulations.

Semitransparent stains are most effective on rough lumber or rough-sawn plywood surfaces. They may be used on smooth surfaces but have less than half the service life compared with that on rough surfaces. Stains are available in a variety of colors and are especially popular in the brown or red earth tones because these give a natural or rustic appearance to the wood. They are an excellent finish for weathered wood. Semitransparent stains are not effective when applied over a solid-color stain or old paint.

Many resin and paint manufacturers have tried to achieve the properties of solventborne semitransparent stains using waterborne formulations. Some of these finishes achieved a semitransparent appearance by the formation of a rather thin coating on the wood surface. The resins used in these formulations did not penetrate the wood surface. Therefore, these finishes were prone to fail within a few years through flaking of the thin coating from the surface. When the surfaces were refinished, the subsequent finish increased the film thickness and obscured the original appearance of the wood. Because the film buildup is not sufficient to give the good performance provided by a film-forming finish, waterborne semitransparent stains generally continue to fail by flaking. Many new formulations are modified with oil–alkyds. The oil penetrates the surface, thus improving the performance of the finish. Efforts are continuing to improve these formulations; it is advisable to check with a local paint supplier for the latest developments in this area.

Oils

Drying oils, such as linseed and tung, are sometimes used by themselves as natural finishes. Such oils are not recommended for exterior use unless they are formulated with a mildewcide. These oils are natural products and therefore provide food for mildew. When drying oils are used on highly colored woods such as redwood or the cedars, they tend to increase problems with mildew.

Film-Forming Finishes

Clear Varnish

Clear varnish is the primary transparent film-forming material used for a natural wood finish, and it greatly enhances the natural beauty and figure of wood. However, varnish lacks exterior permanence unless protected from direct exposure to sunlight, and varnish finishes on wood exposed outdoors without protection will generally require refinishing every l to 2 years. Thus, varnish is not generally recommended for exterior use on wood. Varnish coatings embrittle by exposure to sunlight and develop severe cracking and peeling. Varnish used in areas that are protected from direct sunlight by an overhang or used on the north side of the structure will last considerably longer. However, even in protected areas, a minimum of three coats of varnish is recommended, and the wood should be treated with a paintable water-repellent preservative before finishing. The use of pigmented stains and sealers as undercoats will also contribute to greater life of the clear finish. In marine exposures, up to six coats of varnish should be used for best performance.

Pigmented Varnish

Several finish manufacturers have formulated varnish with finely ground inorganic pigments that partially block UV radiation yet allow much of the visible light to pass through the finish. These products give much better performance than do traditional clear varnishes, and if a clear film is desired for exterior use, they may be a better choice. Pigmented varnish gives excellent performance on structures that are protected from sunlight by wide overhangs and wooded surroundings. The degradation of pigmented varnish initially occurs on the film surface as crazing and checking. These surface checks can be repaired by refinishing in a timely manner. Eventually, however, the buildup of coats will block much of the visible light and the wood will appear dark.

Solid-Color Stains

Solid-color stains are opaque finishes (also called hiding, heavy-bodied, or blocking) that come in a wide range of colors and are made with a much higher concentration of pigment than are semitransparent penetrating stains. As a result, solid-color stains totally obscure the natural color and grain of the wood. Solid-color stains (both oil- and latex-based) tend to form a film much like paint, and as a result they can also peel from the substrate. Both oil and latex solid-color stains are similar to paints and can usually be applied over old paint or to unfinished wood if adequately primed. As with any film-forming finish, good service life requires 4- to 5-mil dry film thickness.

Paint

Paints are highly pigmented film-forming coatings that give the most protection to wood. Paints are used for esthetic purposes, to protect the wood surface from weathering, and to conceal certain defects. They also provide a cleanable surface. Of all the finishes, paints provide the most protection for wood against surface erosion and offer the widest selection of colors. Paints are the only way to achieve a bright white finish. A nonporous paint film retards penetration of moisture and decreases discoloration by wood extractives as well as checking and warping of the wood. Paint is *not* a preservative. It will not prevent decay if conditions are favorable for fungal growth.

Paints do not penetrate the surface of the wood except to fill cut cells and vessels. They do not penetrate the cell wall of the wood as do some penetrating finishes. The wood grain is completely obscured as the surface film is formed. Paints perform best on vertical-grain lumber of species with low specific gravity. As with other film-forming finishes, paints can blister or peel if the wood is wetted or if inside water vapor moves through the house wall to the wood.

Latex paints are generally easier to use because water is used in cleanup. They are also porous and thus allow some moisture movement. In comparison, oil-based paints require organic solvents for cleanup, and some oil-based paints are resistant to moisture movement. Latex paints mainly formulated with acrylic resins are extremely resistant to weathering and maintain their gloss better than do oil-based paints. Such latex paints remain flexible throughout their service life. Oil-based paints tend to lose gloss within a year or two and are prone to embrittle over time.

The cost of finishes varies widely depending on the type of finish and quality (Table 15–4). Within a particular type of finish (for example, oil-based paint, all-acrylic latex paint, oil-based solid-color stain), cost usually correlates with quality. Better quality paints usually contain higher amounts of solids by weight. Paints with a lower percentage of solids may cost less by the unit but be more expensive per unit of solids, and more or heavier coats will have to be applied to achieve equal coverage. Comparing solids content and price can be the first criterion for selecting the better value because only the solids are left on the surface after the solvent evaporates. For example, if one paint is 50% solids and costs $20 and a second paint is 40% solids and costs $18, all other things being equal the $20 paint is a better value (25% more solids for about 11% more money). Another criterion is the amount and type of pigment because these determine the hiding power of the finish. Paint that contains primarily titanium dioxide pigment will have better hiding power than that with calcium carbonate filler. A paint with poor hiding power may require the application of more coats. Finally, the type and amount of binder affect the quality of the paint. For latex paints, all acrylic binders are more weather-resistant than are vinyl and vinyl–acrylic binders.

Fire-Retardant Coatings

Many commercial fire-retardant coating products are available to provide varying degrees of protection of wood against fire. These paint coatings generally have low surface flammability characteristics and “intumesce” to form an expanded low-density film upon exposure to fire, thus insulating the wood surface from heat and retarding pyrolysis reactions. The paints have added ingredients to restrict the flaming of any released combustible vapors. Chemicals may also be present in these paints to promote decomposition of the wood surface to charcoal and water rather than the formation of volatile flammable products. Most fire-retardant coatings are intended for interior use, but some are available for exterior application. Wood shakes and shingles are often impregnated with a fire retardant.

Compliance of VOC Finishes With Pollution Regulations

Volatile organic compounds (VOCs) are those organic materials in finishes that evaporate as the finish dries and/or cures. These materials are regarded as air pollutants, and the amount that can be released for a given amount of solids (for example, binder, pigments) in the paints is now regulated in many areas. Regulations that restrict the amount of VOCs in paints have been enacted in many states, including California, New York, Texas, Massachusetts, New Jersey, and Arizona, and legislation is pending in many others.

The result of such legislation is that all major paint companies have had to either change their paint formulation or market additional low-VOC formulations. Some smaller companies have been unaffected by VOC regulations because they market their products in limited geographic areas outside those affected by existing State and local legislation. This situation is slated to change soon. Under the 1990 New Clean Air Act, the U.S. Environmental Protection Agency (EPA) has been charged to enact a regulation that affects all of the United States. This regulation will take effect in 1999 and will regulate the amount of VOC in all types of architectural finishes, including paints, solid-color stains, and penetrating finishes, such as semitransparent stains and water-repellent preservatives.

Existing and pending regulations are a serious concern throughout the U.S. paint industry, particularly with regard to a national rule that will affect areas of the country that have not previously had to comply with VOC regulations. Many traditional wood finishes may no longer be acceptable, including oil-based semi-transparent stains, oil- and alkyd-based primers and top coats, solventborne water-repellents, and solventborne water-repellent preservatives. Many current wood finishes, including some latex-based materials, may be reformulated. These changes affect the properties of the finish, application, interaction with the wood (for example, adhesion, penetration, moisture-excluding effectiveness), and possibly durability.

Many penetrating finishes, such as semitransparent stains, have low solids content (pigment, oils, polymers) levels and are being reformulated to meet low-VOC regulations. To meet the VOC requirements, these reformulated finishes may contain higher solids content, reactive diluents, new types of solvents and/or cosolvents, or other nontraditional substituents. These low-VOC formulations are prone to form films rather than penetrate the wood surface. There is little information about the way these new penetrating finishes interact with the substrate to protect the wood or about the degradation mechanisms of these finishes when exposed to various outdoor conditions. Because such formulations may not interact with the wood in the same way as do traditional finishes, the effect of moisture may be different.

Application of Wood Finishes

Type of Finish

Water-Repellent Preservatives

The most effective method of applying a water repellent or water-repellent preservative is to dip the entire board into the solution. However, other application methods can be used if they are followed by back brushing. It is advantageous to treat the back side of the siding, particularly with highly colored wood species. (See section on back-priming.) When wood is treated in place, liberal amounts of the solution should be applied to all lap and butt joints, edges and ends of boards, and edges of panels with end grain. Other areas especially vulnerable to moisture, such as the bottoms of doors and window frames, should also be treated. Coverage is about 6.1 m^2/L (250 ft^2/gal) on a smooth surface or 3.7 m^2/L (150 ft^2/gal) on a rough surface. Smooth wood will usually accept only a single coat; a second coat will not penetrate the wood. Water-repellent preservative treatment generally lasts longer on rough surfaces than on smooth surfaces because more finish penetrates the wood. As a natural finish, the life expectancy of a water-repellent preservative is only 1 to 2 years, depending upon the wood and exposure. However, reapplication is easy, particularly on decks and fences. Multiple coats brush-applied to the point of refusal (failure to penetrate) will enhance durability and performance of the wood.

Water-repellent-preservative-treated wood that is painted will not need retreatment unless the protective paint layer has peeled or weathered away. The water-repellent preservative should be applied only to the areas where the paint has peeled. The water-repellent preservative should be allowed

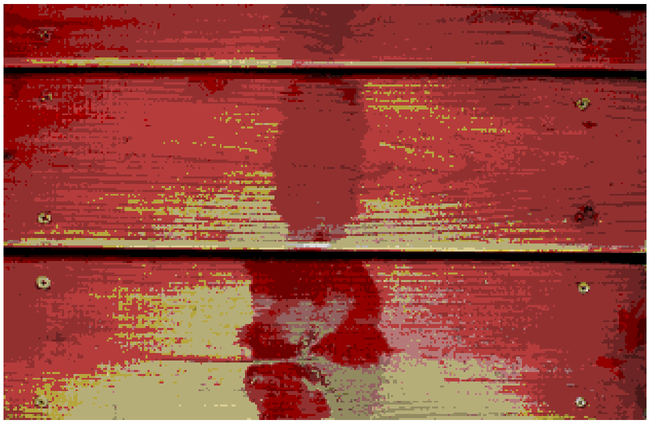

Figure 15–14. Lap marks on wood finished with semitransparent stain.

to dry for 3 days, and the peeled area should be reprimed before it is repainted.

Semitransparent Penetrating Stains

Semitransparent penetrating stains may be brushed, sprayed, or rolled on, but they must be back-brushed. Brushing works the finish into the wood and evens out the application so that there is less chance for lap marks. Semitransparent penetrating stains are generally thin and runny, so application can be messy. Lap marks may form if stains are improperly applied, but such marks can be prevented by staining only a small number of boards or one panel at a time (Fig. 15–14). This method prevents the front edge of the stained area from drying out before a logical stopping place is reached. Working in the shade is desirable because the drying rate is slower. Coverage is usually about 4.9 to 9.8 m^2/L (200 to 400 ft^2/gal) on a smooth wood surface and from 2.4 to 4.9 m^2/L (100 to 200 ft^2/gal) on a rough or weathered surface. Stains perform much better on rough-sawn wood.

To give penetrating oil-based semitransparent stains a long life on rough-sawn or weathered lumber, use two coats and apply the second coat before the first is dry (wet on wet application). Apply the first coat to a panel or area in a manner to prevent lap marks. Then, work on another area so that the first coat can soak into the wood for 20 to 60 min. Apply the second coat before the first coat has dried. If the first coat dries completely, it may seal the wood surface so that the second coat cannot penetrate the wood. About an hour after applying the second coat, use a cloth, sponge, or dry brush lightly wetted with stain to wipe off excess stain that has not penetrated into the wood. Otherwise, areas of stain that did not penetrate may form an unsightly shiny surface film. Avoid intermixing different brands or batches of stain. Stir the stain occasionally and thoroughly during application to prevent settling and color change.

A two-coat system of semitransparent penetrating stain may last as long as 10 years on rough wood in certain exposures as a result of the large amount of stain absorbed. By comparison, the life expectancy of one coat of stain on new smooth wood is only 2 to 4 years; successive recoats last longer (Table 15–5).

> **Caution**: Sponges or cloths that are wet with oil-based stain are particularly susceptible to spontaneous combustion. To prevent fires, immerse such materials in water and seal in a water-filled air-tight metal container immediately after use.

Waterborne Semitransparent Stains

Waterborne semitransparent stains do not penetrate the wood surface as well as oilborne semitransparent stains, but they are easy to apply and less likely to form lap marks. These stains form a thin film, and a second coat will improve their durability. Apply the second coat any time after the first has dried.

Solid-Color Stains

Solid-color stains may be applied to a smooth wood surface by brush, spray, or roller; if the finish is applied by spray or roller, it is necessary to "back-brush" immediately after application. Solid-color stains act much like paint. One coat of solid-color stain is **not** considered adequate for siding. Some manufacturers recommend using the first coat as a primer, but a primer paint might be better, particularly if there is a possibility for extractives bleed. Two coats of solid-color stain applied over a quality latex or oil primer should give service life similar to that of a good paint system. Solid-color stains are not generally recommended for horizontal wood surfaces such as decks, roofs, and window sills.

Unlike paint, solid-color stain is subject to lap marks during application. Latex-based stains are particularly fast-drying and are more likely to show lap marks than are oil-based stains. To prevent lap marks, follow the procedures suggested in the section on application of semitransparent penetrating stains.

Paint

Wood and wood-based products should be protected from sunlight and water while stored prior to delivery to a construction site and while stored on the construction site. The finish should be applied as soon as possible after the wood is installed. Surface contamination from dirt, oil, and other foreign substances must be eliminated. The paint bond with the wood is greatly increased if the wood is painted within 1 week, weather permitting, after installation (see Weathering—Effect of weathering on paint adhesion). To achieve maximum paint life, do the following:

1. Treat wood siding and trim with a paintable water-repellent preservative or water repellent. Water repellents protect the wood against the absorption of rain and dew and thus help to minimize swelling and shrinking. Water repellents can be applied by brushing or dipping. Lap and butt joints and the edges of panel products such as plywood, hardboard, and particleboard should be especially well treated because these areas are prone to absorb

moisture, which leads to paint failure. Allow at least three warm, sunny days for adequate drying before painting the treated surface. If the wood has been dip treated, allow at least 1 week of favorable weather before painting.

2. Prime the bare wood after the water-repellent preservative has dried (see section on back-priming). The primer coat forms a base for all succeeding paint coats. For woods with water-soluble extractives, such as redwood and cedar, primers block the bleed of extractives into the top coat. Use a primer that is labeled to "block extractives bleed," usually a quality alkyd-based paint. Many manufacturers are also formulating stain-blocking acrylic-latex-based paints. Allow a latex stain-blocking primer to dry for at least 24 to 48 h before applying the top coat. If the primer has not fully cured, extractives may bleed into the top coat. Apply a primer regardless of whether the top coat is an oil-based or latex-based paint. For species that are predominantly sapwood and free of extractives, such as pine, using a quality primer is still necessary to give a good base for the top coat. Apply enough primer to obscure the wood grain. Follow the application rates recommended by the manufacturer. Do not spread the primer too thinly. A primer coat that is uniform and of the proper thickness will distribute the swelling stresses that develop in wood and thus help to prevent premature paint failure.

3. Apply two coats of a good-quality acrylic latex house paint over the primer. Oil-based, alkyd-based, and vinyl–acrylic paints can also be used. If it is not practical to apply two top-coats to the entire house, consider two top-coats for fully exposed areas on the south and west sides as a minimum for good protection. Areas fully exposed to sunshine and rain are the first to deteriorate and therefore should receive two top-coats. On those wood surfaces best suited for painting, one coat of a good house paint over a properly applied primer (a conventional two-coat paint system) should last 4 to 5 years, but two top-coats can last 10 years (Table 15–5).

   Primer will cover about 6.1 to 7.4 m^2/L (250 to 300 ft^2/gal) on smooth bare wood; for repainting, coverage will be about 9.8 m^2/L (400 ft^2/gal). However, coverage can vary with different paints, surface characteristics, and application procedures. Research has indicated that the optimal thickness for the total dry paint coat (primer and two top-coats) is 0.10 to 0.13 mm (4 to 5 mils) (or about the thickness of a sheet of newspaper). The quality of paint is usually, but not always, related to price. Brush application is always superior to roller or spray application, especially for the first coat.

4. To avoid peeling between paint coats, apply the first top-coat within 2 weeks after the primer and the second coat within 2 weeks of the first. As certain paints weather, they can form a soaplike substance on their surface that may prevent proper adhesion of new paint coats. If more than 2 weeks elapse before applying another paint coat, scrub the old surface with water using a bristle brush or sponge. If necessary, use a mild detergent to remove all dirt and deteriorated paint. Then rinse the cleaned wood with water and allow all surfaces to dry before painting.

5. To avoid temperature blistering, do not apply oil-based paint on a cool surface that will be heated by the sun within a few hours. Temperature blistering is most common with thick coats of dark-colored paint applied in cool weather. The blisters usually show up in the last coat of paint and occur within a few hours or up to 1 or 2 days after painting. They do not contain water.

6. Apply latex-based waterborne paints when the temperature is at least 10°C (50°F); oil-based paint may be applied when the temperature is at least 4°C (40°F). For proper curing of latex paint films, the temperature should not drop below 10°C (50°F) for at least 24 h after paint application. Low temperatures will result in poor coalescence of the paint film and early paint failure. Some new latex formulations are being developed for application at lower temperatures. Refer to application instructions on the label of the paint can.

7. To avoid wrinkling, fading, or loss of gloss of oil-based paints and streaking of latex paints, do not apply the paint during autumn days or cool spring evenings when heavy dews form during the night. Serious water absorption problems and major finish failure can occur with some paints when applied under these conditions.

Porches, Decks, and Fences

Exposed flooring on porches is usually painted. Since porches often get wet from windblown rain, it is particularly important to pretreat the wood surface with a water-repellent preservative prior to painting. Use primers and paints specially formulated for porches. These paints are formulated to resist abrasion and wear.

Many fully exposed decks are more effectively finished with only a water-repellent preservative or a penetrating-type semitransparent pigmented stain. Decks finished with these finishes will need more frequent refinishing than do painted surfaces, but refinishing is easy because there is no need for the laborious surface preparation required for painted surfaces that have peeled. It is essential to limit the application of semitransparent stain to what the surface can absorb. Roller and spray application may put too much stain on the horizontal surfaces of decks. The best application method for such smooth surfaces is by brush. Unless specially formulated for use on decks, solid-color stains should not be used on any horizontal surface because they lack abrasion resistance, and because they form a film, they tend to fail by flaking.

Like decks, fences are fully exposed to the weather and at least some parts (such as posts) are in contact with the soil. As a result, wood decay and termite attack are potential problems. Often in the design of fences, little consideration is given to protecting exposed end-grain of various fence components or to avoiding trapped moisture. If a film-forming finish is to be used on a fence, it is extremely important to seal the end grain and protect exposed end-grain wherever possible. Use lumber pressure-treated with preservatives or naturally durable wood species for all posts and other fence components that are in ground contact.

In regard to the service life of naturally durable wood species compared with wood pressure-treated with preservatives, there are no absolute "rules." In ground contact uses, pressure-treated wood species often outperform naturally durable species in warm wet climates, but less difference in service life often occurs in dry climates. The service life of naturally durable and preservative-treated woods is quite comparable in aboveground exposures, such as decking boards, railing, and fence boards. In selecting wood for porches, decks, and fences, whether preservative treated or a naturally durable species, consideration must be given to the exposure conditions, design of the structure, and properties of the wood, including its variability.

In aboveground uses, the weathering of wood can be as much a factor in long-term service life as is decay resistance. Whether naturally durable wood species or preservative-treated wood is used in full exposures to weather, it is necessary to protect the wood with a finish. Periodic treatment with a penetrating sealer, such as a water-repellent preservative, will decrease checking and splitting, and pigmented finishes will retard weathering.

Treated Wood

Treated wood is often used to construct porches, decks, and fences, particularly wood treated with chromated copper arsenate (CCA). Woods that have been pressure treated for decay sometimes have special finishing requirements. Wood pressure treated with waterborne chemicals, such as copper, chromium, and arsenic salts (CCA), that react with the wood or form an insoluble residue presents no major problem in finishing if the wood is properly redried and thoroughly cleaned after treating. The finishing characteristics are more controlled by species and grain orientation than by preservative treatment. Wood treated with solvent- or oilborne preservative chemicals, such as creosote or pentachlorophenol, is not considered paintable.

None of the common pressure preservative treatments (creosote, pentachlorophenol, water-repellent preservatives, and waterborne preservatives) will significantly change the weathering characteristics of woods. All preservative-treated wood will weather when exposed above ground and may develop severe checking and cracking. Finishing generally retards this weathering. However, there is one exception: waterborne treatments containing chromium decrease the degrading effects of weathering.

Creosote and pentachlorophenol are generally used only for industrial and commercial applications where applying a finish is not considered practical. Creosote is oily and therefore does not accept a finish very well. Pentachlorophenol is often formulated in heavy oil. In general, preservatives formulated in oil will not accept a finish. In some cases, oil-based semitransparent penetrating stains can be used on these products, but only after the preservative-treated wood has weathered for 1 to 2 years, depending on exposure.

The only preservative-treated woods that should be painted or stained immediately after treatment and without further exposure are the waterborne preservative treatments (such as CCA-treated wood). Since wood treated with these preservatives is often used for residential structures, it needs to be finished not only for esthetic reasons, but also to protect it from weathering. Many manufacturers of chemicals for treating wood with waterborne preservatives include a water-repellent treatment to give the treated wood better resistance to weathering, particularly checking and splitting. Even if the wood was treated with water repellent by the manufacturer, it should be maintained with a finish to extend its service life. Wood used in aboveground applications that has been properly treated with preservative is usually replaced because of weathering, not decay.

Marine Uses

The marine environment is particularly harsh on wood. As discussed, the natural surface deterioration process occurs slowly. Marine environments speed up the natural weathering process to some extent, and wood for marine uses is often finished with paint or varnish for protection. Certain antifouling paints are also used to protect piers and ship hulls against marine organisms.

For best protection, wood exposed to marine environments above water and above ground should be treated with a paintable water-repellent preservative, painted with a suitable paint primer, and top coated (at least two coats) with quality exterior marine products.

> **Note:** Any wood in contact with water or the ground should be pressure treated to specifications recommended for in-ground or marine use. Such treated woods are not always paintable. As indicated previously, CCA-treated woods are paintable when dry and clean.

Wood trim on boats is often varnished. When applied to boats, varnish is subjected to greater exposure to sunlight and water than when used on structures; therefore, it needs regular and frequent care and refinishing. Varnishes should be specially formulated for harsh exposure; three to six coats should be applied for best performance. The durability of the varnish can be extended by finishing the wood with a semitransparent stain prior to varnishing, but this obscures many natural characteristics of the wood. Keeping the appearance of varnished wood trim bright and new is labor intensive but often well worth the effort.

Refinishing

Exterior wood surfaces need to be refinished only when the old finish has worn thin and no longer protects the wood. In repainting, one coat may be adequate if the old paint surface is in good condition. Dirty paint can often be renewed and cleaned by washing with detergent. Too-frequent repainting with an oil-based system produces an excessively thick film that is likely to crack abnormally across the grain of the wood. Complete removal of the paint and repainting are the only cure for cross-grain cracking (see subsection on cross-grain cracking under Finish Failure or Discoloration). Latex paints seldom develop cross-grain cracking because they are more flexible than are oil-based paints. Since latex paints have replaced oil-based paints for most exterior application on residential structures, cross-grain cracking is rather rare unless the latex paint has been applied over many coats of oil-based paint. However, even with latex paints, excessive paint buildup should be avoided. Additional top-coats should be applied only when the primer begins to show.

Water-Repellent Preservatives

Water-repellent preservatives used as natural finishes can be renewed by simply brushing the old surface with a dry stiff-bristle brush to remove dirt and applying a new coat of finish. To determine if a water-repellent preservative has lost its effectiveness, splash a small quantity of water against the wood surface. If the water beads up and runs off the surface, the treatment is still effective. If the water soaks in, the wood needs to be refinished. Refinishing is also required when the wood surface shows signs of graying. Gray discoloration can be removed by washing the wood with a commercial mildew cleaner or liquid household bleach (see subsection on mildew under Finish Failure or Discoloration).

Semitransparent Penetrating Stains

Surfaces finished with semitransparent penetrating stains are relatively easy to refinish; heavy scraping and sanding are generally not required. Simply use a dry stiff-bristle brush to remove all surface dirt, dust, and loose wood fibers, and then apply a new coat of stain. The second coat of penetrating stain often lasts longer than the first because it penetrates into small surface checks that open as the wood weathers.

In refinishing surfaces originally finished with semitransparent stains, it is extremely important that the wood accept the stain. That is, the stain must penetrate the wood. Since the weathering rate of a stain varies with exposure, the stain may not penetrate well in some areas. For example, an area under the eaves, even on the south side of a structure, may be relatively unweathered. When applying stain to such an area, feather the new stain into the old. If the stain does not penetrate the wood within an hour, remove the excess. If the excess stain is not removed it will form shiny spots, which will flake from the surface as it weathers. The north side of a structure may not need to be restained nearly as often as the south side (northern hemisphere).

> **Note**: Steel wool and wire brushes should not be used to clean surfaces to be finished with semitransparent stain or water-repellent preservatives because small iron deposits may be left behind. These small iron deposits can react with certain water-soluble extractives in woods like western redcedar, redwood, Douglas-fir, and the oaks, to yield dark blue–black stains on the surface (see subsection on iron stain under Finish Failure or Discoloration).

Paint and Solid-Color Stains

In refinishing painted (or solid-color stained) surfaces, proper surface preparation is essential if the new coat is to have a long service life. First, scrape away all loose paint. Sand areas of exposed wood with 50- to 80-grit sandpaper to remove the weathered surface and to feather the abrupt paint edge. Then scrub any remaining old paint with a brush or sponge and water. Rinse the scrubbed surface with clean water, then wipe the surface with your hand or cloth (see subsection on chalking under Finish Failure or Discoloration). If the surface is still dirty or chalky, scrub it again using a detergent. Use a commercial cleaner or a dilute household bleach solution to remove mildew (see subsection on mildew under Finish Failure or Discoloration). Rinse the cleaned surface thoroughly with fresh water and allow it to dry before repainting. Treat bare wood with a water-repellent preservative and allow it to dry for at least 3 days before priming. Top coats can then be applied.

> **Note:** Special precautions are necessary if the old paint contains lead. See section on lead-based paint**.**

It is particularly important to clean areas that are protected from sun and rain, such as porches, soffits, and side walls protected by overhangs. These areas tend to collect dirt and water-soluble materials that interfere with the adhesion of new paint. It is probably adequate to repaint these protected areas every other time the house is painted.

Latex paint or solid-color stain can be applied over freshly primed surfaces and on weathered paint surfaces if the old paint is clean and sound (chalk-free). Before repainting surfaces with latex paint, conduct a simple test. After cleaning the surface, repaint a small, inconspicuous area with latex paint and allow it to dry at least overnight. Then, to test for adhesion, firmly press one end of an adhesive bandage onto the repainted surface. Remove the bandage with a snapping action. If the tape is free of paint, the fresh latex paint is well-bonded and the old surface does not need priming or additional cleaning. If the fresh latex paint adheres to the tape, the old surface is too chalky and needs more cleaning or priming with an oil-based primer. If both the fresh latex paint and the old paint coat adhere to the tape, the old paint is not well-bonded to the wood and must be removed before repainting.

Back-Priming

Back-priming simply means the application of a primer or water-repellent preservative to the back side of wood (usually wood siding) before the wood is installed. Back-priming retards absorption of water, thus improving dimensional stability and extending the service life of the paint. It improves the appearance of the wood by decreasing extractives staining, particularly run-down extractives bleed. Treating the back side of siding with a water-repellent preservative is probably more effective than back-priming for improving dimensional stability and retarding extractives bleed. Water-repellent preservatives are particularly effective if used as a pretreatment before back-priming. However, back-priming with a stain-blocking primer alone has some benefit.

By slowing the absorption of water, the primer or water-repellent preservative improves dimensional stability of siding. Siding is less likely to cup, an important consideration for flat-grain wood. By decreasing shrinking and swelling, less stress is placed on the finish, thereby extending its service life. At the same time that the siding is back-primed, the end grain should be sealed with primer. This process has an even greater effect in stopping water absorption. Most paint failure near the end grain of siding can be eliminated by including end-grain priming along with the back-priming. When boards are cut during installation, the cut ends should be spot-primed.

Run-down extractives bleed occurs because water from wind-blown rain, leaks, and/or condensation of moisture wets the back of siding and absorbs extractives from the wood. If water from one course of siding runs down the front face of the course below it, the water may deposit the extractives on this surface, causing unsightly streaks (see subsection on extractives bleed under Finish Failure or Discoloration). Back-priming stops extractives bleed by forming a barrier between the water and the extractives. The primer should be stain-blocking, just as the primer used for the front (outside) surface of the siding. When finish is applied to siding in the factory, the back surface of the siding is routinely finished at the same time as the front surface.

Factory Finishing

Many siding, trim, and decking products are now available prefinished. Although it has been standard industry practice to preprime hardboard siding, factory finishing of solid wood products has rapidly grown during the last several years. The industry is currently growing at about 60% per year, and this growth is anticipated to continue into the early part of the next century. Coating suppliers for this industry predict that more than half of all wood siding materials will be factory finished by that time. In addition to siding, other wood products like interior trim and paneling are being prefinished. Much of this factory finishing has been made possible by the development of rapid-cure finish systems and the availability of efficient equipment to apply the finish.

Prefinishing wood at the factory rather than after installation results in overall cost savings as well as several other advantages. Weather and climate conditions during construction do not affect prefinished wood. This is a crucial consideration in northern climates where acceptable exterior finishing is impossible during the winter. In factory finishing, coverage can be controlled to give a consistent 100 to 127 µm (4 to 5 mil) dry film. The controlled conditions enable many factory finishers to guarantee their products against cracking, peeling, and blistering for 15 years. Another advantage of factory finishing is that siding is finished on all sides, including the end grain. When prefinished siding is installed, the end grain is sealed after any cross-cuts are made. This end-grain sealing is seldom done during installation of unfinished siding. The end-grain seal greatly increases resistance of siding to end-grain absorption of water, thus decreasing extractives bleed and other problems related to moisture.

Finish Failure or Discoloration

Paint is probably the most common exterior finish in use on wood today. It appears somewhere on practically every residential structure and on most commercial buildings. Even brick and aluminum-sided structures usually have some painted wood trim. When properly applied to the appropriate type of wood substrate, paint should have a service life of at least 10 years. If it does not, the selection of the paint, application, type of substrate, type of structure, and construction practices were not done properly or were not compatible.

Modern paint formulations based on acrylic polymers are extremely resistant to degradation by ultraviolet (UV) radiation. These paints degrade by a slow erosion process, which eventually exposes the primer. The erosion process depends on the exposure to the weather. Areas that deteriorate rapidly are those exposed to the greatest amount of sunshine and rain, usually on the west and south sides of a building (in the northern hemisphere). The normal deterioration process begins with soiling or a slight accumulation of dirt and then leads to gradual change and erosion of the coating. When the primer begins to show, that side of the structure should be repainted. It may not be necessary to paint all sides of the structure, since the erosion rate varies depending on exposure. This is particularly true for structures finished with white paint.

Note: The most common cause of premature paint failure on wood is moisture.

Early paint failure may develop under certain conditions of service. Excessive moisture, flat grain, high coating porosity, and application of a new paint coat without proper preparation of the old surface can all contribute to early paint failure. Paint on the outside walls of residential structures is subject to wetting from rain, dew, and frost. Equally serious is "unseen" moisture that moves from inside the structure to the outside. This is particularly true for buildings in cold northern climates that do not have effective air and vapor barriers. Many moisture-related problems can be prevented by furring out the siding 9 to 19 mm (3/8 to 3/4 in.) prior to installation. For siding placed directly on insulation board or a wind barrier, placing wedges between the siding courses can reduce problems with moisture.

The next most common cause of paint failure is a poor bond between the substrate and the coating. Even in the absence of moisture, paint can peel if it does not bond well to the wood. If moisture is also present, paint failure is accelerated. The wide bands of latewood on flat-grain surfaces hold paint very poorly. If possible, flat-grain boards should be exposed "bark-side" out to minimize raising and separation of grain, and the boards should either be rough-sawn or scuff-sanded with 50-grit sandpaper prior to priming. Wood must be protected from the weather prior to installation and painted as soon as possible afterwards. Exposure to the weather for as little as 2 weeks will reduce the paint-holding properties of smooth wood. Scuff sanding prior to painting is necessary if the wood is exposed to the weather for more than 2 weeks. In fact, scuff sanding is always a good idea on planed lumber.

Moisture Blisters

Moisture blisters are bubble-like swellings of the paint film on the wood surface. As the name implies, these blisters usually contain moisture when they are formed. Moisture blisters may occur where outside moisture, such as rain, enters through joints and other end-grain areas of boards and siding. Moisture may also enter as a result of poor construction and maintenance practices. The blisters appear after spring rains and throughout the summer. Paint failure is most severe on the sides of buildings that face the prevailing winds and rain. Blisters may occur in both heated and unheated buildings.

Moisture blisters may also result from the movement of water from the inside of a structure to the outside. Plumbing leaks, humidifiers, overflow (sinks, bathtubs), and shower spray are sources of inside water, and improperly sealed walls can contribute to the problem. Such blisters are not seasonal and occur when the faulty condition develops.

Moisture blisters form between the wood substrate and the first coat of paint. After the blisters appear, they may dry out and collapse. Small blisters may disappear completely and fairly large ones may leave rough spots; in severe cases, the paint peels (Fig. 15–15). Thin coatings of new oil-based paint are the most likely to blister. Old, thick coats are usually too rigid to swell and form blisters; cracking and peeling usually result. Elimination of the moisture problem is the only practical way to prevent moisture blisters in paint. In addition, elimination of moisture problems can help prevent more serious problems such as decay (rot), warp, and splitting of the wood substrate.

To prevent moisture-related paint problems, follow good construction and painting practices. First, do whatever is possible to keep the wood dry. Provide an adequate roof overhang and properly maintain shingles, gutters, and downspouts. Window and door casings should slope away from the house, allowing water to drain away rapidly. Vent clothes dryers, showers, and cooking areas to the outside, not to the crawl space or attic. Avoid the use of humidifiers. If the house contains a crawl space, cover the soil with a vapor-retarding material to prevent migration of water vapor into the living quarters. In northern climates, use a vapor retarder on the interior side of all exterior walls and an air barrier to prevent condensation in the wall. In buildings in southern climates that are air conditioned a substantial part of the year, place the vapor retarder directly under the sheathing.

Mill Glaze

Since the mid-1980s, a condition known as "mill glaze" (also called planer's glaze) has occasionally occurred on smooth flat-grain western redcedar siding as well as other species. There is controversy over the exact cause of this condition, but it seems to occur as a result of planing and/or drying of the lumber. The condition seems to be caused by dull planer blades and is exacerbated on flat-grain surfaces, which are more difficult to plane. The problem is most severe on flat-grain boards because of the orientation of latewood to earlywood. Dull blades tend to burnish the surface and crush the less dense earlywood bands that lie directly beneath the more dense latewood bands at the surface. Later, when these boards are exposed to weather, particularly cyclic moisture conditions, the crushed earlywood absorbs moisture and rebounds, which causes the surface latewood bands to raise. In vertical-grain wood, the earlywood–latewood bands are perpendicular to the surface and the lumber is easier to plane, even with dull tooling.

Figure 15–15. Paint can peel from wood when excessive moisture moves through house wall. Some cross-grain cracking is also evident on this older home.

During the planing or milling process, overheating may bring more water-soluble extractives to the surface, creating a hard, varnish-like glaze. Excess water-soluble extractives can also form (bleed) on the surface during kiln drying. As these extractives age, particularly in direct sunlight, they become insoluble and are difficult to remove. If extractives bleed to the surface prior to final planing or sanding of the lumber, this final surface preparation usually removes them.

Sanding may remove some extractives buildup, but it is not likely to remove all the crushed wood. Subsequent wetting may still cause the surface to deform. One or more wetting and drying cycles are necessary to remove these planer-induced stresses in the wood, but the wood should not be exposed to sunlight for more than 2 weeks before application of a film-forming finish because exposure decreases the adhesion of the coating (see Weathering, Effects on Paint Adhesion).

Mill glaze can cause failure of the finish. Failure is most common on flat-grain siding finished with one or two thin coats of oil-based solid-color stain (also called opaque or full-bodied stain). These low-solids coatings provide only 25 to 50 µm (1 to 2 mil) of dry-film thickness, whereas a brush-applied three-coat paint system (primer and two top-coats) provides 100 to 127 µm (4 to 5 mil) of dry-film thickness. Thin coatings of solid-color stain do not build up enough film to withstand the stresses caused by raised grain, particularly if the coating–wood bond is weakened by extractives buildup on the wood surface.

When using flat-grain bevel siding, the simplest and best solution to the problem of mill glaze and finish failure is to install the siding rough-side out. The rough side is the side of choice for application of penetrating semi-transparent stains, and although solid-color stains form films, they also will provide much better service life when applied to the rough-sawn side. In addition to the lack of mill glaze, the rough side gives two additional advantages. The film buildup on the rough side will be greater and the film will have greater mechanical adhesion or “bite.” The best film buildup is obtained by brush application. If the finish is applied by roller or spray, it is advisable to back-brush immediately after application to even out the finish and to work it into the wood surface, thus avoiding bridging, gaps, and lap marks.

If the flat-grain siding must be installed smooth-side out, remove the planing stresses by wetting the surface, then allow 2 to 3 days for the surface to dry before applying the finish. Scratch-sanding the surface with 50- to 80-grit sandpaper also improves paint adhesion. Use either a top quality three-coat paint system or apply a stain-blocking primer prior to applying solid-color stain. In selecting finishes for highly colored wood such as western redcedar or redwood, choose a primer that is impervious to bleed of water-soluble extractives. Although many waterborne primers are being marketed for use on western redcedar and redwood, many paint manufacturers still recommend an oil-based, stain-blocking primer followed by two coats of high quality, acrylic latex top coat. Solid-color stains, particularly the latex formulations, do not block water-soluble extractives very well, especially when only one coat is applied.

Mill glaze has not been common in recent years because paint companies are recommending the use of a primer prior to the application of a solid-color stain, and painting contractors are generally following these recommendations.

Intercoat Peeling

Intercoat peeling is the separation of the new paint film from the old paint coat, which indicates a weak bond between the two (Fig. 15–16). Intercoat peeling usually results from inadequate cleaning of weathered paint and usually occurs within 1 year of repainting. This type of paint peeling can be prevented by following good painting practices. Intercoat peeling can also result from allowing too much time between applying the primer coat and top coat in a new paint job. If more than 2 weeks elapse between applying an oil-based primer and a top coat, soap-like materials may form on the surface and interfere with bonding of the next coat of paint. When the period between applications exceeds 2 weeks, scrub the surface before applying the second coat. Do not apply a primer coat in the fall and wait until spring to finish with the top coat.

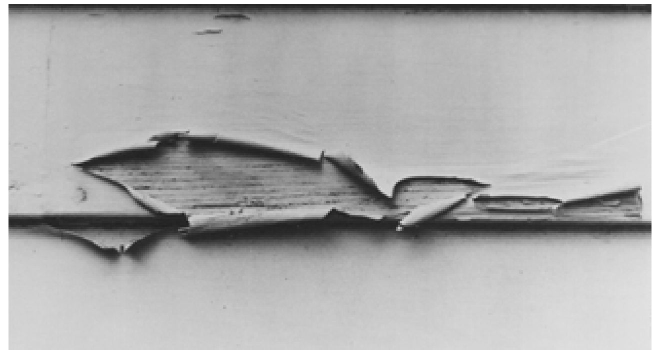

Figure 15–16. Intercoat peeling of paint, usually caused by poor preparation of old paint surface.

Cross-Grain Cracking

Cross-grain cracking occurs when oil-based or alkyd paint coatings become too thick (Fig. 15–17). This problem often occurs on older homes that have been painted many times. Paint usually cracks parallel to the wood grain; cross-grain cracks run across the grain. Once cross-grain cracking has occurred, the only solution is to completely remove the old paint and apply a new finishing system to the bare wood. To prevent cross-grain cracking, follow the paint manufacturer’s recommendations for spreading rates. Do not repaint unweathered, protected areas such as porch ceilings and roof overhangs as often as the rest of the house. If possible, repaint these areas only as they weather and require new paint.

Chalking

Chalking results from weathering of the paint’s surface, which releases pigment and degraded resin particles. These particles form a fine powder on the paint surface. Most paints chalk to some extent. This phenomenon is desirable because it allows the paint surface to self-clean, and it is the most desirable mechanism for removing degraded paint. However, chalking is objectionable when the paint pigment washes down a surface with a different color or when it causes premature paint failure through excessive erosion.

The paint formulation determines how fast the paint chalks; discoloration from chalking can be decreased by selecting a paint with a slow chalking rate. Therefore, if chalking is likely to be a problem, select a paint that the manufacturer has indicated will chalk slowly. Latex paints, particularly those based on acrylic polymers, chalk very slowly.

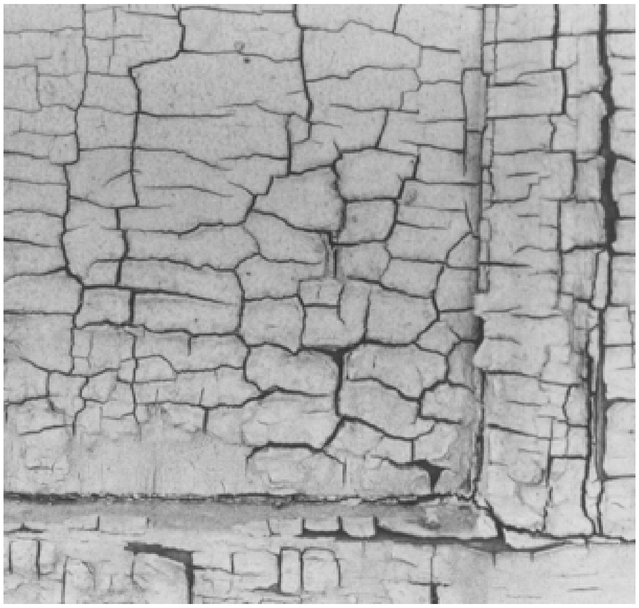

Figure 15–17. Cross-grain cracking from excessive buildup of paint.

When repainting surfaces that have chalked excessively, proper preparation of the old surface is essential to prevent premature paint peeling. Scrub the old surface thoroughly with a detergent solution to remove all old deposits and dirt. Rinse thoroughly with clean water before repainting. To check for excessive chalking, lightly rub the paint surface with a dark (for light-colored paint) or white (for dark-colored paint) cloth. The amount of pigment removed by the cloth is a good indication of the chalking. If the surface is still chalky after cleaning, it may need to be primed prior to repainting. Otherwise, the new paint coat may peel. Discoloration or chalk that has run down a lower surface may be removed by vigorous scrubbing with a good detergent. This discoloration will gradually weather away if chalking on the painted surface above the discolored surface is corrected.

Mildew

Mildew is probably the most common cause of house paint discoloration and gray discoloration of unfinished wood (Fig. 15–18). Mildew is a form of microscopic stain fungi. The most common fungal species are black, but some are red, green, or other colors. Mildew grows most extensively in warm, humid climates, but it is also found in cold northern climates. Mildew may be found anywhere on a building, although it is most common on walls behind trees or shrubs where air movement is restricted. Mildew may also be associated with the dew pattern of the house. Dew will form on those parts of the house that are not heated and tend to cool rapidly, such as eaves and ceilings of carports and porches. The dew then provides a source of moisture for mildew fungi.

Mildew fungi can be distinguished from dirt by examination under a high-power magnifying glass. In the growing stage, when the surface is damp or wet, the fungus is characterized by its threadlike growth. In the dormant stage, when the surface is dry, the fungus has numerous egg-shaped spores; by contrast, granular particles of dirt appear irregular in size and shape. A simple test for the presence of mildew on wood or paint is to apply a drop or two of liquid household bleach solution (5% sodium hypochlorite) to the discolored surface. The dark color of mildew will usually bleach out in 1 or 2 min. A surface discoloration that does not bleach is probably dirt. It is important to use fresh bleach solution because bleach deteriorates upon aging and loses its potency.

Figure 15–18. Mildew is most common in shaded, moist, or protected areas.

In warm, damp climates where mildew occurs frequently, use a paint containing zinc oxide and a mildewcide for both the primer and top coats. Before repainting mildew-infected wood or painted wood, the mildew must be killed or it will grow through the new paint coat. To kill mildew on wood or on paint, and to clean an area for general appearance or for repainting, use a bristle brush or sponge to scrub the painted surface with a commercial cleaner formulated for mildew removal. Mildew can also be removed using a dilute solution of household bleach with detergent:

- 1 part household detergent
- 10 parts (5%) sodium hypochlorite (household bleach)
- 30 parts warm water

Warning: Do not mix bleach with ammonia or with any detergents or cleansers that contain ammonia. Mixed together, bleach and ammonia form a lethal combination, similar to mustard gas. Many household cleaners contain ammonia, so be extremely careful in selecting the type of cleaner to mix with bleach. Avoid splashing the cleaning solution on yourself or on shrubbery or grass.

Rinse the cleaned surface thoroughly with fresh water. Before the cleaned surface can become contaminated, repaint it with a paint containing a mildewcide. When finishing new wood or refinishing areas that have peeled, pretreatment of wood surfaces with a water-repellent preservative prior to priming can also help deter mildew growth, even after the wood has been painted. Oil-based paints are somewhat more prone to mildew than are latex paints because the oils may be a food source for mildew.

Discoloration From Water-Soluble Extractives

In some wood species, the heartwood contains water-soluble extractives. (Sapwood does not contain extractives.) These extractives can occur in both hardwoods and softwoods. Western redcedar and redwood are two common softwood species that contain large quantities of extractives. The extractives give these species their attractive color, good stability, and natural decay resistance, but they can also discolor paint. Extractive staining problems can occur occasionally with such woods as Douglas-fir and southern yellow pine.

When extractives discolor paint, moisture is usually the culprit. The extractives are dissolved and leached from the wood by water. The water then moves to the paint surface, evaporates, and leaves the extractives behind as a reddish brown stain (Fig. 15–19). Diffused discoloration from wood extractives is caused by water from rain and dew that penetrates a porous or thin paint coat. It may also be caused by rain and dew that penetrates joints in the siding or by water from faulty roof drainage and gutters.

Diffused discoloration is best prevented by following good painting practices. Apply a water-repellent preservative or water repellent to the bare wood before priming. Use an oil-based, stain-resistant primer or a latex primer especially formulated for use over woods likely to discolor from extractives. Do not use porous paints such as flat alkyds and latex directly over these extractive-rich woods. If the wood is already painted, clean the surface, apply an oil-based or latex stain-resistant primer and then the top coat. Be sure to allow sufficient time for the primer to cure so that it blocks the extractives stain. Before priming and repainting, apply a water-repellent preservative or water repellent to any wood exposed by peeled paint.

Water-soluble extractives can also cause a run-down or streaked type of discoloration. This discoloration results when the back of siding is wetted, the extractives are dissolved, and the colored water then runs down the face of the adjacent painted board below the lap joint.

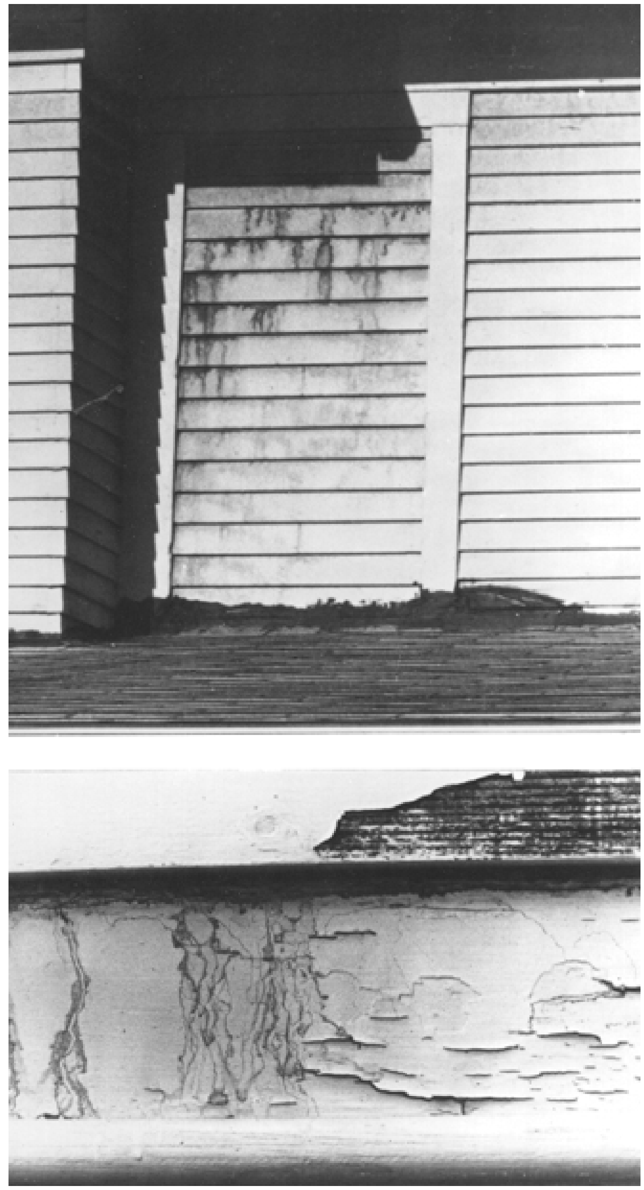

Figure 15–19. Water-soluble extractive discoloration can result from water wetting the back of the siding and then running down the front (top). Water causing discoloration also leads to paint failure (bottom).

Water that produces a run-down discoloration can result from the movement of water vapor within the house to the exterior walls and condensation during cold weather. Major sources of water vapor are humidifiers, unvented clothes dryers, showers, and moisture from cooking and dishwashing. Run-down discoloration may also be caused by draining of water into exterior walls from roof leaks, faulty gutters, ice dams, and wind-driven rain blown beneath the siding.

Run-down discoloration can be prevented by decreasing condensation or the accumulation of moisture in the wall. The same precautions to avoid moisture buildup in walls as described in the section on moisture blisters will also prevent extractives bleed. Water from rain and snow can be prevented from entering the walls by proper maintenance of the gutters and roof. The formation of ice dams can be prevented by installing adequate insulation in the attic and by providing adequate ventilation. If discoloration is to be stopped, moisture problems must be eliminated.

Extractives discoloration will usually weather away in a few months once the cause of the extractives bleed is eliminated. However, discoloration in protected areas can become darker and more difficult to remove with time. In these cases, wash the discolored areas with a mild detergent soon after the problem develops. Paint cleaners are effective on darker stains.

Highly colored woods such as redwood and the cedars benefit from back-priming or treatment with a water-repellent preservative. Although such methods will not completely eliminate extractives staining, they will help reduce staining, particularly from wind-driven rain blown underneath siding (see subsection on back-priming in Application of Wood Finishes).

Blue Stain

Blue stain is caused by microscopic fungi that commonly infect only the sapwood of trees. In some species, these fungi are prone to develop a blue–black discoloration of the wood. Blue stain does not weaken wood structurally, but conditions that favor blue stain are also ideal for wood decay and paint failure.

Wood in service may contain blue stain, and no detrimental effects will result as long as the moisture content is kept below 20%. (Wood in properly designed and well-maintained structures usually has a moisture content of 8% to 13%.) However, if the wood is exposed to moisture from sources such as rain, condensation, or leaky plumbing, the moisture content will increase and the blue-stain fungi may develop and become visible.

A commercial mildew cleaner or a 5% sodium hypochlorite solution (ordinary liquid household bleach) with detergent may remove some blue discoloration, but it is not a permanent cure. The bleach removes the stain from the surface only. To prevent blue stain, the lumber must be cut and dried as soon as possible after harvesting the logs. The lumber must then be kept dry until used and while it is in service. With some wood species that are prone to develop blue stain, the logs are often treated with a fungicide while in storage before the lumber is cut.

Iron Stain

Iron stains on wood can occur through rusting of fasteners or by the reaction of iron with tannins in the wood. When standard steel nails are used on exterior siding and then painted, a reddish brown discoloration may occur through the paint in the immediate vicinity of the nailhead. This reddish brown discoloration is rust, and it can be prevented by using corrosion-resistant nails, which include high-quality galvanized, stainless steel, and aluminum nails. Poor quality galvanized nails can corrode easily and, like steel nails, can cause unsightly staining of the wood and paint. The galvanizing on nailheads should not "chip loose" as the nails are driven into the wood.

Unsightly rust stains may also occur when standard steel nails are used in association with finishing systems such as solid-color or opaque stains, semitransparent penetrating stains, and water-repellent preservatives. Rust stains can also result from screens and other steel objects or fasteners, which corrode and/or release iron compounds.

A chemical reaction of iron with tannins in wood results in an unsightly blue–black discoloration of wood. In this case, discoloration results from the reaction of iron with certain wood extractives. Steel nails are the most common source of iron for such discoloration, but problems have also been associated with traces of iron left from cleaning the wood surface with steel wool or wire brushes. The discoloration can sometimes become sealed beneath a new finishing system. When this happens, the problem is extremely difficult to fix. The coating must be stripped before the iron stain can be removed.

Oxalic acid will remove the blue–black discoloration from iron. Apply a saturated solution containing about 0.5 kg (1 lb) of oxalic acid per 4 L (1 gal) of hot water to the stained surface. Many commercial brighteners contain oxalic acid, and these are usually effective for removing iron stains. A saturated solution of sodium bifluoride ($NaHF_2$) works as well but it may be more difficult to obtain than oxalic acid. After removing the stain, wash the surface thoroughly with warm fresh water to remove the oxalic acid. If all sources of iron are not removed or the wood is not protected from corrosion, the discoloration will recur.

> **Caution**: Use extreme care when using oxalic acid, which is toxic.

If iron stain is a serious problem on a painted surface, the nails can be countersunk and caulked, and the area spot primed and top coated. This is a costly and time-consuming process that is only possible with opaque finishes. Little can be done to give a permanent fix to iron stains on natural finishes other than removing the fasteners, cleaning the affected areas with oxalic acid solution, and replacing the fasteners. It is best to use corrosion-resistant fasteners such as stainless steel rather than risk iron stain, particularly when using natural finishes on wood containing high amounts of tannin, such as western redcedar, redwood, and oak.

Brown Stain Over Knots

The knots in many softwood species, particularly pine, contain an abundance of resins and other highly colored compounds. These compounds can sometimes cause paint to peel or turn brown. The resins that compose pitch can be "set" or hardened by the high temperatures used in kiln drying construction lumber if the proper kiln schedule is used. Some of the other compounds are not affected by kiln drying.

The elimination of staining of paint by colored resins and water-soluble extractives in knots is often difficult because the resins are soluble in oil-based primers and diffuse through them. Latex-based formulations are also not very effective in this regard. It is generally necessary to treat the knot with a specially formulated knot sealer or shellac. Do not use ordinary shellac or varnish to seal knots because such finishes are not formulated for this use; they can cause early paint failure in outdoor exposure. After sealing the knots, apply primer, followed by two top-coats.

Finishing of Interior Wood

Interior finishing differs from exterior finishing primarily in that interior woodwork usually requires much less protection against moisture but more exacting standards of appearance and cleanability. A much wider range of finishes and finish methods are possible indoors because weathering does not occur. Good finishes used indoors should last much longer than paint or other coatings on exterior surfaces. The finishing of veneered panels and plywood may still require extra care because of the tendency of these wood composites to surface check.

Much of the variation in finishing methods for wood used indoors is caused by the wide latitude in the uses of wood—from wood floors to cutting boards. There is a wide range of finishing methods for just furniture. Factory finishing of furniture is often proprietary and may involve more than a dozen steps. Methods for furniture finishing will not be included in this publication; however, most public libraries contain books on furniture finishing. In addition, product literature often contains recommendations for application methods. This section will include general information on wood properties, some products for use in interior finishing, and brief subsections on finishing of wood floors and kitchen utensils.

Color change of wood can sometimes cause concern when using wood in interiors, particularly if the wood is finished to enhance its natural appearance. This color change is a natural aging of the newly cut wood, and nothing can be done to prevent it, except, of course, to keep the wood in the dark. The color change is caused by visible light, not the UV radiation associated with weathering. It is best to keep all paintings and other wall coverings off paneling until most of the color change has occurred. Most of this change occurs within 2 to 3 months, depending on the light intensity. If a picture is removed from paneling and there is a color difference caused by shadowing by the picture, it can be corrected by leaving the wood exposed to light. The color will even out within several months.

To avoid knots, the use of fingerjointed lumber has become common for interior trim. As with exterior wood, the quality of the lumber is determined by the poorest board. Pieces of wood for fingerjointed lumber often come from many different trees that have different amounts of extractives and resins. These extractives and resins can discolor the finish, particularly in humid environments such as bathrooms and kitchens. When finishing fingerjointed lumber, it is prudent to use a high-quality stain-blocking primer to minimize discoloration.

Types of Finish and Wood Fillers

Opaque Finishes

The procedures used to paint interior wood surfaces are similar to those used for exterior surfaces. However, interior woodwork, especially wood trim, requires smoother surfaces, better color, and a more lasting sheen. Therefore, enamels or semigloss enamels are preferable to flat paints. Imperfections such as planer marks, hammer marks, and raised grain are accentuated by high-gloss finishes. Raised grain is especially troublesome on flat-grain surfaces of the denser softwoods because the hard bands of latewood are sometimes crushed into the soft earlywood in planing, and later expand when the wood moisture content changes. To obtain the smoothest wood surface, it is helpful to sponge it with water, allow to dry thoroughly, and sand before finishing. Remove surface dust with a tack cloth. In new buildings, allow woodwork adequate time to come to equilibrium moisture content in the completed building before finishing the woodwork.

To effectively paint hardwoods with large pores, such as oak and ash, the pores must be filled with wood filler (see subsection on wood fillers). The pores are first filled and sanded, then interior primer/sealer, undercoat, and top coat are applied. Knots, particularly in the pines, should be sealed with shellac or a special knot-sealer before priming to retard discoloration of light-colored finishes by colored resins in the heartwood of these species. One or two coats of undercoat are next applied, which should completely hide the wood and also provide a surface that can be easily sanded smooth. For best results, the surface should be sanded just before applying the coats of finish. After the final coat has been applied, the finish may be left as is, with its natural gloss, or rubbed to a soft sheen.

Transparent Finishes

Transparent finishes are often used on hardwoods and some softwood trim and paneling. Most finish processes consist of some combination of the fundamental operations of sanding, staining, filling, sealing, surface coating, and sometimes waxing. Before finishing, planer marks and other blemishes on the wood surface that would be accentuated by the finish must be removed.

Stains

Some softwoods and hardwoods are often finished without staining, especially if the wood has an attractive color. When stain is used, however, it often accentuates color differences in the wood surface because of unequal absorption into different parts of the grain pattern. With hardwoods, such emphasis of the grain is usually desirable; the best stains for this purpose are dyes dissolved in either water or solvent. The water-soluble stains give the most pleasing results, but they raise the grain of the wood and require extra sanding after they dry.

The most commonly used stains are those that do not raise grain and are dissolved in solvents that dry quickly. These stains often approach the water-soluble stains in clearness and uniformity of color. Stains on softwoods color the earlywood more strongly than the latewood, reversing the natural gradation in color unless the wood has been initially sealed. To give more nearly uniform color, softwoods may be coated with penetrating clear sealer before applying any type of stain. This sealer is often called a "wash coat."

If stain absorbs into wood unevenly causing a blotchy appearance, the tree was probably infected with bacteria and/or blue-stain fungi prior to being cut for lumber. Once the log is cut into lumber, the infection occurs across grain boundaries and makes infected areas more porous than normal wood. When such areas are stained, they absorb excessive amounts of stain very quickly, giving the wood an uneven blotchy appearance. Although this problem is not very common, should it occur it can be difficult to fix. Blue stain on lumber can easily be seen; the infected pieces can either be discarded or sealed before staining. However, bacteria-infected areas cannot be detected prior to staining. If the wood is to be used for furniture or fine woodwork, it might be a good idea to check the lumber, before planing, by applying a stain. Pieces on which the stain appears blotchy should not be used. Sealing the lumber with varnish diluted 50/50 with mineral spirits prior to staining may help; commercial sealers are also available. Bacteria or blue-stain infection may occur in the sapwood of any species, but it seems to be more problematic with the hardwoods because these species tend to be used for furniture, cabinets, and fine woodwork.

Fillers

In hardwoods with large pores, the pores must be filled, usually after staining and before varnish or lacquer is applied, if a smooth coating is desired. The filler may be transparent and not affect the color of the finish, or it may be colored to either match or contrast with the surrounding wood. For finishing purposes, hardwoods may be classified as shown in Table 15–6. Hardwoods with small pores may be finished with paints, enamels, and varnishes in exactly the same manner as softwoods. A filler may be a paste or liquid, natural or colored. Apply the filler by brushing it first across and then with the grain. Remove surplus filler immediately after the glossy wet appearance disappears. First, wipe across the grain of the wood to pack the filler into the pores; then, wipe with a few light strokes along the grain. Allow the filler to dry thoroughly and lightly sand it before finishing the wood.

Sealers

Sealers are thinned varnish, shellac, or lacquer that are used to prevent absorption of surface coatings and to prevent the bleeding of some stains and fillers into surface coatings, especially lacquer coatings. Lacquer and shellac sealers have the advantage of drying very quickly.

Table 15–6. Classification of hardwoods by size of pores[a]

Large pores	Small pores
Ash	Aspen
Butternut	Basswood
Chestnut	Beech
Elm	Cherry
Hackberry	Cottonwood
Hickory	Gum
Lauan	Magnolia
Mahogany	Maple
Mahogany, African	Red alder
Oak	Sycamore
Sugarberry	Yellow-poplar
Walnut	

[a]Birch has pores large enough to take wood filler effectively, but small enough to be finished satisfactorily without filling.

Surface Coats

Transparent surface coatings over the sealer may be gloss varnish, semigloss varnish, shellac, nitrocellulose lacquer, or wax. Wax provides protection without forming a thick coating and without greatly enhancing the natural luster of the wood. Other coatings are more resinous, especially lacquer and varnish; they accentuate the natural luster of some hardwoods and seem to give the surface more "depth." Shellac applied by the laborious process of French polishing probably achieves this impression of depth most fully, but the coating is expensive and easily marred by water. Rubbing varnishes made with resins of high refractive index for light (ability to bend light rays) are nearly as effective as shellac. Lacquers have the advantages of drying rapidly and forming a hard surface, but more applications of lacquer than varnish are required to build up a lustrous coating. If sufficient film buildup is not obtained and the surface is cleaned often, such as the surface of kitchen cabinets, these thin films can fail.

Varnish and lacquer usually dry to a high gloss. To decrease the gloss, surfaces may be rubbed with pumice stone and water or polishing oil. Waterproof sandpaper and water may be used instead of pumice stone. The final sheen varies with the fineness of the powdered pumice stone; coarse powders make a dull surface and fine powders produce a bright sheen. For very smooth surfaces with high polish, the final rubbing is done with rottenstone and oil. Varnish and lacquer made to produce a semigloss or satin finish are also available.

Flat oil finishes commonly called Danish oils are also very popular. This type of finish penetrates the wood and does not form a noticeable film on the surface. Two or more coats of oil are usually applied; the oil may be followed by a paste wax. Such finishes are easily applied and maintained but they are more subject to soiling than is a film-forming type of finish. Simple boiled linseed oil or tung oil are also used extensively as wood finishes.

Finishes for Floors

Wood possesses a variety of properties that make it a highly desirable flooring material for homes, factories, and public buildings. A variety of wood flooring products are available, both unfinished and prefinished, in many wood species, grain characteristics, flooring types, and flooring patterns.

The natural color and grain of wood floors accentuate many architectural styles. Floor finishes enhance the natural beauty of wood, protect it from excessive wear and abrasion, and make the floor easier to clean. The finishing process consists of four steps: sanding the surface, applying a filler (for open-grain woods), staining to achieve a desired color effect, and finishing. Detailed procedures and specified materials depend to a great extent on the species of wood used and finish preference.

Careful sanding to provide a smooth surface is essential for a good finish because any irregularities or roughness in the surface will be accentuated by the finish. Development of a top-quality surface requires sanding in several steps with progressively finer sandpaper, usually with a machine unless the area is small. When sanding is complete, all dust must be removed with a vacuum cleaner and then a tack cloth. Steel wool should not be used on floors unprotected by finish because minute steel particles left in the wood later cause iron stains. A filler is required for wood with large pores, such as oak and walnut, if a smooth, glossy varnish finish is desired (Table 15–6).

Stains are sometimes used to obtain a more nearly uniform color when individual boards vary too much in their natural color. However, stains may also be used to accent the grain pattern. The stain should be an oil-based or non-grain-raising type. Stains penetrate wood only slightly; therefore, the finish should be carefully maintained to prevent wearing through to the wood surface; the clear top-coats must be replaced as they wear. It is difficult to renew the stain at worn spots in a way that will match the color of the surrounding area.

Finishes commonly used for wood floors are classified as sealers or varnishes. Sealers, which are usually thinned varnishes, are widely used for residential flooring. They penetrate the wood just enough to avoid formation of a surface coating of appreciable thickness. Wax is usually applied over the sealer; however, if greater gloss is desired, the sealed floor makes an excellent base for varnish. The thin surface coat of sealer and wax needs more frequent attention than do varnished surfaces. However, rewaxing or resealing and waxing of high traffic areas is a relatively simple maintenance procedure, as long as the stained surface of the wood hasn’t been worn.

Varnish may be based on phenolic, alkyd, epoxy, or polyurethane resins. Varnish forms a distinct coating over the wood and gives a lustrous finish. The kind of service expected usually determines the type of varnish. Varnishes especially designed for homes, schools, gymnasiums, or other public buildings are available. Information on types of floor finishes can be obtained from flooring associations or individual flooring manufacturers.

The durability of floor finishes can be improved by keeping them waxed. Paste waxes generally provide the best appearance and durability. Two coats are recommended, and if a liquid wax is used, additional coats may be necessary to get an adequate film for good performance.

Finishes for Items Used for Food

The durability and beauty of wood make it an attractive material for bowls, butcher blocks, and other items used to serve or prepare food. A finish also helps keep the wood dry, which makes it less prone to harbor bacteria and less likely to crack. When wood soaks up water, it swells; when it dries out, it shrinks. If the wood dries out rapidly, its surface dries faster than the inside, resulting in cracks and checks. Finishes that repel water will decrease the effects of brief periods of moisture (washing), making the wood easier to clean.

Finishes that form a film on wood, such as varnish or lacquer, may be used but they may eventually chip, crack, and peel. Penetrating finishes, either drying or nondrying, are often a better choice for some products.

Types of Finish

Sealers and Drying Oils

Sealers and drying oils penetrate the wood surface, then solidify to form a barrier to liquid water. Many commercial sealers are similar to thinned varnish. These finishes can include a wide range of formulations including polyurethane, alkyds, and modified oils. Unmodified oils such as tung, linseed, and walnut oil can also be used as sealers if they are thinned to penetrate the wood.

Nondrying Oils

Nondrying oils simply penetrate the wood. They include both vegetable and mineral oils. Vegetable oils (such as olive, corn, peanut, and safflower) are edible and are sometimes used to finish wood utensils. Mineral (or paraffin) oil is a nondrying oil from petroleum. Since it is not a natural product, it is not prone to mildew or to harbor bacteria.

Paraffin Wax

Paraffin wax is similar to paraffin oil but is solid at room temperature. Paraffin wax is one of the simplest ways to finish wood utensils, especially countertops, butcher blocks, and cutting boards.

Eating Utensils

Wood salad bowls, spoons, and forks used for food service need a finish that is resistant to abrasion, water, acids, and stains and a surface that is easy to clean when soiled.

Appropriate finishes are varnishes and lacquers, penetrating wood sealers and drying oils, and nondrying vegetable oils.

Many varnishes and lacquers are available, and some of these are specifically formulated for use on wood utensils, bowls, and/or cutting boards. These film-forming finishes resist staining and provide a surface that is easy to keep clean; however, they may eventually chip, peel, alligator, or crack. These film-forming finishes should perform well if care is taken to minimize their exposure to water. Utensils finished with such finishes should never be placed in a dishwasher.

Penetrating wood sealers and drying oils may also be used for eating utensils. Some of these may be formulated for use on utensils. Wood sealers and oils absorb into the pores of the wood and fill the cavities of the wood cells. This decreases the absorption of water and makes the surface easy to clean and more resistant to scratching compared with unfinished wood. Penetrating wood sealers are easy to apply and dry quickly. Worn places in the finish may be easily refinished. Some of these finishes, particularly drying oils, should be allowed to dry thoroughly for several weeks before use.

Nondrying vegetable oils are edible and are sometimes used to finish wood utensils. They penetrate the wood surface, improve its resistance to water, and can be refurbished easily. However, such finishes can become rancid and can sometimes impart undesirable odors and/or flavors to food.

Of these finish types, the impermeable varnishes and lacquers may be the best option for bowls and eating utensils; this kind of finish is easiest to keep clean and most resistant to absorption of stains.

> **Note**: Whatever finish is chosen for wood utensils used to store, handle, or eat food, it is important to be sure that the finish is safe and not toxic (poisonous). Also be sure that the finish you select is recommended for use with food or is described as food grade. For information on the safety and toxicity of any finish, check the label, contact the manufacturer and/or the Food and Drug Administration, or check with your local extension home economics expert or county agent.

Butcher Blocks and Cutting Boards

One of the simplest treatments for wood butcher blocks and cutting boards is the application of melted paraffin wax (the type used for home canning). The wax is melted in a double-boiler over hot water and liberally brushed on the wood surface. Excess wax, which has solidified on the surface, can be melted with an iron to absorb it into the wood, or it may be scraped off. Refinishing is simple and easy. Other penetrating finishes (sealers, drying and nondrying oils) may also be used for butcher blocks and cutting boards. As mentioned in the subsection on eating utensils, vegetable oils may become rancid. If a nondrying oil is desired, mineral oil may be used. Film-forming finishes are not recommended for butcher blocks or cutting boards.

Wood Cleaners and Brighteners

The popularity of wood decks and the desire to keep them looking bright and new has led to a proliferation of commercial cleaners and brighteners. The removal of mildew from wood was discussed in an earlier section of this chapter (see Finish Failure or Discoloration). Mildew growth on unpainted and painted wood continues to be the primary cause of discoloration. Although it can be removed with a dilute solution of household bleach and detergent, many commercial products are available that can both remove mildew and brighten the wood surface.

The active ingredient in many of these products is sodium percarbonate (disodium peroxypercarbonate). This chemical is an oxidizing agent as is bleach, and it is an effective mildew cleaner. It also helps brighten the wood surface. Some cleaners and brighteners are reported to restore color to wood. It is not possible to add color to wood by cleaning it. Removing the discoloration reveals the original color. Brightening the wood may make it appear as if it has more color. Once all the colored components of the wood surface have been removed through the weathering process, the surface will be a silvery gray. If color is desired after weathering occurs, it must be added to the wood by staining.

In addition to sodium percarbonate, other oxidizing products may contain hydrogen peroxide by itself or in combination with sodium hydroxide. If sodium hydroxide is used without a brightener, it will darken the wood. Commercial products are also formulated with sodium hypochlorite and/or calcium hypochlorite (household bleach is a solution of sodium hypochlorite). These products usually contain a surfactant or detergent to enhance the cleansing action of the oxidizing agent. Other types of brighteners contain oxalic acid. This chemical removes stains caused by extractives bleed and iron stains and also brightens the wood, but it is not very effective for removing mildew.

Paint Strippers

Removing paint and other film-forming finishes from wood is a time-consuming and often difficult process. It is generally not done unless absolutely necessary to refinish the wood. Removing the finish is necessary if the old finish has extensive cross-grain cracking caused by buildup of many layers of paint, particularly oil-based paint. If cracking and peeling are extensive, it is usually best to remove all the paint from the affected area. Total removal of paint is also necessary if the paint has failed by intercoat peeling. It may be necessary to remove paint containing lead; however, if the paint is still sound and it is not illegal to leave it on the structure, it is best to repaint the surface without removing the old paint (see Lead-Based Paint).

This discussion of paint strippers is limited to film-forming finishes on wood used in structures. Removing paint from furniture can be done using the same methods as described here. Companies that specialize in stripping furniture usually immerse the furniture in a vat of paint stripper and then clean and brighten the wood. This procedure removes the paint very efficiently.

Some of the same methods can be used for the removal of interior and exterior paint. Because of the dust caused by mechanical methods or the fumes given off by chemical strippers, it is extremely important to use effective safety equipment, particularly when working indoors. A good respirator is essential, even if the paint does not contain lead (see Lead-Based Paint).

Note: The dust masks sold in hardware stores do not block chemical fumes and are not very effective against dust.

Two general types of stripping methods are discussed here: mechanical and chemical. The processes are discussed in general terms primarily in regard to their effect on wood; some attention is given to their ease of use and safety requirements. Consult product literature for additional information on appropriate uses and safety precautions.

Mechanical Methods

Finishes can be removed by scraping, sanding, wet or dry sandblasting, spraying with pressurized water (power washing), and using electrically heated pads, hot air guns, and blow torches. Scraping is effective only in removing loosely bonded paint or paint that has already partially peeled from the wood. It is generally used when paint needs to be removed only from small areas of the structure, and it is generally combined with sanding to feather the edge of the paint still bonded to the wood (see Lead-Based Paint).

When the paint is peeling and partially debonded on large areas of a structure, the finish is usually removed by power washing or wet sandblasting. These methods work well for paint that is loosely bonded to the wood. If the paint is well bonded, complete removal can be difficult without severely damaging the wood surface. The pressure necessary to debond paint from the wood can easily cause deep erosion of the wood. The less dense earlywood erodes more than the dense latewood, leaving behind a surface consisting of latewood, which is more difficult to repaint. Power washing is less damaging to the wood than is wet or dry sandblasting, particularly if low pressure is used. If high pressure is necessary to remove the paint, it is probably bonded well enough that it does not need to be removed for normal refinishing. If more aggressive mechanical methods are required, wet sandblasting can remove even well-bonded paint, but it causes more damage to the wood than does water blasting. Dry sandblasting is not very suitable for removing paint from wood because it can quickly erode the wood surface along with the paint, and it tends to glaze the surface.

A number of power sanders and similar devices are available for complete paint removal. Many of these devices are suitable for removing paint that contains lead; they have attachments for containing the dust. Equipment that has a series of blades similar to a power hand-planer is less likely to "gum up" with paint than equipment that merely sands the surface. Some of this equipment is advertised in the *Old House Journal* and the *Journal of Light Construction*. Please consult the manufacturers' technical data sheets for detailed information to determine the suitability of their equipment for your needs and to meet government regulations on lead-containing paint.

Paint can be removed by heating then scraping it from the wood, but this method must not be used for paint that contains lead. Paint can be softened by using electrically heated pads, hot air guns, or blow torches. Heated pads and hot air guns are slow methods, but they cause little damage to the wood. Sanding is still necessary, but the wood should be sound after the paint is removed. Blow torches have been used to remove paint and, if carefully used, do not damage the wood. Blow torches are extremely hazardous; the flames can easily ignite flammable materials beneath the siding through gaps in the siding. These materials may smolder, undetected, for hours before bursting into flame and causing loss of the structure.

Note: Removing paint with a blow torch is not recommended.

Chemical Methods

If all the paint needs to be removed, then mechanical methods should be used in concert with other methods, such as chemical paint strippers. For all chemical paint strippers, the process involves applying paint stripper, waiting, scraping off the softened paint, washing the wood (and possibly neutralizing the stripper), and sanding the surface to remove the wood damaged by the stripper and/or the raised grain caused by washing. Chemical paint strippers, although tedious to use, are sometimes the most reasonable choice. A range of paint strippers are available. Some are extremely strong chemicals that quickly remove paint but are dangerous to use. Others remove the paint slowly but are safer. With the exception of alkali paint stripper (discussed below), there appears to be an inverse correlation between how safe a product is and how fast it removes the paint.

Solvent-Based Strippers

Fast-working paint strippers usually contain methylene chloride, a possible carcinogen that can burn eyes and skin. Eye and skin protection and a supplied-air respirator are essential when using this paint stripper. Paint strippers having methylene chloride can remove paint in as little as 10 min. Because of concerns with methylene chloride, some paint strippers are being formulated using other strong solvents; the same safety precautions should be used with these formulations as with those containing methylene chloride. To remain effective in removing paint, a paint stripper must remain liquid or semiliquid; slow-acting paint stripers are often covered to keep them active. Solvent-type strippers contain a wax that floats to the surface to slow the evaporation of the solvent. Covering the paint stripper with plastic wrap also helps to contain the solvent.

Alkali-Based Strippers

As an alternative to strong solvents, some paint strippers contain strong bases (alkali). Like solvent-based paint strippers, alkali-based strippers require eye and skin protection. Follow the manufacturer's recommendations about whether a respirator is necessary as well. Although alkali-based paint strippers soften the paint rather slowly, they are strong chemicals and can severely damage the wood substrate. Because they degrade the paint slowly, these strippers are often left on the painted wood a full day or overnight. They are usually covered with a cloth, which helps in peeling the weakened paint from the surface.

These cloth-covered types of products have the advantage of containing the paint stripper and paint extremely well, an important consideration when removing paint containing lead. They have the disadvantage of severely degrading the wood substrate. Strong alkali actually pulps the wood surface. Once the paint is removed, it is essential to neutralize the surface with acid. Oxalic acid is frequently used for this process. Unfortunately, it is extremely difficult to balance the acid and base concentrations. If excess alkali is left in the wood, it will continue to degrade it and to degrade the subsequent paint coating. Excess oxalic acid can also damage the wood. The neutralization procedure leaves behind reaction products of the acid and base (water and a salt). Often, the salt is hygroscopic (absorbs moisture from the air) and causes the wood to get wet. Wet wood does not hold paint very well.

> **Note:** Alkali-based strippers require extra care to ensure that the wood is neutralized and that residual salts are washed from the wood. The surface must be sanded before repainting.

Since the surface must be sanded before repainting, paint performance might be improved by letting the wood weather for an extended period (possibly as long as a year) before repainting to let rain leach unwanted chemicals from the wood. In addition, rinse the siding periodically using a hose, particularly areas that rain does not reach, such as siding under eaves and porches. Once all the residue has been removed, the surface can be sanded (50-grit sandpaper) and painted.

Although alkali paint strippers can cause burns on unprotected skin, the fumes are not nearly as toxic as those in solvent-type strippers. Alkali paint strippers are an excellent choice for indoor use such as door and window trim and fireplace mantles. Indoors, the weakened wood surface may not be as much of a concern because less stress is placed on the wood–paint interface; the wood is not exposed to weather extremes.

"Safe" Paint Strippers

Several paint strippers are being marketed under the "safe" caveat. These strippers work much slower than those having strong chemical solvents. The active ingredient in such paint strippers is usually proprietary. In regard to safety, follow the manufacturer's recommendations.

Avoidance of Problems

Failure of the finish on wood that has been stripped can be avoided by using methods that do not damage the wood surface. The best way to remove paint may involve a combination of methods. For example, use power washing to remove as much paint as possible. Then, use a solvent-based chemical paint stripper on paint that could not be removed by power washing. Avoid using excessive amounts of chemical stripper. Applying too much stripper or leaving it on the painted wood for too long can damage the wood. It is better to use less stripper and reapply it, if necessary, than to try to remove all the paint with one application, leaving the stripper on the paint for an extended period.

The problem of paint removal is complicated by the wide range of paint types and wood species. Companies that make paint strippers may optimize the formulations without considering their effects on the wood. Removing the paint from the wood is only half the task. Getting a paintable surface is the other half. Companies that formulate paint strippers must consider this other half. Those who use paint strippers need to understand the added burden of surface preparation.

Disposal of Old Paint

No matter what method you use to remove paint, be careful in disposing of the old paint, particularly paint that contains lead. Lead is considered hazardous waste, and there are regulations that restrict the handling and disposal of this material. Be sure to follow all regulations, both national and local, during the removal, storage, and disposal of paint, especially paint containing lead (see Lead-Based Paint).

Lead-Based Paint

The information in this section is taken from material prepared by the National Association of Home Builders (NAHB) and is contained in *Rehabilitation of Wood-Frame Houses* (USDA 1998). Lead-based paint was widely used in residential applications in the United States until the early 1940s, and its use was continued to some extent, particularly for the exterior of dwellings, until 1976. In 1971, Congress passed the Lead-Based Paint Poisoning Prevention Act, and in 1976, the Consumer Product Safety Commission (CPSC) issued a ruling under this Act that limited the lead content of paint used in residential dwellings, toys, and furniture to 0.06%.

Lead-based paint is still manufactured today for applications not covered by the CPSC ruling, such as paint for metal products, particularly those made of steel. Occasionally, such lead-based paint (for example, surplus paint from a shipyard) inadvertently gets into retail stores and the hands of consumers. A study conducted for the Environmental Protection Agency in 1986 indicated that about 42 million U.S. homes still contain interior and/or exterior lead-based paint. As rehabilitation of these homes increases, how to abate the toxicity of lead-based paint has become the subject of increased public and official concern.

Studies have shown that ingestion of even minute amounts of lead can have serious effects on health, including hypertension, fetal injury, and damage to the brain, kidneys, and red blood cells. Low levels of ingestion can also cause partial loss of hearing, impairment of mental development and IQ, growth retardation, inhibited metabolism of vitamin D, and disturbances in blood formation. The American Academy of Pediatrics regards lead as one of the foremost toxicological dangers to children.

Lead-based paint applied to the exterior of homes disintegrates into chalk and powder as a result of the effects of moisture and ultraviolet radiation. This extremely fine lead dust can accumulate in the soil near the house and can ultimately enter the house. Poor quality lead-based paint used on interior surfaces can also produce dust. Lead dust can be generated when coatings on surfaces are broken through aging or as a result of rehabilitation. The dust cannot be completely removed by conventional house-cleaning methods.

Methods used to abate the toxicity of lead-based paint or to remove the paint can themselves generate lead dust. This is particularly true when unacceptable methods and work practices are used. Poorly performed abatement can be worse than no abatement. The micron-sized lead dust particles can remain airborne for substantial periods and cannot be fully removed by standard cleaning methods from the surfaces on which they have settled. When working on old painted surfaces, the worker should assume that one or more of the paint coats contain lead. Proper precautions should be taken accordingly.

Paint coats may be checked for lead content. A portable x-ray fluorescence (XRF) analyzer is commonly used to determine the level of lead in paint. Because this device has the potential for giving very inaccurate results if used by an inexperienced person, the analysis should be done by a qualified professional. Chemical spot testing, using a solution of 6% to 8% sodium sulfide in water, is sometimes used to screen painted surfaces for the presence of lead. Be certain to check all paint coats, because the older ones are more likely to be lead based. Test kits for detecting lead-based paint are available in most paint and hardware stores.

Removal of lead-based paints can present some serious health problems. The U.S. Department of Health and Urban Development (HUD) has taken a leading role in developing guidelines for the removal of lead-based paints. At this time, HUD has approved three approaches to abating the toxicity of lead-based paint:

1. Covering the painted surface with wallboard, a fiberglass cloth barrier, or permanently attached wallpaper
2. Removing the paint
3. Replacing the entire surface to which lead-based paint has been applied

Certain practices are prohibited in residential structures owned and operated by HUD: machine sanding without an attached high-efficiency particulate air (HEPA) vacuum filtration apparatus, use of propane torches, contained water blasting, washing, and repainting.

Removal of lead-based paint by scraping or application of heat does not solve the problem of lead-particulate dust. Scraping should be accompanied by misting. Dry scraping is prohibited by Maryland abatement regulations. Sanding without a HEPA-filtered vacuum should not be used as a finishing method after scraping or any other method of toxicity abatement. The HEPA sanders are recommended for limited surface areas only; they are most appropriate for flat surfaces such as door jambs and stair risers. Open abrasive blasting is also prohibited by some regulations.

High levels of airborne lead can be produced by heat guns, and the use of a respirator is essential. Some lead is likely to be volatilized at the operating temperatures of most heat guns. Lead fumes are released at about 371°C (700°F). Heat guns capable of reaching or exceeding this temperature should not be operated in that range.

Chemical methods for removing lead-based paint may require multiple applications, depending on the number of paint coats. Caustic and solvent-based chemicals should not be allowed to dry on the lead-painted surface. If drying occurs, paint removal will not be satisfactory and the potential for creating lead dust will be increased.

Chemical substances used for paint removal are usually hazardous and should be used with great care. Some solvent-based chemical strippers are flammable and require ventilation. They may contain methylene chloride, which is a central nervous system depressant that at high concentrations can cause kidney and liver damage and is a possible carcinogen. Supplied-air respirators should be used when working with strippers containing this substance. If the solvent-based strippers do not contain methylene chloride, organic vapor filters must be added to respirators. Caustic chemical strippers also have a very high pH (alkaline content), which can cause severe skin and eye injuries.

> **Caution:** Remodeling or refinishing projects that require disturbing, removing, or demolishing portions of the structure that are coated with lead-based paint pose serious problems. The consumer should seek information, advice, and perhaps professional assistance for addressing these problems. Contact HUD for the latest information on the removal of lead-based paints. Debris coated with lead-based paint is regarded as hazardous waste.

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Use of Wood in Buildings and Bridges

Russell C. Moody and Anton TenWolde

Contents

In North America, most housing and commercial structures built prior to the 20th century used wood as the major structural material. The abundant wood resource formed the basic structure for most houses, commercial buildings, bridges, and utility poles. Today, houses and many light commercial and industrial buildings are made using modern wood structural materials. Recently, there has been increased interest in using wood for various types of transportation structures, including bridges.

In this chapter, the features of various types of building systems are described. Emphasis is placed on how these systems have adapted to the use of modern materials and techniques. For example, where floor, wall, and roof sheathing for light-frame construction were once commonly made from wood boards, sheathing is now commonly made from structural panel products, such as plywood and structural flakeboard. Compared with boards, these panel products are quicker to install and provide improved structural resistance to wind and earthquake loadings. Furthermore, prefabricated floor and wall panels along with prefabricated roof and floor trusses or I-joists are replacing piece-by-piece on-site construction with dimension lumber. A structure can be enclosed within a short time on site using factory-made panelized systems.

Glulam and other panelized wood systems are being used increasingly for both highway and railroad bridges. A brief description of the uses of wood in these types of structures is included.

Light-Frame Buildings

Historically, two general types of light-frame construction have been used—balloon and platform framing. Balloon framing, which was used in the early part of the 20th century, consists of full-height wall framing members for two-story construction. Additional information on balloon framing is available from older construction manuals. In the latter part of the 20th century, platform framing has dominated the housing market and is widely used in commercial and light industrial applications. Platform framing features the construction of each floor on top of the one beneath. Platform framing construction differs from that of 50 years ago in the use of new and innovative materials, panel products for floor and roof sheathing, and prefabricated components and modules as opposed to “stick built” or on-site construction. A detailed description of the platform-type of construction is given in *Wood Frame House Construction* (Sherwood and Stroh 1989); additional information is given in the *Wood Frame Construction Manual for One- and Two-Family Dwellings, 1995 SBC High Wind Edition* (AF&PA 1995).

Foundations

Light-frame buildings with basements are typically supported on cast-in-place concrete walls or concrete block walls supported by footings. This type of construction with a basement is common in northern climates. Another practice is to have concrete block foundations extend a short distance above ground to support a floor system over a “crawl space.” In southern and western climates, some buildings have no foundation; the walls are supported by a concrete slab, thus having no basement or crawl space.

Treated wood is also used for basement foundation walls. Basically, such foundations consist of wood-frame wall sections with studs and plywood sheathing supported on treated wood plates, all of which are preservatively treated to a specified level of protection. To distribute the load, the plates are laid on a layer of crushed stone or gravel. Walls, which must be designed to resist the lateral loads of the backfill, are built using the same techniques as conventional walls. The exterior surface of the foundation wall below grade is draped with a continuous moisture barrier to prevent direct water contact with the wall panels. The backfill must be designed to permit easy drainage and provide drainage from the lowest level of the foundation.

Because a foundation wall needs to be permanent, the preservative treatment of the plywood and framing as well as the fasteners used for connections are very important. A special foundation (FDN) treatment has been established for the plywood and framing, with strict requirements for depth of chemical penetration and amount of chemical retention. Corrosion-resistant fasteners (for example, stainless steel) are recommended for all preservatively treated wood. Additional information and materials and construction procedures are given in *Permanent Wood Foundation Basic Requirements* (AF&PA 1987).

Floors

For houses with basements, the central supporting structure may consist of wood posts on suitable footings that carry a built-up girder, which is frequently composed of planks the same width as the joists (standard 38 by 184 mm to 38 by 286 mm (nominal 2 by 8 in. to 2 by 12 in.)), face-nailed together, and set on edge. Because planks are seldom sufficiently long enough to span the full length of the beam, butt joints are required in the layers. The joints are staggered in the individual layers near the column supports. The girder may also be a glulam beam or steel I-beam, often supported on adjustable steel pipe columns. Similar details may be applied to a house over a crawl space. The floor framing in residential structures typically consists of wood joists on 400- or 600-mm (16- or 24-in.) centers supported by the foundation walls and the center girder (Fig. 16–1).

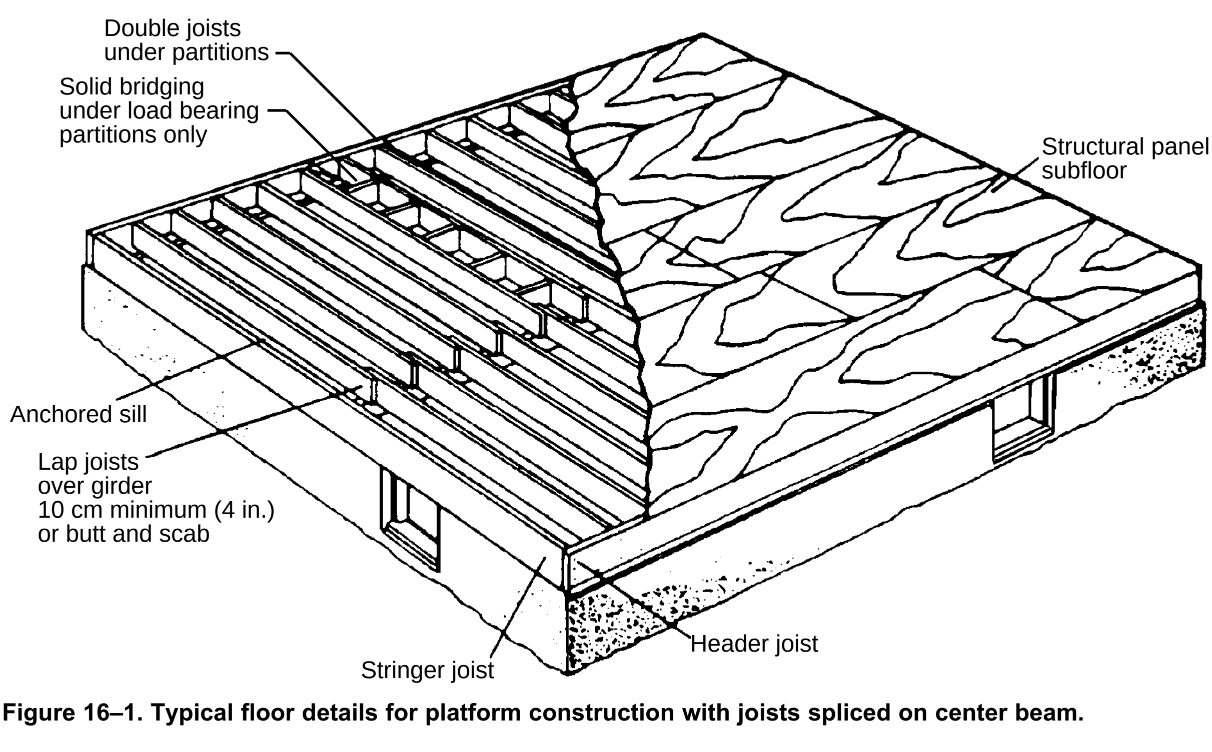

Figure 16–1. Typical floor details for platform construction with joists spliced on center beam.

Joist size depends on the anticipated loading, spacing between joists, distance between supports (span), species, and grade of lumber. Commonly used joists are standard 38- by 184-mm or 38- by 235-mm (nominal 2- by 8-in. or 2- by 10-in.) lumber, prefabricated wood I-joists, or parallel chord trusses. Lumber joists typically span from 3.6 to 4.8 m (12 to 16 ft). Span tables are available from the American Forest & Paper Association (AF&PA 1993). Span capabilities of the prefabricated wood I-joists or parallel chord trusses are recommended by the manufacturer.

Floor openings for stairways, fireplaces, and chimneys may interrupt one or more joists. Preferably, such openings are parallel to the length of the joists to reduce the number of joists that will be interrupted. At the interruption, a support (header) is placed between the uninterrupted joists and attached to them. A single header is usually adequate for openings up to about 1.2 m (4 ft) in width, but double headers are required for wider openings. Special care must be taken to provide adequate support at headers (using joist hangers, for example).

Cutting of framing members to install items such as plumbing lines and heating ducts should be minimized. Cut members may require a reinforcing scab, or a supplementary member may be needed. Areas of highly concentrated loads, such as under bathtubs, require doubling of joists or other measures to provide adequate support. One advantage of framing floors with parallel-chord trusses or prefabricated I-joists is that their longer span capabilities may eliminate the need for interior supports. An additional advantage is that the web areas of these components are designed for easy passing of plumbing, electrical, and heating ducts.

Floor sheathing, or subflooring, is used over the floor framing to provide a working platform and a base for the finish flooring. Older homes have board sheathing but newer homes generally use panel products. Common sheathing materials include plywood and structural flakeboard, which are available in a number of types to meet various sheathing requirements. Exterior-type panels with water-resistant adhesive are desirable in locations where moisture may be a problem, such as floors near plumbing fixtures or situations where the subfloor may be exposed to the weather for some time during construction.

Plywood should be installed with the grain direction of the face plies at right angles to the joists. Structural flakeboard also has a preferred direction of installation. Nailing patterns are either prescribed by code or recommended by the manufacturer. About 3 mm (1/8 in.) of space should be left between the edges and ends of abutting panels to provide for dimensional changes associated with moisture content.

Literature from APA–The Engineered Wood Association includes information on the selection and installation of the types of structural panels suitable for subfloors (APA 1996).

Exterior Walls

Exterior walls of light-frame structures are generally load bearing; they support upper floors and the roof. An exception is the gable ends of a one- or two-story building. Basically, wall framing consists of vertical studs and horizontal members, including top and bottom plates and headers (or lintels) over window and door openings. The studs are generally standard 38- by 89 mm, 38- by 114-mm, or 38- by 140-mm (nominal 2- by 4-in., 2- by 5-in., or 2- by 6-in.) members spaced between 300 and 600 mm (12 and 24 in.) on center. Selection of the stud size depends on the load the wall will carry, the need for support of wall-covering materials, and the need for insulation thickness in the walls. Headers over openings up to 1.2 m (4 ft) are often 38 by 140 mm (2 by 6 in.), nailed together face to face with spacers to bring the headers flush with the faces of the studs. Special headers that match the wall thickness are also available in the form of either prefabricated I-joists or structural composite lumber. Wall framing is erected over the platform formed by the first-floor joists and subfloor. In most cases, an entire wall is framed in a horizontal position on the subfloor, then tilted into place. If a wall is too long to make this procedure practical, sections of the wall can be formed horizontally and tilted up, then joined to adjacent sections.

Corner studs are usually prefabricated in such a configuration as to provide a nailing edge for the interior finish (Fig. 16–2). Studs are sometimes doubled at the points of intersection with an interior partition to provide backup support for the interior wall finish. Alternatively, a horizontal block is placed midheight between exterior studs to support the partition wall. In such a case, backup clips on the partition stud are needed to accommodate the interior finish.

Upper plates are usually doubled, especially when rafters or floor joists will bear on the top plate between studs. The second top plate is added in such a way that it overlaps the first plate at corners and interior wall intersections. This provides a tie and additional rigidity to the walls. In areas subject to high winds or earthquakes, ties should be provided between the wall, floor framing, and sill plate that should be anchored to the foundation. If a second story is added to the structure, the edge floor joist is nailed to the top wall plate, and subfloor and wall framing are added in the same way as the first floor.

Sheathing for exterior walls is commonly some type of panel product. Here again, plywood or structural flakeboard may be used. Fiberboard that has been treated to impart some degree of water resistance is another option. Several types of fiberboard are available. Regular-density board sometimes requires additional bracing to provide necessary resistance to lateral loads. Intermediate-density board is used where structural support is needed. Numerous foam-type panels can also be used to impart greater thermal resistance to the walls.

In cases where the sheathing cannot provide the required racking resistance, diagonal bracing must be used. Many foam sheathings cannot provide adequate racking resistance,

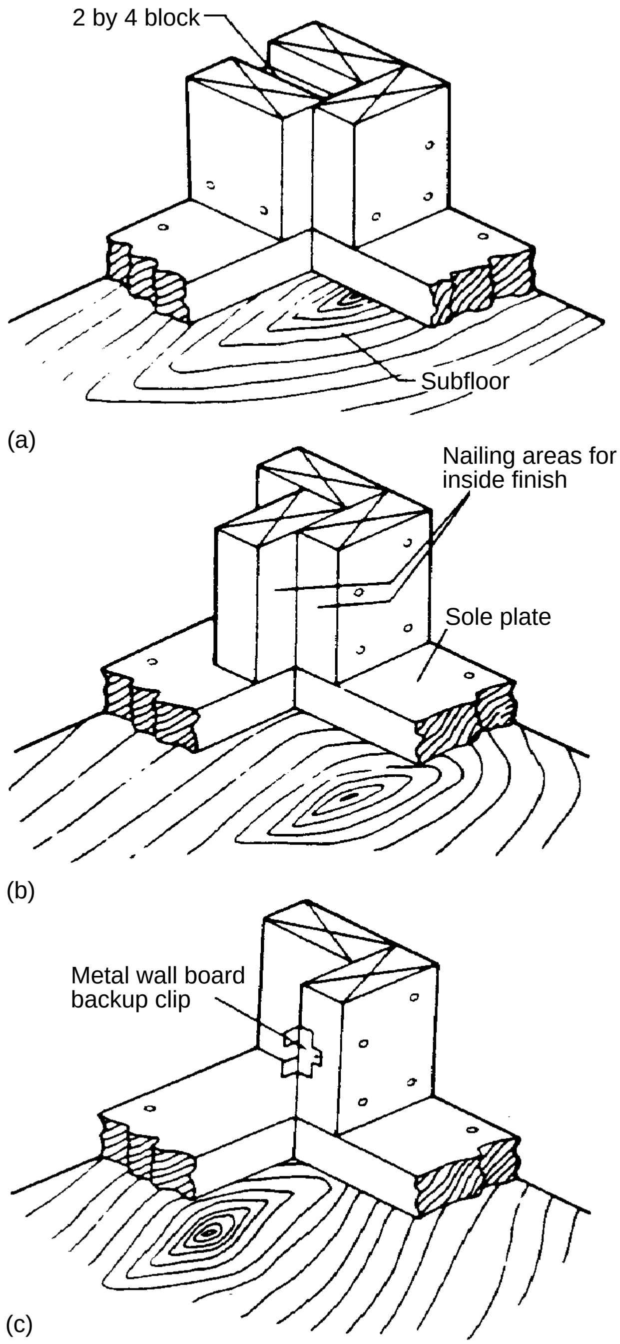

Figure 16–2. Corner details for wood stud walls that provide support for interior sheathing: (a) traditional three-stud corner with blocking; (b) three-stud corner without blocking; (c) two-stud corner with wallboard backup clips.

so either diagonal braces must be placed at the corners or structural panels must be applied over the first 1.2 m (4 ft) of the wall from the corner. When light-weight insulating foam sheathings are used, bracing is commonly provided by standard 19- by 89-mm (nominal 1- by 4-in.) lumber or steel strapping.

Ceiling and Roof

Roof systems are generally made of either the joists-and-rafter systems or with trusses. Engineered trusses reduce on-site labor and can span greater distances without intermediate support, thus eliminating the need for interior load-carrying partitions. This provides greater flexibility in the layout of interior walls. Prefabricated roof trusses are used to form the ceiling and sloped roof of more than two-thirds of current light-frame buildings. For residential buildings, the trusses are generally made using standard 38- by 89-mm (nominal 2- by 4-in.) lumber and metal plate connectors with teeth that are pressed into the pieces that form the joints (TPI 1995).

Joists and rafter systems are found in most buildings constructed prior to 1950. Rafters are generally supported on the top plate of the wall and attached to a ridge board at the roof peak. However, because the rafters slope, they tend to push out the tops of the walls. This is prevented by nailing the rafters to the ceiling joists and nailing the ceiling joists to the top wall plates (Fig. 16–3a).

A valley or hip is formed where two roof sections meet perpendicular to each other. A valley rafter is used to support short-length jack rafters that are nailed to the valley rafter and the ridge board (Fig. 16–3b). In some cases, the roof does not extend to a gable end but is sloped from some point down to the end wall to form a "hip" roof. A hip rafter supports the jack rafters, and the other ends of the jack rafters are attached to the top plates (Fig. 16–3c). In general, the same materials used for wall sheathing and subflooring are used for roof sheathing.

Wood Decks

A popular method of expanding the living area of a home is to build a wood deck adjacent to one of the exterior walls. Decks are made of preservatively treated lumber, which is generally available from the local building supply dealer and, depending upon the complexity, may be built by the "do-it-yourselfer." To ensure long life, acceptable appearance, and structural safety, several important guidelines should be followed. Proper material selection is the first step. Then, proper construction techniques are necessary. Finally, proper maintenance practices are necessary. Detailed recommendations for all these areas are included in *Wood Decks: Materials, Construction, and Finishing* (McDonald and others 1996).

Post-Frame and Pole Buildings

In post-frame and pole buildings, round poles or rectangular posts serve both as the foundation and the principal vertical framing element. This type of construction was known as "pole buildings" but today, with the extensive use of posts, is commonly referred to as "post-frame" construction. For relatively low structures, light wall and roof framing are nailed to poles or posts set at fairly frequent centers, commonly 2.4 to 3.6 m (8 to 12 ft). This type of construction

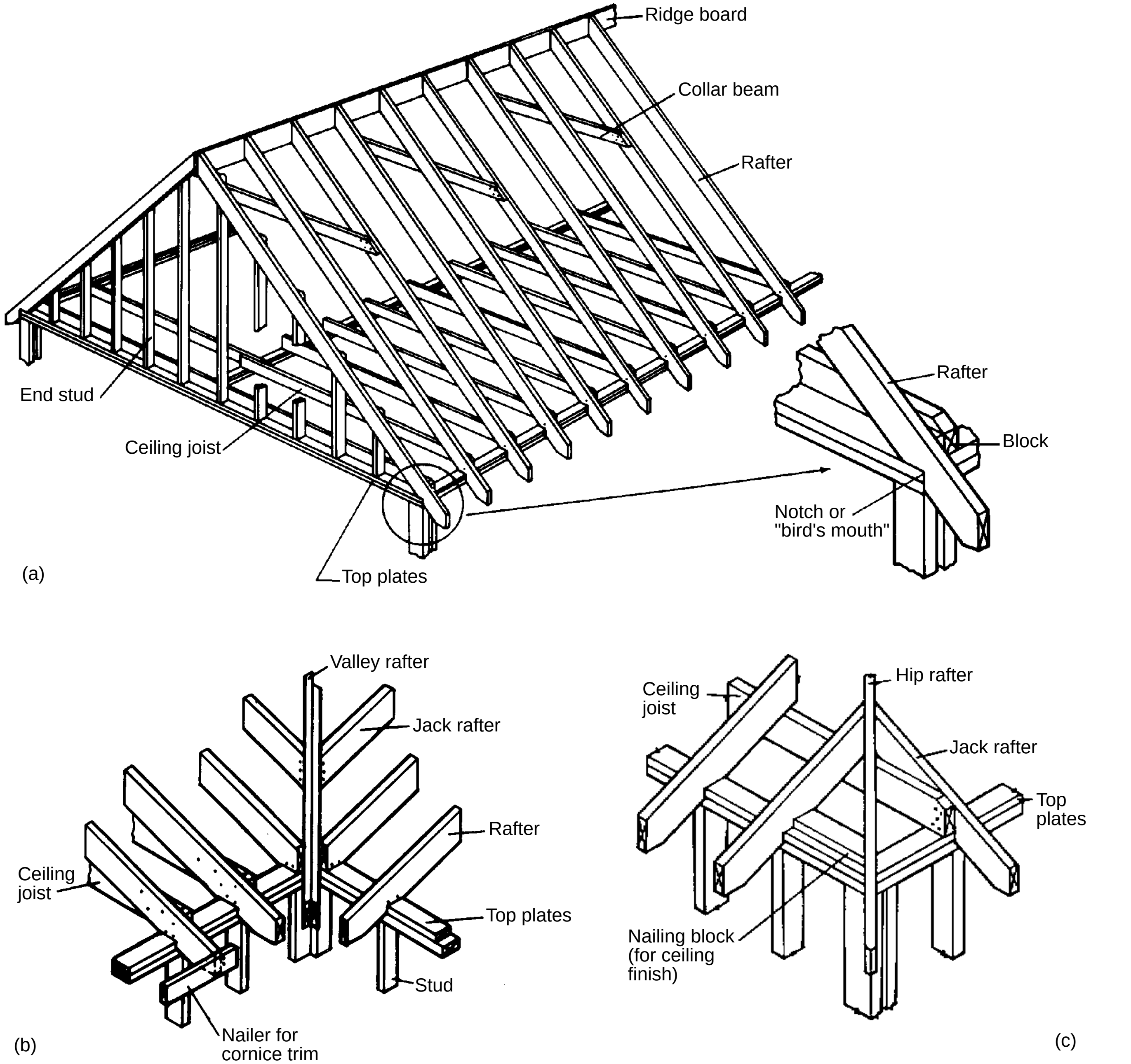

Figure 16–3. (a) A rafter-type roof with typical framing details for (b) a valley and (c) a hip corner.

was originally used with round poles for agricultural buildings, but the structural principle has been extended to commercial and residential buildings (Fig. 16–4).

Round poles present some problems for connecting framing members; these problems can be eased by slabbing the outer face of the pole. For corner poles, two faces may be slabbed at right angles. This permits better attachment of both light and heavy framing by nails or timber connectors. When the pole is left round, the outer face may be notched to provide seats for beams.

Rectangular posts are the most commonly used and may be solid sawn, glulam, or built-up by nail laminating. Built-up posts are advantageous because only the base of the post must be preservatively treated. The treated portion in the ground may have laminations of varying lengths that are matched with the lengths of untreated laminations in the upper part of the post. The design of these types of posts must consider the integrity of the splice between the treated and untreated lumber. The wall system consists of horizontal girts often covered by light-gauge metal that provides some degree of racking resistance.

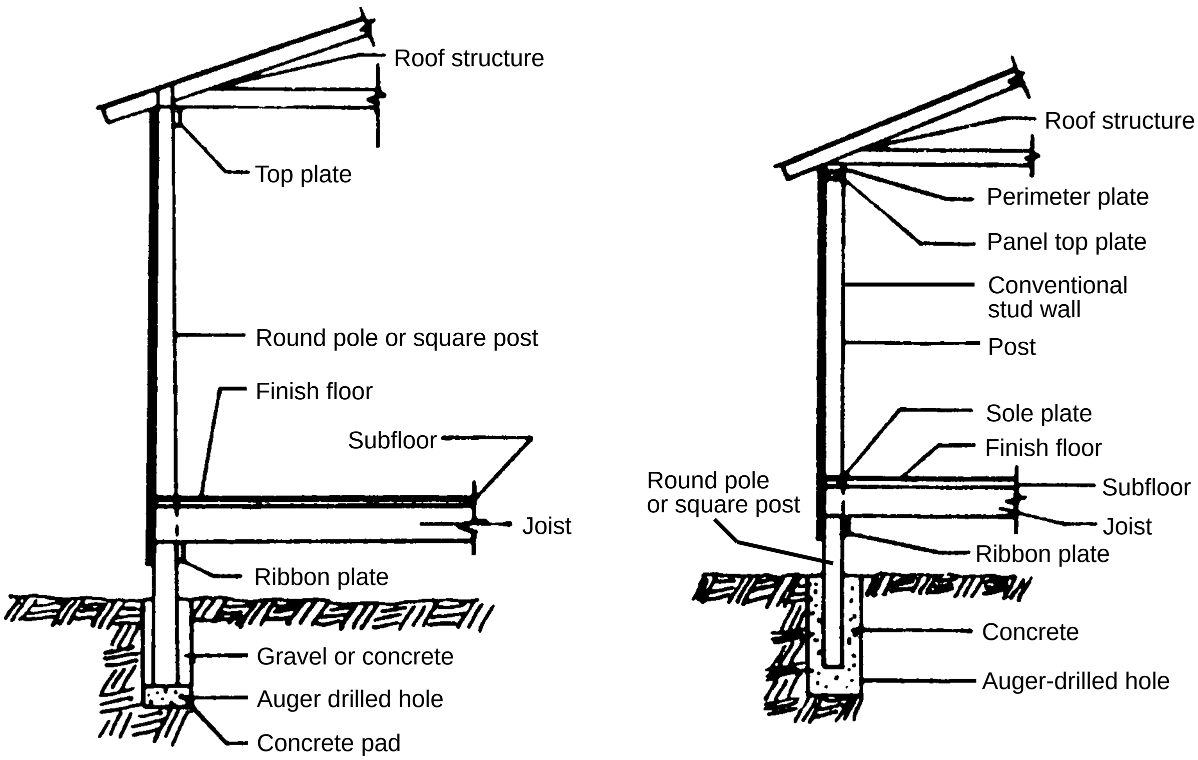

Figure 16–4. Pole and post-frame buildings: (left) pole or post forms both foundation and wall; (right) pole or post forms only the foundation for conventional platform-framed structure.

Roof trusses made with metal plate connectors are attached to each pole, or posts, and roof purlins are installed perpendicular to the trusses at spacings from 1.2 to 3.7 m (4 to 12 ft), with 2.4 m (8 ft) as a common spacing. For 2.4-m (8-ft) truss spacing, these purlins are often standard 38 by 89 mm (nominal 2 by 4 in.) spaced on 0.6-m (2-ft) centers and attached to either the top of the trusses or between the trusses using joists hangers. The roofing is often light-gauge metal that provides some diaphragm stiffness to the roof and transmits a portion of the lateral loading to the walls parallel to the direction of the load. Detailed information on the design of post-frame buildings is given in the *National Frame Builders Association* ([n.d.]) or Walker and Woeste (1992).

Log Buildings

Interest is growing in log houses—from small, simple houses for vacation use to large, permanent residences (Fig. 16–5). Many U.S. firms specialize in the design and material for log houses. Log homes nearly always feature wall systems built from natural or manufactured logs rather than from dimension lumber. Roof and floor systems may be also be built with logs or conventional framing. Log home companies tend to categorize log types into two systems: round and shaped. In the round log system, the logs are machined to a smooth, fully rounded surface, and they are generally all the same diameter. In the shaped system, the logs are machined to specific shapes, generally not fully round. The exterior surfaces of the logs are generally rounded, but the interior surfaces may be either flat or round. The interface between logs is machined to form an interlocking joint.

Consensus standards have been developed for log grading and the assignment of allowable properties, and these standards are being adopted by building codes (ASTM 1996). Builders and designers need to realize that logs can reach the building site at moisture content levels greater than ideal. The effects of seasoning and the consequences of associated shrinkage and checking must be considered. Additional information on log homes is available from The Log Home Council, National Association of Home Builders, Washington, DC.

Heavy Timber Buildings

Timber Frame

Timber frame houses were common in early America and are enjoying some renewed popularity today. Most barns and factory buildings dating prior to the middle of the 20th century were heavy timber frame. The traditional timber frame is made of large sawn timbers (larger than 114 by 114 mm (5 by 5 in.)) connected to one another by hand-fabricated joints, such as mortise and tenon. Construction of such a frame involves rather sophisticated joinery, as illustrated in Figure 16–6.

Figure 16–5. Modern log homes are available in a variety of designs.

In today's timber frame home, a prefabricated, composite sheathing panel (1.2 by 2.4 m (4 by 8 ft)) is frequently applied directly to the frame. This panel may consist of an inside layer of 13-mm (1/2-in.) gypsum, a core layer of rigid foam insulation, and an outside layer of exterior plywood or structural flakeboard. Finish siding is applied over the composite panel. In some cases, a layer of standard 19-mm (nominal l-in.) tongue-and-groove, solid-wood boards is applied to the frame, and a rigid, foam-exterior, plywood composite panel is then applied over the boards to form the building exterior. Local fire regulations should be consulted about the acceptance of various foam insulations.

Framing members are cut in large cross sections; therefore, seasoning them before installation is difficult, if not impossible. Thus, the builder (and the owner) should recognize the dimensional changes that may occur as the members dry in place. The structure must be designed to accommodate these dimensional changes as well as seasoning checks, which are almost inevitable.

Mill Type

Mill-type construction has been widely used for warehouse and manufacturing structures, particularly in the eastern United States. This type of construction uses timbers of large cross sections with columns spaced in a grid according to the available lengths of beam and girder timbers. The size of the timbers makes this type of construction resistant to fire. The good insulating qualities of wood as well as the char that develops during fire result in slow penetration of fire into the large members. Thus, the members retain a large proportion of their original load-carrying capacity and stiffness for a relatively lengthy period after the onset of fire. Mill-type construction is recognized by some building codes as a 1-h fire-resistant construction, with some limitations.

To be recognized as mill-type construction, the structural elements must meet specific sizes—columns cannot be less than standard 184 mm (nominal 8 in.) in dimension and beams and girders cannot be less than standard 140 by 235 mm (nominal 6 by 10 in.) in cross section. Other limitations must be observed as well. For example, walls must be made of masonry, and concealed spaces must be avoided. The structural frame has typically been constructed of solid-sawn timbers, which should be stress graded. These timbers can now be supplanted with glulam timbers, and longer spans are permitted.

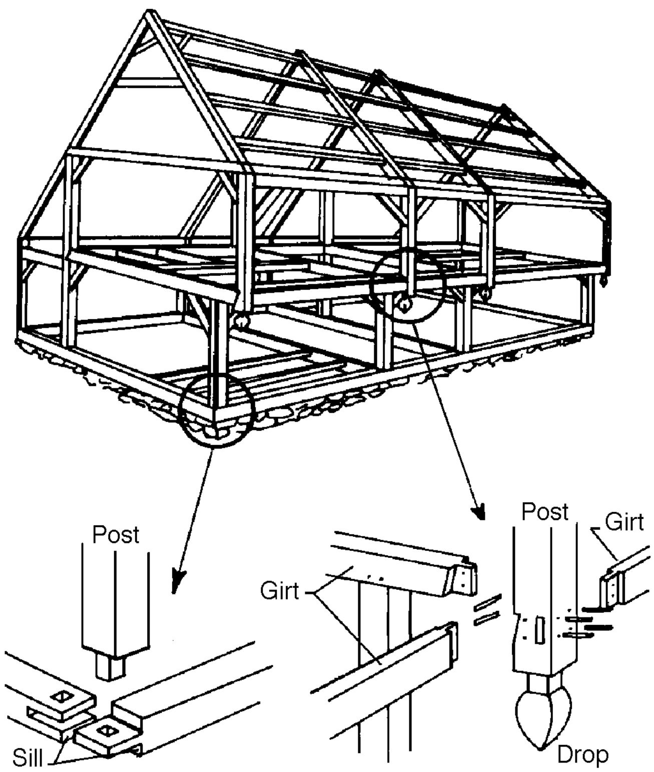

Figure 16–6. Timber frame structure with typical joint details.

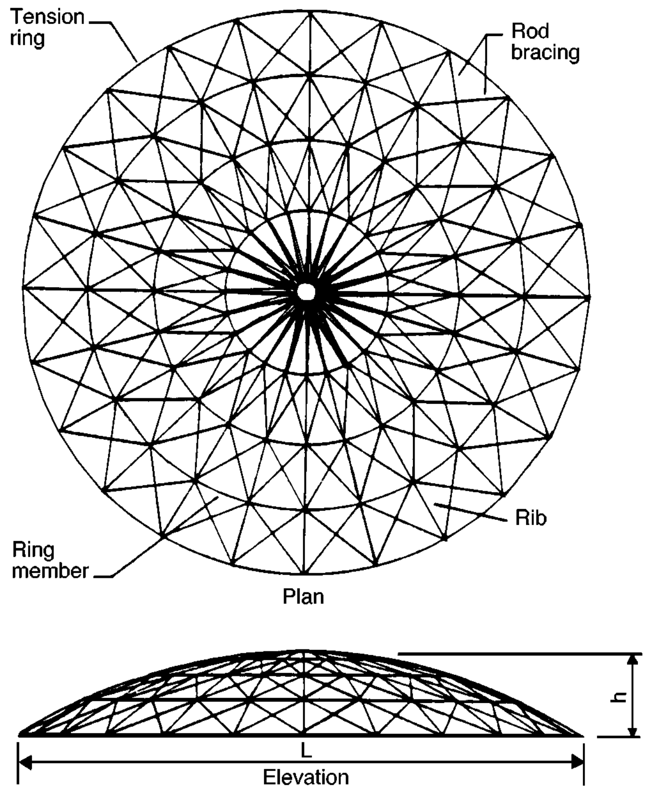

Figure 16–7. Member layout for a radial-rib dome.

Glulam Beam

A panelized roof system using glulam roof framing is widely used for single-story commercial buildings in the southwestern United States. This system is based on supporting columns located at the corners of pre-established grids. The main glulam beams support purlins, which may be sawn timbers, glulam, parallel chord trusses, or prefabricated wood I-joists. These purlins, which are normally on 2.4-m (8-ft) centers, support preframed structural panels. The basic unit of the preframed system is a 1.2- by 2.4-m (4- by 8-ft) structural panel nailed to standard 38- by 89-mm or 38- by 140-mm (nominal 2- by 4-in. or 2- by 6-in.) stiffeners (subpurlins). The stiffeners run parallel to the 2.4-m (8-ft) dimension of the structural panel. One stiffener is located at the centerline of the panel; the other is located at an edge, with the plywood edge at the stiffener centerline. The stiffeners are precut to a length equal to the long dimension of the plywood less the thickness of the purlin, with a small allowance for the hanger.

In some cases, the purlins are erected with the hangers in place. The prefabricated panels are lifted and set into place in the hangers, and the adjoining basic panels are then attached to each other. In other cases, the basic panels are attached to one purlin on the ground. An entire panel is lifted into place to support the loose ends of the stiffeners. This system is fully described in the *Laminated Timber Design Guide* (AITC 1994a).

Arch Structure

Arch structures are particularly suited to applications in which large, unobstructed areas are needed, such as churches, recreational buildings, and aircraft hangars. Many arch forms are possible with the variety limited only by the imagination of the architect. Churches have used arches from the beginning of glulam manufacture in the United States. Additional information on the use and design of arches is given in *The Timber Construction Manual* (AITC 1994b).

Dome

Radial-rib domes consist of curved members extending from the base ring (tension ring) to a compression ring at the top of the dome along with other ring members at various elevations between the tension and compression rings (Fig. 16–7). The ring members may be curved or straight. If they are curved to the same radius as the rib and have their centers at the center of the sphere, the dome will have a spherical surface. If the ring members are straight, the dome will have an umbrella look. Connections between the ribs and the ring members are critical because of the high compressive loads in the ring members. During construction, care must be taken to stabilize the structure because the dome has a tendency to rotate about the central vertical axis.

Other dome patterns called Varax and Triax are also used. Their geometries are quite complex and specialized computer

Figure 16–8. This 161.5-m- (530-ft-) diameter Tacoma dome (Tacoma, Washington), built in 1982–1983, is one of the longest clear roof spans in the world. (Photo courtesy of Western Wood Structures, Inc., Tualatin, Oregon.)

programs are used in their design. Steel hubs used at the joints and supports are critical. An example of a Triax dome is shown in Figure 16–8.

Timber Bridges

Prior to the 20th century, timber was the major material used for both highway and railroad bridges. The development of steel and reinforced concrete provided other options, and these have become major bridge building materials. However, the U.S. inventory does contain a significant number of timber bridges, many of which continue to carry loads beyond their design life. A recent initiative in the United States has focused research and technology transfer efforts on improving the design and performance of timber bridges. As a result, hundreds of timber highway bridges were built across the United States during the 1990s; many using innovative designs and materials.

Bridges consist of a substructure and a superstructure. The substructure consists of abutments, piers, or piling, and it supports the superstructure that consists of stringers and/or a deck. The deck is often covered with a wearing surface of asphalt. Timber may be combined with other materials to form the superstructure, for example, timber deck over steel stringers. Covered bridges, although once popular, are usually not economically feasible. The various types of timber bridge superstructures are described in the following sections. Detailed information on modern timber bridges is given in T*imber Bridges: Design, Construction, Inspection, and Maintenance* (Ritter 1990).

Log Stringer

A simple bridge type that has been used for centuries consists of one or more logs used to span the opening. Several logs may be laid side-by-side and fastened together. The log stringer bridge has been used to access logging areas and is advantageous when adequate-sized logs are available and the bridge is only needed for a short time. Unless built with a durable species, the life span of log stringer bridges is usually limited to less than 10 years.

Sawn Lumber

Several types of bridges can be built with sawn lumber. Even though the span is usually limited to about 9 m (30 ft) because of the limited size of lumber available, this span length entails the majority of bridges in the United States.

Several timbers can be used to span the opening, and a transverse lumber deck can be placed over them to form a stringer and deck bridge. Lumber can be placed side-by-side and used to span the entire opening, forming a longitudinal deck bridge. The lumber can be fastened together with large spikes or held together with tensioned rods to form a “stress-laminated” deck.

Figure 16–9. Glulam beam bridge over the Dangerous River, near Yukatat, Alaska, consists of three 43.5-m (143-ft) spans. Each span is supported by four 2.3-m- (91.5-in.-) deep glulam beams.

Glulam

Structural glued-laminated (glulam) timber greatly extends the span capabilities of the same types of bridges described in the previous paragraph. Glulam stringers placed 0.6 to 1.8 m (2 to 6 ft) on center can support a glulam deck system and result in spans of 12 to 30 m (40 to 100 ft) or more (Fig. 16–9). Using glulam panels to span the opening results in a longitudinal deck system, but this is usually limited to about 9-m (30-ft) spans. These panels are either interconnected or supported at one or more locations with transverse distributor beams. Glulam beams can be used to form a solid deck and are held together with tensioned rods to form a stress-laminated deck. Curved glulam members can be used to produce various aesthetic effects and special types of bridges (Fig. 16–10).

Structural Composite Lumber

Two types of structural composite lumber (SCL)—laminated veneer and oriented strand—are beginning to be used to build timber bridges. Most of the same type of bridges built with either solid sawn or glulam timber can be built with SCL (Ch. 11).

Considerations for Wood Buildings

Many factors must be considered when designing and constructing wood buildings, including structural, insulation, moisture, and sound control. The following sections provide a brief description of the design considerations for these factors. Fire safety, another important consideration, is addressed in Chapter 17.

Structural

The structural design of any building consists of combining the prescribed performance requirements with the anticipated loading. One major performance requirement is that there be an adequate margin of safety between the structures ultimate capacity and the maximum anticipated loading. The probability that the building will ever collapse is minimized using material property information recommended by the material manufacturers along with code-recommended design loads.

Another structural performance requirement relates to serviceability. These requirements are directed at ensuring that the structure is functional, and the most notable one is that

Figure 16–10. Three-hinge glulam deck arch bridge at the Keystone Wye interchange off U.S. Highway 16, near Mount Rushmore, South Dakota. The arch spans 47 m (155 ft) and supports an 8-m- (26-ft-) wide roadway.

deformations are limited. It is important to limit deformations so that floors are not too "bouncy" or that doors do not bind under certain loadings. Building codes often include recommended limits on deformation, but the designer may be provided some latitude in selecting the limits. The basic reference for structural design of wood in all building systems is the *National Design Specification for Wood Construction* (AF&PA 1991).

Thermal Insulation and Air Infiltration Control

For most U.S. climates, the exterior envelope of a building needs to be insulated either to keep heat in the building or prevent heat from entering. Wood frame construction is well-suited to application of both cavity insulation and surface-applied insulation. The most common materials used for cavity insulation are glass fiber, mineral fiber, cellulose insulation, and spray-applied foams. For surface applications, a wide variety of sheathing insulations exist, such as rigid foam panels. Insulating sheathing placed on exterior walls may also have sufficient structural properties to provide required lateral bracing. Prefinished insulating paneling can be used as an inside finish on exterior walls or one or both sides of the interior partitions. In addition, prefinished insulation can underlay other finishes.

Attic construction with conventional rafters and ceiling joists or roof trusses can be insulated between framing members with batt, blanket, or loose-fill insulation. In some warm climates, radiant barriers and reflective insulations can provide an additional reduction in cooling loads. The "Radiant Barrier Attic Fact Sheet" from the U.S. Department of Energy (1991) provides information on climatic areas that are best suited for radiant barrier applications. This document also provides comparative information on the relative performance of these products and conventional fibrous insulations.

Existing frame construction can be insulated pneumatically using suitable loose-fill insulating material. When loose-fill materials are used in wall retrofit applications, extra care must be taken during the installation to eliminate the existence of voids within the wall cavity. All cavities should be checked prior to installation for obstructions, such as fire stop headers and wiring, that would prevent the cavity from being completely filled. Care must also be taken to install the material at the manufacturer's recommended density to ensure that the desired thermal performance is obtained.

Accessible space can be insulated by manual placement of batt, blanket, or loose-fill material.

In addition to being properly insulated, the exterior envelope of all buildings should be constructed to minimize air flow into or through the building envelope. Air flow can degrade the thermal performance of insulation and cause excessive moisture accumulation in the building envelope.

More information on insulation and air flow retarders can be found in the ASHRAE *Handbook of Fundamentals*, chapters 22 to 24 (ASHRAE 1997).

Moisture Control

Moisture control is necessary to avoid moisture-related problems with building energy performance, building maintenance and durability, and human comfort and health. Moisture degradation is the largest factor limiting the useful life of a building and can be visible or invisible. Invisible degradation includes the degradation of thermal resistance of building materials and the decrease in strength and stiffness of some materials. Visible degradation may be in the form of (a) mold and mildew, (b) decay of wood-based materials, (c) spalling caused by freeze–thaw cycles, (d) hydration of plastic materials, (e) corrosion of metals, (f) damage caused by expansion of materials from moisture (for example, buckling of wood floors), and (g) decline in visual appearance (for example, buckling of wood siding or efflorescence of masonry materials). In addition, high moisture levels can lead to mold spores in indoor air and odors, seriously affecting the occupant's health and comfort. Detailed discussions on the effects of moisture can be found in the ASHRAE *Handbook of Fundamentals,* chapters 22 and 23, (ASHRAE 1997) and Lstiburek and Carmody (1991).

Mold, Mildew, Dust Mites, and Human Health

Mold and mildew in buildings are offensive, and the spores can cause respiratory problems and allergic reactions in humans. Mold and mildew will grow on most surfaces if the relative humidity at the surface is above a critical value and the surface temperatures are conducive to growth. The longer the surface remains above this critical relative humidity level, the more likely mold will appear; the higher the humidity or temperature, the shorter the time needed for germination. The surface relative humidity is a complex function of material moisture content, material properties, local temperature, and humidity conditions. In addition, mold growth depends on the type of surface. Mildew and mold can usually be avoided by limiting surface relative humidity conditions >80% to short periods. Only for nonporous surfaces that are regularly cleaned should this criterion be relaxed. Most molds grow at temperatures approximately above 4°C (40°F). Moisture accumulation at temperatures below 4°C (40°F) may not cause mold and mildew if the material is allowed to dry out below the critical moisture content before the temperature increases above 4°C (40°F).

Dust mites can trigger allergies and are an important cause of asthma. They thrive at high relative humidity levels (>70%) at room temperature, but will not survive at sustained relative humidity levels less than 50%. However, these relative humidity levels relate to local conditions in the typical places that mites tend to inhabit (for example, mattresses, carpets, soft furniture).

Paint Failure and Other Appearance Problems

Moisture trapped behind paint films may cause failure of the paint (Ch. 15). Water or condensation may also cause streaking or staining. Excessive swings in moisture content of wood-based panels or boards may cause buckling or warp. Excessive moisture in masonry and concrete can produce efflorescence, a white powdery area or lines. When combined with low temperatures, excessive moisture can cause freeze–thaw damage and spalling (chipping).

Structural Failures

Structural failures caused by decay of wood are rare but have occurred. Decay generally requires a wood moisture content equal to or greater than fiber saturation (usually about 30%) and between 10°C (50°F) and 43°C (100°F). Wood moisture content levels above fiber saturation are only possible in green lumber or by absorption of liquid water from condensation, leaks, ground water, or other saturated materials in contact with the wood. To maintain a safety margin, a 20% moisture content is sometimes used during field inspections as the maximum allowable level. Once established, decay fungi produce water that enables them to maintain moisture conditions conducive to their growth. See Chapter 13 for more information on wood decay.

Rusting or corrosion of nails, nail plates, or other metal building products is also a potential cause of structural failure. Corrosion may occur at high relative humidity levels near the metal surface or as a result of liquid water from elsewhere. Wood moisture content levels >20% encourage corrosion of steel fasteners in wood, especially if the wood is treated with preservatives. In buildings, metal fasteners are often the coldest surfaces, which encourages condensation and corrosion of fasteners.

Effect on Heat Flow

Moisture in the building envelope can significantly degrade the thermal performance of most insulation materials but especially the thermal resistance of fibrous insulations and open cell foams. The degradation is most pronounced when daily temperature reversals across the insulation drive moisture back and forth through the insulation.

Moisture Control Strategies

Strategies to control moisture accumulation fall into two general categories: (1) minimize moisture entry into the building envelope and (2) remove moisture from the building envelope. When basic moisture transport mechanisms and specific moisture control practices are understood, roof, wall, and foundation constructions for various climates can be reviewed in a systematic fashion to determine if every potentially significant moisture transport mechanism is explicitly controlled. It is not possible to prevent moisture migration completely; therefore, construction should include drainage, ventilation, and removal by capillary suction, or other provisions to carry away unwanted water.

The major moisture transport mechanisms, in order of importance, are (a) liquid water movement, including capillary movement; (b) water vapor transport by air movement; and (c) water vapor diffusion. In the past, much attention has focused on limiting movement by diffusion with vapor retarders (sometimes called vapor barriers), even though vapor diffusion is the least important of all transport mechanisms. Control of moisture entry should be accomplished in accordance with the importance of the transport mechanism: (a) control of liquid entry by proper site grading and installing gutters and downspouts and appropriate flashing around windows, doors, and chimneys; (b) control of air leakage by installing air flow retarders or careful sealing by taping and caulking; and (c) control of vapor diffusion by placing vapor retarders on the "warm" side of the insulation.

Options for moisture control under heating conditions often differ from those under cooling conditions, even though the physical principles of moisture movement are the same. Which moisture control options apply depends on whether the local climate is predominantly a heating or cooling climate. In heating climates, ventilation with outdoor air and limiting indoor sources of moisture (wet fire wood, unvented dryers, humidifiers) can be effective strategies. In cooling climates, proper dehumidification can provide moisture control. More information on the definition of heating and cooling climates and specific moisture control strategies can be found in the ASHRAE *Handbook of Fundamentals,* chapter 23 (ASHRAE 1997).

Sound Control

An important design consideration for residential and office buildings is the control of sound that either enters the structure from outside or is transmitted from one room to another. Wood frame construction can achieve the levels of sound control equal to or greater than more massive construction, such as concrete. However, to do so requires designing for both airborne and impact noise insulation.

Airborne noise insulation is the resistance to transmission of airborne noises, such as traffic or speech, either through or around an assembly such as a wall. Noises create vibrations on the structural surfaces that they contact, and the design challenge is to prevent this vibration from reaching and leaving the opposite side of the structural surface. Sound transmission class (STC) is the rating used to characterize airborne noise insulation. A wall system with a high STC rating is effective in preventing the transmission of sound. Table 16–1 lists the STC ratings for several types of wall systems; detailed information for both wall and floor are given in FPL–GTR–43 (Rudder 1985).

Impact noise insulation is the resistance to noise generated by footsteps or dropping objects, generally addressed at floor–ceiling assemblies in multi-family dwellings. Impact insulation class (IIC) is the rating used to characterize the impact noise insulation of an assembly. Both the character of the flooring material and the structural details of the floor influence the IIC rating. Additional information on IIC ratings for wood construction is given in FPL–GTR–59 (Sherwood and Moody 1989).

Table 16–1. Sound transmission class (STC) ratings for typical wood-frame walls

STC rating	Privacy afforded	Wall structure
25	Normal speech easily understood	6-mm (1/4-in.) wood panels nailed on each side of standard 38- by 89-mm (nominal 2- by 4-in.) studs.
30	Normal speech audible but not intelligible	9.5-mm (3/8-in.) gypsum wallboard nailed to one side of standard 38- by 89-mm (nominal 2- by 4-in.) studs.
35	Loud speech audible and fairly understandable	20-mm (5/8-in.) gypsum wallboard nailed to both sides of standard 38- by 89-mm (nominal 2- by 4-in.) studs.
40	Loud speech audible but not intelligible	Two layers of 20-mm (5/8-in.) gypsum wallboard nailed to both sides of standard 38- by 89-mm (nominal 2- by 4-in.) studs.
45	Loud speech barely audible	Two sets of standard 38- by 64-mm (nominal 2- by 3-in.) studs staggered 0.2 m (8 in.) on centers fastened by standard 38- by 89-mm (nominal 2- by 4-in.) base and head plates with two layers of 20-mm (5/8-in.) gypsum wallboard nailed on the outer edge of each set of studs.
50	Shouting barely audible	Standard 38- by 89-mm (nominal 2- by 4-in.) wood studs with resilient channels nailed horizontally to both sides with 20-mm (5/8-in.) gypsum wallboard screwed to channels on each side.
55	Shouting not audible	Double row of standard 38- by 89-mm (nominal 2- by 4-in.) studs 0.4 m (16 in.) on centers fastened to separate plates spaced 25 mm (1 in.) apart. Two layers of 20-mm (5/8-in.) gypsum wallboard screwed 0.3 m (12 in.) on center to the studs. An 89-mm- (3.5-in.-) thick sound-attenuation blanket is installed in one stud cavity.

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Chapter 17

Fire Safety

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Contents

Fire safety is an important concern in all types of construction. The high level of national concern for fire safety is reflected in limitations and design requirements in building codes. These code requirements are discussed in the context of fire safety design and evaluation in the initial section of this chapter. Since basic data on fire behavior of wood products are needed to evaluate fire safety for wood construction, the second major section of this chapter covers fire performance characteristics of wood products. The chapter concludes with a discussion of flame-retardant treatments that can be used to reduce the combustibility of wood.

Fire Safety Design and Evaluation

Fire safety involves prevention, containment, detection, and evacuation. Fire prevention basically means preventing the ignition of combustible materials by controlling either the source of heat or the combustible materials. This involves proper design, installation or construction, and maintenance of the building and its contents. Proper fire safety measures depend upon the occupancy or processes taking place in the building. Design deficiencies are often responsible for spread of heat and smoke in a fire. Spread of a fire can be prevented with design methods that limit fire growth and spread within a compartment and with methods that contain fire to the compartment of origin. Egress, or the ability to escape from a fire, often is a critical factor in life safety. Early detection is essential for ensuring adequate time for egress.

Statutory requirements pertaining to fire safety are specified in the building codes or fire codes. These requirements fall into two broad categories: material requirements and building requirements. Material requirements include such things as combustibility, flame spread, and fire endurance. Building requirements include area and height limitations, firestops and draftstops, doors and other exits, automatic sprinklers, and fire detectors.

Adherence to codes will result in improved fire safety. Code officials should be consulted early in the design of a building because the codes offer alternatives. For example, floor areas can be increased if automatic sprinkler systems are added. Code officials have the option to approve alternative materials and methods of construction and to modify provisions of the codes when equivalent fire protection and structural integrity is documented.

Most building codes in the United States are based on model building codes produced by the three building code organizations (Building Officials and Code Administrators International, Inc.; International Conference of Building Officials; and the Southern Building Code Congress International, Inc.). These three organizations are developing a single international building code that will replace the existing three model building codes. In addition to the building codes and the fire codes, the National Fire Protection Association's Life Safety Code provides guidelines for life safety from fire in buildings and structures. As with the model building codes, provisions of the life safety code are statutory requirements when adopted by local or State authorities.

In the following sections, various aspects of the building code provisions pertaining to fire safety of building materials are discussed under the broad categories of (a) types of construction, (b) fire growth within compartment, and (c) containment to compartment of origin. These are largely requirements for materials. Information on prevention and building requirements not related to materials (for example, detection) can be found in publications such as those listed at the end of this chapter. Central aspects of the fire safety provisions of the building codes are the classification of buildings by types of construction and the use or occupancy.

Types of Construction

Based on classifications of building type and occupancy, the codes set limits on the areas and heights of buildings. Major building codes generally recognize five classifications of construction based on types of materials and required fire resistance ratings. The two classifications known as fire-resistant construction (Type I) and noncombustible construction (Type II) basically restrict the construction to noncombustible materials. Wood is permitted to be used more liberally in the other three classifications, which are ordinary (Type III), heavy timber (Type IV), and light-frame (Type V). Heavy timber construction has wood columns, beams, floors, and roofs of certain minimum dimensions. Ordinary construction has smaller wood members used for walls, floors, and roofs including wood studs, wood joists, wood trusses, and wood I-joists. In both heavy timber and ordinary construction, the exterior walls must be of noncombustible materials. In light-frame construction, the walls, floors, and roofs may be of any dimension lumber and the exterior walls may be of combustible materials. Type II, III, and IV constructions are further subdivided based on fire-resistance requirements. Light-frame construction, or Type V, is subdivided into two parts, protected (1-hour) and unprotected.

In protected light-frame construction, most of the structural elements have a 1-hour fire resistance rating. There are no general requirements for fire resistance for buildings of unprotected light-frame construction.

Based on their performance in the American Society for Testing and Materials (ASTM) E136 test, both untreated and fire-retardant-treated wood are combustible materials. However, the building codes permit substitution of fire-retardant-treated wood for noncombustible materials in some specific applications otherwise limited to noncombustible materials.

In addition to the type of construction, the height and area limitations also depend on the use or occupancy of a structure. Fire safety is improved by automatic sprinklers, property line setbacks, or more fire-resistant construction. Building codes recognize the improved fire safety resulting from application of these factors by increasing the allowable areas and heights beyond that designated for a particular type of construction and occupancy. Thus, proper site planning and building design may result in a desired building area classification being achieved with wood construction.

Fire Growth Within Compartment

A second major set of provisions in the building codes are those that regulate the exposed interior surface of walls and ceilings (that is, the interior finish). Codes typically exclude trim and incidental finish, as well as decorations and furnishings that are not affixed to the structure, from the more rigid requirements for walls and ceilings. For regulatory purposes, interior finish materials are classified according to their flame spread index. Thus, flame spread is one of the most tested fire performance properties of a material. Numerous flame spread tests are used, but the one cited by building codes is ASTM E84, the "25-ft tunnel" test. In this test method, the 508-mm-wide, 7.32-m-long specimen completes the top of the tunnel furnace. Flames from a burner at one end of the tunnel provide the fire exposure, which includes forced draft conditions. The furnace operator records the flame front position as a function of time and the time of maximum flame front travel during a 10-min period. The standard prescribes a formula to convert these data to a flame spread index (FSI), which is a measure of the overall rate of flame spreading in the direction of air flow. In the codes, the classes for flame spread index are I (FSI of 0 to 25), II (FSI of 26 to 75), and III (FSI of 76 to 200). Some codes use A, B, and C instead of I, II, and III. Generally, codes specify FSI for interior finish based on building occupancy, location within the building, and availability of automatic sprinkler protection. The more restrictive classes, Classes I and II, are generally prescribed for stairways and corridors that provide access to exits. In general, the more flammable classification (Class III) is permitted for the interior finish of other areas of the building that are not considered exit ways or where the area in question is protected by automatic sprinklers. In other areas, there are no flammability restrictions on the interior finish and unclassified materials (that is, more than 200 FSI) can be used.

Table 17–1. ASTM E84 flame spread indexes for 19-mm-thick solid lumber of various wood species as reported in the literature

Species[a]	Flame spread index[b]	Smoke developed index[b]	Source[c]
Softwoods			
Yellow-cedar (Pacific Coast yellow cedar)	78	90	CWC
Baldcypress (cypress)	145–150	—	UL
Douglas-fir	70–100	—	UL
Fir, Pacific silver	69	58	CWC
Hemlock, western (West Coast)	60–75	—	UL
Pine, eastern white (eastern white, northern white)	85, 120–215[d]	122, —	CWC, UL
Pine, lodgepole	93	210	CWC
Pine, ponderosa	105–230[d]	—	UL
Pine, red	142	229	CWC
Pine, Southern (southern)	130–195	—	UL
Pine, western white	75[e]	—	UL
Redcedar, western	70	213	HPVA
Redwood	70	—	UL
Spruce, eastern (northern, white)	65	—	UL, CWC
Spruce, Sitka (western, Sitka)	100, 74	—, 74	UL, CWC
Hardwoods			
Birch, yellow	105–110	—	UL
Cottonwood	115	—	UL
Maple (maple flooring)	104	—	CWC
Oak (red, white)	100	100	UL
Sweetgum (gum, red)	140–155	—	UL
Walnut	130–140	—	UL
Yellow-poplar (poplar)	170–185	—	UL

[a]In cases where the name given in the source did not conform to the official nomenclature of the Forest Service, the probable official nomenclature name is given and the name given by the source is given in parentheses.

[b]Data are as reported in the literature (dash where data do not exist). Changes in the ASTM E84 test method have occurred over the years. However, data indicate that the changes have not significantly changed earlier data reported in this table. The change in the calculation procedure has usually resulted in slightly lower flame spread results for untreated wood. Smoke developed index is not known to exceed 450, the limiting value often cited in the building codes.

[c]CWC, Canadian Wood Council (CWC 1996); HPVA, Hardwood Plywood Manufacturers Association (Tests) (now Hardwood Plywood & Veneer Assoc.); UL, Underwriters Laboratories, Inc. (Wood-fire hazard classification. Card Data Service, Serial No. UL 527, 1971).

[d]Footnote of UL: In 18 tests of ponderosa pine, three had values over 200 and the average of all tests is 154.

[e]Footnote of UL: Due to wide variations in the different species of the pine family and local connotations of their popular names, exact identification of the types of pine tested was not possible. The effects of differing climatic and soil conditions on the burning characteristics of given species have not been determined.

The FSI for most domestic wood species is between 90 and 160 (Table 17–1). Thus, unfinished lumber, 10 mm or thicker, is generally acceptable for interior finish applications requiring a Class III rating. Flame-retardant treatments are usually necessary when a Class I or II flame spread index is required for a wood product. A few domestic softwood species can meet the Class II flame spread index and only require flame-retardant treatments to meet a Class I rating. A few imported species have reported FSIs of less than 25.

Additional FSI for many solid-sawn and panel products are provided in the American Forest and Paper Association's (AF&PA) design for code acceptance (DCA) No. 1, "Flame Spread Performance of Wood Products" (AWC 1999).

There are many other test methods for flame spread or flammability. Most are used only for research and development or quality control, but some are used in product specifications and regulations of materials in a variety of applications.

Since the fire exposure is on the underside of a horizontal specimen in the ASTM E84 test, it is not suitable for materials that melt and drip or are not self-supporting. Code provisions pertaining to floors and floor coverings may be based on another test criterion, the critical radiant flux test (ASTM E648, Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source). The critical radiant flux apparatus is also used to test the flammability of cellulosic insulation (ASTM E970, Critical Radiant Flux of Exposed Attic Floor Insulation Using a Radiant Heat Energy Source). In the critical radiant flux test, the placement of the radiant panel is such that the radiant heat being imposed on the surface has a gradient in intensity down the length of the horizontal specimen. Flames spread from the ignition source at the end of high heat flux (or intensity) to the other end until they reach a location where the heat flux is not sufficient for further propagation. This is reported as the critical radiant flux. Thus, low critical radiant flux reflects materials with high flammability. Typical requirements are for a minimum critical radiant flux level of 2.2 or 4.5 kW/m^2 depending on location and occupancy. Data in the literature indicate that oak flooring has a critical radiant flux of 3.5 kW/m^2 (Benjamin and Adams 1976).

There is also a smoldering combustion test for cellulosic insulation. Cellulosic insulation is regulated by a product safety standard of the U.S. Consumer Product Safety Commission (Interim Safety Standard for Cellulosic Insulation: Cellulosic Insulation Labeling and Requirements, 44FR 39938, 16CFR Part 1209, 1979; also Gen. Serv. Admin. Spec. HH–I–515d). Proper chemical treatments of cellulosic insulation are required to reduce its tendency for smoldering combustion and to reduce flame spread. Proper installation around recessed light fixtures and other electrical devices is necessary.

Other tests for flammability include those that measure heat release. Other flammability tests and fire growth modeling are discussed in the Fire Performance Characteristics of Wood section.

Rated roof covering materials are designated either Class A, B, or C according to their performance in the tests described in ASTM E108, Fire Tests of Roof Coverings. This test standard includes intermittent flame exposure, spread of flame, burning brand, flying brand, and rain tests. There is a different version of the pass/fail test for each of the three classes. Class A test is the most severe and Class C the least. In the case of the burning brand tests, the brand for the Class B test is larger than that for the Class C test. Leach-resistant fire-retardant-treated shingles are available that carry a Class B or C fire rating.

Information on ratings for different products can be obtained from industry literature, evaluation reports issued by the model code organizations, and listings published by testing laboratories or quality assurance agencies. Products listed by Underwriters Laboratories, Inc., and other such organizations are stamped with the rating information.

Flashover

With sufficient heat generation, the initial growth of a fire in a compartment leads to the condition known as flashover. The visual criteria for flashover are full involvement of the compartment and flames out the door or window. The intensity over time of a fire starting in one room or compartment of a building depends on the amount and distribution of combustible contents in the room and the amount of ventilation.

The standard full-scale test for pre-flashover fire growth is the room/corner test (International Organization for Standardization (ISO) 9705, Fire Tests—Full-Scale Room Test for Surface Products). In this test, a gas burner is placed in the corner of the room, which has a single door for ventilation. Three of the walls are lined with the test material, and the ceiling may also be lined with the test material. Other room/corner tests use a wood crib or similar item as the ignition source. Such a room/corner test is used to regulate foam plastic insulation, a material that is not properly evaluated in the ASTM E84 test.

Observations are made of the growth of the fire and the duration of the test until flashover occurs. Instruments record the heat generation, temperature development within the room, and the heat flux to the floor. Results of full-scale room/corner tests are used to validate fire growth models and bench-scale test results. Fire endurance tests evaluate the relative performance of the assemblies during a post-flashover fire.

Containment to Compartment of Origin

The growth, intensity, and duration of the fire is the "load" that determines whether a fire is confined to the room of origin. Whether a given fire will be contained to the compartment depends on the fire resistance of the walls, doors, ceilings, and floors of the compartment. Requirements for fire resistance or fire endurance ratings of structural members and assemblies are another major component of the building code provisions. Fire resistance is the ability of materials or their assemblies to prevent or retard the passage of excessive heat, hot gases, or flames while continuing to support their structural loads. Fire-resistance ratings are usually obtained by conducting standard fire tests. In the standard fire-resistance test (ASTM E119), there are three failure criteria: element collapse, passage of flames, or excessive temperature rise on the non-fire-exposed surface (average increase of several locations exceeding 139°C or 181°C at a single location).

The self-insulating qualities of wood, particularly in the large wood sections of heavy timber construction, are an important factor in providing a degree of fire resistance. In Type IV or heavy timber construction, the need for fire-resistance requirements is achieved in the codes by specifying minimum sizes for the various members or portions of a building and other prescriptive requirements. In this type of construction, the wood members are not required to have specific fire-resistance ratings. The acceptance of heavy timber construction is based on historical experience with its performance in actual fires. Proper heavy timber construction includes using approved fastenings, avoiding concealed spaces under floors or roofs, and providing required fire resistance in the interior and exterior walls.

In recent years, the availability and code acceptance of a procedure to calculate the fire-resistance ratings for large timber beams and columns have allowed their use in fire-rated buildings not classified as heavy timber construction (Type IV). In the other types of construction, the structural members and assemblies are required to have specified fire-resistance ratings. Details on the procedure for large timbers can be found in American Institute of Timber Construction (AITC) Technical Note 7 and the AF&PA DCA #2 "Design of Fire-Resistive Exposed Wood Members" (AWC 1985).

The fire resistance of glued-laminated structural members, such as arches, beams, and columns, is approximately equivalent to the fire resistance of solid members of similar size. Available information indicates that laminated members glued with phenol, resorcinol, or melamine adhesives are at least equal in their fire resistance to a one-piece member of the same size. Laminated members glued with casein have only slightly less fire resistance.

Light-frame wood construction can provide a high degree of fire containment through use of gypsum board as the interior finish. This effective protective membrane provides the initial fire resistance rating. Many recognized assemblies involving wood-frame walls, floors, and roofs provide a 1- or 2-hour fire resistance rating. Fire-rated gypsum board (Type X or C) is used in rated assemblies. Type X and the higher grade Type C gypsum boards have textile glass filaments and other ingredients that help to keep the gypsum core intact during a fire. Fire-resistance ratings of various assemblies are listed in the model codes and other publications such as the *Fire Resistance Design Manual* (Gypsum Association). Traditional constructions of regular gypsum wallboard (that is, not fire rated) or lath and plaster over wood joists and studs have fire-resistance ratings of 15 to 30 min.

While fire-resistance ratings are for the entire wall, floor, or roof assembly, the fire resistance of a wall or floor can be viewed as the sum of the resistance of the interior finish and the resistance of the framing members. In a code-accepted procedure, the fire rating of a light-frame assembly is calculated by adding the tabulated times for the fire-exposed membrane to the tabulated times for the framing. For example, the fire-resistance rating of a wood stud wall with 16-mm-thick Type X gypsum board and rock wool insulation is computed by adding the 20 min listed for the stud wall, the 40 min listed for the gypsum board, and the 15 min listed for the rock wool insulation to obtain a rating for the assembly of 75 min. Additional information on this component additive method (CAM) can be found in the AF&PA DCA No. 4 "Component Additive Method (CAM) for Calculating and Demonstrating Assembly Fire Endurance" (AWC 1991). More sophisticated mechanistic models are being developed.

The relatively good structural behavior of a traditional wood member in a fire test results from the fact that its strength is generally uniform through the mass of the piece. Thus, the unburned fraction of the member retains high strength, and its load-carrying capacity is diminished only in proportion to its loss of cross section. Innovative designs for structural wood members may reduce the mass of the member and locate the principal load-carrying components at the outer edges where they are most vulnerable to fire, as in structural sandwich panels. With high strength facings attached to a low-strength core, unprotected load-bearing sandwich panels have failed to support their load in less than 6 min when tested in the standard test. If a sandwich panel is to be used as a load-bearing assembly, it should be protected with gypsum wallboard or some other thermal barrier. In any protected assembly, the performance of the protective membrane is the critical factor in the performance of the assembly.

Unprotected light-frame wood buildings do not have the natural fire resistance achieved with heavier wood members. In these, as in all buildings, attention to good construction details is important to minimize fire hazards. Quality of workmanship is important in achieving adequate fire resistance. Inadequate nailing and less than required thickness of the interior finish can reduce the fire resistance of an assembly. The method of fastening the interior finish to the framing members and the treatment of the joints are significant factors in the fire resistance of an assembly. The type and quantity of any insulation installed within the assembly may also affect the fire resistance of an assembly. Electrical receptacle outlets, pipe chases, and other through openings that are not adequately firestopped can affect the fire resistance. In addition to the design of walls, ceilings, floors, and roofs for fire resistance, stairways, doors, and firestops are of particular importance.

Fires in buildings can spread by the movement of hot fire gases through open channels in concealed spaces. Codes specify where firestops and draftstops are required in concealed spaces, and they must be designed to interfere with the passage of flames up or across a building. In addition to going along halls, stairways, and other large spaces, heated gases also follow the concealed spaces between floor joists and between studs in partitions and walls of frame construction. Obstruction of these hidden channels provides an effective means of restricting fire from spreading to other parts of the structure. Firestops are materials used to block off relatively small openings passing through building components such as floors and walls. Draftstops are barriers in larger concealed spaces such as those found within wood joist floor assemblies with suspended dropped ceilings or within an attic space with pitched chord trusses.

Doors can be critical in preventing the spread of fires. Doors left open or doors with little fire resistance can easily defeat the purpose of a fire-rated wall or partition. Listings of fire-rated doors, frames, and accessories are provided by various fire testing agencies. When a fire-rated door is selected, details about which type of door, mounting, hardware, and closing mechanism need to be considered.

Fire Safety Engineering

The field of fire safety engineering is undergoing rapid changes because of the development of more engineering and scientific approaches to fire safety. This development is evidenced by the publication of *The Society of Fire Protection Engineers Handbook of Fire Protection Engineering* and formation of fire safety engineering subcommittees in ISO and ASTM. Steady advances are being made in the fields of fire dynamics, fire hazard calculations, fire design calculations, and fire risk analysis. Such efforts support the worldwide trend to develop alternative building codes based on performance criteria rather than prescriptive requirements. Additional information on fire protection can be found in the various publications of the National Fire Protection Association (NFPA).

Fire Performance Characteristics of Wood

Wood will burn when exposed to heat and air. Thermal degradation of wood occurs in stages. The degradation process and the exact products of thermal degradation depend upon the rate of heating as well as the temperatures. The sequence of events for wood combustion is as follows:

- The wood, responding to heating, decomposes or pyrolyzes into volatiles and char. Char is the dominant product at internal temperatures less than 300°C, whereas volatiles become much more pronounced above 300°C.
- The volatiles, some of which are flammable, can be ignited if the volatile–air mixture is of the right composition in a temperature range of about 400°C to 500°C within the mixture. This gas-phase combustion appears as flames.
- With air ventilation, the char oxidation becomes significant around 200°C with two peaks in intensity reported at 360°C and 520°C. This char oxidation is seen as glowing or smoldering combustion until only ash residue remains. This solid-phase combustion will not proceed if flaming combustion prevents a supply of fresh air to the char surfaces.

Several characteristics are used to quantify this burning behavior of wood, including ignition from heat sources, growing rate of heat release leading to room flashover, flame spread in heated environments, smoke and toxic gases, flashover, and charring rates in a contained room.

Ignition

Ignition of wood takes place when wood is subject to sufficient heat and in atmospheres that have sufficient oxygen. Ignition can be of two types: piloted or unpiloted. Piloted ignition occurs in the presence of an ignition source (such as a spark or a flame). Unpiloted ignition is ignition that occurs where no pilot source is available. The wood surface is ignited by the flow of energy or heat flux from a fire or other heated objects. This flow of energy or heat flux can have both convective and radiative components.

Piloted ignition above a single flat surface has recently been studied in some depth because of the advent of fire growth research. The surface temperature of wood materials has been measured somewhere between 300°C to 400°C prior to piloted ignition. Surface temperature at ignition is an illusive quantity that is experimentally difficult to obtain. Equipment such as the Ohio State University (OSU) apparatus (ASTM E906), the cone calorimeter (ASTM 1354), and the lateral ignition and flame spread test (LIFT) apparatus (ASTM 1321) are used to obtain data on time to piloted ignition as a function of heater irradiance. Table 17–2 indicates the decrease in time to ignition with the increase in imposed heat flux for different species of wood measured with the OSU apparatus. Similar, perhaps identical, materials have been tested recently in cone calorimeter and LIFT apparatuses with somewhat similar results. From such tests, values of ignition temperature, critical ignition flux (heat flux below which ignition would not occur), and thermophysical properties have been derived using a transient heat conduction theory. These properties are also material dependent; they depend heavily on density of the material and moisture content. A range of wood products tested have ignition surface temperatures of 300°C to 400°C and a critical ignition flux of between 10 and 13 kW/m^2 in the cone calorimeter. The ignition surface temperature is lower for low density woods. Estimates of piloted ignition in various scenarios can be obtained using the derived thermal properties and an applicable heat conduction model.

Some, typically old, apparatuses for testing piloted ignition measured the temperature of the air flow rather than the imposed heat flux with the time to ignition measurement. These results were often reported as the ignition temperature and as varying with time to ignition, which is misleading. When the imposed heat flux is due to a radiant source, such reported air flow ignition temperature can be as much as 100°C lower than the ignition surface temperature. For a proper heat conduction analysis in deriving thermal properties, measurements of the radiant source flux and air flow rate are also required. Since imposed heat flux to the surface and the surface ignition temperature are the factors that directly determine ignition, some data of piloted ignition are inadequate or misleading.

Unpiloted ignition depends on special circumstances that result in different ranges of ignition temperatures. At this time, it is not possible to give specific ignition data that apply to a broad range of cases. For radiant heating of cellulosic solids, unpiloted transient ignition has been reported at 600°C. With convective heating of wood, unpiloted ignition has been reported as low as 270°C and as high as 470°C.

Unpiloted spontaneous ignition can occur when a heat source within the wood product is located such that the heat is not readily dissipated. This kind of ignition involves smoldering and generally occurs over a longer period of time. Smoldering is thermal degradation that proceeds without flames or

Table 17–2. Flammability data for selected wood species

Species	Density[a] (kg/m^3)	Ignition time[b] (s) 18-kW/m^2 heat flux	Ignition time[b] (s) 55-kW/m^2 heat flux	Higher heating value[c] (MJ/kg)	Effective heat of combustion[d] (MJ/kg) 18-kW/m^2 heat flux	Effective heat of combustion[d] (MJ/kg) 55-kW/m^2 heat flux	Average heat release rate[b] (kW/m^2) 18-kW/m^2 heat flux	Average heat release rate[b] (kW/m^2) 55-kW/m^2 heat flux
Softwoods								
Pine, Southern	508	740	5	20.5	9.1	13.9	40.4	119.6
Redwood	312	741	3	21.1	10.7	14.2	39.0	85.9
Hardwoods								
Basswood	312	183	5	20.0	10.9	12.2	52.8	113.0
Oak, red	660	930	13	19.8	9.0	11.7	48.7	113.3

[a]Based on weight and volume of ovendried wood.
[b]Ignition times, effective heat of combustion, and average rate of heat release (HRR) obtained using an ASTM E906 heat release apparatus modified to measured heat release using oxygen consumption method. Test durations were 50 to 98 min for 18-kW/m^2 heat flux and 30 to 53 min for 55-kW/m^2 heat flux. Test was terminated prior to the usual increase in HRR to a second peak as the specimen is consumed.
[c]From oxygen bomb calorimeter test.
[d]Apparent effective heat of combustion based on average HRR and mass loss rate, which includes the moisture driven from the wood. See footnote b.

visible glowing. Examples of such fires are (a) panels or paper removed from the press or dryer and stacked in large piles without adequate cooling and (b) very large piles of chips or sawdust with internal exothermic reactions such as biological activities. Potential mechanisms of internal heat generation include respiration, metabolism of microorganisms, heat of pyrolysis, abiotic oxidation, and adsorptive heat. These mechanisms, often in combination, may proceed to smoldering or flaming ignition through a thermal runaway effect within the pile if sufficient heat is generated and is not dissipated. The minimum environmental temperature to achieve ignition is called the self-accelerating decomposition temperature and includes the effects of specimen mass and air ventilation.

Unpiloted ignitions that involve wood exposed to low level external heat sources over very long periods is an area of dispute. This kind of ignition, which involves considerable charring, does appear to occur, based on fire investigations. However, these circumstances do not lend themselves easily to experimentation and observation. There is some evidence that the char produced under low heating temperatures can have a different chemical composition, which results in a somewhat lower ignition temperature than normally recorded. Thus, a major issue is the question of safe working temperature for wood exposed for long periods. Temperatures between 80°C to 100°C have been recommended as safe surface temperatures for wood. Since thermal degradation is a prerequisite for ignition of the char layer, conservative criteria for determining safe working temperatures can be the temperature and duration needed for thermal degradation. Schaffer (1980) used a residual weight criterion of 40% of the initial weight to suggest that wood can safely be heated to 150°C for a year or more before satisfying this conservative predictor of heating time to reach an incipient smoldering state.

Building codes do not generally regulate building materials on the basis of ignition or ignitability. As a result, general fire safety design criteria have not been developed. Rather, this subject is considered in conjunction with limits on combustibility and flame spread.

Heat Release

Heat release rates are important because they indicate the potential fire hazard of a material and also the combustibility of a material. Materials that release their potential chemical energy (and also the smoke and toxic gases) relatively quickly are more hazardous than those that release it more slowly. There are materials that will not pass the current definition of noncombustible in the model codes but will release only limited amounts of heat during the initial and critical periods of fire exposure. There is also some criticism of using limited flammability to partially define noncombustibility. One early attempt was to define combustibility in terms of heat release in a potential heat method (NFPA 259), with the low levels used to define low combustibility or noncombustibility. This test method is being used to regulate materials under some codes. The ground-up wood sample in this method is completely consumed during the exposure to 750°C for 2 h, which makes the potential heat for wood identical to the gross heat of combustion from the oxygen bomb calorimeter (the higher heating value in Table 17–2). The typical gross heat of combustion averaged around 20 MJ/kg for ovendried wood, depending on the lignin and extractive content of the wood.

A better or a supplementary measure of degrees of combustibility is a determination of the rate of heat release (RHR) or heat release rate (HRR). This measurement efficiently assesses the relative heat contribution of materials—thick, thin, untreated, or treated—under fire exposure. The cone calorimeter (ASTM E1354) is the most commonly used bench-scale HRR apparatus and is based on the oxygen consumption method. An average value of 13.1 kJ/g of oxygen consumed was the constant found for organic solids and is accurate with very few exceptions to within 5%. Thus, it is sufficient to measure the mass flow rate of oxygen consumed in a combustion system to determine the net HRR. The procedure known as ASTM E906 (the OSU apparatus) is a well-known and widely used calorimeter based on measurements of heat content of incoming and exiting air flow through the apparatus. Because of the errors caused by the heat losses and the fact that the mass flow rate is controlled in the OSU apparatus, several researchers have modified it to the oxygen consumption method. These bench-scale apparatuses use a radiant source to provide the external heat exposure to the test specimen. The imposed heat flux is kept constant at a specified heat flux level. The intermediate-scale apparatus (ASTM E1623) for testing 1- by 1-m assemblies or composites and the room full-scale test (ISO 9705) also use the oxygen consumption technique to measure the HRR of fires at larger scales.

The cone calorimeter is ideal for product development with its small specimen size of 100 by 100 mm. The specimen is continuously weighed by use of a load cell. In conjunction with HRR measurements, the effective heat of combustion as a function of time is calculated by the ASTM E1354 method. Basically, the effective heat of combustion is the HRR divided by the mass loss rate as determined from the cone calorimeter test as a function of time. A typical HRR profile as shown in Figure 17–1 for plywood begins with a sharp peak upon ignition, and as the surface chars, the HRR drops to some minimum value. After the thermal wave travels completely through the wood thickness, the back side of a wood sample reaches pyrolysis temperature, thus giving rise to a second, broader, and even higher HRR peak. For fire-retardant-treated wood products, the first HRR peak may be reduced or eliminated. Table 17–3 provides the peak and averaged HRR at 1-, 3-, and 5-min periods for various wood species.

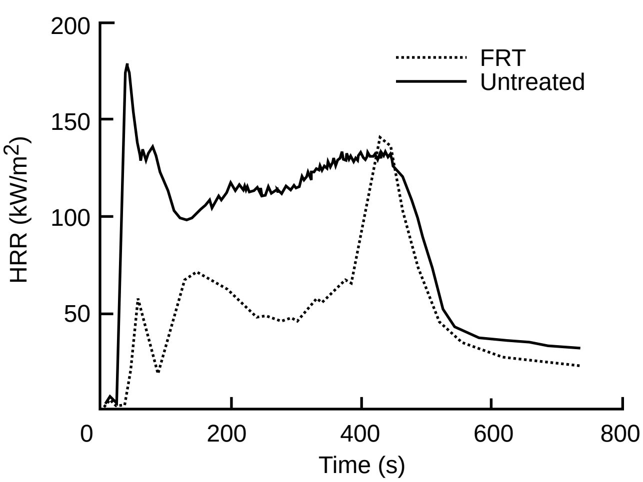

Figure 17–1. Heat release curves for untreated and FRT plywood exposed to 50-kW/m^2 radiance.

Heat release rate depends upon the intensity of the imposed heat flux. Table 17–2 provides the average effective heat of combustion and average HRR for four wood species and two levels of heat flux (18 and 55 kW/m^2). These results were obtained in an OSU apparatus modified by the Forest Products Laboratory (FPL). Similar values were also obtained in the cone calorimeter (Table 17–3). Generally, the averaged effective heat of combustion is about 65% of the oxygen bomb heat of combustion (higher heating value) with a small linear increase with irradiance. The HRR itself has a large linear increase with the heat flux. Data indicate that HRRs decrease with increasing moisture content of the sample and are markedly reduced by fire-retardant treatment (Fig. 17–1).

Flame Spread

The spread of flames over solids is a very important phenomenon in the growth of compartment fires. Indeed, in fires where large fuel surfaces are involved, the increase in HRR with time is primarily due to the increase in burning area. Many data have been acquired with the flame spread tests used in building codes. Table 17–1 lists the FSI and smoke index of ASTM E84 for solid wood. Some consistencies in the FSI behavior of the hardwood species can be related to their density. Considerable variations are found for wood-based composites; for example, the FSI of four structural flakeboards ranged from 71 to 189.

As a prescriptive regulation, the ASTM E84 tunnel test is a success in the reduction of fire hazards but is impractical in providing scientific data for fire modeling or in useful bench-scale tests for product development. Other full-scale tests (such as the ISO 9705 room/corner test) also use both an ignition burner and the ensuing flame spread to assist flow but can produce quite different results because of the size of the ignition burner or the test geometry. This is the case with foam plastic panels that melt and drip during a fire test. In the tunnel test, with the test material on top, a material that melts can have low flammability since the specimen does not stay in place. With an adequate burner in the room/corner test, the same material will exhibit very high flammability.

A flame spreads over a solid material when part of the fuel, ahead of the pyrolysis front, is heated to the critical condition of ignition. The rate of flame spread is controlled by how rapidly the fuel reaches the ignition temperature in response to heating by the flame front and external sources. The material's thermal conductivity, heat capacitance, thickness, and blackbody surface reflectivity influence the material's thermal response, and an increase in the values of these properties corresponds to a decrease in flame spread rate. On the other hand, an increase in values of the flame features, such as the imposed surface fluxes and spatial lengths, corresponds to a increase in the flame spread rate.

Table 17–3. Heat release data for selected wood species[a]

Species	Density[b] (kg/m^3)	Heat release rate (kW/m^2) Peak	60-s avg	180-s avg	300-s avg	Average effective heat of combustion[c] (MJ/kg)	Ignition time (s)
Softwoods							
Pine, red	525	209	163	143	132	12.9	24
Pine, white	359	209	150	117	103	13.6	17
Redcedar, eastern	—	175	92	95	85	11.7	25
Redwood	408	227	118	105	95	13.2	17
Hardwoods							
Birch	618	218	117	150	141	12.2	29
Maple, hard	626	218	128	146	137	11.7	31
Oak, red	593	214	115	140	129	11.4	28

[a]Data for 50-kW/m^2 heat flux in cone calorimeter. Tested in specimen holder without retaining frame. Specimens conditioned to 23°C, 50% relative humidity.
[b]Ovendry mass and volume.
[c]Tests terminated when average mass loss rate dropped below 1.5 g/s m^2 during 1-min period.

Flame spread occurs in different configurations, which are organized by orientation of the fuel and direction of the main flow of gases relative to that of flame spread. Downward and lateral creeping flame spread involves a fuel orientation with buoyantly heated air flowing opposite of the flame spread direction. Related bench-scale test methods are ASTM E162 for downward flame spread, ASTM E648 for horizontal flame spread to the critical flux level, and ASTM E1321 (LIFT apparatus) for lateral flame spread on vertical specimen to the critical flux level. The heat transfer from the flame to the virgin fuel is primarily conductive within a spatial extent of a few millimeters and is affected by ambient conditions such as oxygen, pressure, buoyancy, and external irradiance. For most wood materials, this heat transfer from the flame is less than or equal to surface radiant heat loss in normal ambient conditions, so that excess heat is not available to further raise the virgin fuel temperature; flame spread is prevented as a result. Therefore, to achieve creeping flame spread, an external heat source is required in the vicinity of the pyrolysis front.

Upward or ceiling flame spread involves a fuel orientation with the main air flowing in the same direction as the flame spread (assisting flow). At present, there are no small-scale tests for upward flame spread potential. Thus, testing of flame spread in assisting flow exists mostly in both the tunnel tests and the room/corner burn tests. The heat transfer from the flame is both conductive and radiative, has a large spatial feature, and is relatively unaffected by ambient conditions. Rapid acceleration in flame spread can develop because of a large, increasing magnitude of flame heat transfer as a result of increasing total HRR in assisting flows. These complexities and the importance of the flame spread processes explain the many and often incompatible flame spread tests and models in existence worldwide.

Smoke and Toxic Gases

One of the most important problems associated with fires is the smoke they produce. The term smoke is frequently used in an all-inclusive sense to mean the mixture of pyrolysis products and air that is present near the fire site. In this context, smoke contains gases, solid particles, and droplets of liquid. Smoke presents potential hazards because it interacts with light to obscure vision and because it contains noxious and toxic substances.

Generally, two approaches are used to deal with the smoke problem: limit smoke production and control the smoke that has been produced. The control of smoke flow is most often a factor in the design and construction of large or tall buildings. In these buildings, combustion products may have serious effects in areas remote from the actual fire site.

Currently, several bench-scale test methods provide comparative smoke yield information on materials and assemblies. Each method has entirely different exposure conditions; none is generally correlated to full-scale fire conditions or experience. Until the middle 1970s, smoke yield restrictions in building codes were almost always based on data from ASTM E84. The smoke measurement is based on a percentage attenuation of white light passing through the tunnel exhaust stream and detected by a photocell. This is converted to the smoke development index (SDI), with red oak flooring set at 100. The flame spread requirements for interior finish generally are linked to an added requirement that the SDI be less than 450.

In the 1970s, the apparatus known as the NBS smoke chamber was developed and approved as an ASTM standard for research and development (ASTM E662). This test is a static smoke test because the specimen is tested in a closed chamber of fixed volume and the light attenuation is recorded over a known optical path length. The corresponding light transmission is reported as specific optical density as a function of time. Samples are normally tested in both flaming (pilot flame) and nonflaming conditions using a radiant flux of 25 kW/m^2.

The dynamic measurement of smoke in the heat release calorimeter (ASTM E906 and E1354) has recently gained increasing recognition and use. The E906 and E1354 tests are dynamic in that the smoke continuously flows out the exhaust pipe where the optical density is measured continuously. The appropriate smoke parameter is the smoke release rate (SRR), which is the optical density multiplied by the volume flow rate of air into the exhaust pipe and divided by the product of exposed surface area of the specimen and the light path length. Often the smoke extinction area, which is the product of SRR and the specimen area, is preferred because it can be correlated linearly with HRR in many cases. This also permits comparison with the smoke measured in the room/corner fire test because HRR is a readily available test result. Although SRR can be integrated with time to get the same units as the specific optical density, they are not equivalent because static tests involve the direct accumulation of smoke in a volume, whereas SRR involves accumulation of freshly entrained air volume flow for each unit of smoke. Methods investigated to correlate smoke between different tests included alternative parameters such as particulate mass emitted per area of exposed sample.

Toxicity of combustion products is an area of concern. About 75% to 80% of fire victims are not touched by flame but die as a result of exposure to smoke, exposure to toxic gases, or oxygen depletion. These life-threatening conditions can result from burning contents, such as furnishings, as well as from the structural materials involved. The toxicity resulting from the thermal decomposition of wood and cellulosic substances is complex because of the wide variety of types of wood smoke. The composition and the concentration of the individual constituents depend on such factors as the fire exposure, the oxygen and moisture present, the species of wood, any treatments or finishes that may have been applied, and other considerations. Toxicity data may be more widely available in the future with the recent adoption of a standard test method (ASTM E1678).

Carbon monoxide is a particularly insidious toxic gas. Small amounts of carbon monoxide are particularly toxic because the hemoglobin in the blood is much more likely to combine with carbon monoxide than with oxygen, even with plenty of breathable oxygen. This poisoning is called carboxyhemoglobin. Recent research has shown that the kind of fires that kill people by toxicity are principally those that reach flashover in a compartment or room some distance from the people. The vast majority of fires that attain flashover generate dangerous levels of carbon monoxide, independent of what is burning. The supertoxicants, such as hydrogen cyanide and neurotoxin, have been proven to be extremely rare, even in the laboratory. These factors impact the choice of test furnace and the adjustment methods used in a standardized toxicity test.

Charring and Fire Resistance

As noted earlier in this chapter, wood exposed to high temperatures will decompose to provide an insulating layer of char that retards further degradation of the wood. The load-carrying capacity of a structural wood member depends upon its cross-sectional dimensions. Thus, the amount of charring of the cross section is the major factor in the fire endurance of structural wood members.

When wood is first exposed to fire, the wood chars and eventually flames. Ignition occurs in about 2 min under the standard ASTM E119 fire-test exposures. Charring into the depth of the wood then proceeds at a rate of approximately 0.8 mm/min for the next 8 min (or 1.25 min/mm). Thereafter, the char layer has an insulating effect, and the rate decreases to 0.6 mm/min (1.6 min/mm). Considering the initial ignition delay, the fast initial charring, and then the slowing down to a constant rate, the average constant charring rate is about 0.6 mm/min (or 1.5 in/h) (Douglas-fir, 7% moisture content). In the standard fire-resistance test, this linear charring rate is generally assumed for solid wood directly exposed to fire.

There are differences among species associated with their density, anatomy, chemical composition, and permeability. Moisture content is a major factor affecting charring rate. Density relates to the mass needed to be degraded and the thermal properties, which are affected by anatomical features. Charring in the longitudinal grain direction is reportedly double that in the transverse direction, and chemical composition affects the relative thickness of the char layer. Permeability affects the movement of moisture being driven from the wood or that being driven into the wood beneath the char layer. Normally, a simple linear model for charring where t is time (min), C is char rate (min/mm), and x_c is char depth (mm) is assumed:

$$t = Cx_c \qquad (17\text{–}1)$$

The temperature at the base of the char layer is generally taken to be 300°C or 550°F (288°C). With this temperature criterion, empirical equations for charring rate have been developed. Equations relating charring rate under ASTM E119 fire exposure to density and moisture content are available for Douglas-Fir, Southern Pine, and White Oak. These equations for rates transverse to the grain are

$$C = (0.002269 + 0.00457\mu)\rho + 0.331 \text{ for Douglas Fir} \qquad (17\text{–}2a)$$

$$C = (0.000461 + 0.00095\mu)\rho + 1.016 \text{ for Southern Pine} \qquad (17\text{–}2b)$$

$$C = (0.001583 + 0.00318\mu)\rho + 0.594 \text{ for White Oak} \qquad (17\text{–}2c)$$

where μ is moisture content (fraction of ovendry mass) and ρ is density, dry mass volume at moisture content μ (kg/m^3).

Table 17–4. Charring rate data for selected wood species

Species	Density[c] (kg/m^3)	Wood exposed to ASTM E119 exposure[a]: Char contraction factor[d]	Linear charring rate[e] (min/mm)	Nonlinear charring rate[f] (min/mm$^{1.23}$)	Thermal penetration depth[g] (mm)	Wood exposed to a constant heat flux[b]: Linear charring rate[e] (min/mm): 18-kW/m^2 heat flux	55-kW/m^2 heat flux	Thermal penetration depth d[g] (mm): 18-kW/m^2 heat flux	55-kW/m^2 heat flux	Average mass loss rate (g/m^2 s): 18-kW/m^2 heat flux	55-kW/m^2 heat flux
Softwoods											
Southern Pine	509	0.60	1.24	0.56	33	2.27	1.17	38	26.5	3.8	8.6
Western redcedar	310	0.83	1.22	0.56	33	—	—	—	—	—	—
Redwood	343	0.86	1.28	0.58	35	1.68	0.98	36.5	24.9	2.9	6.0
Engelmann spruce	425	0.82	1.56	0.70	34	—	—	—	—	—	—
Hardwoods											
Basswood	399	0.52	1.06	0.48	32	1.32	0.76	38.2	22.1	4.5	9.3
Maple, hard	691	0.59	1.46	0.66	31	—	—	—	—	—	—
Oak, red	664	0.70	1.59	0.72	32	2.56	1.38	27.7	27.0	4.1	9.6
Yellow-poplar	504	0.67	1.36	0.61	32	—	—	—	—	—	—

[a]Moisture contents of 8% to 9%.
[b]Charring rate and average mass loss rate obtained using ASTM E906 heat release apparatus. Test durations were 50 to 98 min for 18-kW/m^2 heat flux and 30 to 53 min for 55-kW/m^2 heat flux. Charring rate based on temperature criterion of 300°C and linear model. Mass loss rate based on initial and final weight of sample, which includes moisture driven from the wood. Initial average moisture content of 8% to 9%.
[c]Based on weight and volume of ovendried wood.
[d]Thickness of char layer at end of fire exposure divided by original thickness of charred wood layer (char depth).
[e]Based on temperature criterion of 288°C and linear model.
[f]Based on temperature criterion of 288°C and nonlinear model of Equation (17–3).
[g]As defined in Equation (17–6). Not sensitive to moisture content.

A nonlinear char rate model has been found useful. This alternative model is

$$t = m x_c^{1.23} \qquad (17\text{–}3)$$

where m is char rate coefficient (min/mm$^{1.23}$).

Based on data from eight species (Table 17–4), the following equation was developed for the char rate coefficient:

$$m = -0.147 + 0.000564\rho + 1.21\mu + 0.532 f_c \qquad (17\text{–}4)$$

where ρ is density, ovendry mass and volume, and f_c is char contraction factor (dimensionless).

The char contraction factor is the thickness of the residual char layer divided by the original thickness of the wood layer that was charred (char depth). Average values for the eight species tested in the development of the equation are listed in Table 17–4.

These equations and data are valid when the member is thick enough to be a semi-infinite slab. For smaller dimensions, the charring rate increases once the temperature has risen above the initial temperature at the center of the member or at the unexposed surface of the panel. As a beam or column chars, the corners become rounded.

Charring rate is also affected by the severity of the fire exposure. Data on charring rates for fire exposures other than ASTM E119 have been limited. Data for exposure to constant temperatures of 538°C, 815°C, and 927°C are available in Schaffer (1967). Data for a constant heat flux are given in Table 17–4.

The temperature at the innermost zone of the char layer is assumed to be 300°C. Because of the low thermal conductivity of wood, the temperature 6 mm inward from the base of the char layer is about 180°C. This steep temperature gradient means the remaining uncharred cross-sectional area of a large wood member remains at a low temperature and can continue to carry a load. Moisture is driven into the wood as charring progresses. A moisture content peak is created inward from the char base. The peak moisture content occurs where the temperature of the wood is about 100°C, which is at about 13 mm from the char base.

Once a quasi-steady-state charring rate has been obtained, the temperature profile beneath the char layer can be expressed as an exponential term or a power term. An equation based on a power term is

$$T = T_i + (300 - T_i)(1 - x/d)^2 \qquad (17\text{–}5)$$

where T is temperature (°C), T_i initial temperature (°C), x distance from the char front (mm), and d thermal penetration depth (mm).

In Table 17–4, values for the thermal penetration depth parameter are listed for both the standard fire exposure and the constant heat flux exposure. As with the charring rate, these temperature profiles assume a semi-infinite slab. The equation does not provide for the plateau in temperatures that often occurs at 100°C in moist wood. In addition to these empirical data, there are mechanistic models for estimating the charring rate and temperature profiles. The temperature profile within the remaining wood cross-section can be used with other data to estimate the remaining load-carrying capacity of the uncharred wood during a fire and the residual capacity after a fire.

Flame-Retardant Treatments

To meet building code and standards specifications, lumber and plywood are treated with flame retardants to improve their fire performance. The two general application methods are pressure treating and surface coating.

Fire-Retardant-Treated Wood

To meet the specifications in the building codes and various standards, fire-retardant-treated lumber and plywood is wood that has been pressure treated with chemicals to reduce its flame spread characteristics. Flame-retardant treatment of wood generally improves the fire performance by reducing the amount of flammable volatiles released during fire exposure or by reducing the effective heat of combustion, or both. Both results have the effect of reducing the HRR, particularly during the initial stages of fire, and thus consequently reducing the rate of flame spread over the surface. The wood may then self-extinguish when the primary heat source is removed.

The performance requirement for fire-retardant-treated wood is that its FSI is 25 or less when tested according to the ASTM E84 flame spread test and that it shows no evidence of significant progressive combustion when this 10-min test is continued for an additional 20 min. In addition, it is required that the flame front in the test shall not progress more than 3.2 m beyond the centerline of the burner at any given time during the test. Underwriters Laboratories, Inc., assigns the designation FR–S to products that satisfy these requirements. In applications where the requirement is not for fire-retardant-treated wood but only for Class I or II flame spread, the flame-retardant treatments only need to reduce the FSI to the required level in the ASTM E84 flame spread test (25 for Class I, 75 for Class II). Various laboratories perform fire-performance rating tests on these treated materials and maintain lists of products that meet certain standards.

Fire-retardant-treated wood and plywood are often used for interior finish and trim in rooms, auditoriums, and corridors where codes require materials with low surface flammability. While fire-retardant-treated wood is not considered a noncombustible material, many codes have accepted the use of fire-retardant-treated wood and plywood in fire-resistive and noncombustible construction for the framing of nonload-bearing walls, roof assemblies, and decking. Fire-retardant-treated wood is also used for such special purposes as wood scaffolding and for the frame, rails, and stiles of wood fire doors.

In addition to specifications for flame spread performance, fire-retardant-treated wood for use in certain applications is specified to meet other performance requirements. Wood treated with inorganic flame-retardant salts is usually more hygroscopic than is untreated wood, particularly at high relative humidities. Increases in equilibrium moisture content of this treated wood will depend upon the type of chemical, level of chemical retention, and size and species of wood involved. Applications that involve high humidity will likely require wood with low hygroscopicity. The American Wood Preservers' Association (AWPA) Standards C20 and C27 requirements for low hygroscopicity (Interior Type A treatment) stipulate that the material shall have an equilibrium moisture content of not more than 28% when tested in accordance with ASTM D3201 procedures at 92% relative humidity.

Exterior flame-retardant treatments should be specified whenever the wood is exposed to exterior weathering conditions. The AWPA Standards C20 and C27 also mandate that an exterior type treatment is one that has shown no increase in fire hazard classification after being subjected to the rain test specified in ASTM D2898 as Method A.

For structural applications, information on the fire-retardant-treated wood product needs to be obtained from the treater or chemical supplier. This includes the design modification factors for initial strength properties of the fire-retardant-treated wood, including values for the fasteners. Flame-retardant treatment generally results in reductions in the mechanical properties of wood. Fire-retardant-treated wood is often more brash than untreated wood.

In field applications with elevated temperatures, such as roof sheathings, there is the potential for further losses in strength with time. For such applications in elevated temperatures and high humidity, appropriate design modification factors need to be obtained from the treater or chemical supplier. The AWPA Standards C20 and C27 mandate that fire-retardant-treated wood that will be used in high-temperature applications (Interior Type A High Temperature), such as roof framing and roof sheathing, be strength tested in accordance with ASTM D5664 (lumber) or ASTM D5516 (plywood) or by an equivalent methodology. Some flame-retardant treatments are not acceptable because of thermal degradation of the wood that will occur with time at high temperatures. Screw-withdrawal tests to predict residual in-place strength of fire-retardant-treated plywood roof sheathing have been developed (Winandy and others 1998).

Corrosion of fasteners can be accelerated under conditions of high humidity and in the presence of flame-retardant salts.

For flame-retardant treatments containing inorganic salts, the type of metal and chemical in contact with each other greatly affects the rate of corrosion. Thus, information on proper fasteners also needs to be obtained from the treater or chemical supplier. Other issues that may require contacting the treater or chemical supplier include machinability, gluing characteristics, and paintability.

Flame-retardant treatment of wood does not prevent the wood from decomposing and charring under fire exposure (the rate of fire penetration through treated wood approximates the rate through untreated wood). Fire-retardant-treated wood used in doors and walls can slightly improve fire endurance of these doors and walls. Most of this improvement is associated with the reduction in surface flammability rather than any changes in charring rates.

Flame-Retardant Pressure Treatments

In the impregnation treatments, wood is pressure impregnated with chemical solutions using pressure processes similar to those used for chemical preservative treatments. However, considerably heavier absorptions of chemicals are necessary for flame-retardant protection. Standards C20 and C27 of the AWPA recommend the treating conditions for lumber and plywood. The penetration of the chemicals into the wood depends on the species, wood structure, and moisture content. Since some species are difficult to treat, the degree of impregnation needed to meet the performance requirements for fire-retardant-treated wood may not be possible. One option is to incise the wood prior to treatment to improve the depth of penetration.

Inorganic salts are the most commonly used flame retardants for interior wood products, and their characteristics have been known for more than 50 years. These salts include monoammonium and diammonium phosphate, ammonium sulfate, zinc chloride, sodium tetraborate, and boric acid. Guanylurea phosphate is also used. These chemicals are combined in formulations to develop optimum fire performance yet still retain acceptable hygroscopicity, strength, corrosivity, machinability, surface appearance, glueability, and paintability. Cost is also a factor in these formulations. Many commercial formulations are available. The AWPA Standard P17 provides information on formulations of some current proprietary waterborne treatments. The fire-retardant salts are water soluble and are leached out in exterior applications or with repeated washings. Water-insoluble organic flame retardants have been developed to meet the need for leach-resistant systems. Such treatments are also an alternative when a low hygroscopic treatment is needed. These water-insoluble systems include (a) resins polymerized after impregnation into wood and (b) graft polymer flame retardants attached directly to cellulose. An amino resin system based on urea, melamine, dicyandiamide, and related compounds is of the first type.

Flame-Retardant Coatings

For some applications, the alternative method of applying the flame-retardant chemical as a coating to the wood surface may be acceptable. Such commercial coating products are available to reduce the surface flammability characteristics of wood. The two types of coatings are intumescent and nonintumescent. The widely used intumescent coatings “intumesce” to form an expanded low-density film upon exposure to fire. This multicellular carbonaceous film insulates the wood surface below from the high temperatures. Intumescent formulations include a dehydrating agent, a char former, and a blowing agent. Potential dehydrating agents include polyammonium phosphate. Ingredients for the char former include starch, glucose, and dipentaerythritol. Potential blowing agents for the intumescent coatings include urea, melamine, and chlorinate parafins. Nonintumescent coating products include formulations of the water-soluble salts such as diammonium phosphate, ammonium sulfate, and borax.

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Chapter 18

Round Timbers and Ties

Ronald W. Wolfe

Contents

Round timbers and ties represent some of the most efficient uses of our forest resources. They require a minimum of processing between harvesting the tree and marketing the structural commodity. Poles and piles are debarked or peeled, seasoned, and often treated with preservative prior to use as structural members. Construction logs are usually shaped to facilitate construction. Ties, used for railroads, landscaping, and mining, are slab-cut to provide flat surfaces. Because these products are relatively economical to produce, compared with glulam, steel, and concrete products, they are commonly used throughout the United States.

Standards and Specifications

Material standards and specifications listed in Table 18–1 were created through the joint efforts of producers and users to ensure compatibility between product quality and end use. These guidelines include recommendations for production, treatment, and engineering design. They are updated periodically to conform to changes in material and design technology.

Material Requirements

Round timber and tie material requirements vary with intended use. The majority of uses involve exposure to harsh environments. Thus, in addition to availability, form, and weight, durability is also an important consideration for the use of round timbers and ties. Availability reflects the economic feasibility of procuring members of the required size and grade. Form or physical appearance refers to visual characteristics, such as straightness and occurrence of knots and spiral grain. Weight affects shipping and handling costs and is a function of volume, moisture content, and wood density. Durability is directly related to expected service life and is a function of treatability and natural decay resistance. Finally, regardless of the application, any structural member must be strong enough to resist imposed loads with a reasonable factor of safety. Material specifications available for most applications of round timbers and ties contain guidelines for evaluating these factors.

Table 18–1. Standards and specifications for round timbers and ties[a]

Product	Material requirements	Preservative treatment	Engineering design stresses	
			Procedures	Design values
Utility poles	ANSI O5.1	TT-W-571 AWPA C1,C4,C35	—	ANSI O5.1
Construction poles	ANSI O5.1	TT-W-571 AWPA C23	ASTM D3200	ASAE EP 388
Piles	ASTM D25	TT-W-571 AWPA CI,C3	ASTM D2899	NDS
Construction logs	(See material supplier)	—	ASTM D3957	(See material supplier)
Ties	AREA	TT-W-571 AWPA C2,C6 AREA	—	AREA

[a]ANSI, American National Standards Institute; ASTM, American Society for Testing and Materials; ASAE, American Society of Agricultural Engineers; AREA, American Railway Engineers Association; NDS, National Design Specification (for Wood Construction); AWPA, American Wood-Preservers' Association.

Availability

Material evaluation begins with an assessment of availability. For some applications, local species of timber may be readily available in an acceptable form and quality. However, this is not normally the case. Pole producers and tie mills are scattered throughout heavily forested regions. Their products are shipped to users throughout North America.

Poles

Most structural applications of poles require timbers that are relatively straight and free of large knots. Poles used to support electric utility distribution and transmission lines (Fig. 18–1) range in length from 6 to 38 m (20 to 125 ft) and from 0.13 to 0.76 m (5 to 30 in.) in diameter, 1.8 m (6 ft) from the butt. Poles used to support local area distribution lines are normally <15 m (<50 ft) long and are predominately Southern Pine.

Hardwood species can be used for poles when the trees are of suitable size and form; their use is limited, however, by their weight, by their excessive checking, and because of the lack of experience in preservative treatment of hardwoods. Thus, most poles are softwoods.

The Southern Pine lumber group (principally loblolly, longleaf, shortleaf, and slash) accounts for roughly 80% of poles treated in the United States. Three traits of these pines account for their extensive use: thick and easily treated sapwood, favorable strength properties and form, and availability in popular pole sizes. In longer lengths, Southern Pine poles are in limited supply, so Douglas-fir, and to some extent western redcedar, Ponderosa pine, and western larch, are used to meet requirements for 15-m (50-ft) and longer transmission poles.

Douglas-fir is used throughout the United States for transmission poles and is used in the Pacific Coast region for distribution and building poles. Because the heartwood of Douglas-fir is resistant to preservative penetration and has limited decay and termite resistance, serviceable poles need a well-treated shell of sapwood that is free of checking. To minimize checking after treatment, poles should be adequately seasoned or conditioned before treatment. With these precautions, the poles should compare favorably with treated Southern Pine poles in serviceability.

A small percentage of the poles treated in the United States are of western redcedar, produced mostly in British Columbia. The number of poles of this species used without treatment is not known but is considered to be small. Used primarily for utility lines in northern and western United States, well-treated redcedar poles have a service life that compares favorably with poles made from other species and could be used effectively in pole-type buildings.

Lodgepole pine is also used in small quantities for treated poles. This species is used both for utility lines and for pole-type buildings. It has a good service record when well treated. Special attention is necessary, however, to obtain poles with sufficient sapwood thickness to ensure adequate penetration of preservative, because the heartwood is not usually penetrated and is not decay resistant. The poles must also be well seasoned prior to treatment to avoid checking and exposure of unpenetrated heartwood to attack by decay fungi.

Western larch poles produced in Montana and Idaho came into use after World War II because of their favorable size, shape, and strength properties. Western larch requires preservative treatment full length for use in most areas and, as in the case of lodgepole pine poles, must be selected for adequate sapwood thickness and must be well seasoned prior to treatment. Other species occasionally used for poles are listed in the American National Standards Institute (ANSI) O5.1 standard. These minor species make up a very small portion of pole production and are used locally.

Figure 18–1. Round timber poles form the major structural element in these transmission structures. (Photo courtesy of Koppers Co.)

Glued-laminated, or glulam, poles are also available for use where special sizes or shapes are required. The ANSI Standard O5.2 provides guidelines for specifying these poles.

Piles

Material available for timber piles is more restricted than that for poles. Most timber piles used in the eastern half of the United States are Southern Pine, while those used in western United States are coast Douglas-fir. Oak, red pine, and cedar piles are also referenced in timber pile literature but are not as widely used as Southern Pine and Douglas-fir.

Construction Logs

Round timbers have been used in a variety of structures, including bridges, log cabins, and pole buildings. Log stringer bridges (Fig. 18–2) are generally designed for a limited life on logging roads intended to provide access to remote areas. In Alaska where logs may exceed 1 m (3 ft) in diameter, bridge spans may exceed 9 m (30 ft). Building poles, on the other hand, are preservative-treated logs in the 0.15- to 0.25-m- (6- to 10-in.-) diameter range. These poles rarely exceed 9 m (30 ft) in length. Although poles sold for this application are predominately Southern Pine, there is potential for competition from local species in this category. Finally, log cabin logs normally range from 0.2 to 0.25 m (8 to 10 in.) in diameter, and the availability of logs in this size range is not often a problem. However, because logs are not normally preservative treated for this application, those species that offer moderate to high natural decay resistance, such as western redcedar, are preferred. Pole buildings, which incorporate round timbers as vertical columns and cantilever supports, require preservative-treated wood. Preservative-treated poles for this use may not be readily available.

Ties

The most important availability consideration for railroad cross ties is quantity. Ties are produced from most native species of timber that yield log lengths >2.4 m (8 ft) with diameters >0.18 m (7 in.). The American Railway Engineering Association (AREA) lists 26 U.S. species that may be used for ties. Thus, the tie market provides a use for many low-grade hardwood and softwood logs.

Form

Natural growth properties of trees play an important role in their use as structural round timbers. Three important form considerations are cross-sectional dimensions, straightness, and the presence of surface characteristics such as knots.

Poles and Piles

Standards for poles and piles have been written with the assumption that trees have a round cross section with a circumference that decreases linearly with height. Thus, the shape of a pole or pile is often assumed to be that of the frustum of a cone. Actual measurements of tree shape indicate that taper is rarely linear and often varies with location along the height of the tree. Average taper values from the ANSI O5.1 standard are shown in Table 18–2 for the more popular pole species. Guidelines to account for the effect of taper on the location of the critical section above the groundline are given in ANSI O5.1. The standard also tabulates pole dimensions for up to 15 size classes of 11 major pole species.

Taper also affects construction detailing of pole buildings. Where siding or other exterior covering is applied, poles are generally set with the taper to the interior side of the structures to provide a vertical exterior surface (Fig. 18–3). Another common practice is to modify the round poles by slabbing to provide a continuous flat face. The slabbed face permits more secure attachment of sheathing and framing members and facilitates the alignment and setting of intermediate wall and corner poles. The slabbing consists of a minimum cut to provide a single continuous flat face from the groundline to the top of intermediate wall poles and two continuous flat faces at right angles to one another from the groundline to the top of corner poles. However, preservative

Figure 18–2. Logs are used to construct logging bridges in remote forest areas.

Table 18–2. Circumference taper

Species	Centimeter change in circum-ference per meter	Inch change in circum-ference per foot[a]
Western redcedar	3.7	0.38
Ponderosa pine	2.4	0.29
Jack, lodgepole, and red pine	2.5	0.30
Southern Pine	2.1	0.25
Douglas-fir, larch	1.7	0.21
Western hemlock	1.7	0.20

[a]Taken from ANSI O5.1.

penetration is generally limited to the sapwood of most species; therefore slabbing, particularly in the groundline area of poles with thin sapwood, may result in somewhat less protection than that of an unslabbed pole. All cutting and sawing should be confined to that portion of the pole above the groundline and should be performed before treatment.

The American Standards for Testing and Materials (ASTM) D25 standard provides tables of pile sizes for either friction piles or end-bearing piles. Friction piles rely on skin friction rather than tip area for support, whereas end-bearing piles resist compressive force at the tip. For this reason, a friction pile is specified by butt circumference and may have a smaller tip than an end-bearing pile. Conversely, end-bearing piles are specified by tip area and butt circumference is minimized.

Straightness of poles or piles is determined by two form properties: sweep and crook. Sweep is a measure of bow or gradual deviation from a straight line joining the ends of the pole or pile. Crook is an abrupt change in direction of the centroidal axis. Limits on these two properties are specified in both ANSI O5.1 and ASTM D25.

Construction Logs

Logs used in construction are generally specified to meet the same criteria for straightness and knots as poles and piles (ASTM D25). For log stringer bridges, the log selection criteria may vary with the experience of the person doing the selection but straightness, spiral grain, wind shake, and knots are limiting criteria. Although no consensus standard

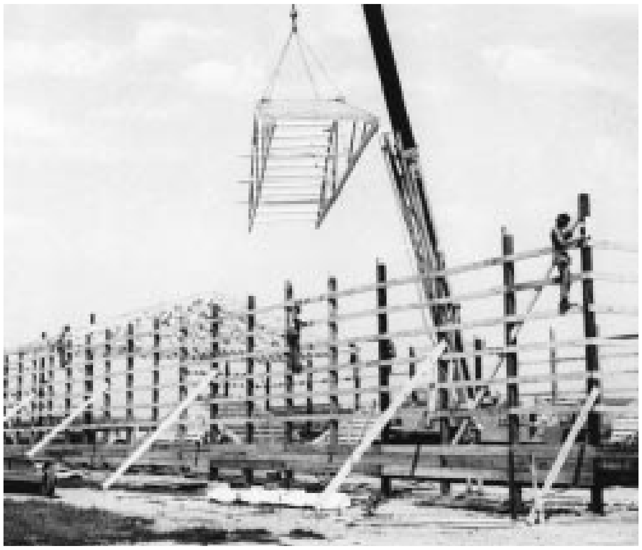

Figure 18–3. Poles provide economical foundation and wall systems for agricultural and storage buildings.

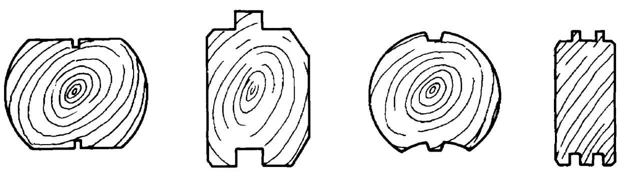

Figure 18–4. Construction logs can be formed in a variety of shapes for log homes. Vertical surfaces may be varied for aesthetic purposes, while the horizontal surfaces generally reflect structural and thermal considerations.

is available for specifying and designing log stringers, the *Design Guide for Native Log Stringer Bridges* was prepared by the USDA Forest Service.

Logs used for log cabins come in a wide variety of cross-sectional shapes (Fig. 18–4). Commercial cabin logs are usually milled so that their shape is uniform along their length. The ASTM D3957 standard, a guide for establishing stress grades for building logs, recommends stress grading on the basis of the largest rectangular section that can be inscribed totally within the log section. The standard also provides commentary on the effects of knots and slope of grain.

Ties

Railroad ties are commonly shaped to a fairly uniform section along their length. The AREA publishes specifications for the sizes, which include seven size classes ranging from 0.13 by 0.13 m (5 by 5 in.) to 0.18 by 0.25 m (7 by 10 in.). These tie classes may be ordered in any of three standard lengths: 2.4 m (8 ft), 2.6 m (8.5 ft), or 2.7 m (9 ft).

Weight and Volume

The weight of any wood product is a function of its volume, density, moisture content, and any retained treatment substance. An accurate estimate of volume of a round pole would require numerous measurements of the circumference and shape along the length, because poles commonly exhibit neither a uniform linear taper nor a perfectly round shape. The American Wood Preservers' Association (AWPA) Standard F3 therefore recommends volume estimates be based on the assumption that the pole is shaped as the frustum of a cone (that is, a cone with the top cut perpendicular to the axis), with adjustments dependent on species. The volume in this case is determined as the average cross-sectional area A times the length. Estimates of average cross-sectional area may be obtained either by measuring the circumference at mid-length ($A = C_m^2/4\pi$) or taking the average of the butt and tip diameters ($A = \pi(D + d)^2/16$) to estimate the area of a circle. The AWPA recommends that these estimates then be adjusted by the following correction factors for the given species and application:

Oak piles	0.82
Southern Pine piles	0.93
Southern Pine and red pine poles	0.95

Tables for round timber volume are given in AWPA Standard F3. The volume of a round timber differs little whether it is green or dry. Drying of round timbers causes checks to open, but there is little reduction of the gross diameter of the pole.

Wood density also differs with species, age, and growing conditions. It will even vary along the height of a single tree. Average values, tabulated by species, are normally expressed as specific gravity (SG), which is density expressed as a ratio of the density of water (see Ch. 4). For commercial species grown in the United States, SG varies from 0.32 to 0.65. If you know the green volume of a round timber and its SG, its dry weight is a product of its SG, its volume, and the unit weight of water (1000 kg/m^3 (62.4 lb/ft^3)). Wood moisture content can also be highly variable. A pole cut in the spring when sap is flowing may have a moisture content exceeding 100% (the weight of the water it contains may exceed the weight of the dry wood substance). If you know the moisture content (MC) of the timber, multiply the dry weight by (1 + MC/100) to get the wet weight.

Finally, in estimating the weight of a treated wood product such as a pole, pile, or tie, you must take into account the weight of the preservative. Recommended preservative retentions are listed in Table 14–3 in Chapter 14. By knowing the volume, the preservative weight can be approximated by multiplying volume by the recommended preservative retention.

Durability

For most applications of round timbers and ties, durability is primarily a question of decay resistance. Some species are noted for their natural decay resistance; however, even these may require preservative treatment, depending upon the environmental conditions under which the material is used and the required service life. For some applications, natural decay resistance is sufficient. This is the case for temporary piles, marine piles in fresh water entirely below the permanent water level, and construction logs used in building construction. Any wood members used in ground contact should be pressure treated, and the first two or three logs above a concrete foundation should be brush treated with a preservative–sealer.

Preservative Treatment

Federal Specification TT–W–571 (U.S. Federal Supply Service (USFSS)) covers the inspection and treatment requirements for various wood products including poles, piles, and ties. This specification refers to the AWPA Standards C1 and C3 for pressure treatment, C2 and C6 for treatment of ties, C8 for full-length thermal (hot and cold) treatment of western redcedar poles, C10 for full-length thermal (hot and cold) treatment of lodgepole pine poles, and C23 for pressure treatment of construction poles. The AREA specifications for cross ties and switch ties also cover preservative treatment. Retention and types of various preservatives recommended for various applications are given in Table 14–3.

Inspection and treatment of poles in service has been effective in prolonging the useful life of untreated poles and those with inadequate preservative penetration or retention. The Forest Research Laboratory at Oregon State University has published guidelines for developing an in-service pole maintenance program.

Service Life

Service conditions for round timbers and ties vary from mild for construction logs to severe for cross ties. Construction logs used in log homes may last indefinitely if kept dry and properly protected from insects. Most railroad ties, on the other hand, are continually in ground contact and are subject to mechanical damage.

Poles

The life of poles can vary within wide limits, depending upon properties of the pole, preservative treatments, service conditions, and maintenance practices. In distribution or transmission line supports, however, service life is often limited by obsolescence of the line rather than the physical life of the pole.

It is common to report the average life of untreated or treated poles based on observations over a period of years. These average life values are useful as a rough guide to the service life to be expected from a group of poles, but it should be kept in mind that, within a given group, 60% of the poles will have failed before reaching an age equal to the average life.

Early or premature failure of treated poles can generally be attributed to one or more of three factors: (a) poor penetration and distribution of preservative, (b) an inadequate retention of preservative, or (c) use of a substandard preservative. Properly treated poles can last 35 years or longer.

Western redcedar is one species with a naturally decay-resistant heartwood. If used without treatment, however, the average life is somewhat less than 20 years.

Piles

The expected life of a pile is also determined by treatment and use. Wood that remains completely submerged in water does not decay although bacteria may cause some degradation; therefore, decay resistance is not necessary in all piles, but it is necessary in any part of the pile that may extend above the permanent water level. When piles that support the foundations of bridges or buildings are to be cut off above the permanent water level, they should be treated to conform to recognized specifications such as Federal Specification TT-W-571 and AWPA Standards C1 and C3. The untreated surfaces exposed at the cutoffs should also be given protection by thoroughly brushing the cut surface with coal-tar creosote. A coat of pitch, asphalt, or similar material may then be applied over the creosote and a protective sheet material, such as metal, roofing felt, or saturated fabric, should be fitted over the pile cut-off in accordance with AWPA Standard M4. Correct application and maintenance of these materials are critical in maintaining the integrity of piles.

Piles driven into earth that is not constantly wet are subject to about the same service conditions as apply to poles but are generally required to last longer. Preservative retention requirements for piles are therefore greater than for poles (Table 14–3). Piles used in salt water are subject to destruction by marine borers even though they do not decay below the waterline. The most effective practical protection against marine borers has been a treatment first with a waterborne preservative, followed by seasoning with a creosote treatment. Other preservative treatments of marine piles are covered in Federal Specification TT–W–571 and AWPA Standard C3 (Table 14–3).

Ties

The life of ties in service depends on their ability to resist decay and mechanical destruction. Under sufficiently light traffic, heartwood ties of naturally durable wood, even if of low strength, may give 10 or 15 years of average service without preservative treatment; under heavy traffic without adequate mechanical protection, the same ties might fail in 2 or 3 years. Advances in preservatives and treatment processes, coupled with increasing loads, are shifting the primary cause of tie failure from decay to mechanical damage. Well-treated ties, properly designed to carry intended loads, should last from 25 to 40 years on average. Records on life of treated and untreated ties are occasionally published in the annual proceedings of the American Railway Engineering Association (AREA) and AWPA.

Strength Properties

Allowable strength properties of round timbers have been developed and published in several standards. In most cases, published values are based on strength of small clear test samples. Allowable stresses are derived by adjusting small clear values for effects of growth characteristics, conditioning, shape, and load conditions as discussed in applicable standards. In addition, published values for some species of poles and piles reflect results of full-sized tests.

Poles

Most poles are used as structural members in support structures for distribution and transmission lines. For this application, poles may be designed as single-member or guyed cantilevers or as structural members of a more complex structure. Specifications for wood poles used in single pole structures have been published by ANSI in Standard O5.1. Guidelines for the design of pole structures are given in the ANSI National Electric Safety Code (NESC) (ANSI C2).

The ANSI O5.1 standard gives values for fiber stress in bending for species commonly used as transmission or distribution poles. These values represent the near-ultimate fiber stress for poles used as cantilever beams. For most species, these values are based partly on full-sized pole tests and include adjustments for moisture content and pretreatment conditioning. The values in ANSI O5.1 are compatible with the ultimate strength design philosophy of the NESC, but they are not compatible with the working stress design philosophy of the *National Design Specification* (NDS).

Reliability-based design techniques have been developed for the design of distribution–transmission line systems. This approach requires a strong database on the performance of pole structures. Supporting information for these design procedures is available in a series of reports published by the Electric Power Research Institute (EPRI).

Piles

Bearing loads on piles are sustained by earth friction along their surface (skin friction), by bearing of the tip on a solid stratum, or by a combination of these two methods. Wood piles, because of their tapered form, are particularly efficient in supporting loads by skin friction. Bearing values that depend upon friction are related to the stability of the soil and generally do not approach the ultimate strength of the pile. Where wood piles sustain foundation loads by bearing of the tip on a solid stratum, loads may be limited by the compressive strength of the wood parallel to the grain. If a large proportion of the length of a pile extends above ground, its bearing value may be limited by its strength as a long column. Side loads may also be applied to piles extending above ground. In such instances, however, bracing is often used to reduce the unsupported column length or to resist the side loads.

The most critical loads on piles often occur during driving. Under hard driving conditions, piles that are too dry (<18% moisture content at a 51-mm (2-in.) depth) have literally exploded under the force of the driving hammers. Steel banding is recommended to increase resistance to splitting, and driving the piles into predrilled holes reduces driving stresses.

The reduction in strength of a wood column resulting from crooks, eccentric loading, or any other condition that will result in combined bending and compression is not as great as would be predicted with the NDS interaction equations. This does not imply that crooks and eccentricity should be without restriction, but it should relieve anxiety as to the influence of crooks, such as those found in piles. Design procedures for eccentrically loaded columns are given in Chapter 8.

There are several ways to determine bearing capacity of piles. Engineering formulas can estimate bearing values from the penetration under blows of known energy from the driving hammer. Some engineers prefer to estimate bearing capacity from experience or observation of the behavior of pile foundations under similar conditions or from the results of static-load tests.

Working stresses for piles are governed by building code requirements and by recommendations of ASTM D2899. This standard gives recommendations for adjusting small clear strength values listed in ASTM D2555 for use in the design of full-sized piles. In addition to adjustments for properties inherent to the full-sized pile, the ASTM D2899 standard also provides recommendations for adjusting allowable stresses for the effects of pretreatment conditioning.

Design stresses for timber piles are tabulated in the NDS for wood construction. The NDS values include adjustments for the effects of moisture content, load duration, and preservative treatment. Recommendations are also given to adjust for lateral support conditions and factors of safety.

Construction Logs

Design values for round timbers used as structural members in pole or log buildings may be determined following standards published by ASTM and ASAE. The ASTM standard refers pole designers to the same standard used to derive design stresses for timber piles (D2899). The ASAE standard (EP388), which governed the derivation of construction poles for agricultural building applications, is being revised.
The future revision will be designated EP560 and will deal only with round wood poles. Derivation of design stresses for construction logs used in log homes is covered in ASTM D3957, which provides a method of establishing stress grades for structural members of any of the more common log configurations. Manufacturers can use this standard to develop grading specifications and derive engineering design stresses for their construction logs.

Ties

Railroad cross and switch ties have historically been over-designed from the standpoint of rail loads. Tie service life was limited largely by deterioration rather than mechanical damage. However, because of advances in decay-inhibiting treatment and increased axle loads, adequate structural design is becoming more important in increasing railroad tie service life.

Rail loads induce stresses in bending and shear as well as in compression perpendicular to the grain in railroad ties. The AREA manual gives recommended limits on ballast bearing pressure and allowable stresses for cross ties. This information may be used by the designer to determine adequate tie size and spacing to avoid premature failure due to mechanical damage.

Specific gravity and compressive strength parallel to the grain are also important properties to consider in evaluating cross tie material. These properties indicate the resistance of the wood to both pull out and lateral thrust of spikes.

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Specialty Treatments

Roger M. Rowell

Contents

Many specialty treatments can be applied to wood to either improve its performance or change its properties. Treatments addressed in this chapter are those that make permanent changes in the shape of a wood product, improvements in dimensional stability, or improvements in performance through combinations with nonwood resources.

Plasticizing Wood

Principles of Plasticizing and Bending

In simple terms, the wood cell wall is a composite made of a rigid cellulose polymer in a matrix of lignin and the hemicelluloses. The lignin polymer in the middle lamella and S2 layer is thermoplastic; that is, it softens upon heating. The glass transition temperature T_g of the lignin in the matrix is approximately 170°C (338°F). Above the matrix T_g, it is possible to cause the lignin to undergo thermoplastic flow and, upon cooling, reset in the same or modified configuration. This is the principal behind bending of wood.

The matrix can be thermoplasticized by heat alone, but the T_g of the unmodified matrix is so high that some fiber decomposition can occur if high temperatures are maintained for a lengthy period. The T_g of the matrix can be decreased with the addition of moisture or through the use of plasticizers or softeners.

Heat and moisture make certain species of wood sufficiently plastic for bending operations. Steaming at atmospheric or a low gage pressure, soaking in boiling or nearly boiling water, or microwave heating moist wood are satisfactory methods of plasticizing wood. Wood at 20% to 25% moisture content needs to be heated without losing moisture; at a lower moisture content, heat and moisture must be added. As a consequence, the recommended plasticizing processes are steaming or boiling for about 15 min/cm (38 min/in) of thickness for wood at 20% to 25% moisture content and steaming or boiling for about 30 min/cm (75 min/in) of thickness for wood at lower moisture content levels. Steaming at high pressures causes wood to become plastic, but wood treated with high pressure steam generally does not bend as successfully as does wood treated at atmospheric or low pressure. Microwave heating requires much shorter times.

Wood can be plasticized by a variety of chemicals. Common chemicals that plasticize wood include water, urea, dimethylol urea, low molecular weight phenol-formaldehyde resin, dimethyl sulfoxide, and liquid ammonia. Urea and dimethylol urea have received limited commercial attention, and a bending process using liquid ammonia has been patented. Wood members can be readily molded or shaped after immersion in liquid ammonia or treatment under pressure with ammonia in the gas phase. As the ammonia evaporates, the lignin resets, the wood stiffens and retains its new shape. Plasticization of the matrix alone can be done using chemical modification technologies, which are covered later in this chapter.

It is also possible to bend wood without softening or plasticizing treatments. However, the stability of the final product may not be as permanent as from treatments in which softening and plasticizing methods are used.

Bent Wood Members

Bending can provide a variety of functional and esthetically pleasing wood members, ranging from large curved arches to small furniture components. The curvature of the bend, size of the member, and intended use of the product determine the production method.

Laminated Members

At one time in the United States, curved pieces of wood were laminated chiefly to produce small items such as parts for furniture and pianos. However, the principle was extended to the manufacture of arches for roof supports in farm, industrial, and public buildings and other types of structural members (see Ch. 11). The laminations are bent without end pressure against a form and adhesively bonded together. Both softwoods and hardwoods are suitable for laminated bent structural members, and thin material of any species can be bent satisfactorily for such purposes. The choice of species and adhesive depends primarily on the cost, required strength, and demands of the application.

Laminated curved members are produced from dry stock in a single bending and adhesive bond formation operation. This process has the following advantages compared with bending single-piece members:

- Bending thin laminations to the required radius involves only moderate stress and deformation of the wood fibers, eliminating the need for treatment with steam or hot water and associated drying and conditioning of the finished product. In addition, the moderate stresses involved in curving laminated members result in stronger members when compared with curved single-piece members.
- The tendency of laminated members to change shape with changes in moisture content is less than that of single-piece bent members.
- Ratios of thickness of member to radius of curvature that are impossible to obtain by bending single pieces can be attained readily by laminating.
- Curved members of any desired length can be produced.

Design criteria for glued-laminated timber are discussed in Chapter 11. Straight-laminated members can be steamed and bent after they are bonded together. However, this type of procedure requires an adhesive that will not be affected by the steaming or boiling treatment and complicates conditioning of the finished product.

Curved Plywood

Curved plywood is produced either by bending and adhesive bonding the plies in one operation or by bending previously bonded flat plywood. Plywood curved by bending and bonding simultaneously is more stable in curvature than plywood curved by bending previously bonded material.

Plywood Bent and Adhesively Bonded Simultaneously

In bending and bonding plywood in a single operation, adhesive-coated pieces of veneer are assembled and pressed over or between curved forms. Pressure and sometimes heat are applied through steam or electrically heated forms until the adhesive sets and holds the assembly to the desired curvature. Some laminations are at an angle, usually 90°, to other laminations, as in the manufacture of flat plywood. The grain direction of the thicker laminations is normally parallel to the axis of the bend to facilitate bending.

A high degree of compound curvature can be obtained in an assembly comprising a considerable number of thin veneers. First, for both the face and back of the assembly, the two outer plies are bonded at 90° to each other in a flat press. The remaining veneers are then adhesive-coated and assembled at any desired angle to each other. The entire assembly is hot-pressed to the desired curvature.

Bonding the two outer plies before molding allows a higher degree of compound curvature without cracking the face plies than could otherwise be obtained. Where a high degree of compound curvature is required, the veneer should be relatively thin (under 3 mm (1/8 in.)) with a moisture content of about 12%.

The molding of plywood with fluid pressure applied by flexible bags of some impermeable material produces plywood parts of various degrees of compound curvature. In "bag molding," fluid pressure is applied through a rubber bag by air, steam, or water. The veneer is wrapped around a form, and the whole assembly is enclosed in a bag and subjected to pressure in an autoclave, the pressure in the bag being "bled." Or, the veneer may be inserted inside a metal form and, after the ends have been attached and sealed, pressure is applied by inflating a rubber bag. The form may be heated electrically or by steam.

The advantages of bending and bonding plywood simultaneously to form a curved shape are similar to those for curved-laminated members. In addition, the cross plies give the curved members properties that are characteristic of cross-banded plywood. Curved plywood shells for furniture manufacture are examples of these bent veneer and adhesive-bonded products.

Plywood Bent After Bonding

After the plies are bonded together, flat plywood is often bent by methods that are somewhat similar to those used in bending solid wood. To bend plywood properly to shape, it must be plasticized by some means, usually moisture or heat, or a combination of both. The amount of curvature that can be introduced into a flat piece of plywood depends on numerous variables, such as moisture content, direction of grain, thickness and number of plies, species and quality of veneer, and the technique applied in producing the bend. Plywood is normally bent over a form or a bending mandrel.

Flat plywood bonded with a waterproof adhesive can be bent to compound curvatures after bonding. However, no simple criterion is available for predetermining whether a specific compound curvature can be imparted to flat plywood. Soaking the plywood prior to bending and using heat during forming are aids in manipulation. Usually, the plywood to be postformed is first thoroughly soaked in hot water, then dried between heated forming dies attached to a hydraulic press. If the use of postforming for bending flat plywood to compound curvatures is contemplated, exploratory trials to determine the practicability and the best procedure are recommended. Remember that in postforming plywood to compound curvatures, all the deformation must be by compression or shear because plywood cannot be stretched. Hardwood species, such as birch, poplar, and gum, are usually used in plywood that is to be postformed.

Veneered Curved Members

Veneered curved members are usually produced by bonding veneer to one or both faces of a curved solid-wood base. The bases are ordinarily sawn to the desired shape or bent from a piece grooved with saw kerfs on the concave side at right angles to the direction of bend. Pieces bent by making saw kerfs on the concave side are commonly reinforced and kept to the required curvature by bonding splines, veneer, or other pieces to the curved base. Veneering over curved solid wood is used mainly in furniture. The grain of the veneer is commonly laid in the same general direction as the grain of the curved wood base. The use of crossband veneers, that is, veneers laid with the grain at right angles to the grain of the back and face veneer, reduces the tendency of the member to split.

Bending of Solid Members

Wood of certain species that is steamed, microwaved, or soaked in boiling water can be compressed as much as 25% to 30% parallel to the grain. The same wood can be stretched only 1% to 2%. Because of the relation between attainable tensile and compressive deformations, if bending involves severe deformation, then most of the deformation must be compression. The inner or concave side must assume the maximum amount of compression, and the outer or convex side must experience zero strain or a slight tension. To accomplish this, a metal strap equipped with end fittings is customarily used. The strap makes contact with the outer or convex side and, acting through the end fittings, places the whole piece of wood in compression. The tensile stress that would normally develop in the outer side of the piece of wood during bending is borne by the metal strap. A bending form is shown in Figure 19–1.

Selection of Stock

In general, hardwoods possess better bending quality than softwoods, and certain hardwoods surpass others in this quality. This is interesting from a theoretical point of view because hardwoods contain less lignin than softwoods. Hardwoods also contain much more hemicelluloses in the matrix than do softwoods. The species commonly used to produce bent members are white oak, red oak, elm, hickory, ash, beech, birch, maple, walnut, sweetgum, and mahogany. As stated, most softwoods have a poor bending quality and are not often used in bending operations. However, Pacific yew and yellow-cedar are exceptions to this rule. In addition, Douglas-fir, southern yellow pine, northern and Atlantic white-cedar, and redwood are used for ship and boat planking for which purpose they are often bent to moderate curvature after being steamed or soaked.

Bending stock should be free from serious cross grain and distorted grain, such as may occur near knots. The slope of cross grain should not be steeper than about 1 to 15. Decay, knots, shake, pith, surface checks, and exceptionally light or brashy wood should be avoided.

Moisture Content of Bending Stock

Although green wood can be bent to produce many curved members, difficulties are encountered in drying and fixing the bend. Another disadvantage with green stock is that hydrostatic pressure may be developed during bending. Hydrostatic pressure can cause compression failures on the concave side if the wood is compressed by an amount greater than the air space in the cells of the green wood. Bending stock that has been dried to a low moisture content level requires a lengthy steaming or soaking process to increase its moisture content to the point where it can be made sufficiently plastic for successful bending. For most chair and furniture parts, the moisture content of the bending stock should be 12% to 20% before it is steamed or microwave heated. The preferred moisture content level varies with the severity of the curvature to which the wood is bent and the method used in drying and fixing the bent member. For example, chair-back slats, which have a slight curvature and are subjected to severe drying conditions between steam-heated platens, can be produced successfully from stock at 12% moisture content. For furniture parts that need a more severe bend where the part must be bent over a form, 15% to 20% moisture content is recommended.

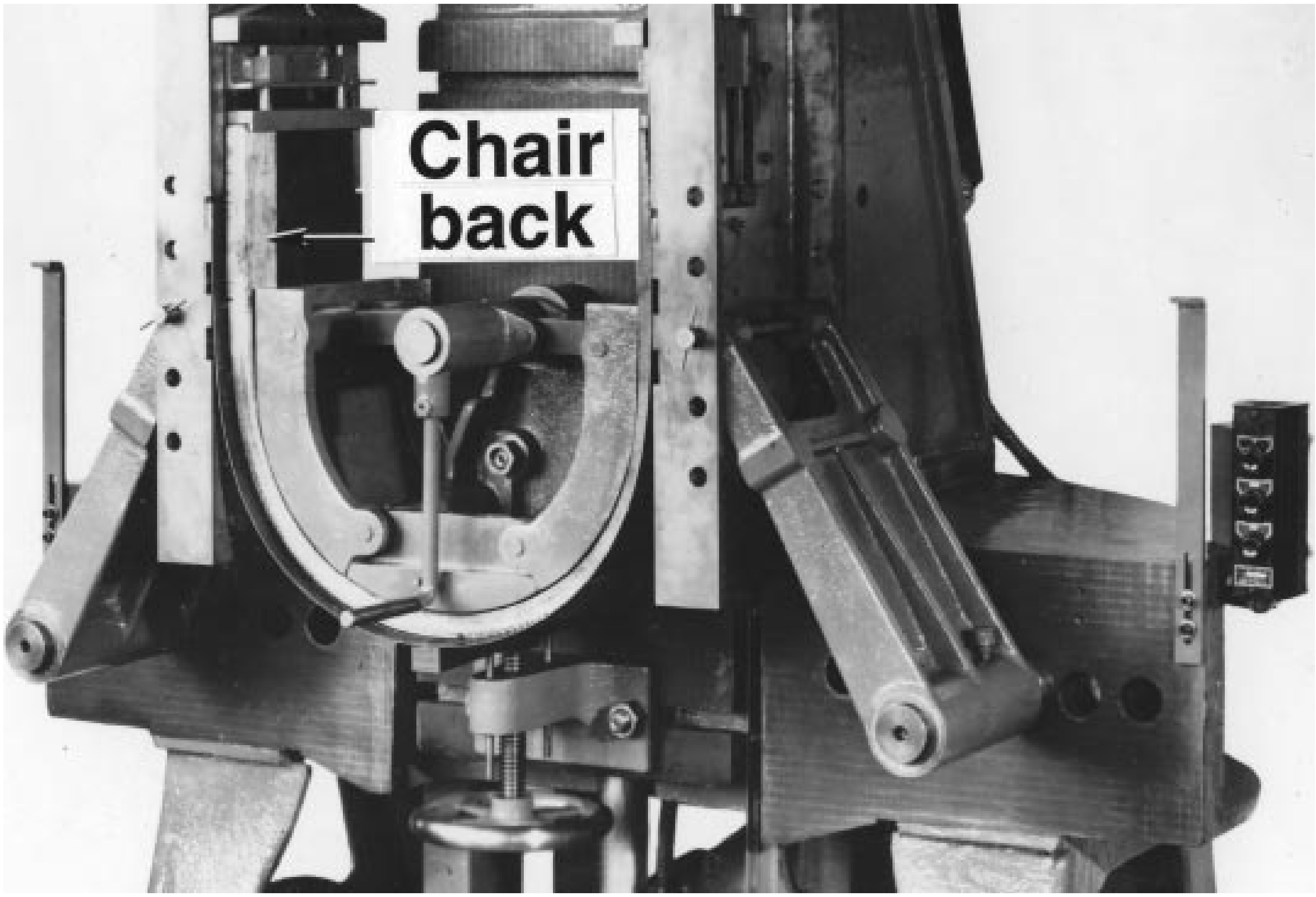

Figure 19–1. Chair back being bent through an arc of 180° in a bending machine.

Bending Operation and Apparatus

After being plasticized, the stock should be quickly placed in the bending apparatus and bent to shape. The bending apparatus consists essentially of a form (or forms) and a means of forcing the piece of steamed wood against the form. If the curvature to be obtained demands a difference of much more than 3% between lengths of the outer and inner surfaces of the pieces, then the apparatus should include a device for applying end pressure. This generally takes the form of a metal strap or pan provided with end blocks, end bars, or clamps.

Fixing the Bend

After being bent, the piece should be cooled and dried while held in its curved shape. One method is to dry the piece in the bending machine between the plates of a hot-plate press. Another method is to secure the bent piece to the form and place both the piece and the form in a drying room. Still another is to keep the bent piece in a minor strap with tie rods or stays so that it can be removed from the form and placed in a drying room. When the bent member has cooled and dried to a moisture content suitable for its intended use, the restraining devices can be removed and the piece will hold its curved shape.

Characteristics of Bent Wood

After a bent piece of wood is cooled and dried, the curvature will be maintained. An increase in moisture content may cause the piece to lose some of its curvature. A decrease in moisture content may cause the curve to become sharper, although repeated changes in moisture content bring about a gradual straightening. These changes are caused primarily by lengthwise swelling or shrinking of the inner (concave) face, the fibers of which were wrinkled or folded during the bending operation.

A bent piece of wood has less strength than a similar unbent piece. However, the reduction in strength brought about by bending is seldom serious enough to affect the utility value of the member.

Modified Woods

Wood can be chemically modified to improve water repellency, dimensional stability, resistance to acids or bases, ultraviolet radiation, biodeterioration, and thermal degradation. Wood can also be chemically treated, then compressed to improve dimensional stability and increase hardness.

Sheets of paper treated with resins or polymers can be laminated and hot pressed into thick panels that have the appearance of plastic rather than paper. These sheets are used in special applications because of their structural properties and in items requiring hard, impervious, and decorative surfaces.

Modified woods, modified wood-based materials, and paper-based laminates are usually more expensive than wood because of the cost of the chemicals and the special processing required to produce them. Thus, modified wood use is generally limited to special applications where the increased cost is justified by the special properties needed.

Wood is treated with chemicals to increase hardness and other mechanical properties, as well as its resistance to decay, fire, weathering, and moisture. The rate and extent of swelling and shrinking of the wood when in contact with water is reduced by application of water-resistant chemicals to the surface of wood, impregnation of the wood with such chemicals dissolved in water or volatile solvents, or bonding chemicals to the cell wall polymer. Such treatments may also reduce the rate at which wood changes dimension as a result of humidity, even though these treatments do not affect the final dimensional changes caused by lengthy duration exposures. Paints, varnishes, lacquers, wood-penetrating water repellents, and plastic and metallic films retard the rate of moisture absorption but have little effect on total dimensional change if exposure to moisture is extensive and prolonged.

Resin-Treated Wood (Impreg)

Permanent stabilization of the dimensions of wood is needed for certain specialty uses. This can be accomplished by depositing a bulking agent within the swollen structure of the wood fibers. The most successful bulking agents that have been commercially applied are highly water-soluble, thermosetting, phenol-formaldehyde resin-forming systems, with initially low molecular weights. No thermoplastic resins have been found that effectively stabilize the dimensions of wood.

Wood treated with a thermosetting, fiber-penetrating resin and cured without compression is known as impreg. The wood (preferably green veneer to facilitate resin pickup) is soaked in the aqueous resin-forming solution or, if air dry, is impregnated with the solution under pressure until the resin content equals 25% to 35% of the weight of dry wood. The treated wood is allowed to stand under nondrying conditions for 1 to 2 days to permit uniform distribution of the solution throughout the wood. The resin-containing wood is dried at moderate temperatures to remove the water, then heated to higher temperatures to cure the resin.

Uniform distribution of the resin has been effectively accomplished with thick wood specimens only in sapwood of readily penetrated species. Although thicker material can be treated, the process is usually applied to veneers up to about 8 mm (0.3 in.) thick, because treating time increases rapidly with increases in thickness. Drying thick, resin-treated wood may result in checking and honeycombing. For these reasons, treatments should be confined to veneer and the treated-cured veneer used to build the desired products. Any species can be used for the veneer except the resinous pines. The stronger the original wood, the stronger the end product.

Impreg has a number of properties differing from those of normal wood and ordinary plywood. These properties are given in Table 19–1, with similar generalized findings for other modified woods. Data for the strength properties of yellow birch impreg are given in Table 19–2. Information on thermal expansion properties of ovendry impreg is given in Table 19–3.

The good dimensional stability of impreg is the basis of one use where its cost is not a deterrent. Wood dies of automobile body parts serve as the master from which the metal-forming dies are made for actual manufacture of parts. Small changes in moisture content, even with the most dimensionally stable wood, produce changes in dimension and curvature of an unmodified wood die. Such changes create major problems in making the metal-forming dies where close final tolerances are required. The substitution of impreg, with its high antishrink efficiency (ASE) (Table 19–4), almost entirely eliminated the problem of dimensional change during the entire period that the wood master dies were needed. Despite the tendency of the resins to dull cutting tools, pattern makers accepted the impreg readily because it machines with less splitting than unmodified wood.

Patterns made from impreg are also superior to unmodified wood in resisting heat when used with shell-molding techniques where temperatures as high as 205°C (400°F) are required to cure the resin in the molding sand.

Resin-Treated Compressed Wood (Compreg)

Compreg is similar to impreg except that it is compressed before the resin is cured within the wood. The resin-forming chemicals (usually phenol-formaldehyde) act as plasticizers for the wood so that it can be compressed under modest pressure (6.9 MPa; 1,000 lb/in^2) to a specific gravity of 1.35. Some properties of compreg are similar to those of impreg, and others vary considerably (Tables 19–1 and 19–2). Compared with impreg, the advantages of compreg are its natural lustrous finish that can be developed on any cut surface by sanding with fine-grit paper and buffing, its greater strength properties, and its ability to mold (Tables 19–1 and 19–2). However, thermal expansion coefficients of ovendry compreg are also increased (Table 19–3).

Compreg can be molded by (a) gluing blocks of resin-treated (but still uncured) wood with a phenolic glue so that the gluelines and resin within the plies are only partially set; (b) cutting to the desired length and width but two to three times the desired thickness; and (c) compressing in a split mold at about 150°C (300°F). Only a small flash squeeze out at the parting line between the two halves of the mold needs to be machined off. This technique was used for motor-test propellers and airplane antenna masts during World War II.

Table 19–1. Properties of modified woods

Property	Impreg	Compreg	Staypak
Specific gravity	15% to 20% greater than normal wood	Usually 1.0 to 1.4	1.25 to 1.40
Equilibrium swelling and shrinking	1/4 to 1/3 that of normal wood	1/4 to 1/3 that of normal wood at right angle to direction of compression, greater in direction of compression but very slow to attain	Same as normal wood at right angle to compression, greater in direction of compression but very slow to attain
Springback	None	Very small when properly made	Moderate when properly made
Face checking	Practically eliminated	Practically eliminated for specific gravities less than 1.3	About the same as in normal wood
Grain raising	Greatly reduced	Greatly reduced for uniform-texture woods, considerable for contrasting grain woods	About the same as in normal wood
Surface finish	Similar to normal wood	Varnished-like appearance for specific gravities greater than about 1.0. Cut surfaces can be given this surface by sanding and buffing	Varnished-like appearance. Cut surfaces can be given this surface by sanding and buffing
Permeability to water vapor	About 1/10 that of normal wood	No data but presumably much less than impreg	No data but presumably lower than impreg
Decay and termite resistance	Considerably better than normal wood	Considerably better than normal wood	Normal but decay occurs somewhat more slowly
Acid resistance	Considerably better than normal wood	Better than impreg because of impermeability	Better than normal wood because of impermeability but not as good as compreg
Alkali resistance	Same as normal wood	Somewhat better than normal wood because of impermeability	Somewhat better than normal wood because of impermeability
Fire resistance	Same as normal wood	Same as normal wood for long exposures somewhat better for short exposures	Same as normal wood for long exposures somewhat better for short exposures
Heat resistance	Greatly increased	Greatly increased	No data
Electrical conductivity	1/10 that of normal wood at 30% RH; 1/1,000 that of normal wood at 90% RH	Slightly more than impreg at low relative humidity values due to entrapped water	No data
Heat conductivity	Slightly increased	Increased about in proportion to specific gravity increase	No data but should increase about in proportion to specific gravity increase
Compressive strength	Increased more than proportional to specific gravity increase	Increased considerably more than proportional to specific gravity increase	Increased about in proportion to specific gravity increase parallel to grain, increased more perpendicular to grain
Tensile strength	Decreased significantly	Increased less than proportional to specific gravity increase	Increased about in proportion to specific gravity increase
Flexural strength	Increased less than proportional to specific gravity increase	Increased less than proportional to specific gravity increase parallel to grain, increased more perpendicular to grain	Increased proportional to specific gravity increase parallel to grain, increased more perpendicular to grain
Hardness	Increased considerably more than proportional to specific gravity increase	10 to 20 times that of normal wood	10 to 18 times that of normal wood
Impact strength			
Toughness	About 1/2 of value for normal wood but very susceptible to the variables of manufacture	1/2 to 3/4 of value for normal wood but very susceptible to the variables of manufacture	Same to somewhat greater than normal wood
Izod	About 1/5 of value for normal wood	1/3 to 3/4 of value for normal wood	Same to somewhat greater than normal wood
Abrasion resistance (tangential)	About 1/2 of value for normal wood	Increased about in proportion to specific gravity increase	Increased about in proportion to specific gravity increase
Machinability	Cuts cleaner than normal wood but dulls tools more	Requires metalworking tools and metalworking tool speeds	Requires metalworking tools and metalworking tool speeds
Moldability	Cannot be molded but can be formed to single curvatures at time of assembly	Can be molded by compression and expansion molding methods	Cannot be molded
Gluabilily	Same as normal wood	Same as normal wood after light sanding or in the case of thick stock, machining surfaces plane	Same as normal wood after light sanding, or in the case of thick stock, machining surfaces plane

Table 19–2. Strength properties of normal and modified laminates[a] of yellow birch and a laminated paper plastic

Property	Normal laminated wood[b]	Impreg (impregnated, uncompressed)[c]	Compreg (impregnated, highly compressed)[c]	Staypak (unimpreg-nated, highly compressed)[b]	Paper laminate (impregnated, highly compressed)[d]
Thickness of laminate (mm (in.))	23.9 (0.94)	26.2 (1.03)	16.0 (0.63)	12.2 (0.48)	3.2 (0.126) 13.0 (0.512)
Moisture content at time of test (%)	9.2	5.0	5.0	4.0	—
Specific gravity (based on weight and volume at test)	0.7	0.8	1.3	1.4	1.4
Parallel laminates					
Flexure—grain parallel to span (flatwise)[e]					
Proportional limit stress (MPa (lb/in^2))	79.3 (11,500)	109.6 (15,900)	184.1 (26,700)	138.6 (20,100)	109.6 (15,900)
Modulus of rupture (MPa (lb/in^2))	140.6 (20,400)	129.6 (18,800)	250.3 (36,300)	271.6 (39,400)	252.3 (36,600)
Modulus of elasticity (GPa (1,000 lb/in^2))	16.0 (2,320)	16.4 (2,380)	25.4 (3,690)	30.7 (4,450)	20.8 (3,010)
Flexure—grain perpendicular to span (flatwise)[e]					
Proportional limit stress (MPa (lb/in^2))	6.9 (1,000)	9.0 (1,300)	29.0 (4,200)	22.1 (3,200)	72.4 (10,500)
Modulus of rupture (MPa (lb/in^2))	13.1 (1,900)	11.7 (1,700)	31.7 (4,600)	34.5 (5,000)	167.5 (24,300)
Modulus of elasticity (GPa (1,000 lb/in^2))	1.0 (153)	1.5 (220)	4.3 (626)	4.2 (602)	10.2 (1,480)
Compression parallel to grain (edgewise)[e]					
Proportional limit stress (MPa (lb/in^2))	44.1 (6,400)	70.3 (10,200)	113.1 (16,400)	66.9 (9,700)	49.6 (7,200)
Ultimate strength (MPa (lb/in^2))	65.5 (9,500)	106.2 (15,400)	180.0 (26,100)	131.7 (19,100)	144.1 (20,900)
Modulus of elasticity (GPa (1,000 lb/in^2))	15.8 (2,300)	17.0 (2,470)	26.1 (3,790)	32.2 (4,670)	21.5 (3,120)
Compression perpendicular to grain (edgewise)[f]					
Proportional limit stress (MPa (lb/in^2))	4.6 (670)	6.9 (1,000)	33.1 (4,800)	17.9 (2,600)	29.0 (4,200)
Ultimate strength (MPa (lb/in^2))	14.5 (2,100)	24.8 (3,600)	96.5 (14,000)	64.8 (9,400)	125.5 (18,200)
Modulus of elasticity (GPa (1,000 lb/in^2))	1.1 (162)	1.7 (243)	3.9 (571)	4.0 (583)	11.0 (1,600)
Compression perpendicular to grain (flatwise)[e]					
Maximum crushing strength (MPa (lb/in^2))	—	29.5 (4,280)	115.1 (16,700)	91.0 (13,200)	291.0 (42,200)
Tension parallel to grain (lengthwise)					
Ultimate strength (MPa (lb/in^2))	153.1 (22,200)	108.9 (15,800)	255.1 (37,000)	310.3 (45,000)	245.4 (35,600)
Modulus of elasticity (GPa (1,000 lb/in^2))	15.8 (2,300)	17.3 (2,510)	27.2 (3,950)	31.8 (4,610)	25.1 (3,640)
Tension perpendicular to grain (edgewise)					
Ultimate strength (MPa (lb/in^2))	9.6 (1,400)	9.6 (1,400)	22.1 (3,200)	22.8 (3,300)	137.9 (20,000)
Modulus of elasticity (GPa (1,000 lb/in^2))	1.1 (166)	1.6 (227)	4.3 (622)	4.0 (575)	11.8 (1,710)
Shear strength parallel to grain (edgewise)[f]					
Johnson double shear across laminations (MPa (lb/in^2))	20.5 (2,980)	23.8 (3,460)	50.8 (7,370)	43.9 (6,370)	122.7 (17,800)
Cylindrical double shear parallel to laminations (MPa (lb/in^2))	20.8 (3,020)	24.5 (3,560)	39.2 (5,690)	21.2 (3,080)	20.7 (3,000)
Shear modulus					
Tension method (GPa (1,000 lb/in^2))	1.2 (182)	1.8 (255)	3.1 (454)	—	—
Plate shear method (FPL test) (GPa (1,000 lb/in^2))	—	—	—	2.6 (385)	6.3 (909)
Toughness (FPL test edgewise)[f] (J (in-lb))	26.6 (235)	14.1 (125)	16.4 (145)	28.2 (250)	—
Toughness (FPL test edgewise)[f] (J/mm of width (in-lb/in of width))	1.1 (250)	0.53 (120)	1.0 (230)	2.3 (515)	—
Impact strength (Izod)—grain lengthwise					
Flatwise (notch in face) (J/mm of notch (ft–lb/in of notch))	0.75 (14.0)	0.12 (2.3)	0.23 (4.3)	0.68 (12.7)	0.25 (4.7)
Edgewise (notch in face) (J/mm of notch (ft-lb/in of notch))	0.60 (11.3)	0.10 (1.9)	0.17 (3.2)[g]	—	0.036 (0.67)

Table 19–2. Strength properties of normal and modified laminates[a] of yellow birch and a laminated paper plastic—con.

Property	Normal laminated wood[b]	Impreg (impregnated, uncompressed)[c]	Compreg (impregnated, highly compressed)[c]	Staypak (unimpregnated, highly compressed)[b]	Paper laminate (impregnated, highly compressed)[d]
Hardness:					
Rockwell flatwise[e] (M–numbers)	—	22	84	—	110
Load to embed 11.3-mm (0.444-in.) steel ball to 1/2 its diameter (kN (lb))	7.1 (1,600)	10.7 (2,400)	—	—	—
Hardness modulus (H_M)[h] (MPa (lb/in^2))	37.2 (5,400)	63.4 (9,200)	284.8 (41,300)	302.0 (43,800)	245.4 (35,600)
Abrasion—Navy wear-test machine (flatwise)[e] wear per 1,000 revolutions (mm (in.))	0.76 (0.030)	1.45 (0.057)	0.46 (0.018)	0.38 (0.015)	0.46 (0.018)
Water absorption (24-h immersion) increase in weight (%)	43.6	13.7	2.7	4.3	2.2
Dimensional stability in thickness direction					
Equilibrium swelling (%)	9.9	2.8	8.0	29	—
Recovery from compression (%)	—	0	0	4	—
Crossband laminates					
Flexure—face grain parallel to span (flatwise)[e]					
Proportional limit stress (MPa (lb/in^2))	47.6 (6,900)	55.8 (8,100)	99.3 (14,400)	78.6 (11,400)	86.9 (12,600)
Modulus of rupture (MPa (lb/in^2))	90.3 (13,100)	78.6 (11,400)	157.2 (22,800)	173.0 (25,100)	215.8 (31,300)
Modulus of elasticity (GPa (1,000 lb/in^2))	9.0 (1,310)	11.5 (1,670)	17.1 (2,480)	20.0 (2,900)	15.4 (2,240)
Compression parallel to face grain (edgewise)[f]					
Proportional limit stress (MPa (lb/in^2))	22.8 (3,300)	35.8 (5,200)	60.0 (8,700)	35.8 (5,200)	34.5 (5,000)
Ultimate strength (MPa (lb/in^2))	40.0 (5,800)	78.6 (11,400)	164.8 (23,900)	96.5 (14,000)	130.3 (18,900)
Modulus of elasticity (GPa (1,000 lb/in^2))	9.4 (1,360)	10.3 (1,500)	15.8 (2,300)	18.6 (2,700)	16.3 (2,370)
Tension parallel to face grain (lengthwise)					
Ultimate strength (MPa (lb/in^2))	84.8 (12,300)	54.5 (7,900)	113.8 (16,500)	168.9 (24,500)	187.5 (27,200)
Modulus of elasticity (GPa (1,000 lb/in^2))	8.9 (1,290)	10.1 (1,460)	15.1 (2,190)	17.7 (2,570)	18.6 (2,700)
Toughness (FPL test edgewise)[f] (J/mm of width (in-lb/in of width))	0.47 (105)	0.18 (40)	0.51 (115)	1.4 (320)	—

[a]Laminates made from 17 plies of 1.6-mm (1/16-in.) rotary-cut yellow birch veneer.
[b]Veneer conditioned at 27°C (80°F) and 65% relative humidity before assembly with phenol resin film adhesive.
[c]Impregnation, 25% to 30% of water-soluble phenol-formaldehyde resin based on the dry weight of untreated veneer.
[d]High-strength paper (0.076-mm (0.003-in. thickness)) made from commercial unbleached black spruce pulp (*Mitscherlich subtile*), phenol resin content 36.3% based on weight of treated paper, Izod impact abrasion, flatwise compression, and shear specimens, all on 12.7-mm - (1/2-in.-) thick laminate.
[e]Load applied to the surface of the original material (parallel to laminating pressure direction).
[f]Forest Products Laboratory (FPL) test procedure: load applied to edge of laminations (perpendicular to laminating pressure direction).
[g]Values as high as 0.53 J/mm (10.0 ft-lb/in.) of notch have been reported for compreg made with alcohol-soluble resins and 0.37 J/mm (7.0 ft-lb/in) with water-soluble resins.
[h]Values based on the average slope of load–penetration plots where H_M is an expression for load per unit of spherical area of penetration of the 11.3-mm (0.444-in.) steel ball expressed in MPa (lb/in^2).

A more satisfactory molding technique, known as expansion molding, has been developed. The method consists of rapidly precompressing dry but uncured single sheets of resin-treated veneer in a cold press after preheating the sheets at 90°C to 120°C (195°F to 250°F). The heat-plasticized wood responds to compression before cooling. The heat is insufficient to cure the resin, but the subsequent cooling sets the resin temporarily. These compressed sheets are cut to the desired size, and the assembly of plies is placed in a split mold of the final desired dimensions. Because the wood was precompressed, the filled mold can be closed and locked. When the mold is heated, the wood is again plasticized and tends to recover its uncompressed dimensions. This exerts an internal pressure in all directions against the mold equal to about half the original compressing pressure. On continued heating, the resin is set. After cooling, the object may be removed from the mold in finished form. Metal inserts or metal surfaces can be molded to compreg or its handles are molded onto tools by this means. Compreg bands have been molded to the outside of turned wood cylinders without compressing the core. Compreg tubes and small airplane propellers have been molded in this way.

Past uses of compreg were related largely to aircraft; however, it is a suitable material where bolt-bearing strength is

Table 19–3. Coefficients of linear thermal expansion per degree Celsius of wood, hydrolyzed wood, and paper products[a]

Material[b]	Specific gravity of product	Resin content[c] (%)	Linear expansion per °C (values multiplied by 10^6): Fiber or machine direction	Perpendicular to fiber or machine direction in plane of laminations	Pressing direction	Cubical expansion per °C (values multiplied by 10^6)
Yellow birch laminate	0.72	3.1	3.254	40.29	36.64	80.18
Yellow birch staypak laminate	1.30	4.7	3.406	37.88	65.34	106.63
Yellow birch impreg laminate	0.86	33.2	4.648	35.11	37.05	76.81
Yellow birch compreg laminate	1.30	24.8	4.251	39.47	59.14	102.86
	1.31	34.3	4.931	39.32	54.83	99.08
Sitka spruce laminate	0.53	6.0[d]	3.887	37.14	27.67	68.65
Parallel-laminated paper laminate	1.40	36.5	5.73	15.14	65.10	85.97
Crossbanded paper laminate	1.40	36.5	10.89	11.0[e]	62.2	84.09
Molded hydrolyzed-wood plastic	1.33	25	42.69	42.69	42.69	128.07
Hydrolyzed-wood sheet laminate	1.39	18	13.49	224.68	77.41	115.58

[a]These coefficients refer to bone-dry material. Generally, air-dry material has a negative thermal coefficient, because the shrinkage resulting from the loss in moisture is greater than the normal thermal expansion.
[b]All wood laminates made from rotary-cut veneer, annual rings in plane of sheet.
[c]On basis of dry weight of product.
[d]Approximate.
[e]Calculated value.

Table 19–4. Comparison of wood treatments and the degree of dimensional stability achieved

Treatment	Antishrink efficiency (%)
Simple wax dip	2 to 5
Wood–plastic combination	10 to 15
Staypak/staybwood	30 to 40
Impreg	65 to 70
Chemical modification	65 to 75
Polyethylene glycol	80 to 85
Formaldehyde	82 to 87
Compreg	90 to 95

required, as in connector plates, because of its good specific strength (strength per unit of weight). Layers of veneer making up the compreg for such uses are often cross laminated (alternate plies at right angles to each other, as in plywood) to give nearly equal properties in all directions.

As a result of its excellent strength properties, dimensional stability, low thermal conductivity, and ease of fabrication, compreg is extremely useful for aluminum drawing and forming dies, drilling jigs, and jigs for holding parts in place while welding.

Compreg has also been used in silent gears, pulleys, water-lubricated bearings, fan blades, shuttles, bobbins, and picker sticks for looms, nuts and bolts, instrument bases and cases, musical instruments, electrical insulators, tool handles, and various novelties. At present, compreg finds considerable use in handles for knives and other cutlery. The expansion-molding techniques of forming and curing of the compreg around the metal parts of the handle as well as attaching previously made compreg with rivets are two methods used.

Veneer of any nonresinous species can be used for making compreg. Most properties depend upon the specific gravity to which the wood is compressed rather than the species used. Up to the present, however, compreg has been made almost exclusively from yellow birch or sugar maple.

Untreated Compressed Wood (Staypak)

Resin-treated wood in both the uncompressed (impreg) and compressed (compreg) forms is more brittle than the original wood. To meet the demand for a tougher compressed product than compreg, a compressed wood containing no resin (staypak) was developed. It will not lose its compression under swelling conditions as will untreated compressed wood. In making staypak, the compressing conditions are modified so that the lignin-cementing material between the cellulose fibers flows sufficiently to eliminate internal stresses.

Staypak is not as water resistant as compreg, but it is about twice as tough and has higher tensile and flexural strength properties (Tables 19–1 and 19–2). The natural finish of staypak is almost equal to that of compreg. Under weathering conditions, however, it is definitely inferior to compreg. For outdoor use, a good synthetic resin varnish or paint finish should be applied to staypak.

Staypak can be used in the same way as compreg where extremely high water resistance is not needed. It shows promise in tool handles, forming dies, connector plates, propellers, and picker sticks and shuttles for weaving, where high impact strength is needed. Staypak is not impregnated; therefore, it can be made from solid wood as well as from veneer. The cost of staypak is less than compreg.

A material similar to staypak was produced in Germany prior to World War II. It was a compressed solid wood with much less dimensional stability than staypak and was known as lignostone. Another similar German product was a laminated compressed wood known as lignofol.

Untreated Heated Wood (Staybwood)

Heating wood under drying conditions at higher temperatures (95°C to 320°C (200°F to 600°F)) than those normally used in kiln drying produces a product known as staybwood that reduces the hygroscopicity and subsequent swelling and shrinking of the wood appreciably. However, the stabilization is always accompanied by loss of mechanical properties. Toughness and resistance to abrasion are most seriously affected.

Under conditions that cause a reduction of 40% in shrinking and swelling, the toughness is reduced to less than half that of the original wood. Extensive research to minimize this loss was not successful. Because of the reduction in strength properties from heating at such high temperatures, wood that is dimensionally stabilized in this manner is not used commercially.

Wood Treated With Polyethylene Glycol (PEG)

The dimensional stabilization of wood with polyethylene glycol-1000 (PEG), also known as Carbowax, is accomplished by bulking the fiber to keep the wood in a partially swollen condition. PEG acts in the same manner as does the previously described phenolic resin. It cannot be further cured. The only reason for heating the wood after treatment is to drive off water. PEG remains water soluble in the wood. Above 60% relative humidity, it is a strong humectant and, unless used with care and properly protected, PEG-treated wood can become sticky at high levels of relative humidity. Because of this, PEG-treated wood is usually finished with a polyurethane varnish.

Treatment with PEG is facilitated by using green wood. Here, pressure is not applied because the treatment is based on diffusion. Treating times are such that uniform uptakes of 25% to 30% of chemical are achieved (based on dry weight of wood). The time necessary for this uptake depends on the thickness of the wood and may require weeks. The PEG treatment is being effectively used for cross-sectional wood plaques and other decorative items. Table tops of high quality furniture stay remarkably flat and dimensionally stable when made from PEG-treated wood.

Another application of this chemical is to reduce the checking of green wood during drying. For this application, a high degree of PEG penetration is not required. This method of treatment has been used to reduce checking during drying of small wood blanks or turnings.

Cracking and distortion that old, waterlogged wood undergoes when it is dried can be substantially reduced by treating the wood with PEG. The process was used to dry 200-year-old waterlogged wooden boats raised from Lake George, New York. The "Vasa," a Swedish ship that sank on its initial trial voyage in 1628, was also treated after it was raised. There have been many applications of PEG treatment for the restoration of waterlogged wood from archeological sites.

Wood–Polymer Composites

In the modified wood products previously discussed, most of the chemical resides in cell walls; the lumens are essentially empty. If wood is vacuum impregnated with certain liquid vinyl monomers that do not swell wood and are later polymerized *in situ* by gamma radiation or chemical catalyst-heat systems, the resulting polymer resides almost exclusively in the lumens. Methyl methacrylate is a common monomer used for a wood–polymer composites. It is converted to polymethyl methacrylate. The hygroscopic characteristics of the wood substance are not altered because little, if any, polymer penetrates the cell walls. However, because of the high polymer content (70% to 100% based on the dry weight of wood), the normally high void volume of wood is greatly reduced. With the elimination of this very important pathway for vapor or liquid water diffusion, the response of the wood substance to changes in relative humidity or water is very slow, and moisture resistance or water repellent effectiveness (WRE) is greatly improved. Water repellent effectiveness is measured as follows:

WRE = [(Swelling or moisture uptake of control specimen during exposure to water for t minutes)
÷ (Swelling or moisture uptake of treated specimen during exposure to water also for t minutes)]
× 100

Hardness is increased appreciably. Wood–polymer composite materials offer desirable aesthetic appearance, high compression strength, and abrasion resistance and are much stronger than untreated wood (Table 19–5), and commercial application of these products is largely based on increased strength and hardness properties. Improvements in physical properties

Table 19–5. Strength properties of wood–polymer composites[a]

Strength property	Unit	Untreated[b]		Treated[b]	
Static bending					
Modulus of elasticity	MPa (10^3 lb/in^2)	9.3	(1.356)	11.6	(1.691)
Fiber stress at proportional limit	MPa (lb/in^2)	44.0	(6,387)	79.8	(11,582)
Modulus of rupture	MPa (lb/in^2)	73.4	(10,649)	130.6	(18,944)
Work to proportional limit	µJ/mm^3 (in-lb/in^3)	11.4	(1.66)	29.1	(4.22)
Work to maximum load	µJ/mm^3 (in-lb/in^3)	69.4	(10.06)	122.8	(17.81)
Compression parallel to grain					
Modulus of elasticity	GPa (10^6 lb/in^2)	7.7	(1.113)	11.4	(1.650)
Fiber stress at proportional limit	MPa (lb/in^2)	29.6	(4,295)	52.0	(7,543)
Maximum crushing strength	MPa (lb/in^2)	44.8	(6,505)	68.0	(9,864)
Work to proportional limit	µJ/mm^3 (in-lb/in^3)	77.8	(11.28)	147.6	(21.41)
Toughness	µJ/mm^3 (in-lb/in^3)	288.2	(41.8)	431.6	(62.6)

[a]Menthyl methacrylate impregnated basswood.
[b]Moisture content 7.2%.

of wood–polymer composites are related to polymer loading. This, in turn, depends not only on the permeability of the wood species but also on the particular piece of wood being treated. Sapwood is filled to a much greater extent than heartwood for most species. The most commonly used monomers include styrene, methyl methacrylate, vinyl acetate, and acrylonitrile. Industrial applications include certain sporting equipment, musical instruments, decorative objects, and high performance flooring.

At present, the main commercial use of wood polymer composites is hardwood flooring. Comparative tests with conventional wood flooring indicate that wood–polymer materials resisted indentation from rolling, concentrated, and impact loads better than did white oak. This is largely attributed to improved hardness. Abrasion resistance is also increased. A finish is usually used on these products to increase hardness and wear resistance even more.

Wood–polymer composites are also being used for sporting goods, musical instruments, and novelty items.

Chemical Modification

Through chemical reactions, it is possible to add an organic chemical to the hydroxyl groups on wood cell wall components. This type of treatment bulks the cell wall with a permanently bonded chemical. Many reactive chemicals have been used experimentally to chemically modify wood. For best results, chemicals used should be capable of reacting with wood hydroxyls under neutral or mildly alkaline conditions at temperatures less than 120°C. The chemical system should be simple and must be capable of swelling the wood structure to facilitate penetration. The complete molecule should react quickly with wood components to yield stable chemical bonds while the treated wood retains the desirable properties of untreated wood. Reaction of wood with chemicals such as anhydrides, epoxides, isocyanates, acid chlorides, carboxylic acids, lactones, alkyl chlorides, and nitriles result in antishrink efficiency (ASE) values (Table 19–4) of 65% to 75% at chemical weight gains of 20% to 30%. Antishrink efficiency is determined as follows:

$$S = \frac{V_2 - V_1}{V_1} \times 100$$

where S is volumetric swelling coefficient, V_2 is wood volume after humidity conditioning or wetting with water, and V_1 is wood volume of ovendried sample before conditioning or wetting.

Then,

$$\text{ASE} = \frac{S_2 - S_1}{S_1} \times 100$$

where ASE is reduction in swelling or antishrink efficiency resulting from a treatment, S_2 is treated volumetric swelling coefficient, and S_1 is untreated volumetric swelling coefficient.

Reaction of these chemicals with wood yields a modified wood with increased dimensional stability and improved resistance to termites, decay, and marine organisms.

Mechanical properties of chemically modified wood are essentially unchanged compared with untreated wood.

The reaction of formaldehyde with wood hydroxyl groups is an interesting variation of chemical modification. At weight gains as low as 2%, formaldehyde-treated wood is not attacked by wood-destroying fungi. An antishrink efficiency

(Table 19–4) of 47% is achieved at a weight gain of 3.1%, 55% at 4.1, 60% at 5.5, and 90% at 7. The mechanical properties of formaldehyde-treated wood are all reduced from those of untreated wood. A definite embrittlement is observed, toughness and abrasion resistance are greatly reduced, crushing strength and bending strength are reduced about 20%, and impact bending strength is reduced up to 50%.

Paper-Based Plastic Laminates

Commercially, paper-based plastic laminates are of two types: industrial and decorative. Total annual production is equally divided between the two types. They are made by superimposing layers of paper that have been impregnated with a resinous binder and curing the assembly under heat and pressure.

Industrial Laminates

Industrial laminates are produced to perform specific functions requiring materials with predetermined balances of mechanical, electrical, and chemical properties. The most common use of such laminates is electrical insulation. The paper reinforcements used in the laminates are kraft pulp, alpha pulp, cotton linters, or blends of these. Kraft paper emphasizes mechanical strength and dielectric strength perpendicular to laminations. Alpha paper is used for its electric and electronic properties, machineability, and dimensional stability. Cotton linter paper combines greater strength than alpha paper with excellent moisture resistance.

Phenolic resins are the most suitable resins for impregnating the paper from the standpoint of high water resistance, low swelling and shrinking, and high strength properties (except for impact). Phenolics also cost less than do other resins that give comparable properties. Water-soluble resins of the type used for impreg impart the highest water resistance and compressive strength properties to the product, but they make the product brittle (low impact strength). Alcohol-soluble phenolic resins produce a considerably tougher product, but the resins fail to penetrate the fibers as well as water-soluble resins, thus imparting less water resistance and dimensional stability to the product. In practice, alcohol-soluble phenolic resins are generally used.

Paper-based plastic laminates inherit their final properties from the paper from which they are made. High strength papers yield higher strength plastic laminates than do low strength papers. Papers with definite directional properties result in plastic laminates with definite directional properties unless they are cross laminated (alternate sheets oriented with the machine direction at 90° to each other).

Improving the paper used has helped develop paper-based laminates suitable for structural use. Pulping under milder conditions and operating the paper machines to give optimum orientation of the fibers in one direction, together with the desired absorbency, contribute markedly to improvements in strength.

Strength and other properties of a paper plastic laminate are shown in Table 19–2. The National Electric Manufacturers Association L1–1 specification has additional information on industrial laminates. Paper is considerably less expensive than glass fabric or other woven fabric mats and can be molded at considerably lower pressures; therefore, the paper-based laminates generally have an appreciable price advantage over fabric laminates. However, some fabric laminates give superior electrical properties and higher impact properties. Glass fabric laminates can be molded to greater double curvatures than can paper laminates.

During World War II, a high strength paper plastic known as papreg was used for molding nonstructural and semistructural airplane parts such as gunner's seats and turrets, ammunition boxes, wing tabs, and the surfaces of cargo aircraft flooring and catwalks. Papreg was tried to a limited extent for the skin surface of airplane structural parts, such as wing tips. One major objection to its use for such parts is that it is more brittle than aluminum and requires special fittings. Papreg has been used to some extent for heavy-duty truck floors and industrial processing trays for nonedible materials. Because it can be molded at low pressures and is made from thin paper, papreg is advantageous for use where accurate control of panel thickness is required.

Decorative Laminates

Although made by the same process as industrial laminates, decorative laminates are used for different purposes and bear little outward resemblance to industrial laminate. They are used as facings for doors and walls and tops of counters, flooring, tables, desks, and other furniture.

These decorative laminates are usually composed of a combination of phenolic- and melamine-impregnated sheets of paper. Phenolic-impregnated sheets are brown because of the impregnating resins and comprise most of the built-up thickness of the laminate. Phenolic sheets are overlaid with paper impregnated with melamine resin. One sheet of the overlay is usually a relatively thick one of high opacity and has the color or design printed on it. Then, one or more tissue-thin sheets, which become transparent after the resin is cured, are overlaid on the printed sheet to protect it in service. The thin sheets generally contain more melamine resin than do the printed sheets, providing stain and abrasion resistance as well as resistance to cigarette burns, boiling water, and common household solvents.

The resin-impregnated sheets of paper are hot pressed, cured, then bonded to a wood-based core, usually plywood, hardboard, or particleboard. The thin transparent (when cured) papers impregnated with melamine resin can be used alone as a covering for decorative veneers in furniture to provide a permanent finish. In this use, the impregnated sheet is bonded to the wood surface in hot presses at the same time the resin is cured. The heat and stain resistance and the strength of this kind of film make it a superior finish.

The overall thickness of a laminate may obviously be varied by the number of sheets of kraft-phenolic used in the core assembly. Some years ago, a 2-mm (0.08-in.) thickness was used with little exception because of its high impact strength and resistance to substrate show through. Recently, a 1-mm (0.04-in.) thickness has become popular on vertical surfaces such as walls, cabinet doors, and vertical furniture faces. This results in better economy, because the greater strength of the heavier laminate is not necessary. As applications have proliferated, a whole series of thicknesses have been offered from about 20 to 60 mm (0.8 to 2.4 in.), even up to 150 mm (6 in.) when self-supportive types are needed. These laminates may have decorative faces on both sides if desired, especially in the heavier thicknesses. Replacement bowling lanes made from high-density fiberboard core and phenolic-melamine, high-pressure laminated paper on the face and back are commercially used.

The phenolic sheets may also contain special postforming-type phenolic resins or extensible papers that make it possible to postform the laminate. By heating to 160°C (320°F) for a short time, the structure can readily undergo simple bending to a radius of 10 mm (0.4 in.) and 5 to 6 mm (0.20 to 0.24 in.) with careful control. Rolled furniture edges, decorative moldings, curved counter tops, shower enclosures, and many other applications are served by this technique. Finally, the core composition may be modified to yield a fire-retardant, low smoking laminate to comply with fire codes. These high-pressure decorative laminates are covered by the National Electrical Manufacturers Association Specification LD3.

Paper will absorb or give off moisture, depending upon conditions of exposure. This moisture change causes paper to shrink and swell, usually more across the machine direction than along it. In the same manner, the laminated paper plastics shrink and swell, although at a much slower rate. Cross laminating minimizes the amount of this shrinking and swelling. In many furniture uses where laminates are bonded to cores, the changes in dimension, as a result of moisture fluctuating with the seasons, are different than those of the core material. To balance the construction, a paper plastic with similar properties may be glued to the opposite face of the core to prevent bowing or cupping caused by the moisture variation.

Lignin-Filled Laminates

The cost of phenolic resins at one time resulted in considerable effort to find impregnating and bonding agents that were less expensive and yet readily available. Lignin-filled laminates made with lignin recovered from the spent liquor of the soda pulping process have been produced as a result of this search. Lignin is precipitated from solution within the pulp or added in a pre-precipitated form before the paper is made. The lignin-filled sheets of paper can be laminated without the addition of other resins, but their water resistance is considerably enhanced when some phenolic resin is applied to the paper in a second operation. The water resistance can also be improved by impregnating only the surface sheet with phenolic resin. It is also possible to introduce lignin, together with phenolic resin, into untreated paper sheets.

The lignin-filled laminates are always dark brown or black. They have better toughness than phenolic laminates; in most other strength properties, they are comparable or lower.

Reduction in cost of phenolic resins has virtually eliminated the lignin-filled laminates from American commerce. These laminates have several potential applications, however, where a cheaper laminate with less critical properties than phenolic laminates can be used.

Paper-Face Overlays

Paper has found considerable use as an overlay material for veneer or plywood. Overlays can be classified into three different types according to their use—masking, structural, and decorative. Masking overlays are used to cover minor defects in plywood, such as face checks and patches, minimize grain raising, and provide a more uniform paintable surface, thus making possible the use of lower grade veneer. Paper for this purpose need not be of high strength, because the overlays do not need to add strength to the product. For adequate masking, a single surface sheet with a thickness of 0.5 to 1 mm (0.02 to 0.04 in.) is desirable. Paper impregnated with phenolic resins at 17% to 25% of the weight of the paper gives the best all-around product. Higher resin content makes the product too costly and tends to make the overlay more transparent. Appreciably lower resin content gives a product with low scratch and abrasion resistance, especially when the panels are wet or exposed to high relative humidities.

The paper faces can be applied at the same time that the veneer is assembled into plywood in a hot press. Thermal stresses that might result in checking are not set up if the machine direction of the paper overlays is at right angles to the grain direction of the face plies of the plywood.

The masking-paper-based overlays or vulcanized fiber sheets have been used for such applications as wood house siding that is to be painted. These overlays mask defects in the wood, prevent bleed through of resins and extractives in the wood, and provide a better substrate for paint. The paper-based overlays improve the across-the-board stability from changes in dimension as a result of changes in moisture content.

The structural overlay, also known as the high-density overlay, contains no less than 45% thermosetting resin, generally phenolic. It consists of one or more plies of paper similar to that used in the industrial laminates described previously. The resin-impregnated papers can be bonded directly to the surface of a wood substrate during cure of the sheet, thus requiring only a single pressing operation.

The decorative-type overlay is described in the Decorative Laminates section.

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Glossary

Adherend. A body that is held to another body by an adhesive.

Adhesion. The state in which two surfaces are held together by interfacial forces which may consist of valence forces or interlocking action or both.

Adhesive. A substance capable of holding materials together by surface attachment. It is a general term and includes cements, mucilage, and paste, as well as glue.

Assembly Adhesive—An adhesive that can be used for bonding parts together, such as in the manufacture of a boat, airplane, furniture, and the like.

Cold-Setting Adhesive—An adhesive that sets at temperatures below 20°C (68°F).

Construction Adhesive—Any adhesive used to assemble primary building materials into components during building construction—most commonly applied to elastomer-based mastic-type adhesives.

Contact Adhesive—An adhesive that is apparently dry to the touch and, which will adhere to itself instantaneously upon contact; also called contact bond adhesive or dry bond adhesive.

Gap-Filling Adhesive—An adhesive capable of forming and maintaining a bond between surfaces that are not close fitting.

Hot-Melt Adhesive—An adhesive that is applied in a molten state and forms a bond on cooling to a solid state.

Hot-Setting Adhesive—An adhesive that requires a temperature at or above 100°C (212°F) to set it.

Room-Temperature-Curing Adhesive—An adhesive that sets in the temperature range of 20°C to 30°C (68°F to 86°F), in accordance with the limits for Standard Room Temperature specified in the Standard Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (ASTM D618).

Solvent Adhesive—An adhesive having a volatile organic liquid as a vehicle. (This term excludes water-based adhesives.)

Structural Adhesive—A bonding agent used for transferring required loads between adherends exposed to service environments typical for the structure involved.

Air-Dried. (See **Seasoning.**)

Allowable Property. The value of a property normally published for design use. Allowable properties are identified with grade descriptions and standards, reflect the orthotropic structure of wood, and anticipate certain end uses.

Allowable Stress. (See **Allowable Property.**)

American Lumber Standard. The American Softwood Lumber Standard, Voluntary Product Standard PS–20 (National Institute of Standards and Technology), establishes standard sizes and requirements for the development and coordination of lumber grades of various species, the assignment of design values when called for, and the preparation of grading rules applicable to each species. It provides for implementation of the standard through an accreditation and certification program to assure uniform industry-wide marking and inspection. A purchaser must, however, make use of grading association rules because the basic standards are not in themselves commercial rules.

Anisotropic. Exhibiting different properties when measured along different axes. In general, fibrous materials such as wood are anisotropic.

Assembly Joint. (See **Joint.**)

Assembly Time. (See **Time, Assembly.**)

Balanced Construction. A construction such that the forces induced by uniformly distributed changes in moisture content will not cause warping. Symmetrical construction of plywood in which the grain direction of each ply is perpendicular to that of adjacent plies is balanced construction.

Bark Pocket. An opening between annual growth rings that contains bark. Bark pockets appear as dark streaks on radial surfaces and as rounded areas on tangential surfaces.

Bastard Sawn. Lumber (primarily hardwoods) in which the annual rings make angles of 30° to 60° with the surface of the piece.

Beam. A structural member supporting a load applied transversely to it.

Bending, Steam. The process of forming curved wood members by steaming or boiling the wood and bending it to a form.

Bent Wood. (See **Bending, Steam.**)

Bird Peck. A small hole or patch of distorted grain resulting from birds pecking through the growing cells in the tree. The shape of bird peck usually resembles a carpet tack with the point towards the bark; bird peck is usually accompanied by discoloration extending for considerable distance along the grain and to a much lesser extent across the grain.

Birdseye. Small localized areas in wood with the fibers indented and otherwise contorted to form few to many small circular or elliptical figures remotely resembling birds' eyes on the tangential surface. Sometimes found in sugar maple and used for decorative purposes; rare in other hardwood species.

Blister. An elevation of the surface of an adherend, somewhat resembling in shape a blister on human skin; its boundaries may be indefinitely outlined, and it may have burst and become flattened. (A blister may be caused by insufficient adhesive; inadequate curing time, temperature, or pressure; or trapped air, water, or solvent vapor.)

Bloom. Crystals formed on the surface of treated wood by exudation and evaporation of the solvent in preservative solutions.

Blow. In plywood and particleboard especially, the development of steam pockets during hot pressing of the panel, resulting in an internal separation or rupture when pressure is released, sometimes with an audible report.

Blue Stain. (See **Stain.**)

Board. (See **Lumber.**)

Board Foot. A unit of measurement of lumber represented by a board 12 in. long, 12 in. wide, and 1 in. thick or its cubic equivalent. In practice, the board foot calculation for lumber 1 in. or more in thickness is based on its nominal thickness and width and the actual length. Lumber with a nominal thickness of less than 1 in. is calculated as 1 in.

Bole. The main stem of a tree of substantial diameter—roughly, capable of yielding sawtimber, veneer logs, or large poles. Seedlings, saplings, and small-diameter trees have stems, not boles.

Bolt. (1) A short section of a tree trunk. (2) In veneer production, a short log of a length suitable for peeling in a lathe.

Bond. (1) The union of materials by adhesives. (2) To unite materials by means of an adhesive.

Bondability. Term indicating ease or difficulty in bonding a material with adhesive.

Bond Failure. Rupture of adhesive bond.

Bondline. The layer of adhesive that attaches two adherends.

Bondline Slip. Movement within and parallel to the bondline during shear.

Bond Strength. The unit load applied in tension, compression, flexure, peel impact, cleavage, or shear required to break an adhesive assembly, with failure occurring in or near the plane of the bond.

Bow. The distortion of lumber in which there is a deviation, in a direction perpendicular to the flat face, from a straight line from end-to-end of the piece.

Box Beam. A built-up beam with solid wood flanges and plywood or wood-based panel product webs.

Boxed Heart. The term used when the pith falls entirely within the four faces of a piece of wood anywhere in its length. Also called boxed pith.

Brashness. A condition that causes some pieces of wood to be relatively low in shock resistance for the species and, when broken in bending, to fail abruptly without splintering at comparatively small deflections.

Breaking Radius. The limiting radius of curvature to which wood or plywood can be bent without breaking.

Bright. Free from discoloration.

Broad-Leaved Trees. (See **Hardwoods.**)

Brown Rot. (See **Decay.**)

Brown Stain. (See **Stain.**)

Built-Up Timbers. An assembly made by joining layers of lumber together with mechanical fastenings so that the grain of all laminations is essentially parallel.

Burl. (1) A hard, woody outgrowth on a tree, more or less rounded in form, usually resulting from the entwined growth of a cluster of adventitious buds. Such burls are the source of the highly figured burl veneers used for purely ornamental purposes. (2) In lumber or veneer, a localized severe distortion of the grain generally rounded in outline, usually resulting from overgrowth of dead branch stubs, varying from one to several centimeters (one-half to several inches) in diameter; frequently includes one or more clusters of several small contiguous conical protuberances, each usually having a core or pith but no appreciable amount of end grain (in tangential view) surrounding it.

Butt Joint. (See **Joint.**)

Buttress. A ridge of wood developed in the angle between a lateral root and the butt of a tree, which may extend up the stem to a considerable height.

Cambium. A thin layer of tissue between the bark and wood that repeatedly subdivides to form new wood and bark cells.

Cant. A log that has been slabbed on one or more sides. Ordinarily, cants are intended for resawing at right angles to their widest sawn face. The term is loosely used. (See **Flitch.**)

Casehardening. A condition of stress and set in dry lumber characterized by compressive stress in the outer layers and tensile stress in the center or core.

Catalyst. A substance that initiates or changes the rate of chemical reaction but is not consumed or changed by the reaction.

Cell. A general term for the anatomical units of plant tissue, including wood fibers, vessel members, and other elements of diverse structure and function.

Cellulose. The carbohydrate that is the principal constituent of wood and forms the framework of the wood cells.

Check. A lengthwise separation of the wood that usually extends across the rings of annual growth and commonly results from stresses set up in wood during seasoning.

Chemical Brown Stain. (See **Stain.**)

Chipboard. A paperboard used for many purposes that may or may not have specifications for strength, color, or other characteristics. It is normally made from paper stock with a relatively low density in the thickness of 0.1524 mm (0.006 in.) and up.

Cleavage. In an adhesively bonded joint, a separation in the joint caused by a wedge or other crack-opening-type action.

Close Grained. (See **Grain.**)

Coarse Grained. (See **Grain.**)

Cohesion. The state in which the constituents of a mass of material are held together by chemical and physical forces.

Cold Pressing. A bonding operation in which an assembly is subjected to pressure without the application of heat.

Cold-Press Plywood. (See **Wood-Based Composite Panel.**)

Collapse. The flattening of single cells or rows of cells in heartwood during the drying or pressure treatment of wood. Often characterized by a caved-in or corrugated appearance of the wood surface.

Compartment Kiln. (See **Kiln.**)

Composite Assembly. A combination of two or more materials bonded together that perform as a single unit.

Composite Panel. (See **Wood-Based Composite Panel.**)

Compound Curvature. Wood bent to a compound curvature, no element of which is a straight line.

Compreg. Wood in which the cell walls have been impregnated with synthetic resin and compressed to give it reduced swelling and shrinking characteristics and increased density and strength properties.

Compression Failure. Deformation of the wood fibers resulting from excessive compression along the grain either in direct end compression or in bending. It may develop in standing trees due to bending by wind or snow or to internal longitudinal stresses developed in growth, or it may result from stresses imposed after the tree is cut. In surfaced lumber, compression failures may appear as fine wrinkles across the face of the piece.

Compression Wood. Abnormal wood formed on the lower side of branches and inclined trunks of softwood trees. Compression wood is identified by its relatively wide annual rings (usually eccentric when viewed on cross section of branch or trunk), relatively large amount of latewood (sometimes more than 50% of the width of the annual rings in which it occurs), and its lack of demarcation between earlywood and latewood in the same annual rings. Compression wood shrinks excessively longitudinally, compared with normal wood.

Conditioning (pre and post). The exposure of a material to the influence of a prescribed atmosphere for a stipulated period of time or until a stipulated relation is reached between material and atmosphere.

Conifer. (See **Softwoods.**)

Connector, Timber. Metal rings, plates, or grids that are embedded in the wood of adjacent members, as at the bolted points of a truss, to increase the strength of the joint.

Consistency. That property of a liquid adhesive by virtue of which it tends to resist deformation. (Consistency is not a fundamental property but is composed of rheological properties such as viscosity, plasticity, and other phenomena.)

Construction Adhesive. (See **Adhesive.**)

Contact Angle. The angle between a substrate plane and the free surface of a liquid droplet at the line of contact with the substrate.

Cooperage. Containers consisting of two round heads and a body composed of staves held together with hoops, such as barrels and kegs.

Slack Cooperage—Cooperage used as containers for dry, semidry, or solid products. The staves are usually not closely fitted and are held together with beaded steel, wire, or wood hoops.

Tight Cooperage—Cooperage used as containers for liquids, semisolids, or heavy solids. Staves are well fitted and held tightly with cooperage-grade steel hoops.

Copolymer. Substance obtained when two or more types of monomers polymerize.

Corbel. A projection from the face of a wall or column supporting a weight.

Core Stock. A solid or discontinuous center ply used in panel-type glued structures (such as furniture panels and solid or hollowcore doors).

Coupling Agent. A molecule with different or like functional groups that is capable of reacting with surface molecules of two different substances, thereby chemically bridging the substances.

Covalent Bond. A chemical bond that results when electrons are shared by two atomic nuclei.

Creep. (1) Time dependent deformation of a wood member under sustained wood. (2) In an adhesive, the time-dependent increase in strain resulting from a sustained stress.

Crook. The distortion of lumber in which there is a deviation, in a direction perpendicular to the edge, from a straight line from end-to-end of the piece.

Crossband. To place the grain of layers of wood at right angles in order to minimize shrinking and swelling; also, in plywood of three or more plies, a layer of veneer whose grain direction is at right angles to that of the face plies.

Cross Break. A separation of the wood cells across the grain. Such breaks may be due to internal stress resulting from unequal longitudinal shrinkage or to external forces.

Cross Grained. (See **Grain.**)

Cross-Link. An atom or group connecting adjacent molecules in a complex molecular structure.

Cup. A distortion of a board in which there is a deviation flatwise from a straight line across the width of the board.

Cure. To change the properties of an adhesive by chemical reaction (which may be condensation, polymerization, or vulcanization) and thereby develop maximum strength. Generally accomplished by the action of heat or a catalyst, with or without pressure.

Curing Agent. (See **Hardener**.)

Curing Temperature. (See **Temperature, Curing.**)

Curing Time. (See **Time, Curing.**)

Curly Grained. (See **Grain.**)

Curtain Coating. Applying liquid adhesive to an adherend by passing the adherend under a thin curtain of liquid falling by gravity or pressure.

Cut Stock. (See **Lumber for Dimension**.)

Cuttings. In hardwoods, portions of a board or plank having the quality required by a specific grade or for a particular use. Obtained from a board by crosscutting or ripping.

Decay. The decomposition of wood substance by fungi.

Advanced (Typical) Decay—The older stage of decay in which the destruction is readily recognized because the wood has become punky, soft and spongy, stringy, ringshaked, pitted, or crumbly. Decided discoloration or bleaching of the rotted wood is often apparent.

Brown Rot—In wood, any decay in which the attack concentrates on the cellulose and associated carbohydrates rather than on the lignin, producing a light to dark brown friable residue—hence loosely termed "dry rot." An advanced stage where the wood splits along rectangular planes, in shrinking, is termed "cubical rot."

Dry Rot—A term loosely applied to any dry, crumbly rot but especially to that which, when in an advanced stage, permits the wood to be crushed easily to a dry powder. The term is actually a misnomer for any decay, since all fungi require considerable moisture for growth.

Incipient Decay—The early stage of decay that has not proceeded far enough to soften or otherwise perceptibly impair the hardness of the wood. It is usually accompanied by a slight discoloration or bleaching of the wood.

Heart Rot—Any rot characteristically confined to the heartwood. It generally originates in the living tree.

Pocket Rot—Advanced decay that appears in the form of a hole or pocket, usually surrounded by apparently sound wood.

Soft Rot—A special type of decay developing under very wet conditions (as in cooling towers and boat timbers) in the outer wood layers, caused by cellulose-destroying microfungi that attack the secondary cell walls and not the intercellular layer.

White-Rot—In wood, any decay or rot attacking both the cellulose and the lignin, producing a generally whitish residue that may be spongy or stringy rot, or occur as pocket rot.

Delamination. The separation of layers in laminated wood or plywood because of failure of the adhesive, either within the adhesive itself or at the interface between the adhesive and the adherend.

Delignification. Removal of part or all of the lignin from wood by chemical treatment.

Density. As usually applied to wood of normal cellular form, density is the mass per unit volume of wood substance enclosed within the boundary surfaces of a wood–plus–voids complex. It is variously expressed as pounds per cubic foot, kilograms per cubic meter, or grams per cubic centimeter at a specified moisture content.

Density Rules. A procedure for segregating wood according to density, based on percentage of latewood and number of growth rings per inch of radius.

Dew Point. The temperature at which a vapor begins to deposit as a liquid. Applies especially to water in the atmosphere.

Diagonal Grained. (See **Grain.**)

Diffuse-Porous Wood. Certain hardwoods in which the pores tend to be uniform in size and distribution throughout each annual ring or to decrease in size slightly and gradually toward the outer border of the ring.

Dimension. (See **Lumber for Dimension.**)

Dipole–Dipole Forces. Intermolecular attraction forces between polar molecules that result when positive and negative poles of molecules are attracted to one another.

Dote. “Dote,” “doze,” and “rot” are synonymous with “decay” and are any form of decay that may be evident as either a discoloration or a softening of the wood.

Double Spread. (See **Spread.**)

Dry-Bulb Temperature. The temperature of air as indicated by a standard thermometer. (See **Psychrometer.**)

Dry Kiln. (See **Kiln.**)

Dry Rot. (See **Decay.**)

Dry Strength. The strength of an adhesive joint determined immediately after drying under specified conditions or after a period of conditioning in a standard laboratory atmosphere.

Dry Wall. Interior covering material, such as gypsum board, hardboard, or plywood, which is applied in large sheets or panels.

Durability. A general term for permanence or resistance to deterioration. Frequently used to refer to the degree of resistance of a species of wood to attack by wood-destroying fungi under conditions that favor such attack. In this connection, the term “decay resistance” is more specific. As applied to bondlines, the life expectancy of the structural qualities of the adhesive under the anticipated service conditions of the structure.

Earlywood. The portion of the growth ring that is formed during the early part of the growing season. It is usually less dense and weaker mechanically than latewood.

Edge Grained. (See **Grain.**)

Edge Joint. (See **Joint.**)

Elastomer. A macromolecular material that, at room temperature, is deformed by application of a relatively low force and is capable of recovering substantially in size and shape after removal of the force.

Embrittlement. A loss in strength or energy absorption without a corresponding loss in stiffness. Clear, straight-grained wood is generally considered a ductile material; chemical treatments and elevated temperatures can alter the original chemical composition of wood, thereby embrittling the wood.

Encased Knot. (See **Knot.**)

End Grained. (See **Grain.**)

End Joint. (See **Joint.**)

Equilibrium Moisture Content. The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

Excelsior. (See **Wood Wool.**)

Extender. A substance, generally having some adhesive action, added to an adhesive to reduce the amount of the primary binder required per unit area.

Exterior Plywood. (See **Wood-Based Composite Panel.**)

Extractive. Substances in wood, not an integral part of the cellular structure, that can be removed by solution in hot or cold water, ether, benzene, or other solvents that do not react chemically with wood components.

Extrusion Spreading. A method of adhesive application in which adhesive is forced through small openings in the spreader head.

Factory and Shop Lumber. (See **Lumber.**)

Failure, Adherend. Rupture of an adhesive joint, such that the separation appears to be within the adherend.

Failure, Adhesive. Rupture of an adhesive joint, such that the plane of separation appears to be at the adhesive–adherend interface.

Failure, Cohesive. Rupture of an adhesive joint, such that the separation appears to be within the adhesive.

Feed Rate. The distance that the stock being processed moves during a given interval of time or operational cycle.

Fiber, Wood. A wood cell comparatively long (≤40 to 300 mm, ≤1.5 to 12 in.), narrow, tapering, and closed at both ends.

Fiberboard. (See **Wood-Based Composite Panel.**)

Fiber Saturation Point. The stage in the drying or wetting of wood at which the cell walls are saturated and the cell cavities free from water. It applies to an individual cell or group of cells, not to whole boards. It is usually taken as approximately 30% moisture content, based on ovendry weight.

Fibril. A threadlike component of cell walls, invisible under a light microscope.

Figure. The pattern produced in a wood surface by annual growth rings, rays, knots, deviations from regular grain such as interlocked and wavy grain, and irregular coloration.

Filler. In woodworking, any substance used to fill the holes and irregularities in planed or sanded surfaces to decrease the porosity of the surface before applying finish coatings. As applied to adhesives, a relatively nonadhesive substance added to an adhesive to improve its working properties, strength, or other qualities.

Fine Grained. (See **Grain.**)

Fingerjoint. (See **Joint.**)

Finish (Finishing). (1) Wood products such as doors, stairs, and other fine work required to complete a building, especially the interior. (2) Coatings of paint, varnish, lacquer, wax, or other similar materials applied to wood surfaces to protect and enhance their durability or appearance.

Fire Endurance. A measure of the time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance.

Fire Resistance. The property of a material or assembly to withstand fire or give protection from it. As applied to elements of buildings, it is characterized by the ability to confine a fire or to continue to perform a given structural function, or both.

Fire Retardant. (See **Flame Retardant.**)

Fire-Retardant-Treated Wood. As specified in building codes, a wood product that has been treated with chemicals by a pressure process or treated during the manufacturing process for the purpose of reducing its flame spread performance in an ASTM E84 test conducted for 30 min to performance levels specified in the codes.

Flake. A small flat wood particle of predetermined dimensions, uniform thickness, with fiber direction essentially in the plane of the flake; in overall character resembling a small piece of veneer. Produced by special equipment for use in the manufacture of flakeboard.

Flakeboard. (See **Wood-Based Composite Panel.**)

Flame Retardant. A treatment, coating, or chemicals that when applied to wood products delays ignition and reduces the flame spread of the product.

Flame Spread. The propagation of a flame away from the source of ignition across the surface of a liquid or a solid, or through the volume of a gaseous mixture.

Flat Grained. (See **Grain.**)

Flat Sawn. (See **Grain.**)

Flecks. (See **Rays, Wood.**)

Flitch. A portion of a log sawn on two or more faces—commonly on opposite faces leaving two waney edges. When intended for resawing into lumber, it is resawn parallel to its original wide faces. Or, it may be sliced or sawn into veneer, in which case the resulting sheets of veneer laid together in the sequence of cutting are called a flitch. The term is loosely used. (See **Cant.**)

Framing. Lumber used for the structural member of a building, such as studs and joists.

Full-Cell Process. Any process for impregnating wood with preservatives or chemicals in which a vacuum is drawn to remove air from the wood before admitting the preservative. This favors heavy adsorption and retention of preservative in the treated portions.

Furnish. Wood material that has been reduced for incorporation into wood-based fiber or particle panel products.

Gelatinous Fibers. Modified fibers that are associated with tension wood in hardwoods.

Girder. A large or principal beam used to support concentrated loads at isolated points along its length.

Gluability. (See **Bondability.**)

Glue. Originally, a hard gelatin obtained from hides, tendons, cartilage, bones, etc., of animals. Also, an adhesive prepared from this substance by heating with water. Through general use the term is now synonymous with the term "adhesive."

Glue Laminating. Production of structural or nonstructural wood members by bonding two or more layers of wood together with adhesive.

Glueline. (See **Bondline.**)

Grade. The designation of the quality of a manufactured piece of wood or of logs.

Grain. The direction, size, arrangement, appearance, or quality of the fibers in wood or lumber. To have a specific meaning the term must be qualified.

Close-Grained (Fine-Grained) Wood—Wood with narrow, inconspicuous annual rings. The term is sometimes used to designate wood having small and closely spaced pores, but in this sense the term "fine textured" is more often used.

Coarse-Grained Wood—Wood with wide conspicuous annual rings in which there is considerable difference between earlywood and latewood. The term is sometimes used to designate wood with large pores, such as oak, keruing, meranti, and walnut, but in this sense, the term "open-grained" is more often used.

Cross-Grained Wood—Wood in which the fibers deviate from a line parallel to the sides of the piece. Cross grain may be either diagonal or spiral grain or a combination of the two.

Curly-Grained Wood—Wood in which the fibers are distorted so that they have a curled appearance, as in "birdseye" wood. The areas showing curly grain may vary up to several inches in diameter.

Diagonal-Grained Wood—Wood in which the annual rings are at an angle with the axis of a piece as a result of sawing at an angle with the bark of the tree or log. A form of cross-grain.

Edge-Grained Lumber—Lumber that has been sawed so that the wide surfaces extend approximately at right angles to the annual growth rings. Lumber is considered edge grained when the rings form an angle of 45° to 90° with the wide surface of the piece.

End-Grained Wood—The grain as seen on a cut made at a right angle to the direction of the fibers (such as on a cross section of a tree).

Fiddleback-Grained Wood—Figure produced by a type of fine wavy grain found, for example, in species of maple; such wood being traditionally used for the backs of violins.

Flat-Grained (Flat-Sawn) Lumber—Lumber that has been sawn parallel to the pith and approximately tangent to the growth rings. Lumber is considered flat grained when the annual growth rings make an angle of less than 45° with the surface of the piece.

Interlocked-Grained Wood—Grain in which the fibers put on for several years may slope in a right-handed direction, and then for a number of years the slope reverses to a left-handed direction, and later changes back to a right-handed pitch, and so on. Such wood is exceedingly difficult to split radially, though tangentially it may split fairly easily.

Open-Grained Wood—Common classification for woods with large pores such as oak, keruing, meranti, and walnut. Also known as "coarse textured."

Plainsawn Lumber—Another term for flat-grained lumber.

Quartersawn Lumber—Another term for edge-grained lumber.

Side-Grained Wood—Another term for flat-grained lumber.

Slash-Grained Wood—Another term for flat-grained lumber.

Spiral-Grained Wood—Wood in which the fibers take a spiral course about the trunk of a tree instead of the normal vertical course. The spiral may extend in a right-handed or left-handed direction around the tree trunk. Spiral grain is a form of cross grain.

Straight-Grained Wood—Wood in which the fibers run parallel to the axis of a piece.

Vertical-Grained Lumber—Another term for edge-grained lumber.

Wavy-Grained Wood—Wood in which the fibers collectively take the form of waves or undulations.

Green. Freshly sawed or undried wood. Wood that has become completely wet after immersion in water would not be considered green but may be said to be in the "green condition."

Growth Ring. The layer of wood growth put on a tree during a single growing season. In the temperate zone, the annual growth rings of many species (for example, oaks and pines) are readily distinguished because of differences in the cells formed during the early and late parts of the season. In some temperate zone species (black gum and sweetgum) and many tropical species, annual growth rings are not easily recognized.

Gum. A comprehensive term for nonvolatile viscous plant exudates, which either dissolve or swell up in contact with water. Many substances referred to as gums such as pine and spruce gum are actually oleoresins.

Hardboard. (See **Wood-Based Composite Panel.**)

Hardener. A substance or mixture of substances that is part of an adhesive and is used to promote curing by taking part in the reaction.

Hardness. A property of wood that enables it to resist indentation.

Hardwoods. Generally one of the botanical groups of trees that have vessels or pores and broad leaves, in contrast to the conifers or softwoods. The term has no reference to the actual hardness of the wood.

Heart Rot. (See **Decay.**)

Heartwood. The wood extending from the pith to the sapwood, the cells of which no longer participate in the life processes of the tree. Heartwood may contain phenolic compounds, gums, resins, and other materials that usually make it darker and more decay resistant than sapwood.

Hemicellulose. A celluloselike material (in wood) that is easily decomposable as by dilute acid, yielding several different simple sugars.

Hertz. A unit of frequency equal to one cycle per second.

High Frequency Curing. (See **Radiofrequency Curing.**)

Hollow-Core Construction. A panel construction with faces of plywood, hardboard, or similar material bonded to a framed-core assembly of wood lattice, paperboard rings, or the like, which support the facing at spaced intervals.

Honeycomb Core. A sandwich core material constructed of thin sheet materials or ribbons formed to honeycomb-like configurations.

Honeycombing. Checks, often not visible at the surface, that occur in the interior of a piece of wood, usually along the wood rays.

Horizontally Laminated Timber. (See **Laminated Timbers.**)

Hot-Setting Adhesive. (See **Adhesive.**)

Hydrogen Bond. An intermolecular attraction force that results when the hydrogen of one molecule and a pair of unshared electrons on an electronegative atom of another molecule are attracted to one another.

Hydrophilic. Having a strong tendency to bind or absorb water.

Hydrophobic. Having a strong tendency to repel water.

Impreg. Wood in which the cell walls have been impregnated with synthetic resin so as to reduce materially its swelling and shrinking. Impreg is not compressed.

Incising. A pretreatment process in which incisions, slits, or perforations are made in the wood surface to increase penetration of preservative treatments. Incising is often required to enhance durability of some difficult-to-treat species, but incising reduces strength.

Increment Borer. An augerlike instrument with a hollow bit and an extractor, used to extract thin radial cylinders of wood from trees to determine age and growth rate. Also used in wood preservation to determine the depth of penetration of a preservative.

Insulating Board. (See **Wood-Based Composite Panel.**)

Intergrown Knot. (See **Knot.**)

Interlocked Grained. (See **Grain.**)

Interlocking Action. (See **Mechanical Adhesion.**)

Internal Stresses. Stresses that exist within an adhesive joint even in the absence of applied external forces.

Interphase. In wood bonding, a region of finite thickness as a gradient between the bulk adherend and bulk adhesive in which the adhesive penetrates and alters the adherend's properties and in which the presence of the adherend influences the chemical and/or physical properties of the adhesive.

Intumesce. To expand with heat to provide a low-density film; used in reference to certain fire-retardant coatings.

Isotropic. Exhibiting the same properties in all directions.

Joint. The junction of two pieces of wood or veneer.

Adhesive Joint—The location at which two adherends are held together with a layer of adhesive.

Assembly Joint—Joints between variously shaped parts or subassemblies such as in wood furniture (as opposed to joints in plywood and laminates that are all quite similar).

Butt Joint—An end joint formed by abutting the squared ends of two pieces.

Edge Joint—A joint made by bonding two pieces of wood together edge to edge, commonly by gluing. The joints may be made by gluing two squared edges as in a plain edge joint or by using machined joints of various kinds, such as tongued-and-grooved joints.

End Joint—A joint made by bonding two pieces of wood together end to end, commonly by finger or scarf joint.

Fingerjoint—An end joint made up of several meshing wedges or fingers of wood bonded together with an adhesive. Fingers are sloped and may be cut parallel to either the wide or narrow face of the piece.

Lap Joint—A joint made by placing one member partly over another and bonding the overlapped portions.

Scarf Joint—An end joint formed by joining with adhesive the ends of two pieces that have been tapered or beveled to form sloping plane surfaces, usually to a featheredge, and with the same slope of the plane with respect to the length in both pieces. In some cases, a step or hook may be machined into the scarf to facilitate alignment of the two ends, in which case the plane is discontinuous and the joint is known as a stepped or hooked scarf joint.

Starved Joint—A glue joint that is poorly bonded because an insufficient quantity of adhesive remained in the joint.

Sunken Joint—Depression in wood surface at a joint (usually an edge joint) caused by surfacing material too soon after bonding. (Inadequate time was allowed for moisture added with the adhesive to diffuse away from the joint.)

Joint Efficiency or Factor. The strength of a joint expressed as a percentage of the strength of clear straight-grained material.

Joist. One of a series of parallel beams used to support floor and ceiling loads and supported in turn by larger beams, girders, or bearing walls.

Kiln. A chamber having controlled air-flow, temperature, and relative humidity for drying lumber. The temperature is increased as drying progresses, and the relative humidity is decreased.

Kiln Dried. (See **Seasoning.**)

Knot. That portion of a branch or limb that has been surrounded by subsequent growth of the stem. The shape of the knot as it appears on a cut surface depends on the angle of the cut relative to the long axis of the knot.

Encased Knot—A knot whose rings of annual growth are not intergrown with those of the surrounding wood.

Intergrown Knot—A knot whose rings of annual growth are completely intergrown with those of the surrounding wood.

Loose Knot—A knot that is not held firmly in place by growth or position and that cannot be relied upon to remain in place.

Pin Knot—A knot that is not more than 12 mm (1/2 in.) in diameter.

Sound Knot—A knot that is solid across its face, at least as hard as the surrounding wood, and shows no indication of decay.

Spike Knot—A knot cut approximately parallel to its long axis so that the exposed section is definitely elongated.

Laminate. A product made by bonding together two or more layers (laminations) of material or materials.

Laminate, Paper-Based. A multilayered panel made by compressing sheets of resin-impregnated paper together into a coherent solid mass.

Laminated Timbers. An assembly made by bonding layers of veneer or lumber with an adhesive so that the grain of all laminations is essentially parallel. (See **Built-Up Timbers.**)

Horizontally Laminated Timbers—Laminated timbers designed to resist bending loads applied perpendicular to the wide faces of the laminations.

Vertically Laminated Timbers—Laminated timbers designed to resist bending loads applied parallel to the wide faces of the laminations.

Laminated Veneer Lumber (LVL). (See **Wood-Based Composite Panel.**)

Lap Joint. (See **Joint.**)

Latewood. The portion of the growth ring that is formed after the earlywood formation has ceased. It is usually denser and stronger mechanically than earlywood.

Latex Paint. A paint containing pigments and a stable water suspension of synthetic resins (produced by emulsion polymerization) that forms an opaque film through coalescence of the resin during water evaporation and subsequent curing.

Lathe Checks. In rotary-cut and sliced veneer, the fractures or checks that develop along the grain of the veneer as the knife peels veneer from the log. The knife side of the veneer where checks occur is called the loose side. The opposite and log side of the veneer where checking usually does not occur is called the tight side.

Layup. The process of loosely assembling the adhesive-coated components of a unit, particularly a panel, to be pressed or clamped.

Lbs/MSGL. Abbreviation for rate of adhesive application in pounds of adhesive per 1,000 ft^2 of single glueline (bondline). (See **Spread**.) When both faces of an adherend are spread as in some plywood manufacturing processes, the total weight of adhesive applied may be expressed as Lbs/MDGL (pounds per 1,000 ft^2 double glueline).

Lignin. The second most abundant constituent of wood, located principally in the secondary wall and the middle lamella, which is the thin cementing layer between wood cells. Chemically, it is an irregular polymer of substituted propylphenol groups, and thus, no simple chemical formula can be written for it.

London Dispersion Forces. Intermolecular attraction forces between nonpolar molecules that result when instantaneous (nonpermanent) dipoles induce matching dipoles in neighboring molecules. London forces also exist between polar molecules.

Longitudinal. Generally, parallel to the direction of the wood fibers.

Loose Knot. (See **Knot.**)

Lumber. The product of the saw and planing mill for which manufacturing is limited to sawing, resawing, passing lengthwise through a standard planing machine, crosscutting to length, and matching. Lumber may be made from either softwood or hardwood (See also **Lumber for Dimension**.)

Board—Lumber that is less than 38 mm standard (2 in. nominal) thickness and greater than 38 mm standard (2 in nominal) width. Boards less than 140 mm standard (6 in. nominal) width are sometimes called strips.

Dimension—Lumber with a thickness from 38 mm standard (2 in. nominal) up to but not including 114 mm standard (5 in. nominal) and a width of greater than 38 mm standard (2 in. nominal).

Dressed Size—The dimensions of lumber after being surfaced with a planing machine. The dressed size is usually 1/2 to 3/4 in. less than the nominal or rough size. A 2- by 4-in. stud, for example, actually measures about 1-1/2 by 3-1/2 in. (standard 38 by 89 mm).

Factory and Shop Lumber—Lumber intended to be cut up for use in further manufacture. It is graded on the percentage of the area that will produce a limited number of cuttings of a specified minimum size and quality.

Matched Lumber—Lumber that is edge dressed and shaped to make a close tongued-and-grooved joint at the edges or ends when laid edge to edge or end to end.

Nominal Size—As applied to timber or lumber, the size by which it is known and sold in the market (often differs from the actual size).

Patterned Lumber—Lumber that is shaped to a pattern or to a molded form in addition to being dressed, matched, or shiplapped, or any combination of these workings.

Rough Lumber—Lumber that has not been dressed (surfaced) but has been sawed, edged, and trimmed.

Shiplapped Lumber—Lumber that is edge dressed to make a lapped joint.

Shipping-Dry Lumber—Lumber that is partially dried to prevent stain and mold in transit.

Shop Lumber—(See **Factory and Shop Lumber.**)

Side Lumber—A board from the outer portion of the log—ordinarily one produced when squaring off a log for a tie or timber.

Structural Lumber—Lumber that is intended for use where allowable properties are required. The grading of structural lumber is based on the strength or stiffness of the piece as related to anticipated uses.

Surfaced Lumber—Lumber that is dressed by running it through a planer.

Timbers—Lumber that is standard 114 mm (nominal 5 in.) or more in least dimension. Timbers may be used as beams, stringers, posts, caps, sills, girders, or purlins.

Yard Lumber—A little-used term for lumber of all sizes and patterns that is intended for general building purposes having no design property requirements.

Lumber for Dimension. The National Dimension Manufacturers Association defines both hardwood and softwood dimension components as being cut to a specific size from kiln-dried rough lumber, bolts, cants, or logs. Dimension components include Flat Stock (solid and laminated) for furniture, cabinet, and specialty manufactures. This term has largely superceded the terms "hardwood dimension" and "dimension parts." (See also **Lumber**).

Lumen. In wood anatomy, the cell cavity.

Manufacturing Defects. Includes all defects or blemishes that are produced in manufacturing, such as chipped grain, loosened grain, raised grain, torn grain, skips in dressing, hit and miss (series of surfaced areas with skips between them), variation in sawing, miscut lumber, machine burn, machine gouge, mismatching, and insufficient tongue or groove.

Mastic. A material with adhesive properties, usually used in relatively thick sections, that can be readily applied by extrusion, trowel, or spatula. (See **Adhesive.**)

Matched Lumber. (See **Lumber.**)

Mechanical Adhesion. Adhesion between surfaces in which the adhesive holds the parts together by interlocking action.

Medium-Density Fiberboard. (See **Wood-Based Composite Panel.**)

Millwork. Planed and patterned lumber for finish work in buildings, including items such as sash, doors, cornices, panelwork, and other items of interior or exterior trim. Does not include flooring, ceiling, or siding.

Mineral Streak. An olive to greenish-black or brown discoloration of undetermined cause in hardwoods.

Modified Wood. Wood processed by chemical treatment, compression, or other means (with or without heat) to impart properties quite different from those of the original wood.

Moisture Content. The amount of water contained in the wood, usually expressed as a percentage of the weight of the ovendry wood.

Molecular Weight. The sum of the atomic weights of the atoms in a molecule.

Moulded Plywood. (See **Wood-Based Composite Panel.**)

Moulding. A wood strip having a curved or projecting surface, used for decorative purposes.

Monomer. A relatively simple molecular compound that can react at more than one site to form a polymer.

Mortise. A slot cut into a board, plank, or timber, usually edgewise, to receive the tenon of another board, plank, or timber to form a joint.

Naval Stores. A term applied to the oils, resins, tars, and pitches derived from oleoresin contained in, exuded by, or extracted from trees, chiefly species of pines (genus *Pinus*). Historically, these were important items in the stores of wood sailing vessels.

Nominal-Size Lumber. (See **Lumber for Dimension.**)

Nonpolar. (See **Polar**.)

Nonpressure Process. Any process of treating wood with a preservative or fire retardant where pressure is not applied. Some examples are surface applications by brushing or brief dipping, soaking in preservative oils, or steeping in solutions of waterborne preservatives; diffusion processes with waterborne preservatives; and vacuum treatments.

Oil Paint. A paint containing a suspension of pigments in an organic solvent and a drying oil, modified drying oil, or synthetic polymer that forms an opaque film through a combination of solvent evaporation and curing of the oil or polymer.

Old Growth. Timber in or from a mature, naturally established forest. When the trees have grown during most if not all of their individual lives in active competition with their companions for sunlight and moisture, this timber is usually straight and relatively free of knots.

Oleoresin. A solution of resin in an essential oil that occurs in or exudes from many plants, especially softwoods. The oleoresin from pine is a solution of pine resin (rosin) in turpentine.

Open Assembly Time. (See **Time, Assembly.**)

Open Grain. (See **Grain.**)

Orthotropic. Having unique and independent properties in three mutually orthogonal (perpendicular) planes of symmetry. A special case of anisotropy.

Ovendry Wood. Wood dried to a relatively constant weight in a ventilated oven at 102°C to 105°C (215°F to 220°F).

Overlay. A thin layer of paper, plastic, film, metal foil, or other material bonded to one or both faces of panel products or to lumber to provide a protective or decorative face or a base for painting.

Paint. Any pigmented liquid, liquifiable, or mastic composition designed for application to a substrate in a thin layer that converts to an opaque solid film after application.

Pallet. A low wood or metal platform on which material can be stacked to facilitate mechanical handling, moving, and storage.

Paperboard. The distinction between paper and paperboard is not sharp, but broadly speaking, the thicker (greater than 0.3 mm (0.012 in.)), heavier, and more rigid grades of paper are called paperboard.

Papreg. Any of various paper products made by impregnating sheets of specially manufactured high-strength paper with synthetic resin and laminating the sheets to form a dense, moisture-resistant product.

Parallel Strand Lumber. A structural composite lumber made from wood strand elements with the wood fiber oriented primarily along the length of the member.

Parenchyma. Short cells having simple pits and functioning primarily in the metabolism and storage of plant food materials. They remain alive longer than the tracheids, fibers, and vessel elements, sometimes for many years. Two kinds of parenchyma cells are recognized—those in vertical strands, known more specifically as axial parenchyma, and those in horizontal series in the rays, known as ray parenchyma.

Particles. The aggregate component of particleboard manufactured by mechanical means from wood. These include all small subdivisions of wood such as chips, curls, flakes, sawdust, shavings, slivers, strands, wafers, wood flour, and wood wool.

Peck. Pockets or areas of disintegrated wood caused by advanced stages of localized decay in the living tree. It is usually associated with cypress and incense-cedar. There is no further development of peck once the lumber is seasoned.

Peel. To convert a log into veneer by rotary cutting. In an adhesively bonded joint, the progressive separation of a flexible member from either a rigid member or another flexible member.

Phloem. The tissues of the inner bark, characterized by the presence of sieve tubes and serving for the transport of elaborate foodstuffs.

Pile. A long, heavy timber, round or square, that is driven deep into the ground to provide a secure foundation for structures built on soft, wet, or submerged sites (for example, landing stages, bridge abutments).

Pin Knot. (See **Knot.**)

Pitch Pocket. An opening extending parallel to the annual growth rings and containing, or that has contained, pitch, either solid or liquid.

Pitch Streaks. A well-defined accumulation of pitch in a more or less regular streak in the wood of certain conifers.

Pith. The small, soft core occurring near the center of a tree trunk, branch, twig, or log.

Pith Fleck. A narrow streak, resembling pith on the surface of a piece; usually brownish, up to several centimeters long; results from burrowing of larvae in the growing tissues of the tree.

Plainsawn. (See **Grain.**)

Planing Mill Products. Products worked to pattern, such as flooring, ceiling, and siding.

Plank. A broad, thick board laid with its wide dimension horizontal and used as a bearing surface.

Plasticizing Wood. Softening wood by hot water, steam, or chemical treatment to increase its moldability.

Pocket Rot. (See **Decay.**)

Polar. Characteristic of a molecule in which the positive and negative electrical charges are permanently separated, as opposed to nonpolar molecules in which the charges coincide. Water, alcohol, and wood are polar in nature; most hydrocarbon liquids are not.

Polymer. A compound formed by the reaction of simple molecules having functional groups that permit their combination to proceed to high molecular weights under suitable conditions. Polymers may be formed by polymerization (addition polymer) or polycondensation (condensation polymer). When two or more different monomers are involved, the product is called a copolymer.

Polymerization. A chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more different monomers are involved, the process is called copolymerization.

Pore. (See **Vessel Elements.**)

Postformed Plywood. (See **Wood-Based Composite Panel.**)

Post Cure. (1) A treatment (normally involving heat) applied to an adhesive assembly following the initial cure, to complete cure, or to modify specific properties. (2) To expose an adhesive assembly to an additional cure, following the initial cure; to complete cure; or to modify specific properties.

Pot Life. (See **Working Life.**)

Precure. Condition of too much cure, set, or solvent loss of the adhesive before pressure is applied, resulting in inadequate flow, transfer, and bonding.

Preservative. Any substance that, for a reasonable length of time, is effective in preventing the development and action of wood-rotting fungi, borers of various kinds, and harmful insects that deteriorate wood.

Pressure Process. Any process of treating wood in a closed container whereby the preservative or fire retardant is forced into the wood under pressures greater than one atmosphere. Pressure is generally preceded or followed by vacuum, as in the vacuum-pressure and empty-cell processes respectively; or they may alternate, as in the full-cell and alternating-pressure processes.

Progressive Kiln. (See **Kiln.**)

Psychrometer. An instrument for measuring the amount of water vapor in the atmosphere. It has both a dry-bulb and wet-bulb thermometer. The bulb of the wet-bulb thermometer is kept moistened and is, therefore, cooled by evaporation to a temperature lower than that shown by the dry-bulb thermometer. Because evaporation is greater in dry air, the difference between the two thermometer readings will be greater when the air is dry than when it is moist.

Quartersawn. (See **Grain.**)

Radial. Coincident with a radius from the axis of the tree or log to the circumference. A radial section is a lengthwise section in a plane that passes through the centerline of the tree trunk.

Radiofrequency (RF) Curing. Curing of bondlines by the application of radiofrequency energy. (Sometimes called high-frequency curing.)

Rafter. One of a series of structural members of a roof designed to support roof loads. The rafters of a flat roof are sometimes called roof joists.

Raised Grain. A roughened condition of the surface of dressed lumber in which the hard latewood is raised above the softer earlywood but not torn loose from it.

Rays, Wood. Strips of cells extending radially within a tree and varying in height from a few cells in some species to 4 or more inches in oak. The rays serve primarily to store food and transport it horizontally in the tree. On quartersawn oak, the rays form a conspicuous figure, sometimes referred to as flecks.

Reaction Wood. Wood with more or less distinctive anatomical characters, formed typically in parts of leaning or crooked stems and in branches. In hardwoods, this consists of tension wood, and in softwoods, compression wood.

Relative Humidity. Ratio of the amount of water vapor present in the air to that which the air would hold at saturation at the same temperature. It is usually considered on the basis of the weight of the vapor but, for accuracy, should be considered on the basis of vapor pressures.

Resilience. The property whereby a strained body gives up its stored energy on the removal of the deforming force.

Resin. (1) Solid, semisolid, or pseudosolid resin—An organic material that has an indefinite and often high molecular weight, exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally. (2) Liquid resin—an organic polymeric liquid that, when converted to its final state for use, becomes a resin.

Resin Ducts. Intercellular passages that contain and transmit resinous materials. On a cut surface, they are usually inconspicuous. They may extend vertically parallel to the axis of the tree or at right angles to the axis and parallel to the rays.

Retention by Assay. The determination of preservative retention in a specific zone of treated wood by extraction or analysis of specified samples.

Rheology. The study of the deformation and flow of matter.

Ring Failure. A separation of the wood during seasoning, occurring along the grain and parallel to the growth rings. (See **Shake**.)

Ring-Porous Woods. A group of hardwoods in which the pores are comparatively large at the beginning of each annual ring and decrease in size more or less abruptly toward the outer portion of the ring, thus forming a distinct inner zone of pores, known as the earlywood, and an outer zone with smaller pores, known as the latewood.

Ring Shake. (See **Shake.**)

Rip. To cut lengthwise, parallel to the grain.

Roll Spreading. Application of a film of a liquid material to a surface by means of rollers.

Room-Temperature-Setting Adhesive. (See **Adhesive.**)

Rot. (See **Decay.**)

Rotary-Cut Veneer. (See **Veneer.**)

Rough Lumber. (See **Lumber.**)

Sandwich Construction. (See **Structural Sandwich Construction.**)

Sap Stain. (See **Stain.**)

Sapwood. The wood of pale color near the outside of the log. Under most conditions, the sapwood is more susceptible to decay than heartwood.

Sash. A frame structure, normally glazed (such as a window), that is hung or fixed in a frame set in an opening.

Sawn Veneer. (See **Veneer.**)

Saw Kerf. (1) Grooves or notches made in cutting with a saw. (2) That portion of a log, timber, or other piece of wood removed by the saw in parting the material into two pieces.

Scarf Joint. (See **Joint.**)

Schedule, Kiln Drying. A prescribed series of dry- and wet-bulb temperatures and air velocities used in drying a kiln charge of lumber or other wood products.

Seasoning. Removing moisture from green wood to improve its serviceability.

Air Dried—Dried by exposure to air in a yard or shed, without artificial heat.

Kiln Dried—Dried in a kiln with the use of artificial heat.

Second Growth. Timber that has grown after the removal, whether by cutting, fire, wind, or other agency, of all or a large part of the previous stand.

Semitransparent Stain. A suspension of pigments in either a drying oil–organic solvent mixture or a water–polymer emulsion, designed to color and protect wood surfaces by penetration without forming a surface film and without hiding wood grain.

Set. A permanent or semipermanent deformation. In reference to adhesives, to convert an adhesive into a fixed or hardened state by chemical or physical action, such as condensation, polymerization, oxidation, vulcanization, gelation, hydration, or evaporation of volatile constituents.

Shake. A separation along the grain, the greater part of which occurs between the rings of annual growth. Usually considered to have occurred in the standing tree or during felling.

Shakes. In construction, shakes are a type of shingle usually hand cleft from a bolt and used for roofing or weatherboarding.

Shaving. A small wood particle of indefinite dimensions developed incidental to certain woodworking operations involving rotary cutterheads usually turning in the direction of the grain. This cutting action produces a thin chip of varying thickness, usually feathered along at least one edge and thick at another and generally curled.

Shear. In an adhesively bonded joint, stress, strain, or failure resulting from applied forces that tends to cause adjacent planes of a body to slide parallel in opposite directions.

Sheathing. The structural covering, usually of boards, building fiberboards, or plywood, placed over exterior studding or rafters of a structure.

Shelf Life. (See **Storage Life.**)

Shiplapped Lumber. (See **Lumber.**)

Shipping-Dry Lumber. (See **Lumber.**)

Shop Lumber. (See **Lumber**.)

Side Grained. (See **Grain.**)

Side Lumber. (See **Lumber.**)

Siding. The finish covering of the outside wall of a frame building, whether made of horizontal weatherboards, vertical boards with battens, shingles, or other material.

Slash Grained. (See **Grain.**)

Sliced Veneer. (See **Veneer.**)

Soft Rot. (See **Decay.**)

Softwoods. Generally, one of the botanical groups of trees that have no vessels and in most cases, have needlelike or scalelike leaves, the conifers, also the wood produced by such trees. The term has no reference to the actual hardness of the wood.

Solid Color Stains (Opaque Stains). A suspension of pigments in either a drying oil–organic solvent mixture or a water–polymer emulsion designed to color and protect a wood surface by forming a film. Solid color stains are similar to paints in application techniques and in performance.

Solids Content. The percentage of weight of the nonvolatile matter in an adhesive.

Solvent Adhesive. (See **Adhesive.**)

Sound Knot. (See **Knot.**)

Specific Adhesion. Adhesion between surfaces that are held together by valence forces of the same type as those that give rise to cohesion.

Specific Gravity. As applied to wood, the ratio of the ovendry weight of a sample to the weight of a volume of water equal to the volume of the sample at a specified moisture content (green, air dry, or ovendry).

Spike Knot. (See **Knot.**)

Spiral Grained. (See **Grain.**)

Spread. The quantity of adhesive per unit joint area applied to an adherend. (See **Lbs/MSGL.**)

Single spread—Refers to application of adhesive to only one adherend of a joint.

Double spread—Refers to application of adhesive to both adherends of a joint.

Springwood. (See **Earlywood.**)

Squeezeout. Bead of adhesive squeezed out of a joint when pressure is applied.

Stain. A discoloration in wood that may be caused by such diverse agencies as micro-organisms, metal, or chemicals. The term also applies to materials used to impart color to wood.

Blue Stain—A bluish or grayish discoloration of the sapwood caused by the growth of certain dark-colored fungi on the surface and in the interior of the wood; made possible by the same conditions that favor the growth of other fungi.

Brown Stain—A rich brown to deep chocolate-brown discoloration of the sapwood of some pines caused by a fungus that acts much like the blue-stain fungi.

Chemical Brown Stain—A chemical discoloration of wood, which sometimes occurs during the air drying or kiln drying of several species, apparently caused by the concentration and modification of extractives.

Sap Stain—A discoloration of the sapwood caused by the growth of certain fungi on the surface and in the interior of the wood; made possible by the same conditions that favor the growth of other fungi.

Sticker Stain—A brown or blue stain that develops in seasoning lumber where it has been in contact with the stickers.

Starved Joint. (See **Joint.**)

Static Bending. Bending under a constant or slowly applied load; flexure.

Staypak. Wood that is compressed in its natural state (that is, without resin or other chemical treatment) under controlled conditions of moisture, temperature, and pressure that practically eliminate springback or recovery from compression. The product has increased density and strength characteristics.

Stickers. Strips or boards used to separate the layers of lumber in a pile and thus improve air circulation.

Sticker Stain. (See **Stain.**)

Storage Life. The period of time during which a packaged adhesive can be stored under specific temperature conditions and remain suitable for use. Sometimes called shelf life.

Straight Grained. (See **Grain.**)

Strength. (1) The ability of a member to sustain stress without failure. (2) In a specific mode of test, the maximum stress sustained by a member loaded to failure.

Strength Ratio. The hypothetical ratio of the strength of a structural member to that which it would have if it contained no strength-reducing characteristics (such as knots, slope-of-grain, shake).

Stress-Wave Timing. A method of measuring the apparent stiffness of a material by measuring the speed of an induced compression stress as it propagates through the material.

Stressed-Skin Construction. A construction in which panels are separated from one another by a central partition of spaced strips with the whole assembly bonded so that it acts as a unit when loaded.

Stringer. A timber or other support for cross members in floors or ceilings. In stairs, the support on which the stair treads rest.

Structural Insulating Board. (See **Wood-Based Composite Panel.**)

Structural Lumber. (See **Lumber.**)

Structural Sandwich Construction. A layered construction consisting of a combination of relatively high-strength facing materials intimately bonded to and acting integrally with a low-density core material.

Structural Timbers. Pieces of wood of relatively large size, the strength or stiffness of which is the controlling element in their selection and use. Examples of structural timbers are trestle timbers (stringers, caps, posts, sills, bracing, bridge ties, guardrails); car timbers (car framing, including upper framing, car sills); framing for building (posts, sills, girders); ship timber (ship timbers, ship decking); and crossarms for poles.

Stud. One of a series of slender wood structural members used as supporting elements in walls and partitions.

Substrate. A material upon the surface of which an adhesive-containing substance is spread for any purpose, such as bonding or coating. A broader term than adherend. (See **Adherend.**)

Summerwood. (See **Latewood.**)

Surface Inactivation. In adhesive bonding to wood, physical and chemical modifications of the wood surface that result in reduced ability of an adhesive to properly wet, flow, penetrate, and cure.

Surface Tension. The force per unit length acting in the surface of a liquid that opposes the increase in area of the liquid (spreading).

Surfaced Lumber. (See **Lumber.**)

Symmetrical Construction. Plywood panels in which the plies on one side of a center ply or core are essentially equal in thickness, grain direction, properties, and arrangement to those on the other side of the core.

Tack. The property of an adhesive that enables it to form a bond of measurable strength immediately after adhesive and adherend are brought into contact under low pressure.

Tangential. Strictly, coincident with a tangent at the circumference of a tree or log, or parallel to such a tangent. In practice, however, it often means roughly coincident with a growth ring. A tangential section is a longitudinal section through a tree or limb perpendicular to a radius. Flat-grained lumber is sawed tangentially.

Temperature, Curing. The temperature to which an adhesive or an assembly is subjected to cure the adhesive. The temperature attained by the adhesive in the process of curing (adhesive curing temperature) may differ from the temperature of the atmosphere surrounding the assembly (assembly curing temperature).

Temperature, Setting. (See **Temperature, Curing.**)

Tenon. A projecting member left by cutting away the wood around it for insertion into a mortise to make a joint.

Tension. In an adhesively bonded joint, a uniaxial force tending to cause extension of the assembly, or the counteracting force within the assembly that resists extension.

Tension Wood. Abnormal wood found in leaning trees of some hardwood species and characterized by the presence of gelatinous fibers and excessive longitudinal shrinkage. Tension wood fibers hold together tenaciously, so that sawed surfaces usually have projecting fibers and planed surfaces often are torn or have raised grain. Tension wood may cause warping.

Texture. A term often used interchangeably with grain. Sometimes used to combine the concepts of density and degree of contrast between earlywood and latewood. In this handbook, texture refers to the finer structure of the wood (See **Grain.**) rather than the annual rings.

Thermoplastic. (1) Capable of being repeatedly softened by heat and hardened by cooling. (2) A material that will repeatedly soften when heated and harden when cooled.

Thermoset. A cross-linked polymeric material.

Thermosetting. Having the property of undergoing a chemical reaction by the action of heat, catalyst, ultraviolet light, and hardener, leading to a relatively infusible state.

Timbers, Round. Timbers used in the original round form, such as poles, piling, posts, and mine timbers.

Timber, Standing. Timber still on the stump.

Timbers. (See **Lumber.**)

Time, Assembly. The time interval between the spreading of the adhesive on the adherend and the application of pressure or heat, or both, to the assembly. (For assemblies involving multiple layers or parts, the assembly time begins with the spreading of the adhesive on the first adherend.)

Open Assembly Time—The time interval between the spreading of the adhesive on the adherend and the completion of assembly of the parts for bonding.

Closed Assembly Time—The time interval between completion of assembly of the parts for bonding and the application of pressure or heat, or both, to the assembly.

Time, Curing. The period during which an assembly is subjected to heat or pressure, or both, to cure the adhesive.

Time, Setting. (See **Time, Curing.**)

Toughness. A quality of wood that permits the material to absorb a relatively large amount of energy, to withstand repeated shocks, and to undergo considerable deformation before breaking.

Tracheid. The elongated cells that constitute the greater part of the structure of the softwoods (frequently referred to as fibers). Also present in some hardwoods.

Transfer. In wood bonding, the sharing of adhesive between a spread and an unspread surface when the two adherends are brought into contact.

Transverse. Directions in wood at right angles to the wood fibers. Includes radial and tangential directions. A transverse section is a section through a tree or timber at right angles to the pith.

Treenail. A wooden pin, peg, or spike used chiefly for fastening planking and ceiling to a framework.

Trim. The finish materials in a building, such as moldings, applied around openings (window trim, door trim) or at the floor and ceiling of rooms (baseboard, cornice, and other moldings).

Truss. An assembly of members, such as beams, bars, rods, and the like, so combined as to form a rigid framework. All members are interconnected to form triangles.

Twist. A distortion caused by the turning or winding of the edges of a board so that the four comers of any face are no longer in the same plane.

Tyloses. Masses of parenchyma cells appearing somewhat like froth in the pores of some hardwoods, notably the white oaks and black locust. Tyloses are formed by the extension of the cell wall of the living cells surrounding vessels of hardwood.

Ultrasonics. (See **Stress-Wave Timing.**)

van der Waal Forces. Physical forces of attraction between molecules, which include permanent dipole, induced dipole, hydrogen bond, and London dispersion forces.

Vapor Retarder. A material with a high resistance to vapor movement, such as foil, plastic film, or specially coated paper, that is used in combination with insulation to control condensation.

Veneer. A thin layer or sheet of wood.

Rotary-Cut Veneer—Veneer cut in a lathe that rotates a log or bolt, chucked in the center, against a knife.

Sawn Veneer—Veneer produced by sawing.

Sliced Veneer—Veneer that is sliced off a log, bolt, or flitch with a knife.

Vertical Grained. (See **Grain.**)

Vertically Laminated Timbers. (See **Laminated Timbers.**)

Vessel Elements. Wood cells in hardwoods of comparatively large diameter that have open ends and are set one above the other to form continuous tubes called vessels. The openings of the vessels on the surface of a piece of wood are usually referred to as pores.

Virgin Growth. The growth of mature trees in the original forests.

Viscoelasticity. The ability of a material to simultaneously exhibit viscous and elastic responses to deformation.

Viscosity. The ratio of the shear stress existing between laminae of moving fluid and the rate of shear between these laminae.

Waferboard. (See **Wood-Based Composite Panel.**)

Wane. Bark or lack of wood from any cause on edge or corner of a piece except for eased edges.

Warp. Any variation from a true or plane surface. Warp includes bow, crook, cup, and twist, or any combination thereof.

Water Repellent. A liquid that penetrates wood that materially retards changes in moisture content and dimensions of the dried wood without adversely altering its desirable properties.

Water-Repellent Preservative. A water repellent that contains a preservative that, after application to wood and drying, accomplishes the dual purpose of imparting resistance to attack by fungi or insects and also retards changes in moisture content.

Weathering. The mechanical or chemical disintegration and discoloration of the surface of wood caused by exposure to light, the action of dust and sand carried by winds, and the alternate shrinking and swelling of the surface fibers with the continual variation in moisture content brought by changes in the weather. Weathering does not include decay.

Wet Strength. The strength of an adhesive joint determined immediately after removal from water in which it has been immersed under specified conditions of time, temperature, and pressure.

Wet-Bulb Temperature. The temperature indicated by the wet-bulb thermometer of a psychrometer.

Wettability. A condition of a surface that determines how fast a liquid will wet and spread on the surface or if it will be repelled and not spread on the surface.

Wetting. The process in which a liquid spontaneously adheres to and spreads on a solid surface.

White-Rot. (See **Decay.**)

Wood-Based Composite Panel. A generic term for a material manufactured from wood veneer, strands, flakes, particles, or fibers or other lignocellulosic material and a synthetic resin or other binder.

Cold-Pressed Plywood—Refers to interior-type plywood manufactured in a press without external applications of heat.

Composite Panel—A veneer-faced panel with a reconstituted wood core. The flakeboard core may be random or have alignment in the direction 90° from the grain direction of the veneer faces.

Exterior Plywood—A general term for plywood bonded with a type of adhesive that by systematic tests and service records has proved highly resistant to weather; micro-organisms; cold, hot, and boiling water; steam; and dry heat.

Extruded Particleboard—A particleboard made by ramming bindercoated particles into a heated die, which subsequently cures the binder and forms a rigid mass as the material is moved through the die.

Fiberboard—A broad generic term inclusive of sheet materials of widely varying densities manufactured of refined or partially refined wood (or other vegetable) fibers. Bonding agents and other materials may be added to increase strength, resistance to moisture, fire, or decay, or to improve some other property. (See **Medium-Density Fiberboard.**)

Flakeboard—A particle panel product composed of flakes.

Hardboard—A generic term for a panel manufactured primarily from interfelted lignocellulosic fibers (usually wood), consolidated under heat and pressure in a hot press to a density of 496 kg/m^3 (31 lb/ft^3) or greater and to which other materials may have been added during manufacture to improve certain properties.

Interior Plywood—A general term for plywood manufactured for indoor use or in construction subjected to only temporary moisture. The adhesive used may be interior, intermediate, or exterior.

Laminated Veneer Lumber (LVL)—A structural lumber manufactured from veneers laminated into a panel with the grain of all veneer running parallel to each other. The resulting panel is normally manufactured in 19- to 38-mm (3/4- to 1-1/2-in.) thicknesses and ripped to common lumber widths of 38 to 290 mm (1-1/2 to 11-1/2 in.) or wider.

Marine Plywood—Plywood panels manufactured with the same glueline durability requirements as other exterior-type panels but with more restrictive veneer quality requirements.

Mat-Formed Particleboard—A particleboard in which the particles (being previously coated with the binding agent) are formed into a mat having substantially the same length and width as the finished panel. This mat is then duly pressed in a heated flat-platen press to cure the binding agent.

Medium-Density Fiberboard—A panel product manufactured from lignocellulosic fibers combined with a synthetic resin or other suitable binder. The panels are manufactured to a density of 496 kg/m^3 (31 lb/ft^3) (0.50 specific gravity) to 880 kg/m^3 (55 lb/ft^3) (0.88 specific gravity) by the application of heat and pressure by a process in which the interfiber bond is substantially created by the added binder. Other materials may have been added during manufacturing to improve certain properties.

Mende-Process Board—A particleboard made in a continuous ribbon from wood particles with thermosetting resins used to bond the particles. Thickness ranges from 0.8 to 6.3 mm (1/32 to 1/4 in.).

Moulded Plywood—Plywood that is glued to the desired shape either between curved forms or more commonly by fluid pressure applied with flexible bags or blankets (bag moulding) or other means.

Multilayer Particleboard—A type of construction in which the wood particles are made or classified into different sizes and placed into the preprocessed panel configuration to produce a panel with specific properties. Panels that are destined for primarily nonstructural uses requiring smooth faces are configured with small particles on the outside and coarser particles on the interior (core). Panels designed for structural application may have flakes aligned in orthogonal directions in various layers that mimic the structure of plywood. Three- and five-layer constructions are most common.

Oriented Strandboard—A type of particle panel product composed of strand-type flakes that are purposefully aligned in directions that make a panel stronger, stiffer, and with improved dimensional properties in the alignment directions than a panel with random flake orientation.

Plywood. A glued wood panel made up of relatively thin layers of veneer with the grain of adjacent layers at right angles or of veneer in combination with a core of lumber or of reconstituted wood. The usual constructions have an odd number of layers.

Postformed Plywood—The product formed when flat plywood is reshaped into a curved configuration by steaming or plasticizing agents.

Structural Insulating Board—A generic term for a homogeneous panel made from lignocellulosic fibers (usually wood or cane) characterized by an integral bond produced by interfelting of the fibers, to which other materials may have been added during manufacture to improve certain properties, but which has not been consolidated under heat and pressure as a separate stage in manufacture; has a density of less than 496 kg/m^3 (31 lb/ft^3) (specific gravity 0.50) but more than 160 kg/m^3 (10 lb/ft^3) (specific gravity 0.16).

Waferboard—A particle panel product made of wafer-type flakes. Usually manufactured to possess equal properties in all directions parallel to the plane of the panel.

Wood Failure. The rupturing of wood fibers in strength tests of bonded joints usually expressed as the percentage of the total area involved that shows such failure. (See **Failure, Adherend.**)

Wood Flour. Wood reduced to finely divided particles, approximately the same as those of cereal flours in size, appearance, and texture, and passing a 40 to 100 mesh screen.

Wood Substance. The solid material of which wood is composed. It usually refers to the extractive-free solid substance of which the cell walls are composed, but this is not always true. There is not a wide variation in chemical composition or specific gravity between the wood substance of various species. (The characteristic differences of species are largely due to differences in extractives and variations in relative amounts of cell walls and cell cavities.)

Wood Wool. Long, curly, slender strands of wood used as an aggregate component for some particleboards.

Workability. The degree of ease and smoothness of cut obtainable with hand or machine tools.

Working Life. The period of time during which an adhesive, after mixing with catalyst, solvent, or other compounding ingredients, remains suitable for use. Also called pot life.

Working Properties. The properties of an adhesive that affect or dictate the manner of application to the adherends to be bonded and the assembly of the joint before pressure application (such as viscosity, pot life, assembly time, setting time).

Xylem. The portion of the tree trunk, branches, and roots that lies between the pith and the cambium (that is the wood).

Yard Lumber. (See **Lumber.**)

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