Finishing Wood

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Contents

Wood finishes (paint, varnish, and stain, for example) give a desired appearance, protect wood surfaces, and provide a cleanable surface. Many people consider appearance most important when choosing finishes for wood products. However, from a technical aspect, protection—from water, sunlight, and weathering—is most important for wood used outdoors. For wood indoors, appearance and a cleanable surface are generally most important. When selecting a finish, one should consider appearance, protection, cleanability, how properties of wood affect finish application, and how long it will likely last.

Wood properties vary within and across wood species. Wood composites, such as plywood, fiberboard, and oriented strandboard (OSB), have different properties. Of the 18,000 to 25,000 known wood species, approximately 50 are commercial species used in the United States and Canada. (Chapters 2–4 describe their properties.) Of these commercial species, researchers report finishing characteristics for only a few of the most commonly used species. However, if one understands how wood properties, finish, and environmental conditions interact, it should be possible to predict and avoid issues with finishing performance for most wood products.

Guidelines in this chapter explain how to obtain long service life for contemporary finishes on lumber and wood composites used in the United States and Canada. The chapter begins with a review of wood properties important for wood finishing. This is followed by and properties of various wood products used outdoors and the effect of sunlight, water, and weathering on wood and finishes, and how to control moisture. This background establishes a basis for describing finishes for wood, their application, and common types of finish failures (and ways to avoid them). Publications listed at the end of this chapter provide additional information.

Wood Properties Affecting Finish Performance

Anatomy

Anatomy determines wood density, hardness, and many finishing characteristics, as well as whether a wood is a hardwood or a softwood.

Factors affecting finish performance include the following:

- Swelling and density—An additional factor involves density and thickness of latewood (LW) bands.
- Wood porosity—The end grain of wood is commonly 100 times more porous than the side of a piece of wood, so it will absorb much more stain or other finish. Vessels are large pores in hardwoods that can allow large amounts of finish to flow in, causing deep color in some hardwoods, or leave thin, low spots in film-forming finishes.
- Extractives content—Extractives can bleed through coatings, discoloring the final surface.

A first estimate of paintability comes from swelling, density, and uniformity. Moisture swelling coefficients are listed in Tables 4–3 and 4–4, or they can be estimated from density. Higher density woods typically swell and shrink more with the same change in moisture content or relative humidity. Even if a wood is only moderately high density, but has thick, dense LW bands, paint failure only in the LW might be an issue. Thick LW bands can be difficult for the finish to bridge over. It can also be difficult to prepare quality surfaces when LW bands are thick and dense (see Failures—Peeling and Flaking). Finally, large pores, especially in clusters such as in the oaks, can leave low spots in the finish where flow deep into the wood structure is easy, requiring filler to get a smooth finish.

Most wood cells (called tracheids in softwoods, fibers in hardwoods) align parallel to the stem or branch, or axially. Softwood tracheids support the tree and transport water and minerals. Hardwood fibers just support the tree; hardwoods have special cells (vessels) for transporting water and minerals. Vessel cells are open at each end and stacked to form “pipes.” Axial tracheids and fibers are hollow tubes closed at each end. In softwoods, liquids move in the axial direction by flowing from one tracheid to another through openings called pits. Liquid transport between the bark and center of the stem or branch, in hardwoods and softwoods, is by ray cells. Figures 16–1 to 16–3 are micrographs showing the orientation of axial and ray cells for white spruce, red oak, and red maple, respectively. Note that the softwood (Fig. 16–1) has no vessels. The large openings are resin canal complexes (common to spruce, pine, larch, and Douglas-fir). Figure 16–2 shows red oak, a ring-porous hardwood. Large-diameter vessels in ring-porous species form along with earlywood (EW); later in the growing season, the vessels have smaller diameters. Figure 16–3 shows red maple, a diffuse-porous hardwood; small vessels having similar size form throughout the EW and LW. Hardwoods can also be semi-ring porous. The uniformity and relatively low density of white spruce make it easy to finish. Red oak is more challenging, because it is typically twice the density of white spruce, and the large vessels concentrated in a band make a variable surface.

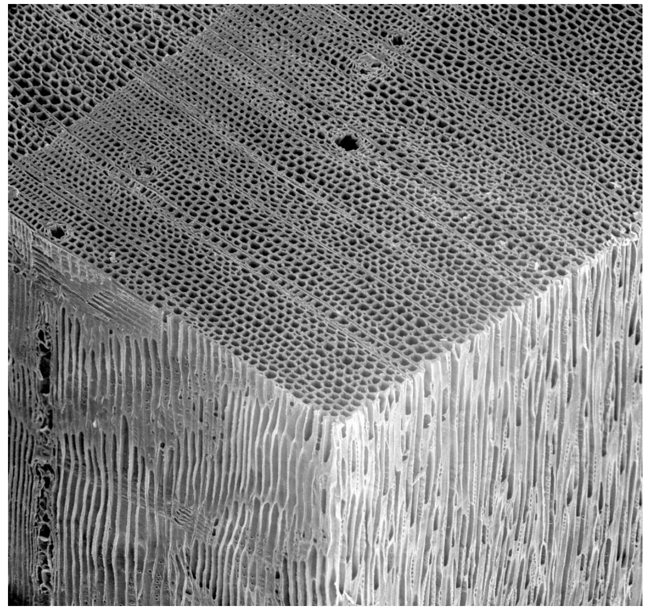

Figure 16–1. Micrograph of white spruce showing only a moderate difference in density between earlywood and latewood, and uniform structure. (Micrographs prepared by H.A. Core, W.A. Côté, and A.C. Day. Copyright by N.C. Brown Center for Ultrastructure Studies, College of Environmental Science and Forestry, State University of New York, Syracuse, New York. Used with permission.)

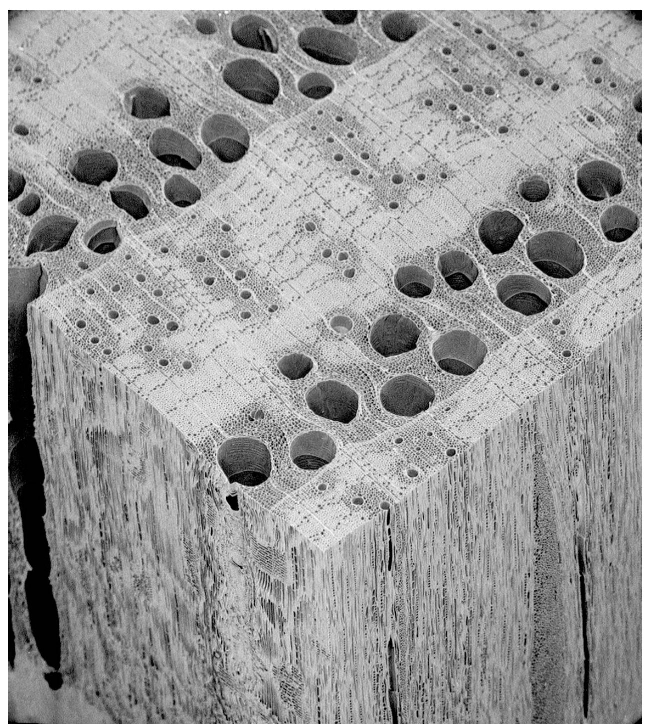

Figure 16–2. Micrograph of red oak showing ring-porous vessels. (Micrographs prepared by H.A. Core, W.A. Côté, and A.C. Day. Copyright by N.C. Brown Center for Ultrastructure Studies, College of Environmental Science and Forestry, State University of New York, Syracuse, New York. Used with permission.)

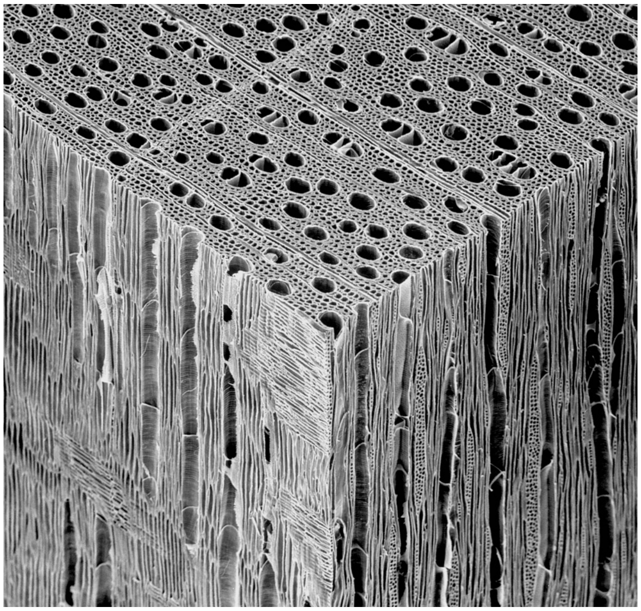

Figure 16–3. Micrograph of red maple showing diffuse-porous vessels. (Micrographs prepared by H.A. Core, W.A. Côté, and A.C. Day. Copyright by N.C. Brown Center for Ultrastructure Studies, College of Environmental Science and Forestry, State University of New York, Syracuse, New York. Used with permission.)

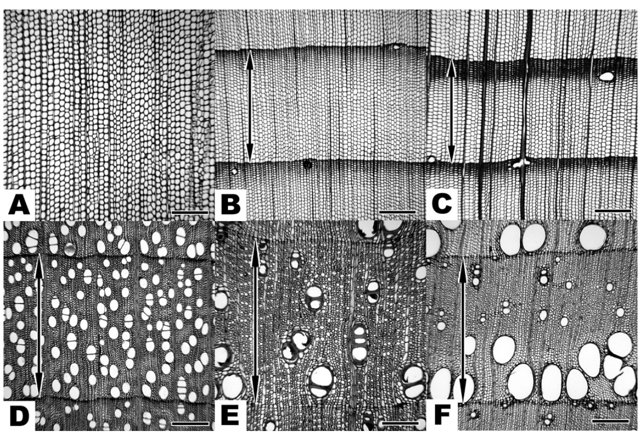

Figure 16–4. Cross-section micrographs of (A) a tropical softwood (*Podocarpus imbricate*), (B) white spruce (*Picea glauca*), (C) Douglas-fir, (D) sugar maple (*Acer saccharum*), (E) persimmon (*Diospyros virginiana*), and (F) white ash (*Fraxinus americana*). The arrows show a single growth year for the temperate species.

All cells form in the cambium, a layer of cells just under the bark. In the early part of the growing season (temperate species), the cells have large open centers (lumens) and thin cell walls—this is EW. As the growing season progresses, cell walls become thicker, forming LW. The combination of EW–LW (and vessels in hardwoods) gives annual growth rings. The properties of these growth rings and other anatomical features affect ease of coating and service life.

Cross-section micrographs of three softwoods and hardwoods (Fig. 16–4) show the growth characteristics for each group. Softwoods may show "no transition" (no EW–LW boundary, Fig. 16–4A), gradual transition (Fig. 16–4B), or abrupt transition (Fig. 16–4C). In contrast, the transition from LW to EW often occurs at a single cell, especially when the tree goes completely dormant in the winter. Note that the "no transition" softwood is a tropical species (that is, no seasons, therefore no EW–LW transition). Hardwoods may be diffuse porous (Fig. 16–4D), semi-ring porous (Fig. 16–4E), or ring porous (Fig. 16–4F). As a first approximation for explaining finishing characteristics of wood, the various wood species can be grouped into three categories:

- Easy to finish—Low density, "no transition" or gradual-transition softwoods with narrow LW bands, and diffuse-porous hardwoods
- Moderately easy to finish—Moderate density/shrinkage, softwoods having narrow or moderate density LW bands, and semi-ring-porous hardwoods
- Difficult to finish—High density and/or large shrinkage, softwoods having wide, high density LW bands

The important message from wood anatomy is to look at the wood. The six micrographs showing end-grain wood-cell structure do not include all possible combinations of growth rate, grain, and surface texture. Look at the width of the LW bands and their prominence. The difference in color between EW and LW is in indication of the density difference. The wood blocks in Figure 16–5 show tangential (flat-grain or flat-sawn) and radial (vertical-grain or quarter-sawn) surfaces on the left and right side of each image, respectively, for five softwoods and two hardwoods. Note the strong density difference and thick latewood bands in southern yellow pine and Douglas-fir. Radiata pine also has thick latewood but not as severe a difference in EW and LW. Western redcedar and white pine have very thin LW bands.

Some species have wide bands of LW. These distinct bands often lead to early paint failure. Wide, prominent bands of LW are characteristic of the southern yellow pines, Douglas-fir, and to some extent radiata pine (Fig. 16–5A,B,C), and getting good paint performance is more difficult on these species. In contrast, white pine, western redcedar, and redwood (Fig. 16–5D,E,F) are lower density and do not have wide LW bands. These species give excellent paint performance. Diffuse-porous hardwoods such as aspen (Fig. 16–5G) have a fine surface texture and are easy to finish, whereas red oak (Fig. 16–5H) has very large vessels in clusters that can leave an uneven finish; these are often filled prior to finishing.

Knots are a common problem for finishes. Paint often peels from knots because they are often high density and in some species contain a lot of pitch. Knots are also extremely prone to cracking. Even the best paints cannot bridge over large cracks or checks that develop in the wood.

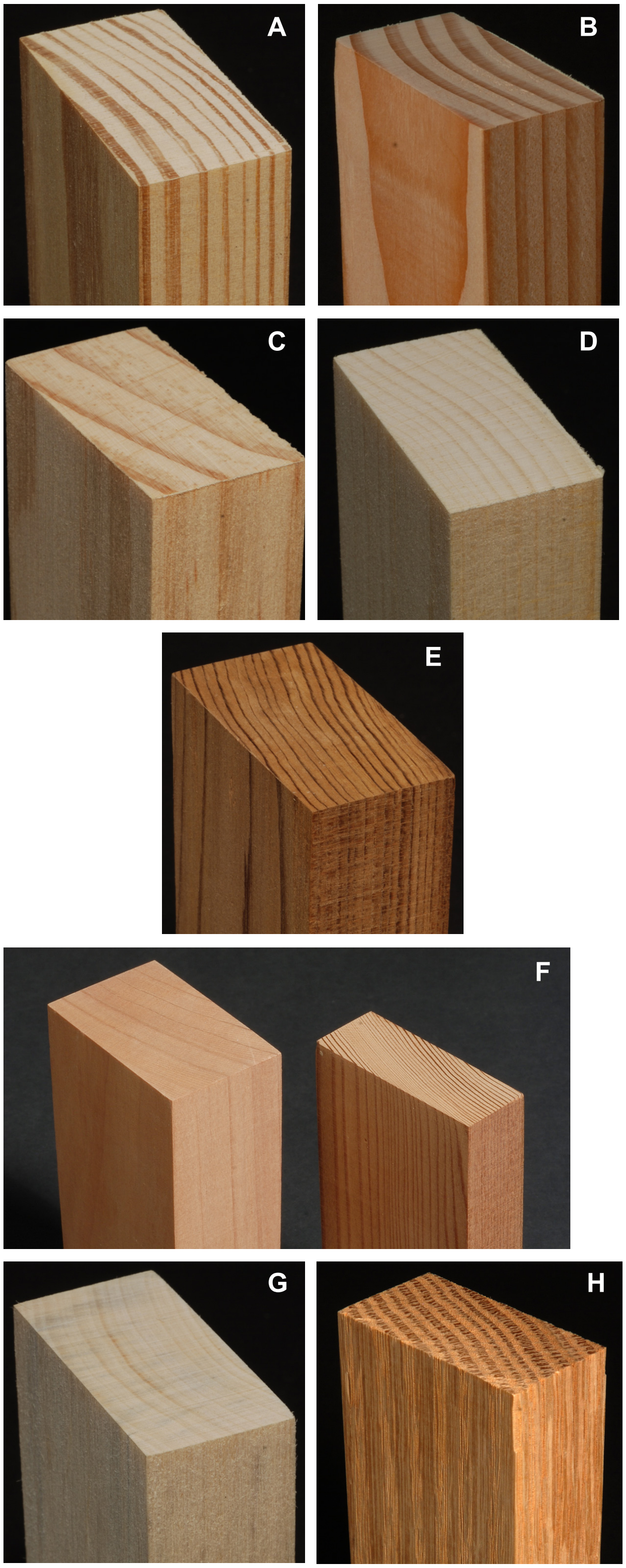

Figure 16–5. Wide LW bands characteristic of (A) the southern yellow pines, (B) Douglas-fir, and (C) radiata pine and narrow LW bands characteristic of D) white pine; (E) western redcedar; (F) redwood (fast grown on left, old growth on right); (G) and (H) are examples of the difference in surface texture between diffuse-porous aspen and ring porous red oak hardwoods, respectively.

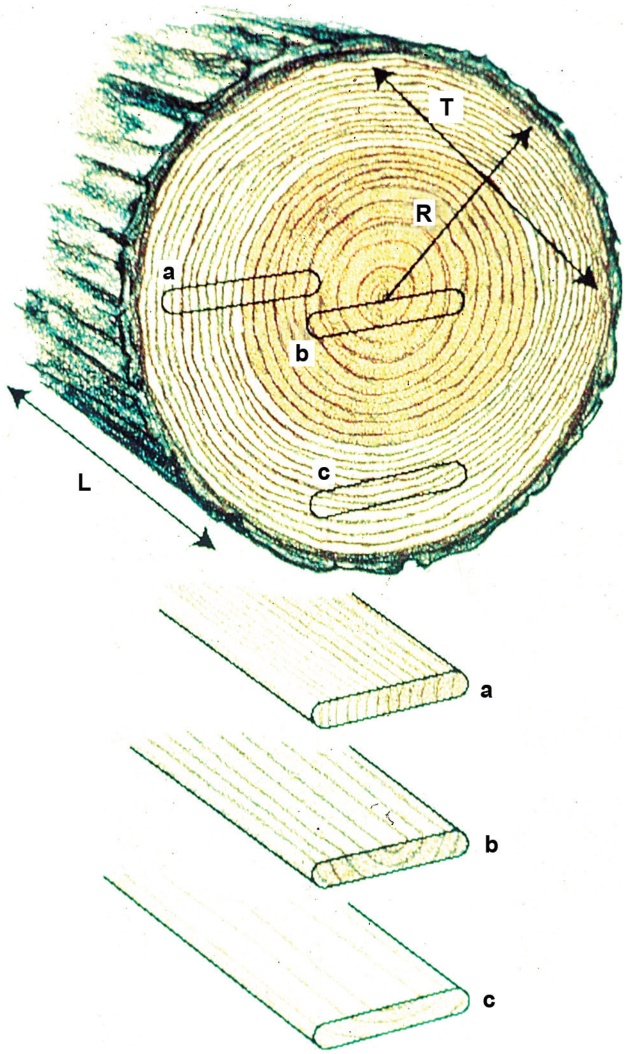

Figure 16–6. Lumber grain affects finish performance: (a) edge-grain (vertical-grain or quarter-sawn) board; (b) edge-grain board containing pith; (c) flat-grain (slash-grain or plain-sawn) board. Arrows show radial (R), tangential (T), and longitudinal (L) orientation of wood grain.

Manufacturing

The axial EW and LW cells in a log yield lumber of various grain angles (Fig. 16–6). At one extreme (board a), the growth rings are perpendicular to the plane of the board; at the other extreme (board c), growth rings are parallel to the plane of the board (although they have an arc). Grain varies between these two extremes. Vertical-grain lumber has a grain angle from 90° (growth rings perpendicular to surface) to approximately 45°. From 45° to the other extreme (board c), lumber is considered flat grain. Board b is different. Lumber cut close to the pith (the center of the log) contains abnormal wood cells. The very first year of growth is not even woody and has no decay resistance. Growth from the 2nd to 15th years is juvenile wood; the very early years of juvenile wood can have extremely high longitudinal dimensional change (2%) compared with normal wood (0.1% to 0.2%). (The values change from green to ovendry—see Chap. 4.) The extreme juvenile wood of a 10-ft (3-m) board attempts to shrink 2.4 in. (61 mm), while the mature wood will shrink 10 to 20 times less. This dimensional instability can lead to severe warping and cross-grain checking in a board with the pith on one side (see Chap. 5).

Before the latter 20th century, most exterior siding and trim in the United States were vertical-grain heartwood of low density, thin-LW species, because they give the best service life for finishes. All-heartwood vertical-grain grades of cedar and redwood are still available but are expensive. Other species are generally available only as flat-grain or a mix of flat- and vertical-grain lumber. Sawing to yield vertical grain is practical only with almost-knot-free wood, which typically comes from large-diameter logs. Species available in small-diameter logs yield mostly flat-grain lumber. Because low density and vertical grain are associated with less swelling, vertical grain boards and lower density woods typically have less checking, cup, and warp. The tendency to cup increases with width/thickness ratio.

Moisture Content

Moisture content (MC) is the amount of water, in any of its forms, contained in wood (see Chap. 4). MC includes bound water inside the cell wall that swells wood and free liquid water within the hollow center of the cells (lumina), if present. MC is expressed as weight percentage: MC% = [(wet weight – dry weight)/dry weight] × 100. Most woods can hold about 30% of their ovendry weight as bound water; the rest will reside as free water. The limit to the amount of water bound in the wood cell wall is the fiber saturation point.

The amount of water in "dry" wood (the MC) depends on the relative humidity (RH) of the surrounding air. As humidity changes, the wood will absorb or release bound water, causing the wood to swell or shrink. RH determines only the approximate MC, though, as there is an effect of history (Chap. 4, Fig. 4–2).

> **Moisture**
> The chemical commonly called water (H_2O) has three states according to temperature and pressure conditions: gas (water vapor or steam), liquid (water), or solid (ice). When water interacts with wood, it can occur in a fourth state, bound water, where it is hydrogen bonded to wood polymers and swells the wood. Moisture is not one of the states of water; it refers collectively to water in all its states in wood. For example, some of the moisture in a board at 50% moisture content will occur as liquid water (or ice, depending on the temperature) within empty spaces of the wood, some will occur as water vapor, and some will be bound water (bound within cell walls). Moisture thus accounts for any or all these states in a single word. In this chapter, the term water means the liquid state.

Wood outdoors under cover in most areas of the United States cycles around a MC of approximately 12% to 14%. In moist climates it is higher (~16% in the Pacific Northwest) and in dryer places lower (6% to 9% in the southwest) (Chap. 13, Tables 13–1 and 13–2). Daily and annual MC may vary from these averages. In general, wood outdoors decreases MC during the summer and increases MC during the winter, when outdoor RH is typically higher. Wood indoors generally is dryer during the heating season. Even in humid areas, RH is rarely high enough for long enough to bring the MC of wood above 20%, where decay starts. Interior wood MC, discussed in Chapter 13, is typically 6% to 12%.

When air warms, its RH decreases. Therefore, wood warmed by the sun is in contact with air of low RH. This dries and shrinks the surface, even while the bulk of the wood may be wet and swollen. Conversely, the surface wets and expands quickly when rain starts, even if the core and bottom are dry and shrunken. The internal stress from differential moisture within boards resulting in roughened wood, raises grain, and causes checks, cracks, warping, and cupping. Horizontal surfaces, such as decks, are often the worst affected. Darker color finishes result in more solar heating, and so result in more warping and checking of wood than light color finishes. Siding exposed facing south has been shown to cup and warp more in Phoenix, Arizona, than South Florida, Ohio, or Wisconsin. This was attributed to swelling associated with larger and faster swings in RH present in Phoenix.

As mentioned previously, fiber saturation is the limit to the amount of water wood can hold inside the cell wall. Water vapor absorbs slowly compared with liquid water. Liquid water can quickly bring wood to high MC, and it is the only way to bring the MC of wood to fiber saturation or higher. As wood continues to absorb liquid water above its fiber saturation point, the water is stored in the lumen; when water replaces all the air in the lumen, the wood is waterlogged and its MC can be several hundred percent (more water than wood). If you can get water from wood by crushing it (for example, with a hammer or vice), it is above the fiber saturation point.

Wood can get wet many ways, such as windblown rain, leaks, condensation, dew, and melting ice and snow. The result is always the same—poor performance of wood and finish. Keeping wood at or below ~20% low moisture content in service by preventing liquid water from entering wood and providing a way for trapped water to evaporate is the single most important step in ensuring good performance from wood products. Water is usually involved if finishes perform poorly on wood. Even if other factors initially cause poor performance, water accelerates degradation. Wood allowed to get wet has many more problems in service. Higher MC in service results in higher swelling when wet and shrinking when wood dries. This leads to more warping, twisting, and checking. Splits and checks in the wood lead to cracks in the paint film. Wood can also decay when it is at high MC, and paint films are more likely to peel from wet wood.

Painting wood after it reaches a MC close to what it will be in service minimizes stress on film-forming finishes. The MC and thus the dimensions of the piece will still fluctuate somewhat, depending on the cyclic changes in RH, but if a paint is applied at a "middle" point of the MC it will see in service, the dimensional change should not be excessive. Minimizing these swelling stresses reduces the tendency for paint films to crack. Most wood products are sold at 20% MC or less, and if they have been kept dry during shipment and storage at the construction site, they should be close to equilibrium moisture content (EMC) by the time they are finished. Painting wet wood increases the risk of blistering and peeling, and water-soluble extractives are more likely to discolor paint.

Dimensional Change

How much a piece of wood swells or shrinks with a given change in moisture content depends on wood species, grain, presence of juvenile and reaction wood, and other factors. Average shrinkage values obtained by drying normal wood from its green state to ovendry vary from 2.4% for radial western redcedar to 11.9% for tangential beech (Chap. 4, Table 4–3). Dimension in service does not vary to this extent because the MC seldom goes below 6%. To estimate the dimensional change of wood with moisture content, see Chapter 13. A film-forming finish applied to all sides, including the end grain, will likely decrease the moisture content change by slowing the rate of water movement into and out of the wood.

Wood having little tendency to shrink and swell gives a stable surface for painting. Vertical-grain (radial) surfaces are more stable than flat-grain surfaces (Chap. 4, Table 4–3) (Figs. 16–6, 16-7), especially outdoors where periodic wetting may produce rapid dimensional change. Wood species having low density tend to be more dimensionally stable than those having high density (Fig. 16–7). Low-density wood, typically more dimensionally stable, generally holds paint better than high-density wood. Other factors, such as wood anatomy (vertical grain or radial surfaces are better) manufacturing, and previous exposure to sunlight also affect paint adhesion.

Dimensional changes produce forces inside wood that are also responsible for checking, splitting, warping, and cupping. Well-maintained finishes protect the wood from these extreme internal forces by slowing water movement. For instance, water can quickly reach the wood surface under a paint crack and swell that portion of the wood while

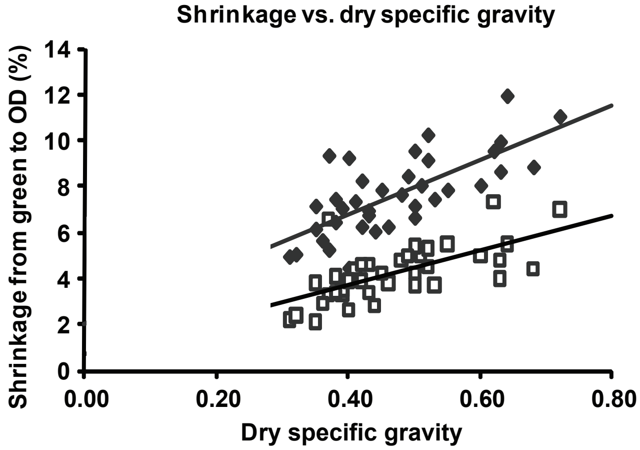

Figure 16–7. Plots of radial (◆) and tangential (□) shrinkage from green to oven dry (OD) as a function of density (g cm^{-3}) for various hardwoods and softwoods from Table 4–3 (Chap. 4).

other portions are still relatively dry. Similarly, a surface in the sun can dry and shrink quickly, especially if a dark color. If the entire board has been kept dry by a good finish, surface checks, warping, and other effects of dimensional changes are less likely.

Wood Extractives

Highly colored extractives occur in the heartwood of softwoods, such as western redcedar and redwood, and hardwoods, such as walnut and mahogany. Extractives give heartwood its color, and many extractives are soluble in water. Discoloration of painted or unpainted wood may occur when rain, condensation, or plumbing leaks leach water-soluble extractives from wood. The water carries extractives to wood or paint surfaces and evaporates, leaving extractives as a yellow to reddish brown stain on the surface. Stain blocking primers are designed to stop this. If by chance extractives bleed into the topcoat, stop and re-prime (and consider another manufacturer). Without the stain-blocking layer, extractives can bleed through as many top coatings as you apply.

Some extractives, such as resins and oils, are insoluble in water. Species and growing conditions determine the type and amount of these compounds. For example, many pines contain pitch, which must be hardened or set—no coating that we are aware of will block its flow. Knots of almost all species contain sufficient oils and resins to discolor light-colored paint. Water-soluble extractives, pitch, and knots are all discussed in more detail in the section "Failures."

Wood Products

Various types of wood products commonly used outdoors have unique characteristics that affect application and performance of finishes. Some general guidelines are given below.

Figure 16–8. Examples of trade association brochures describing wood products.

Lumber

Lumber (solid wood) for exterior use is available in many species and products. These are described in the American Softwood Lumber Standard, published by the U.S. Department of Commerce (NIST 2020). The American Lumber Standard Committee approves six sets of standard specifications or grading rules are within this umbrella in North America, some of which are shown in Figure 16–8.

These publications are the basis for selecting wood to meet codes. They give specifications for appearance grades (such as siding and trim) and for structural lumber (such as framing and decking). Unless specified as vertical grain, the grade contains mostly flat-grain lumber. Grade is important because species, grain orientation, and surface texture affect paint-holding characteristics. In addition, only heartwood is decay resistant. Descriptions of grades and pictures of many wood species are contained in brochures published by trade associations. When specifying lumber, refer to the grade rules for the product to ensure that the product meets code requirements, and use the association brochures to get an idea of appearance.

Textures (roughness or smoothness) of wood surfaces affect selection, application, and service life of finishes. Traditionally, a rule of thumb was to paint smooth wood and stain saw-textured wood. Coatings on saw-textured surfaces generally last longer, in part because their rough surface takes more finish. Film-forming finishes are not recommended for saw-textured surfaces, however. This is not because they do not work, but because when refinishing, if you sand one spot you have to sand everything to avoid unsightly texture changes. The difficulty in finding true penetrating finishes is contributing to the decline in textured siding.

Occasionally a wood surface will be naturally water repellent. This is expected for oily woods, such as teak, but can also occur in “normal” woods like pine. If water beads up on the surface of wood, such as in Figure 10–3 (Chap. 10), finishes are likely to have problems sticking. A few passes with sandpaper is often sufficient to remove the surface contaminant causing the problem.

Glued Composite Lumber

Instead of a single piece of wood, lumber can be made by gluing together many small pieces. This could be finger-jointed wood, typically used to obtain knot-free trim, or parallel boards (glulam), veneers (laminated veneer lumber, LVL), or strands (parallel-strand lumber, PSL) glued together to make lumber (see Chaps. 10 and 12).

In all these products, the finishing should be determined by the worst examples of wood from the species used. For example, if an opaque coating is used, start with a stain-blocking primer, assuming there might be extractive bleed.

Finger joints can become visible because of the difference in swelling in adjacent pieces of wood when there are large changes in humidity levels. Finger-jointed lumber is commonly used for fascia boards, interior and exterior trim, siding, windows, and doors. Paint often fails in a “patchwork” manner according to the paintability of various pieces, or at a joint where the piece on either side moves differently with moisture.

Plywood

As with lumber, species, grain orientation, and surface texture affect finishing of plywood.

Plywood siding can come saw-textured (such as T1-11), smooth, or with a paper overlay on the surface. Saw textured is the best surface for holding a finish, but if the finish forms a film, there is no good solution for putting another film on the surface after it fails. The old surface should be sanded, and the texture will not match.

Smooth surface plywood can be painted but production of the veneer results in small checks in the wood parallel to grain (lathe checks). With wetting and drying cycles, these checks tend to grow and can propagate to the wood surface and through the coating, detracting from the appearance and durability of the paint. Smooth surface plywood can give reasonable paint life if protected, such as on soffits.

Figure 16–9. Absorption of water causes differential dimensional change of surface flakes and strands to give an uneven surface (telegraphing).

Resin-treated paper bonded to plywood forms a medium-density overlay (MDO); MDO eliminates cracks caused by lathe checking and provides plywood with excellent paintability, but the edges are still vulnerable to water. Seal the edges with primer or an edge sealer formulated for this use. Paper overlaid products should give the best long-term performance of all the plywood products with film-forming finishes, such as paints or solid-color stains. They generally do not accept semitransparent stain or other penetrating finishes.

Engineered Wood Siding and OSB

Engineered wood siding is typically made from wood fibers glued together, similar to hardboard (see Chap. 11). Often these products have a paper overlay to improve finish performance. Engineered wood has the advantage over natural wood in that it does not have defects that cause finishes to fail, such as knots or cracks. Coatings applied at the factory (pre-primed or pre-finished), if done well, will typically outlast finishes applied on-site. Sealing all four edges is important to maximize the life of engineered wood siding.

Oriented strandboard (OSB) and flakeboard are made by gluing wood strands or flakes together and is used inside the external envelope of structures for sheathing and underlayment (see Chap. 11). Because it is considered structural, it contains “exterior” adhesives and water repellent. The water repellent gives OSB water resistance while in transit and storage prior to construction, but it is generally not intended to be exposed to the elements. Plain OSB is not a suitable surface for exterior exposure, regardless of whether it is painted. Figure 16–9 shows painted strandboard after 3 years outdoors. The area on the left has one coat of acrylic-latex topcoat, and the area on the right has one coat of oil-alkyd primer and acrylic-latex topcoat. The single coat (topcoat only) has failed, and the area having two-coats (primer and topcoat) is starting to fail, particularly over large flakes. Products intended for outdoor use, such as siding, are overlaid with MDO or wood veneer to improve paint performance. Products having MDO can be finished in the same way as other paper-overlaid products. Seal edges with a product specifically formulated for this use.

Wood–Plastic Composites

Wood–plastic composites (WPCs) account for a significant share of decking material in the United States. Manufacturers combine wood flour, fibers, particles, or a combination, with polyethylene, polyvinyl chloride, or polypropylene and extrude “boards” in various profiles. Wood content and particle size in the boards vary, and thus their ability to accept a finish varies. Boards high in wood content with large particle size at the surface may accept a finish; boards high in plastic content may not. Some manufacturers add a surface layer with high durability and color stability. Solvent-based penetrating stains, if available, are likely to perform better on WPC than waterborne stains. Film-forming finishes (such as solid color stain, paint) may have difficulty wetting and adhering to WPC. If you want to apply a film-forming finish on WPC, check adhesion using the tape pull-off test (see “Testing for Adhesion”). The surface may need strong bleaching to remove dark coloration from mildew before staining.

Treated Wood Products

Wood used in structures fully exposed to the weather, such as in decks and fences (particularly those portions of the structure in ground contact), needs preservative treatment to protect it from decay (rot) and termites if they are not naturally decay resistant (see Chap. 14, Table 14–1). Wood used in marine exposure also faces attack from marine borers. Building codes may require preservative or fire-retardant treatment, or both, of wood for some uses.

Treated wood for residential use is pressure-impregnated with waterborne preservatives containing combinations of copper and/or organic compounds such as triazoles, quarternary ammonium compounds or isothiazolones. Chromated copper arsenate (CCA) was commonly available in the United States until 2004. For industrial applications, CCA, preservative oils such as coal-tar creosote, or organic solvent solution such as pentachlorophenol and copper naphthenate may be available (Chap. 15).

Wood treated with waterborne preservatives, such as copper-based systems, can be painted or stained if the wood is clean and dry. Bleed of preservative through finishes, particularly latex-based paints and solid-color stains, can occur if wood is still wet from the preservative treatment. One week should be sufficient to allow wood surfaces to dry enough to finish. Wood treated with coal-tar creosote or other dark oily preservatives is not paintable, except with specially formulated finishes such as two-component epoxy paints; even if the paint adheres to the treated wood, the dark oils tend to discolor paint, especially light-colored paint. Wood properly treated with a water-repellent preservative (WRP), by vacuum–pressure or dipping, is paintable, but too much WRP can repel the paint, leading to shorter service life.

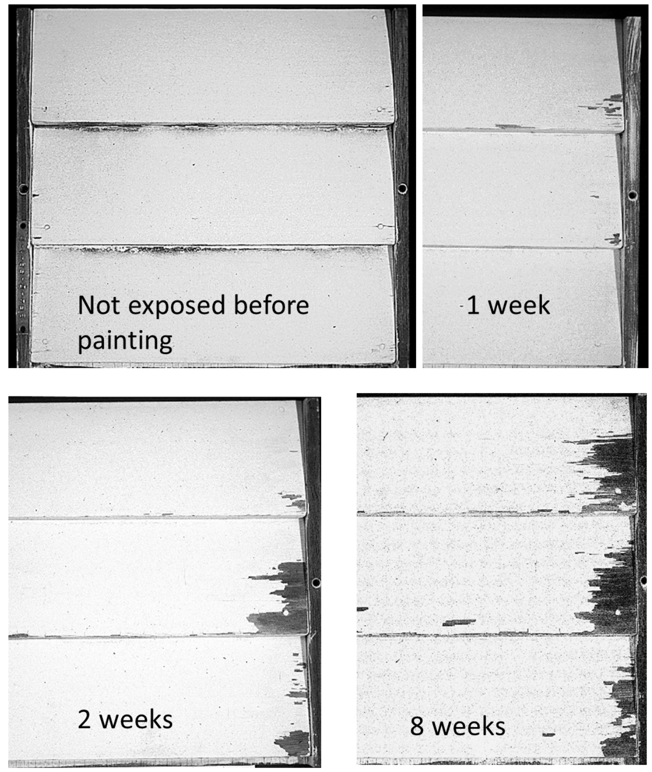

Figure 16–10. Effect of sunburned wood on paint performance. Panels were exposed to the sun 0, 1, 2, or 8 weeks, then washed, dried, and painted. These photos were taken 14 years later. Dark lines in "Not exposed" specimen was mildew, not paint failure.

Fire-retardant (FR) treated wood is generally painted rather than left unfinished because the FR treatment may darken or discolor wood. FR treatment may interfere with adhesion of finishes. Contact the paint manufacturer, the FR manufacturer, and/or the treating company to ensure that the products are compatible. Some FRs may be hydroscopic and cause wood to have high MC. FRs for wood used outdoors are formulated to resist leaching.

Effect of Weathering on Finish Performance

Weathering is the general term describing outdoor degradation of materials. Ultraviolet (UV) radiation in sunlight initiates photodegradation of wood polymers, exacerbated by moisture, temperature change, freeze–thaw cycles, abrasion by windblown particles, and growth of microorganisms. Weathering occurs near the surface of wood, wood products, and finishes. Bare wood that sees even a week of south-facing exposure to sunlight can have significantly lower paint performance than fresh wood.

Sunburn—UV Exposure and Paint Adhesion

Exposure to sunlight before applying a film-forming finish is a major cause of coating failures. Whereas erosion is slow, chemical changes at the surface occur very quickly, even though the wood appears unchanged. Badly weathered wood having loosely attached fibers on the surface cannot hold paint, but this is not obvious on wood that has weathered for only 1 to 3 weeks. Research has shown that surface degradation of wood facing south for as little as one week prior to painting significantly shortened the service life of paint. The longer the wood was exposed, the shorter the time until the paint began to peel. For boards exposed 16 weeks, the paint peeled and needed refinishing within 3 years; for boards exposed only 1 week, the paint started peeling after 13 years, whereas the panels that were not exposed were in good condition after 20 years (Fig. 16–10). This particular experiment used vertical grain western redcedar with commercial primer and two layers of latex topcoat. For low-density species such as cedar, finish the wood as soon as possible after installation, or better yet, prime it before installation. In other tests using wood species having higher density (such as Douglas-fir and southern yellow pine), little loss of paint adhesion occurred until boards had been preweathered for 3 to 4 weeks.

Sunburn can be avoided by preventing UV light from reaching the wood surface. If you cannot see the wood under a paint film, the film is probably blocking the UV. Clear coats or stains that allow view of the wood are often formulated to minimize UV transmission, but they are not perfect, and sunburn over time is likely.

You know that wood is sunburned, and peeling will be a problem, if you can remove wood fibers from the surface by taking a very strongly adhering tape, sticking it well to the wood, and snapping it off quickly. The cells that stayed with the tape were not well adhered to the board; the paint film will tear them off the board just like the tape did. Some people recommend adhesive strip bandages for this test. If wood is already sunburned, sand off about 100 µm (0.004 in.) and repeat the test. Prime before the sanded area becomes sunburned. Any film-forming finish (see Exterior Finishes) will be prone to peeling if applied to sunburned wood. Alternatively, a penetrating finish (see Exterior finishes) lasts longer on sunburned wood than on fresh wood. If wood looks weathered and silver or grey, it is severely sunburned and will likely need much more extensive sanding to get a film-forming finish to stick.

Lignin is the chemical glue that the tree uses to make cells rigid and to hold cells to each other. Ultraviolet (UV) light, and to some extent visible light, breaks the lignin molecule

Testing for Adhesion

If you are unsure about how well paint is adhered to a surface, do a test. After preparing the surface, prime and allow to dry at least overnight. To test for adhesion, firmly press one end of an adhesive bandage onto the primed surface. Remove the bandage with a snapping action. If the tape is free of paint, the new paint is fairly well bonded to the old surface. If the new primer adheres to the tape, the primer was not well bonded to the wood, and premature peeling is likely. Testing several areas of the structure to determine the extent of poor paint bonds before stripping all the paint is recommended.

so that it has no structural role and can be washed away (Fig. 16–11). UV-degraded cells on the wood surface may adhere extremely well to the applied primer, but they do not hold well to the wood underneath. It is not uncommon to find wood cells attached to the flakes of primer that peel away. Another issue that contributes to flaking and peeling is that after raw wood has been exposed to sunlight, the surface oxidizes and often microbes begin to grow.

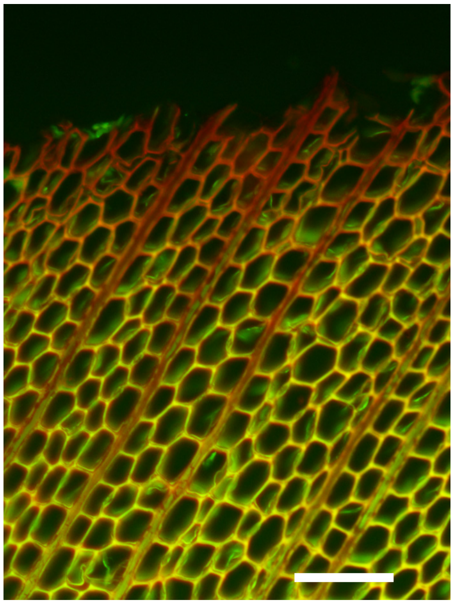

Figure 16–11. Fluorescence image of weathered wood. Green is normal wood; lack of green color on the surface indicates the chemical change from one week of exposure to UV light. Stained with Congo red and acridine orange. Image shows approximately 450 μm (0.018 in.) of width.

General Weathering Effects on Wood

Weathering takes many forms, depending on the material. Wood and wood products initially show color change and slight checking. Color change comes from leaching of water-soluble extractives, chemical changes, and growth of microorganisms on the surface. As weathering continues, wood develops checks on lateral surfaces and checks and cracks near the ends of boards, and wood fibers slowly erode from the surface. Wood consists of three types of organic components: carbohydrates (cellulose and hemicelluloses), lignin, and extractives. Each has a different role in wood, and weathering affects each of these components differently. These physical and chemical changes affect paintability.

Carbohydrates

Carbohydrates (cellulose and hemicelluloses) are polymers of sugars and make up 55% to 65% of wood (Chap. 3). Carbohydrates do not absorb UV radiation and are therefore resistant to UV degradation. However, hemicelluloses and amorphous cellulose readily absorb–desorb moisture; the carbohydrates are primarily responsible for the dimensional changes in wood associated with water.

Lignin

As described in the Sunburn section, UV degradation of lignin is a significant source of exterior paint peeling issues. Approximately 20% to 30% of wood mass is lignin, a polymer that helps glue cells and cell walls together. The region between adjacent wood cells (middle lamella) is rich in lignin. If exposed to UV radiation, lignin in the middle lamella, at the surface of wood, begins to degrade within a few hours. If wood is left to weather, fibers gradually fray off the surface (a process called erosion). Approximately 6 mm (1/4 in.) of wood is lost in a century, with lower density wood generally eroding faster (Fig. 16–12). Other factors such as growth rate, degree of exposure, grain orientation, temperature, and wetting and drying cycles affect erosion rate. Table 16–1 shows erosion rates for several wood species measured over 16 years.

The faster erosion of earlywood contributes to the rough washboard appearance of weathered wood (Fig. 16–12, right). This washboard surface with raised latewood is a sign of weathering by sunburn and/or abrasion, such as sandblasting or aggressive power washing.

Extractives

Extractives (chemicals that can be washed out—they give heartwood its distinctive color) change color when exposed to UV radiation or visible light, and this color change indicates degradation of extractives near the surface. The color change may be lighter or darker. Some wood species change color within minutes of outdoor exposure. Wood also changes color indoors. Ordinary window glass blocks most UV radiation, so visible light causes most indoor color change. UV stabilizers in finishes do not necessarily prevent color change from visible light.

Biological Factors

The most common biological factor associated with weathering is mildew, a type of fungus that contributes

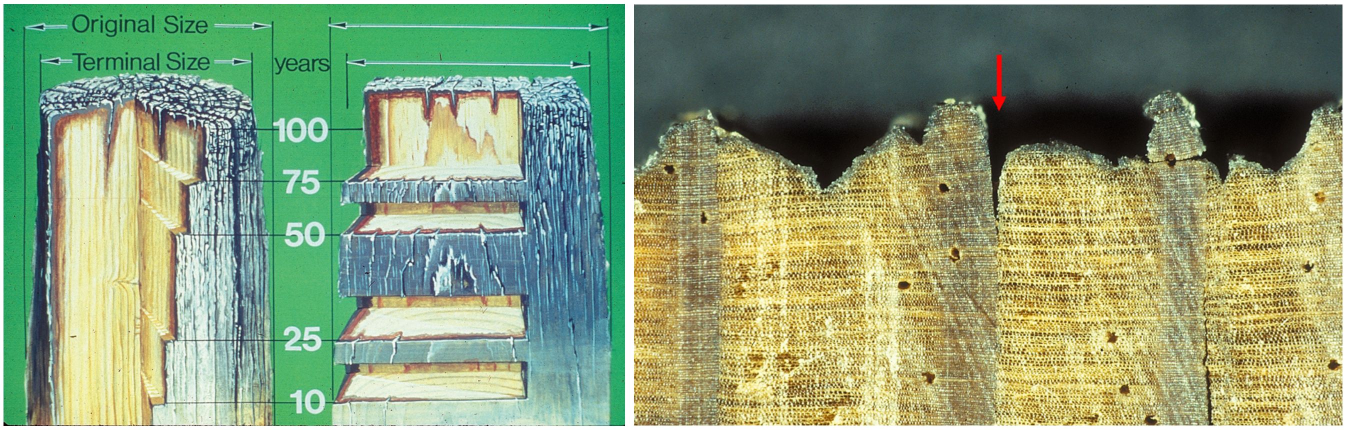

Figure 16–12. (Left) Artist's rendition of weathering process of round and square timbers. As cutaway shows, interior wood below the surface is relatively unchanged; (right) cross section of weathered surface on southern pine. Note the faster erosion of earlywood and the crack starting at the sharp density change between the latewood and earlywood (arrow).

Table 16–1. Erosion of earlywood and latewood on smooth planed surfaces of various wood species after outdoor exposure[a]

		Erosion (μm) after various exposure times[c]											
		4 years		8 years		10 years		12 years		14 years		16 years	
Wood species	Avg. SG[b]	LW	EW	LW	EW	LW	EW	LW	EW	LW	EW	LW	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. EW denotes earlywood; LW, latewood.
[b]SG is specific gravity, grams per cm^3.
[c]All erosion values are averages of nine observations (three measurements of three specimens).

to color change and coating degradation (see Failures—Mildew). Mildew does not decay wood directly, but it often punctures microscopic holes in the coating, breaking the water barrier. Dark-colored fungal spores and mycelia on the wood surface typically cause grey or black color and interfere with adhesion of coatings applied over the mildew. In advanced stages of weathering or after strong bleaching, when extractives and lignin have been removed leaving a cellulose surface, the clear cells at the surface give a bright silvery sheen when dry. This sheen on weathered wood occurs most frequently in arid climates or coastal regions.

Algae can also grow on wood, particularly in damp locations; algae are usually green and often grow in combination with mildew.

Decay and Insects

Decayed wood does not hold paint. Wood should be free of decay, and builders can do several things to keep it that way (see Controlling Water and Water Vapor). When repainting, inspect wood for decay. Problematic areas include any end grain, especially on bottom surfaces where water tends to sit. Wood decay often occurs in the center of a board while

Figure 16–13. Decay and paint failure in wood railing that trapped water. Problems could have been minimized by priming all surfaces before assembly to prevent water entering the wood.

Figure 16–14. Demonstration of proper and improper z-flashing installation: (top) siding installed with a proper 9-mm (3/8-in.) gap between the z-flashing and siding to allow water to drain off the siding; (bottom) siding installed improperly, without a gap. This gives water easy entry into the siding and thus shows extractives staining and promotes decay.

the surface can appear sound; probe several areas with a small-tipped screwdriver to ensure that the wood is sound. Replace decayed boards.

Insects seldom cause problems with finishes; however, they indicate moisture problems and decay. When repainting a structure, inspect it for termite tunnels and carpenter ants. A termite tunnel is a sure sign of infestation. Presence of carpenter ants may indicate decay and/or moisture in the structure. Carpenter ants do not eat wood, but they often tunnel out moist or decayed areas to build their nests. Woodpecker holes often indicate insect infestation.

Controlling Water and Water Vapor

Finishes cannot change the EMC of wood; they only slow down the rate of water entering and leaving the wood. Coatings are generally a barrier to the flow of liquid water but allow vapor movement. This is by design. Because no barrier is perfect, wood will get wet, so the coating must allow vapor to escape to allow the wood to dry. Liquid water moves through wood many times faster than water vapor, so even a small amount of liquid water entering wood can cause problems. Because liquid water enters wood 10 to 100 times faster through the end grain than the other faces, sealing end grain is critical.

Figure 16–15. The siding came too close to the roof, absorbed water from the roof, and rotted.

Structure design and construction practices affect finish performance. Design and construct structures to keep water out, prevent it from condensing, and remove it when it does occur. This section summarizes recommendations for improving finish performance. As a rule, avoid any situation where water stays in contact with wood, especially when unsealed end grain allows water to enter the wood easily (Fig. 16–13). Paint only slows the penetration of water, it does not stop it. All decay, and most exterior paint failures, start with moisture.

Do Not Let Wood Sit in Water

Leave space below the bottom of any board exposed to weather so that the bottom edge does not stay wet after a rain. Between siding and flashing that drains down, 9 to 12 mm (3/8 to 1/2 in.) is recommended, as shown in the upper part of Figure 16–14. The siding in the lower portion of Figure 16–14 has no gap, and the paint is stained. The gap also determined whether boards were rotting or not.

Siding intersecting a sloping roof or roughly horizontal surface should have a 50 mm (2 in.) gap between the end grain of the siding and the roof below to avoid rotting the siding that is close to the roof, as in Figure 16–15. Check for a finish on the end grain; if there is no finish, seal it (see next section). If there is already a coating on the end grain, keep it painted. End grain that butts directly against a horizontal surface is at high risk and if possible should be cut short and the exposed grain sealed. If this is not possible,

Figure 16–16. Cedar heartwood porch styles removed from a railing after 25 years of service. All the styles where end grain was primed before assembly were in perfect condition (left). All the styles without primed end grain on the bottom (center 3) were rotten. The top of a style without primed end grain is show on right—it was protected from water and so performed perfectly.

you can try to wick WRP (see Water Repellent) into the end grain from a wet brush.

Seal End Grain

Seal all end-grain surfaces (Fig. 16–16) to prevent liquid water from entering the wood. This is probably the single most valuable improvement that can be made in standard construction practice to improve the performance of wood exposed to water. The end grain is so important because liquid water can enter wood through the end grain so quickly—100 times faster than from the sides is not unusual. End grain is often impossible to access after assembly so it must be sealed during construction. Note that end grain is exposed at bolt holes and other features, in addition to the ends of boards. Sealing all end grain and minimizing contact with water are both needed to ensure long, worry free service life.

The best products for preventing water from entering (sealing) the end grain are typically those that are very runny and need solvent to clean up. Solvent cleanup means they are completely incompatible with water, and being runny allows them to flow deeply into the wood structure (thinning of lacquer or polyurethane is common for end grain treatment). If an oil-based option is not desirable or possible, physically plugging the pores of wood with water-based primer will dramatically slow the flow of liquid water into end grain. If protected from weathering, a water repellent or water repellent preservative (see Water Repellents and Water Repellent Preservatives) can provide extended protection. Water repellents contain wax, which slows the absorption of liquid water into wood yet allows wood to dry after rain. Because they are clear, thin, and weather away (so they do not cause problem with a future paint job), they are a good option when you discover uncoated end grain after construction is complete. In such cases, flooding the end grain with WRP is a good way to prevent future problems.

Even if liquid water never comes in contact with a surface, it might still be useful to coat wood to slow the movement of water vapor into and out of the wood. Absorbing or releasing water vapor causes swelling and shrinking. Because of this, uneven swelling, such as the painted face and unpainted backside or the face relative to the core, is a common cause of checking, warping, and cupping.

Construction Practices for Avoiding Water Problems

The best way to avoid finish issues on the outside of structures is to limit moisture exposure. In buildings, this means good construction practices. There are many resources available. Even if the exact details do not match your specific application, most manuals address the most common water-control mistakes and are helpful reading. Two free sources are the 144-page EPA *Moisture Control Guidance for Building Design, Construction and Maintenance* (EPA 2013) and the series by APA (APA 2016) and BSC (BSC 2007) in the references. FPL also has a series of construction practice videos (FPL 2012). Many professional associations, such as ASHRAE and ASTM, provide manuals and handbooks but often at a price. Following are some general principles.

Large roof overhangs protect siding from rain and dew; gutters and downspouts greatly decrease the amount of water draining down the siding.

Flash all wall and roof penetrations. Adhesive-backed rubber membranes provide excellent flashing, especially around complex shapes and corners. Always overlap from above so that water is directed away from the structure. Cover the flashing with roofing/siding to keep water moving out of the structure. Similarly, do not seal the horizontal overlap of lap siding. This gap allows liquid water to run out and air to move behind and dry the siding.

Sealants, caulking compounds, and similar compounds that come in a tube are not a substitute for flashing and good design. Sealants often fail, and a failed sealant often traps water, making the situation worse than if no sealant had been used and there was better ventilation. Sealants are inherently less reliable than good design and flashing. Sealants often fail because they are very often installed improperly. Some caulking practices that are extremely common in residential construction are counterproductive—they likely cause more problems than they prevent. Information on proper use of sealants is provided in Carll (2006) and Lacher and others (2019), and in references cited in those documents.

Vent moist air from clothes dryers, showers, and cooking areas to outside, not to the crawl space or attic. Vents in protected places (under an overhang or through a soffit) are better than exposed locations where water entry is more likely. Place an air barrier in exterior walls and top-floor ceilings, and flash penetrations through exterior walls

Figure 16–17. Demonstration of siding installation over a secondary drainage plane (rain screen) showing wall studs, sheathing, water-resistive barrier (WRB), and furring strips. Note that the butt joint is centered directly over the furring strip, a piece of water repellent barrier (felt) is added to drain water to the outside, and the end grain has been sealed.

(doors, windows, and vents). Avoid using humidifiers unless the RH is less than 30%. If the structure contains a crawl space, cover the soil with a vapor-retarding material such as plastic.

Water cannot condense out of air if the air is moving from cold to warm locations, because warm air can carry more water than cold. Therefore, air barriers or vapor retarders should be on the warm side of a wall: interior of the insulation for heated spaces (the north) and exterior of insulation for air-conditioned spaces (the south). For the same reasons, slight pressurization of the interior space is highly desirable in air-conditioned spaces. More on moisture in construction can be found in Chapter 13.

An extra measure to prevent moisture-related problems in siding is the use of rain-screen design (that is, by furring out the siding 9 to 19 mm (3/8 to 3/4 in.) from the sheathing–house wrap) (Fig. 16–17). As always, the wall behind the siding should be air- and watertight. The space between the siding and sheathing should contain a series of vented but stagnant compartments—allowing an easy path for wind to flow behind the siding. Detailed instructions for rain screen construction are given in Rousseau (1990) and OAA (2005).

When installing wood siding or shingles, ensure that the spacing is commensurate with the MC of the wood and the anticipated MC and swelling during the service life. Figure 16–18 shows shingles that were spaced too closely

Figure 16–18. Wood shingles installed with insufficient gap, which later buckled when they expanded after getting wet.

and buckled in service. Wooden floors installed right up to the walls, without a gap, are also prone to buckling.

Avoid beams and joists that go through the exterior moisture barrier. For example, a second-floor floor joist that penetrates a wall to form a porch rafter is destined to have moisture problems leading to decay and finish failure. This type of wall penetration is difficult to seal to avoid air movement. Air carries water vapor that condenses in the space between floors or the porch ceiling. The best seals at this time appear to be made with rubber adhesive-backed membranes.

General Properties of Wood Finishes

Virtually any material has an index of refraction closer to wood than air. Therefore, if a wood lumen is filled with anything clear (such as water, oil, wax, paraffin, varnish, polyurethane), you will see deeper into the wood, and its natural color and texture will be more apparent. This is the reason wet, oiled, or otherwise clear-finished wood looks so much better than bare wood.

Primers and Topcoats

When applying paint or solid-color stain, a primer is strongly recommended. A primer is designed to be sticky and flexible, to adhere well to the wood, and move with wood as moisture content changes. A sticky, flexible topcoat would hold dirt and scratch easily, however. Therefore, topcoats are designed to be hard, easily cleanable (not soft or sticky), and resistant to scratching and wear. Though “paint and primer in one” can be purchased, the properties are not optimal for either the primer or the topcoat.

Primers link wood to topcoats and provide a base for all succeeding top-oats (initial topcoats and refinishing). In addition to being sticky and flexible, they provide another opaque layer to even out color variations and are formulated to deal with variations in wood chemistry. Latex primers are more flexible and stay more flexible; thus, they are less likely to crack as they age than older oil-based products. Latex primers are also generally more permeable to water vapor than old style oil-alkyd primers. A uniform primer coating having sufficient thickness distributes wood swelling stresses and thus helps prevent premature paint failure. Rougher surfaces generally end up with a thicker, more textured film, which generally lasts longer.

Another function of primers is to block extractive bleed. Extractives sometimes migrate out of the wood to the finish surface, resulting in unwanted colors (see Failures—Water-Soluble Extractives). This is especially common over knots and in highly colored woods such as cedar and redwood. Primers, especially stain-blocking primers, are designed to prevent this. If you find extractive bleed, another coat of the same finish will not stop the problem; apply a stain-blocking primer, then another topcoat. Historically, oil-alkyd primers were better at blocking extractive stain than latex primers, but paint manufactures continue to improve latex primers.

Coating adhesion can be improved by flowing into the microscopic pores in wood before cure. Coatings are generally designed to flow naturally into these pores, but especially with rough surfaces, viscous coatings, low application rates, or applicators that do not provide much mechanical action (spray or roller), this does not always occur. Providing some mechanical action to help the coating work its way into the wood can be helpful. This is known as back brushing—using a paint brush to help get the coating to flow into the small crevices in wood.

Water and Vapor Transmission

Ideally, wood should never be exposed to water or changes in relative humidity. Swelling from liquid or vapor absorption causes flaking of coatings and splitting, checking, warping, and cupping in wood, and if moisture levels are high enough, decay. It is tempting to think that we should then design paints that work like a plastic or rubber film, preventing even water vapor from entering the wood. Unfortunately, coatings always fail, from movement at joints, wear, fasteners, or even microbes tunneling through. If liquid water were to enter, and not be able to evaporate, decay would quickly set in. Therefore, paints are designed to block liquid water but allow some water vapor transmission.

Changing Nature of Finishes

The finishes available today in the United States are vastly different from those used in the past. Traditionally, paints and penetrating stains were oil based and contained large quantities of volatile solvents, also known as volatile organic compounds (VOCs). Progressively lower limits on the amount of VOCs allowed in finishes have changed their character. Everything containing solvents, including oil-based semitransparent stains, oil- and oil-alkyd-based primers and topcoats, solvent-borne water repellents, solvent-borne water-repellent preservatives, and even waterborne latexes, have been affected. Most importantly, it can be very difficult to find a penetrating stain that does not form a film. Always test products labelled as penetrating to see whether they form a film.

Another result of VOC regulations is that most research by paint companies has been in waterborne products. Waterborne paints today are far better and more sophisticated than in the past. Because they are engineered products, modern waterborne paints should not be thinned.

Today's coatings typically contain less fungicide than in the past. Many older oil-based paints can be a food source for microorganisms; if you are painting over old oil-based paint, it is recommended that you request extra fungicide from your paint supplier. This can also be helpful if painting areas expected to encounter persistent moisture, such as bathrooms.

Finally, because of the significant changes in both paints and wood products, practices that were traditionally helpful are now sometimes counterproductive. A classic example of this is the advice to let your deck weather before painting it. This was good advice at the time but is now the source of much pain (see Sunburn).

Exterior Finishes

Penetrating and Film-Forming Finishes

Finishes either form a film on the surface or penetrate into the wood and do not form a film. There are dramatic differences in use between film-forming and penetrating finishes. Film-forming coatings applied to wood that has been exposed to sunlight long enough to degrade the surface (approximately 1 week for low-density woods and 4 weeks for high-density woods) is prone to peeling. This is a significant issue when repainting—any wood exposed to sunlight in the past will tend to peel in the future unless it is sanded down to sound wood (see Sunburn). Finishes that do not form a film do not peel—they seem to perform similarly on sunburned or on sound wood. Unfortunately, most penetrating finishes do not last very long. Although a quality primer and two topcoat system on sound, vertical grain western redcedar routinely lasts well over 20 years, a penetrating finish might last only 2 years. This short life is countered by the ease of refinishing—penetrating finishes require minimal surface preparation and can be thinned to blur the boundaries between multiple coats. Surface preparation for film-forming finishes, however, can be extensive and labor intensive.

Penetrating Finishes

Penetrating finishes, such as transparent or clear water-repellent preservatives (WRPs), lightly colored WRPs, oil-based semitransparent stains, and oils, flow into the pores of wood and do not form a film. Because they do not form a film, they cannot crack or flake. They fail one

Table 16–2. Suitability and expected service life of finishes for exterior wood surfaces[a]

	Tinted finishes such as deck finishes		Semitransparent stain		Paint and solid-color stain		
						Expected service life[d] (years)	
Type of exterior wood surface	Suit-ability	Expected service life[b] (years)	Suit-ability	Expected service life[c] (years)	Suit-ability	Paint	Solid-color stain
Siding							
Cedar and redwood							
Smooth (vertical grain)	Low	1–2	Moderate	2–4	High	10–15	8–12
Smooth (flat grain)	Low	1–2	Moderate	2–4	Moderate	8–12	6–10
Saw-textured	High	2–3	High	4–8	Excellent	15–20	10–15
Pine, fir, spruce							
Smooth (flat grain)	Low	1–2	Low	2–3	Moderate	6–10	6–8
Saw-textured (flat grain)	High	2–3	High	4–7	Moderate	8–12	8–10
Shingles (sawn shingles used on side-walls)	High	2–3	High	4–8	Moderate	6–10	6–8
Plywood							
Douglas-fir and Southern Pine							
Sanded	Low	1–2	Moderate	2–4	Moderate	4–8	4–6
Saw-textured	Low	2–3	High	4–8	Moderate	8–12	6–10
MDO plywood[e]	—	—	—	—	Excellent[f]	12–15	10–15
Hardboard, medium density[g]							
Unfinished	—	—	—	—	High	8–12	6–10
Preprimed	—	—	—	—	High	8–12	6–10
MDO overlay	—	—	—	—	Excellent[f]	10–15	10–15
Decking							
New (smooth-sawn)	High	1–2	Moderate	2–3	Low	—	—
Weathered or saw-textured	High	2–3	High	3–6	Low	—	—
Oriented strandboard	—	—	Low	1–3	Moderate	4–5	4–5

[a]Estimates were compiled from observations of many researchers. Expected life predictions are for average location in the contiguous USA; expected life depends on climate and exposure.
[b]The higher the pigment concentration, the longer the service life. Mildew growth on surface usually indicates the need for refinishing.
[c]Smooth unweathered surfaces are generally finished with only one coat of stain. Saw-textured 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 service life of an ideal paint system: three coats (one primer and two top-coats). Applying only a two-coat paint system (primer and one top-coat) will decrease the service life to about half the values shown in the table. Top-quality latex top-coat paints have excellent resistance to weathering. Dark colors may fade within a few years.
[e]Medium-density overlay (MDO) is painted.
[f]Edges are vulnerable to water absorption and need to be sealed.
[g]Water-repellent preservatives and semitransparent stains are not suitable for hardboard. Solid-color stains (latex or alkyd) will perform like paints. Paints give slightly better performance because the solids content of paint is higher than that for solid-color stains and thus paints give greater film build for the same volume of finish used.

pigment particle at a time. This makes refinishing a simple matter of cleaning the surface and applying another coat. Often the finish can be thinned when moving from badly worn areas in need of refinishing to protected areas that do not need another coat. The downside of penetrating finishes is that they may not last very long (Table 16–2). Penetrating finishes are an excellent choice for horizontal outdoor surfaces, such as decks and railings, because film-forming finishes on decks often do not last any longer than penetrating stains. The ease of refinishing with a penetrating stain is a clear advantage. Penetrating finishes give a more "natural" look to the wood than film-forming finishes—that is, they do not smooth out the wood texture.

Almost all pigments block ultraviolet radiation, so in general, more pigment means more protection, for the wood as well as the water repellents and biocides in the coating. There are cases where there is sufficient pigment remaining on the wood, but the water repellency has been lost (a water drop soaks in relatively quickly). In this case, adding a clear water repellent may be all that is needed to provide another year of protection.

Beware—even products labelled "penetrating" can leave a film and so are not "penetrating" as discussed here. Test the product before use. If the surface reflects light, as in a sheen, you have a film, and the film can peel. After application, the wood texture should not be smoothed over by a penetrating finish. Waterborne semitransparent stains having high-solids content are especially prone to film formation. Another hazard is to apply too much penetrating finish—a second coat may form a film even if the first did not. If you see a film forming, wipe off the excess immediately.

Table 16–3. Initial application and maintenance of exterior wood finishes[a]

			Maintenance	
Finish	Application process	Appearance of wood	Process	Service life[b]
Water-repellent preservative (WRP)	Brush-apply 1 coat or dip. Apply a second coat only if it will absorb.	Grain visible; wood tan to brown, fades to gray with age	Brush to remove surface dirt; wash to remove mildew	1–3 years
Tinted clear finish (slightly pigmented deck finish)	Brush-apply 1 coat or dip. Apply a second coat only if it will absorb.	Grain and natural color slightly changed	Same as with WRP	2–3 years
Semitransparent stain	Brush-apply 1 coat or dip. Apply a second coat only if it will absorb.	Grain visible; color as desired	Same as with WRP	4–8 years (on saw-textured or weathered wood)
Paint and solid-color stain	Brush-, roller-, or spray-apply primer and 2 top-coats	Grain and natural color obscured	Clean and apply topcoat if old finish is sound; if not sound, remove peeled finish, prime, and apply topcoats[d]	10–20 years for paint[c]; 6–15 years for solid-color stain[e]

[a]Compilation of data from observations of many researchers.
[b]Vertical exposure; service life depends on surface preparation, climate and exposure, amount and quality of finish, and the wood species and its surface texture.
[c]Service life of 20 years if primer and two coats of top-quality latex top-coats are used on gradual transition wood species having a saw-textured surface. Dark colors may fade within a few years.
[d]If old finish does not contain lead, sand to feather rough edges of paint surrounding bare areas and areas of weathered wood (see Lead-Based Paint).
[e]Service life of 15 years if primer and two top-coats are used on saw-textured wood.

Water Repellents and Water-Repellent Preservatives

Penetrating transparent clear finishes have no pigments, and the generic names for them are water repellents (WRs) or water-repellent preservatives (WRPs). A typical WR formulation contains 10% resin or drying oil, 3% wax or other water repellent, and solvent. WRPs contain a fungicide such as 3-iodo-2-propynyl butyl carbamate (IPBC). They were traditionally formulated using turpentine or mineral spirits, but now paint companies formulate them using VOC-compliant solvent and waterborne systems to comply with VOC regulations.

WRPs give wood a bright, golden-tan color close to the original appearance of the wood and are the first step in protection from weathered wood as a finish. WRPs decrease checking, prevent water staining, and help control mildew growth. They do not last long if exposed to weathering but can protect for several years if wicked into end grain where loading levels are high and the wax is protected (Table 16–3).

Few companies manufacture traditional clear WRs and WRPs; almost all WR and WRP formulations are lightly pigmented and contain other additives to extend their service life. Historically, WRPs were effective when applied before priming and were discussed in earlier versions of the Wood Handbook. References to WRP have been largely removed from this edition because even though they are used industrially, such as in window manufacture, they are difficult to find on the consumer market. The greatest danger of consumer application of WRs is putting on too much. Testing in the 1980s and 1990s showed that water repellency from a single coat of WR or WRP before primer application was beneficial to coating performance, even though there was a slight loss of adhesion. Applying too much WR or WRP before priming resulted in significant loss of adhesion and premature peeling. Recipes for WR and WRP can be found in Black and others (1979) and Knaebe (2013).

When WR or WRP is applied after installation, apply liberally to all end grain areas, edges of panel products, and other areas vulnerable to water, such as the bottoms of doors and window frames. Smooth wood will usually accept only a single coat; a second coat will not penetrate the wood. More WRP will soak into saw-textured, weathered, or badly sunburned surfaces than on smooth surfaces. As a natural finish, the life expectancy of a WRP is only 1 to 2 years, depending upon the wood and exposure. However, reapplication is easy, particularly on decks and fences.

Caution: Fungicides in WRPs and semitransparent stains are toxic and may be herbicides; use caution to avoid skin contact and breathing vapors, and protect plants and the soil around them from accidental contamination.

Penetrating Stains

Lightly pigmented finishes require little work to apply on decks. Water- and solvent-borne formulations are available;

waterborne formulations may be a water emulsion of synthetic polymers. Finely ground pigment gives color and partially blocks UV radiation. Pigment, UV stabilizers, and other additives give these finishes a service life of 2 to 3 years, but they lack sufficient pigment to inhibit UV degradation of the wood. As with clear WRPs, they usually contain a preservative to retard mildew growth.

Truly penetrating (non-film-forming) finishes do not peel; they fade, and if pigmented, the pigments erode. As they weather, they lose their water repellency, turn gray, and develop mildew. Lightly pigmented finishes lose color. If not blackened by mildew, they can often be prepared for refinishing by removing dirt with a stiff-bristle brush. If discolored by mildew, wash the wood with commercial mildew cleaner or dilute liquid household bleach and detergent prior to refinishing (see Mildew).

Oil-based semitransparent stains have more pigment than tinted WRPs, and the pigment gives more protection to wood. Stains usually contain a WR and fungicide. Additional pigment maintains color and increases finish service life, but normal pigments give stain a less natural appearance than lightly colored finishes because they partially hide wood grain and color. Pigment content in semitransparent stains can vary, thus providing a range of UV protection and color. Most people prefer colors that accentuate the natural color of the wood.

Oil or oil-alkyd resin in oil-based semitransparent stains can flow into cut lumina at the wood surface, carrying pigment with it. Some resin penetrates the cell wall; the rest remains on the surface and bonds the pigments to the surface. Oil-based semitransparent stains typically do not form surface films like paints and solid-color stains; therefore, they will not blister or peel even in the presence of excessive water. They will form a film, however, if over-applied. If the coating does not soak in, you have applied too much. Service life varies considerably depending on substrate and amount of pigment.

Resin and paint manufacturers have tried to achieve the properties of solvent-borne semitransparent stains using waterborne formulations. These finishes often achieve a semitransparent appearance by forming a thin coating on the wood and therefore can fail by peeling and flaking. “Semipenetrating” stains are also prone to film formation.

Penetrating stains that use paraffin oil as the solvent are also available in some places. These formulations penetrate wood, and the oil helps improve water repellency. Paraffin oil is not a volatile solvent; therefore, these finishes comply with air quality requirements. They are usually a good value, because virtually all of what comes in the can ends up in the wood. The service life is approximately 1 year, but they are easy to apply. If an excessive amount is applied, the wood surface may remain oily for a few weeks. Do not use them as a pretreatment prior to applying other finishes.

Figure 16–19. Lap marks on wood improperly finished with semitransparent stain.

Because it is very difficult to make truly penetrating finishes with minimal solvent, true penetrating finishes may be hard to find or unavailable in some areas.

Semitransparent stains perform well on saw-textured surfaces. If used on smooth wood, expect approximately half the service life compared with saw-textured surfaces, simply because more finish gets applied to textured wood. They are an excellent finish for weathered wood.

To get consistent application and good penetration of stain, brush-apply oil-based semitransparent penetrating stains. The finish is too fluid to use a roller and spraying leads to an uneven appearance and lap-marks. Brushing works the finish into the wood and evens out the application to minimize lap marks. Lap marks form when application of a stain overlaps a previously stained area (Fig. 16–19). Prevent lap marks by staining two or three boards at a time and keeping a wet edge. This method prevents the front edge of the stained area from drying before reaching a logical stopping place (corner, door, or window) and helps the painter avoid inadvertently giving one area extra heavy coverage. If possible, work in the shade to slow drying. Thinning the stain can also be used to blend edges.

To increase service life of oil-based semitransparent stains on saw-textured or weathered lumber, apply two coats. About an hour after applying the second coat, use a cloth, sponge, or brush lightly wetted with stain to wipe off excess stain that has not penetrated into the wood. Where stain failed to penetrate, it forms an unsightly shiny surface film, and if thick enough, might peel. Stir the stain occasionally and thoroughly during application to prevent settling of pigment.

Two coats of semitransparent penetrating stain may last 10 years on rough or saw-textured wood. By comparison, the life expectancy of one coat of stain on new smooth wood is only 2 to 4 years; however, as the stained wood ages, it becomes more porous and subsequent staining lasts longer.

Semitransparent stain formulations have changed because of VOC regulations. Solvent systems have changed, and the amount of solids has increased. Formulations having high solids may leave excess resin on the surface, particularly the LW. If the finish appears shiny an hour after application, the finish has not penetrated the wood. Remove the excess finish on the surface to avoid forming a thin film; thin films may crack and peel within a year or two. Even if the wood surface has weathered or is saw-textured, it may not be possible for a second coat of these finishes to absorb into wood.

> **Caution:** Sponges, cloths, and paper towels that are wet with oil-based stain, any other oil or oil-alkyd, or urethane finish 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.

When refinishing, simply use a dry stiff-bristle brush to remove surface dirt, dust, and loose wood fibers and re-stain. As with clear finishes, remove mildew prior to refinishing. The subsequent application of penetrating stain often lasts longer than the first because it penetrates the porous weathered surface.

If oil-based semitransparent stain did not penetrate properly and formed a film, it may fail by cracking and flaking. In this case, surface preparation may involve scraping and sanding. For a thick film, it may be necessary to remove all the old finish with a paint stripper prior to re-staining. This is a difficult situation; parts of the structure may have areas where the old finish eroded and the surface is weathered; parts may have an intact or peeling film. Nothing will penetrate areas having a film; film-forming finishes (paint or solid-color stain) do not bond to weathered areas. Either remove the finish in places having a film and re-stain or sand the weathered area, scrape and sand the area having a film, and refinish with solid-color stain or paint.

When refinishing semitransparent stains, the stain must penetrate wood. As mentioned above, stain service life varies with exposure (that is, the weathering of the stain); therefore, 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 compared with the lower part of the wall. When applying stain to such an area, feather the new stain into the old (thinning the stain may help). If the stain does not penetrate the wood within an hour, remove excess stain to avoid forming shiny spots, which indicate a film. The shaded side of a structure may not need to be re-stained nearly as often as the sunny side.

Do not apply oil-based semitransparent stains over film-forming finishes.

> **Note:** Do not use steel wool or steel wire brushes to clean or to prepare tannin-rich wood for refinishing because they contaminate the wood with iron. Minute amounts of iron react with tannins in woods like western redcedar, redwood, and oak to yield dark blue–black stains (see Failures—Iron Stain).

Film-Forming Finishes

Film forming exterior finishes can be classified as clear coats, waterborne semitransparent film-forming stains, solid-color stains, and paint. A primer and topcoat system that protects the wood from UV, water, and microbial growth, properly applied over dimensionally stable wood, can provide long and beautiful service.

Any film-forming finish is prone to peeling if the bare wood has previously been exposed to sunlight (see Sunburn). Films are also prone to blister and peel if there is persistent high moisture in the wood underneath the film. The persistent moisture in the wood is one reason it is so difficult to get a film-forming finish to perform on horizontal surfaces, such as decks. Penetrating finishes often last just as long on decks, are far easier to maintain, and because they do not peel, their failures do not attract as much attention. If you happen to find a film-forming finish that does not contain any water, beware of grain raise (see Grain Raise).

Clear or Lightly Pigmented Films

Clear films are typically made from alkyd, acrylic, or polyurethane resins and form transparent or lightly colored films. A long-lasting exterior clear coat that shows the natural wood is the holy grail of wood coatings research, and to our knowledge, the best products last about ten years when fully exposed. UV and even visible light passing through the clear finish cause color change and wood degradation (see Sunburn). Spar varnishes, formulated for wooden boats with intense solar exposure, often have high levels of UV protection. Reducing the wood's exposure to light and water will increase the service life of the finish. This can be accomplished by staining the wood or using a coating with more color, using it in a location protected from sun and water, and applying multiple coats. Many clear coats include UV blockers and free radical scavengers to minimize light-induced degradation and biocides for microbial control.

Waterborne Latex Semitransparent Stains

Waterborne latex semitransparent stains (introduced in the section on Penetrating Stains) are discussed here because they often form films. (If you find one that does not form a film, refer to Penetrating Finishes.)

Whereas penetrating semitransparent stains (typically oil-based) slowly erode, latex semitransparent stains tend to crack and flake. The film thickness is not sufficient to give paint-like performance. If applied in sufficient coats to give more than a few years performance, they give the appearance of a solid-color stain. As with any stain, it is best to keep working a wet edge and avoid staining over areas that have already dried, which tends to leave lap marks (Fig. 16–19).

Solid-Color Stains

Solid-color stains are opaque finishes (also called hiding, heavy-bodied, or blocking stains) that come in many colors and are made with a higher concentration of resin and pigment than are semitransparent penetrating stains; therefore, solid-color stains obscure the natural color and grain of wood. Solid-color stains form a film, like paints. They are different from paint in that they are designed to erode more quickly so that even after applying many coats, the film does not get too thick. Because they erode, solid color stains need to be reapplied more often than paint.

Some manufacturers recommend applying solid-color stain directly to the wood, but using primer is better because of the different performance needs (see Primers and Topcoats). If you do apply solid-color stains to bare wood, a single coat to smooth wood will tend to crack and flake; the film lacks sufficient cohesive strength to accommodate moisture-driven movement of the wood. Solid-color stains lack abrasion resistance, and manufactures do not generally recommended them for horizontal wood surfaces such as decks.

Solid-color stains can usually be applied over paint. See the following section (Paint) for additional information on refinishing. If the old finish has cracked or peeled, remove it and sand the wood prior to refinishing.

Paint

Paints are highly pigmented film-forming coatings and give the most protection against UV radiation, water, and abrasion (weathering). Paints protect wood surfaces, conceal some surface defects, provide a cleanable surface, offer many colors, and are available in high gloss (high gloss is not possible with stains). Paint is the only finish that can give a bright white appearance. Paint retards penetration of moisture, can decrease discoloration by wood extractives, and retards checking and warping of wood. However, paint is not a preservative. It will not prevent decay if the wood is moist.

Before 1970, most paints were oil based, but now these are rare. In addition, the oil-based paints of today usually have little resemblance to traditional paints because of VOC regulations. Most research by paint companies since 1980 has been devoted to waterborne latex, rather than oil or alkyd paints. Therefore, the advantages traditionally attributed to alkyds are not necessarily true anymore. Latex topcoats can be applied over oil-alkyd primers or previous coats. (See previous editions of the wood handbook for details about oil-based paints.)

Waterborne, or latex, paint is carried by water and cleans up with water. It is a mixture of finely ground pigment in a resin, or binder. The resin is a synthetic polymer that coalesces to form a film as it loses water and other solvents. Solvents keep the polymer flexible while it coalesces. Acrylics and vinyl acrylics are typical resins in wood finishes. Acrylics are especially resistant to weathering.

As always, apply the first coat of film-forming finish (primer) as soon as possible to prevent premature failure (see Sunburn). Consider priming before installation, and always seal all end grain. On smooth-planed wood, the best service life comes from a primer and two topcoats to achieve a 0.10- to 0.13-mm (4 to 5-mil) dry film thickness. If applying two topcoats to the entire structure is not practical, consider two topcoats for fully exposed areas on the south and west sides and a single topcoat on other areas. Many three-coat paint systems in tests at FPL have lasted 30 years.

For woods with water-soluble extractives, such as redwood and western redcedar, stain-blocking primers are advised to block extractives bleed into the topcoat (see Failures–Water Soluble Extractives). For species that do not tend to have extractives bleed, a quality primer is still necessary to give a good base for topcoats. Follow the application rates recommended by the manufacturer to achieve sufficient film thickness.

Apply latex-based waterborne paints when the temperature is at least 10 °C (50 °F) and expected to remain above this temperature for 24 h. (The dew point is a good estimate of nighttime low temperature.) Most latex paints do not coalesce properly if the temperature drops below 10 °C (50 °F). Check with paint manufacturers on the temperature requirements because some paints can be applied at lower temperatures than these. Avoid painting hot surfaces in direct sunlight. Prior to applying latex paints, the surface can be cooled with water mist and allowed to dry.

Avoid painting late in the afternoon if heavy dew is expected during the night. Water absorption into partially coalesced latexes can cause wrinkling, fading, loss of gloss, and streaking.

Refinishing Paints

In the absence of catastrophic failure such as cracking, flaking, and peeling, solid-color stains and paints slowly erode. A three-coat finish system (0.10 to 0.13 mm thick) should last 20 years. When the topcoats begin to wear thin, exposing the primer, reapply one or two new topcoats. One coat may be adequate if the old paint surface is in good condition. Surface preparation merely involves washing the surface to remove mildew, dirt, and chalk. Paint erodes at different rates, so different sides of a structure do not need to be painted on the same schedule. Paint on the shaded side often lasts twice as long as that on a fully exposed, sunny side.

Clean areas that are protected from sun and rain, such as porches, soffits, and walls protected by overhangs. These areas tend to collect dirt that decreases adhesion of new paint. Repainting protected areas every other time the structure is painted usually gives adequate performance.

Do not paint too often. If paint is sound, but discolored with mildew, wash it. It does not need repainting. Too many coats of latex paint can eventually lead to adhesion failure of the primer.

> Refinish exterior wood when the old finish has worn thin and no longer protects the wood. If all factors are working in concert (good structure design to shed water, effective flashing, paintable wood surface, and end grain sealed), paint degradation is benign weathering of paint to expose the primer or, in the case of a penetrating finish, to expose the wood surface. In these cases, there is rarely much surface preparation other than mild washing prior to refinishing. Mildew growth is not paint degradation but rather an appearance problem—remove it with a commercial cleaner or bleach–detergent solution.

In situations where the primer has peeled away from the wood, refinishing with paint and solid-color stains may require extensive surface preparation. First, scrape off all loose paint. In the absence of lead-based paint, sand areas of exposed wood with 50- to 80-grit sandpaper to remove the weathered surface and to feather the abrupt paint edge. Wash the remaining old paint using a commercial cleaner or a dilute household bleach and detergent solution to remove dirt and mildew and rinse thoroughly (see Mildew). Prime the areas of exposed wood, then apply topcoat.

> **Note:** Do not sand lead-based paint. Use special precautions if the old paint contains lead (see Lead-Based Paint).

Table 16–2 summarizes the suitability and expected life of commonly used exterior finishes on several wood species and wood-based products. The information in these tables gives general guideline. Many factors affect paintability of wood and service life of wood finishes. Table 16–3 summarizes the properties, treatment, and maintenance of exterior finishes.

Application of Finishes, Special Uses

Porches, Decks, Deck Railings, and Fences

Porches get wet from windblown rain; therefore, apply a WRP, oil primer, or thinned enamel to all surfaces (flooring, railings, posts), especially the end grain, prior to or during construction. Primers and topcoats for porch floors are formulated to resist abrasion.

Horizontal surfaces exposed to the rain and sun, such as decks, are prone to peeling. Therefore, decks are very difficult to maintain—and many people are disappointed—using a film-forming finish. Therefore, penetrating finishes are recommended if they can be found. Penetrating finishes need more frequent application than paint but do not need extensive surface preparation, because they seldom fail by cracking and peeling. Limit the application of stain to what the surface can absorb. The best application method is by brush; roller and spray application may put too much stain on horizontal surfaces. Solid-color stains form films and so will be prone to peeling just like paint.

Like decks, fences are fully exposed to the weather, and some parts (such as posts) are in contact with the ground; therefore, wood decay and termite attack are potential problems. Use lumber pressure-treated with preservatives or heartwood (the dark, not light-colored, portion) of naturally durable wood species (see Chap. 14, Table 14–1) for all posts and other fence components that are in ground contact. When designing and constructing fences and railings for decks and porches, architects and contractors need to consider protecting exposed end-grain of components to resist water absorption.

Film-forming finishes on fences and railings trap moisture if the end grain is not sealed during construction. Figure 16–13 shows a railing 8 years after construction. Water flowed down the railing and absorbed into the end grain, and the paint kept the wood from drying. Sealing the end grain helps prevent paint peeling and helps stop checking, splitting, and warping. Use treated or decay-resistant wood, particularly where decay of wood is a safety hazard, such as railings.

The service lives of naturally durable and preservative-treated woods are quite comparable in above-ground exposures, such as decking boards. In selecting wood for porches, decks, and fences, whether preservative treated or a naturally durable species, consider the exposure conditions, design of the structure, properties of the wood, and the finish to be used.

Wood weathering can be as much a factor in long-term service life of decks and fences as decay. The most common reason for removal of preservative treated wooden decks is splitting and checking, not decay or structural problems. Checking, splitting, and warp of both naturally durable wood species and preservative-treated wood can be minimized with a finish that slows moisture movement into the wood. Periodic treatment with a penetrating sealer, such as a WRP or lightly pigmented deck finish will decrease checking and splitting. Pigmented finishes retard weathering and protect the mildewcides in coatings.

Sometimes preservative treated lumber is still above the saturation point when it is delivered and installed. You can tell because it is exceptionally heavy or by observing water coming out when a small piece is squeezed by vice or hammer blow. Nothing will coat wet wood well. If you encounter this situation, the best you can do is wait until the wood dries and use a penetrating, rather than film-forming, finish. Alternatively, you can purchase wood kiln dried after treatment, known as KDAT.

Treated Wood

Wooden decks are most commonly replaced because of checking and splitting, not decay. The best way to prevent checking and get 40 or more years of service life from wood is to ensure water beads up on the wood surface rather than soaking in immediately. Water repellents, penetrating stains, or other coatings can greatly extend the life of a deck.

Copper-based preservatives are commonly available to homeowners in the United States and Canada. The treatment has little effect on finishing once the wood has dried; species and grain orientation affect finishing more than preservative treatment does. Waterborne treatments containing copper may maintain a brown color for approximately 2 years. Some copper-based preservatives may have a water repellent included in the treatment to give the treated wood better resistance to weathering. Even if the manufacturer treated the wood with water repellent, maintain it with a finish to extend its service life. As already stated, decks are usually replaced because of weathering, not decay. It is extremely challenging to get film-forming finishes to adhere to decks—peeling is very common. Penetrating finishes have to be refreshed every few years, as they wear and the wood loses water resistance, but the labor associated with preparation and application of penetrating stain or water repellent is small compared to dealing with failed film-forming coatings.

CCA, creosote, and pentachlorophenol treatments are available for industrial and commercial applications. CCA accepts paints and finishes very well. Creosote is oily, and wood treated with creosote does not accept a finish. Pentachlorophenol is often formulated in heavy oil. Wood treated with preservatives formulated in oil generally do not accept a finish.

Marine Uses

The marine environment is particularly harsh on wood because of salt, abrasion by sand and water, repeated wetting and drying, and direct and reflected UV radiation. Any type of finish discussed previously can be used in marine environments, but because of the harsh conditions, service life is usually shortened. Consult paint manufacturers for products formulated for marine use.

Note: Any wood in contact with water must be pressure treated to specifications for marine use. Chromated copper arsenate (CCA) is still used in marine environments, and the chromium in the formulation improves the performance of stains and paints.

Panel Products

The edges of panel products such as plywood, OSB, and fiberboard are especially vulnerable to absorption of water because they contain end grain. To minimize edge swelling and subsequent finish peeling, seal the edges of these products with a WRP, thinned oil-alkyd primer, or sealer formulated for this use. Edges and fastener penetrations are the most common source of water entry and subsequent finish failure. The type of edge sealer depends on the surface finish.

Panel products with a paper overlay (MDO) typically hold film-forming finishes better than those without. Overlays do not accept penetrating finishes, however. The MDO protects the surface from moisture and gives a good surface for film-forming finishes. OSB and fiberboard without an MDO are generally not recommended for exterior exposure at all.

Fire-Retardant Coatings

Intumescent fire-retardant finishes have low surface flammability, and when exposed to fire, they “intumesce” to form an expanded low-density foam. The expanded foam insulates the wood from heat and retards combustion. The finishes may also have additives to promote wood decomposition to charcoal and water rather than flammable vapors. These and other fire-retardant treatments may interfere with coating performance. Consult the manufacturer.

Back Priming

Back priming is applying primer or WRP to the back side of wood (usually siding) before installing it. Back priming with stain-blocking primer retards extractives staining, particularly run-down extractives bleed (Fig. 16–20). It decreases absorption of water, thus improving dimensional stability. Siding is less likely to cup, an important consideration for flat-grain wood. Reducing moisture-driven movement decreases stress on the finish, thus reducing paint failures.

At the time siding is back-primed, seal end grain. This process has an even greater effect in stopping water absorption than back-priming. Sealed end-grain eliminates paint failure near the ends of boards. Seal ends cut during installation.

Figure 16–20. Water-soluble extractive discoloration can result from water wetting the back of the siding and then running down the front of the board below.

Factory Finishing

Priming before installation (even in your garage) is the best way to extend paint life. Factory priming hardboard siding has been a standard industry practice for many years, and now factory-finished (primer and topcoats) siding, trim, and decking are common. Factory finishing offers several advantages: it avoids exposure to light (see Sunburn), avoids finishing during inappropriate weather, gives consistent film thickness, contributes to timely completion of structures, and can decrease overall cost. Factory finishing is advantageous in northern climates where exterior finishing is impossible during the winter. Controlled application ensures consistent optimal film thickness. Siding is normally primed on all sides, including the end grain. When installing factory-finished siding, seal cross-cuts. Controlled conditions enable many factory finishers to guarantee their products against cracking, peeling, and blistering for 15 years.

Failures

Finishes rarely fail prematurely when properly applied to a compatible substrate on a well-designed and constructed structure. In the absence of finish failure (cracking and peeling) or discoloration (extractives bleed, iron stain, and mildew growth), finishes undergo a slow erosion over years or decades. The most common causes of premature failure of film-forming finish (paint and solid-color stains) are water, weathering of wood prior to painting, inadequate surface preparation, and insufficient film thickness. Structure design, wood species, and grain angle can also affect performance. Following are some specific finishing issues, their causes, and solutions.

Blue Stained Wood

Blue stain is a fungus that can infect sapwood of trees and logs (Fig. 16–21) before they are dried. The fungus discolors, but does not weaken, the wood. Neither commercial mildew cleaners nor household bleach with detergent can remove it. If the color is objectionable, use

Figure 16–21. Blue stain may infect and discolor sapwood.

Figure 16–22. Cross-grain checking in juvenile wood. There is no fix other than replacing the board.

a pigmented finish to hide it (see Mildew) or use different wood. Blue stain or other infection can make the wood very porous, allowing it to soak up large amounts of thin liquids, such as stain. (For more on this, see Stain" in the section on finishing interior wood.)

Cracking Paint (Pallel to Grain)

Cracking parallel to grain occurs on smooth flat-grain lumber, often in LW or the EW–LW boundary. Grain raise is a common cause, as is the high density of LW (see Peeling and Flaking). Other contributing factors are coatings having insufficient thickness and lacking flexibility. If the cracking is not too severe, sand and apply one or two topcoats to give additional film-build.

Cross-Grain Cracking

Modern waterborne latex finishes seldom fail by cross-grain cracking. If latex finishes crack across the grain, dimensional instability of wood under the finish probably causes it. For example, cross-grain checking of juvenile wood causes paint to crack (Fig. 16–22). The first few years of growth around the pith is most susceptible. In this case, replace the board and repaint.

If juvenile wood is not to blame, cross-grain cracking usually occurs on structures having thick layers of old oil-alkyd paint. If the wood is not the cause of paint failure, remove the old paint and apply new finish to the bare wood,

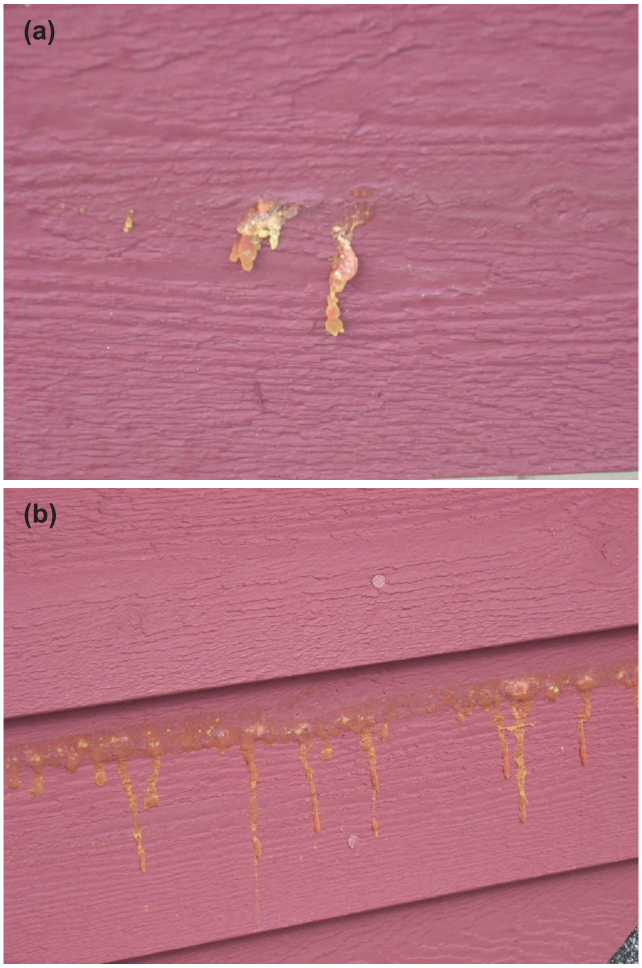

Figure 16–23. (a) Pitch exudation from an isolated spot; (b) pitch exudation from a large pocket or seam.

or replace the wood. Old alkyd paint potentially contains lead (see Lead Paint).

Extractives—Pitch

Pitch and other resins are one of the defense mechanisms that a tree uses to protect itself from harmful infections and insects following injury. Pitch exists as a normal part of the wood of pines (*Pinus* spp.), spruces (*Picea* spp.), larches (*Larix* spp.), and Douglas-firs (*Pseudotsuga* spp.), and it can be found in specialized wound structures called pitch pockets in the wood of most softwood species. Pitch is a solution of natural rosins and turpenes. High temperature and high turpene concentration both make the pitch turn to a liquid. Usually turpenes evaporate during kiln drying, leaving the pitch "set," or permanently hard. However, pitch is not always completely set in the kiln, and so pitch flow can be an issue. In softwood that has not been kiln dried, such as large timbers, pitch will likely flow if present. Pitch bleed to the surface can occur in isolated spots (Fig. 16–23a) or in large pockets or seams (Fig. 16–23b) when pitch gets warm and the turpenes have not yet evaporated. If the wood is finished, the pitch may exude through the coating or cause the finish to discolor or blister.

Coatings will not stop pitch bleed. The only way to prevent pitch bleed in wood prone to it is to set the pitch by heating the wood to evaporate the turpenes or preventing the wood from getting warm enough to liquefy the resin in the future. If you have pitch bleed in service, it goes away naturally over time as the turpentine evaporates. To hasten pitch evaporation, get the pitch hotter than it will ever see in service for a day or two. This can be accomplished by temporarily painting the section black during the heat of the summer, tenting the area in black plastic in the sun, or adding a heater if the sun is not strong enough. For small sections, a heat gun or hair dryer may work, if caution is used not to start the structure on fire. Once the pitch has set (hard even when warm), use a putty knife to scrape off what you can, and sand to bare wood. A very small amount of paint thinner can be used to rub off objectionable residue. Test adhesion with the tape test (see Sunburn). If the pitch bleed occurred on a dark surface, further bleed may be stopped simply by painting it white, thereby lowering the surface temperature.

Extractives—Water-Soluble

In many species, the heartwood contains water-soluble extractives that discolor paint. Sapwood rarely contains problematic water-soluble extractives. The classic sources of extractive stain are western redcedar and redwood, probably because they were so common in the past, but the heartwood of many species contains the highly colored water-soluble extractives necessary to produce this problem. When wood gets wet, water dissolves some extractives, and as the water moves, it carries these extractives. The water evaporates leaving extractives behind as a reddish-brown stain. Discoloration shows in two ways: diffuse and run-down extractives bleed.

Diffused extractives bleed is caused by (1) water from rain and dew that penetrates a porous or thin paint coating, (2) water that penetrates joints in the siding, railings, or trim, and (3) absorption of water vapor in high humidity areas such as bathrooms, swimming pools, and greenhouses (Fig. 16–24). The water then moves through the paint film to the surface, depositing extractives there.

Diffuse extractive bleed (directly through the paint film) is stopped by stain-blocking primers and minimizing water inside the wood. When applying opaque coatings on woods with high extractives content (knots and anything that has good durability, but especially redwood and cedar), use a stain-blocking primer. If the wood is already painted and is discolored by extractives, clean the surface and apply a stain-blocking primer. Allow sufficient time for the primer to cure so that it blocks the extractives, and then apply topcoat. If extractives can bleed through one coat of a particular paint, more coats of the same paint will not stop the problem.

Run-down extractives bleed is caused by water getting onto the back side of the siding, dissolving extractives, and

Figure 16–24. High moisture content of wood can cause diffuse extractives bleed, particularly if a stain-blocking primer is not used.

running onto the front side of the siding below it, where it evaporates leaving streaks (Fig. 16–20). The most common sources of water are (1) roof leaks, faulty gutters, or ice dams, (2) condensation of water vapor, originating inside the structure (often bathrooms or kitchens), and (3) wind-blown water.

Prevent run-down extractives bleed by preventing liquid water from running down the back side of the siding by fixing roof leaks, maintain gutters, and prevent ice dams. Decrease condensation or the accumulation of moisture in wall by lowering indoor humidity and installing effective air barriers in wall systems. Design structures with enough roof overhang to minimize wetting by wind-blown rain. Another approach is to prevent water from coming in contact with the extractives by applying stain blocking primer to the back side of the siding before installation (see Back Priming). This has the added benefit of reducing warping, cupping, and decay in siding by slowing the flow of water into the wood. Using rain-screen construction, especially when vented into the soffit or attic, helps further by providing air flow to dry the back of the siding (see Structure Design and Construction Practices).

By eliminating the cause of extractives bleed, the discoloration will usually weather away in a few months. However, extractives in protected areas (under the eaves, soffits, and porch ceilings) 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 containing oxalic acid (sometimes called wood bleach or wood brightener) often remove stains.

Grain Raise

Finish problem sometimes occur at the boundary between dense latewood and low-density earlywood, especially with flat grained lumber and also with oil-based film-forming coatings. Figure 16–25A shows the end of a southern pine board as received, on the right; on the left is the same board,

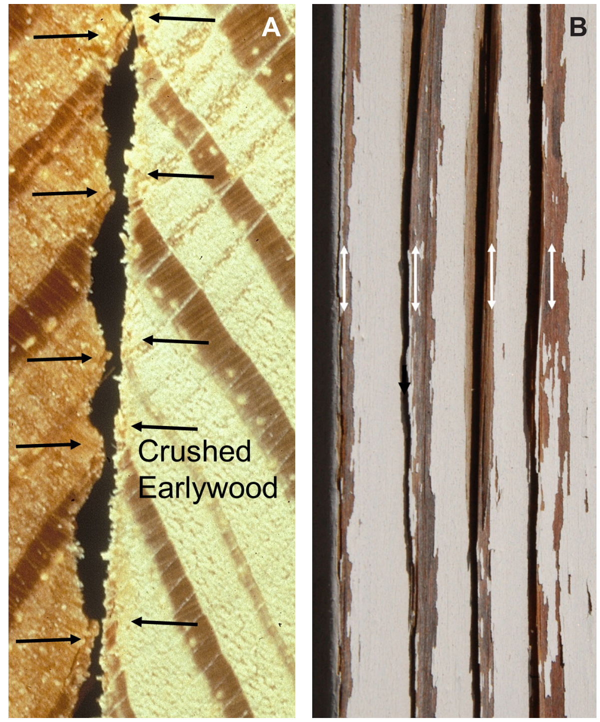

Figure 16–25. (A) Woods with thick, dense LW bands, such as southern pines, are prone to crushing of the EW immediately below the LW, as evidenced by the curve in the EW/LW boundary at the surface (arrows on right). Upon wetting, the crushed EW cells spring back (left). (B) Over time, the crushed EW failed, allowing LW bands to separate from the board.

after the surface has been wetted. In this board, the planer blades pressed the dense LW into the low-density EW, crushing it. Thin arrows point to the curve in the LW band just at the surface. When the wood gets wet, the EW springs back. During spring back, EW pushes the LW out. The resulting movement makes the surface bumpy, objectionable in some cases, and if the coating has formed a film before the grain raises, the film is prone to cracking. The crushing of the EW can be so severe that they fail, allowing LW bands to separate from the board (Fig. 16–25B).

The cause of grain raise is the crushing of EW cells during planing. Optimal planing of high-density LW and low-density EW is challenging, requiring well maintained and sharpened tools, as well as proper feed rates and other factors. When wood has thick bands of LW with density much different than EW (for instance, southern pine), grain raise is common.

Grain raise is easy to diagnose: get the wood wet and feel the surface to see if it develops bumps or roughness by the time it dries. After the grain has been raised (one wetting is typically sufficient), and wood is dry again, the surface can be coated normally. If smoothness is required, sand after raising the grain. Coatings that do not contain water are especially prone to cracking by grain raise because they do not get the wood wet during finishing. Latex paints apply

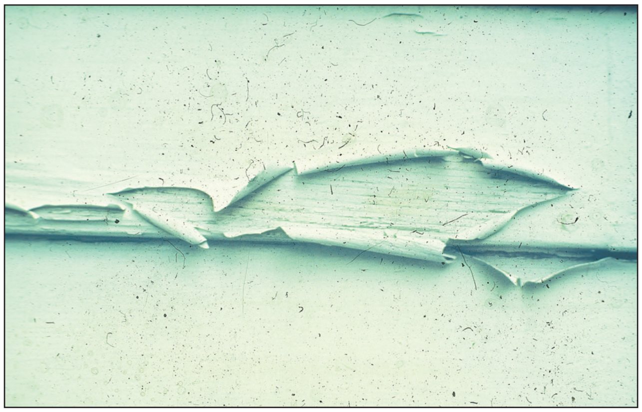

Figure 16–26. Intercoat peeling of paint, usually caused by poor preparation of the old paint surface.

some water to the surface with the paint, so they release some grain raise before the film sets and usually do not result in a problem. If the EW crushing is so severe that the LW bands separate from the board, as in Figure 16–25B, use a penetrating stain, replace the board, or remove the damaged surface by sanding.

Grain raise can be used constructively to repair dents, such as hammer marks. To raise the wood and make the surface flat, get the area wet and warm (such as with a clothes iron).

Intercoat Peeling

As the name implies, intercoat peeling is loss of adhesion between coats of finish, usually peeling of a new paint from old paint (Fig. 16–26). It usually occurs within a year of repainting. Prevent intercoat peeling by ensuring that old paint is clean prior to repainting. To check for intercoat peeling problems, apply paint to a small inconspicuous area and allow it to dry at least overnight. Then do the adhesion test (see Sunburn). No paint should come off with the bandage. If it does, the old surface needs additional cleaning or priming. If both the new 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. You should test several areas of the structure to determine the extent of poor paint bonds before stripping all the paint.

Iron Stain

Iron stains are the result of a reaction of iron with tannins in wood, leaving a black stain (Fig. 16–27A). Iron fasteners are the most common source of iron stain. Iron can also come from steel wool or wire brushes used in cleaning, poor quality woodworking tools, or nearby metalworking or wear of metal parts. The wood moisture content must be above about 16% for iron (or the stain) to move through the wood, so iron stain is primarily a problem in outdoor environments. As an indication of how dark and persistent they are, iron-tannin solutions were traditionally used as black ink.

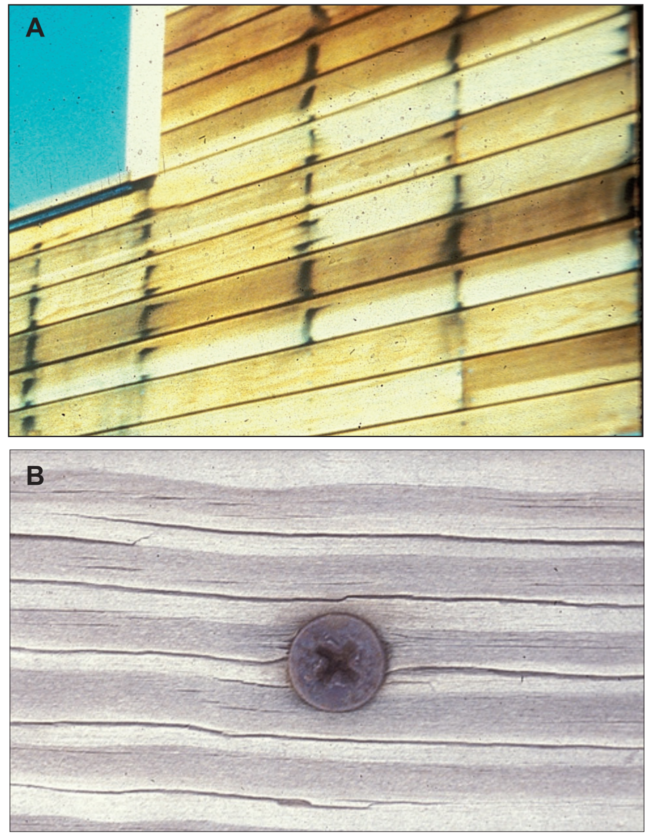

Figure 16–27. (A) Iron stain on newly installed cedar siding. Poor quality galvanized nails corrode easily and, like uncoated steel nails, usually cause unsightly staining of the wood. (B) Pine, on the other hand, does not contain appreciable tannins, so iron stain is not an issue even with rusty fasteners.

Expect iron stain if using plain carbon steel fasteners on naturally finished exterior wood containing high amounts of tannin, such as western redcedar, redwood, and oak. To our knowledge, stainless steel fasteners are safe from iron stain. If stainless steel fasteners cannot be used, high-quality hot-dip galvanized fasteners, such as those meeting standard ASTM A153/A, are far less likely to cause iron stain than plain carbon steel. Unfortunately, iron stain on cedar from inappropriate fasteners is common, even when contractors do the work.

In wood species that lack tannins, such as pine, iron merely rusts, giving a brown stain to the wood surrounding the fastener (Fig. 16–27B). The iron also causes slight degradation of the wood near it (often referred to as "wood sickness"). This discoloration develops over many months or years of exposure.

If iron stain is a serious problem on a painted surface, ensure that the fasteners and stain are completely coated. For the very best results, countersink the fastener, spot prime, caulk, spot prime the caulk, and topcoat.

Iron stain occurring beneath a clear or semitransparent finish is extremely difficult to fix. The coating must be removed before the iron stain can be removed. Oxalic acid will remove the blue–black discoloration. Apply a saturated solution (0.5 kg of oxalic acid per 4 L (1 lb gal^{-1}) of hot water) to the stained surface. Many commercial brighteners contain oxalic acid, and these are usually effective for removing iron stains by forming a clear oxalic acid/iron complex. After removing the stain, wash the surface thoroughly with water to remove the oxalic acid/iron complex. If even minute traces of iron remain, the discoloration will recur after oxalic acid breaks down by sunlight and releases the iron to re-react with extractives. Sodium bifluoride does not appear to break down with exposure to sunlight and so may be a better choice if rinsing is not practical; start with a 5% solution.

Caution: Oxalic acid is toxic when ingested and can harm plants in high concentration; take care when using it. (It is the poison in rhubarb leaves.)

Knots

Knots are more prone to paint peeling and staining than most wood. Knots tend to be high density, contributing to paint peeling. In many species they contain an abundance of resins and other highly colored compounds (see Extractives—Water Soluble). Knots can be sealed with shellac or specially formulated knot sealer, followed by priming of the entire board. Modern high quality stain-blocking primers usually work without any special knot treatment. Another option for knots is to use them to accentuate the wood. Use a stain to bring out the color and make the knots a part of the desired appearance.

Because knots have a grain direction much different from the rest of the board, they shrink differently. Therefore, knots commonly develop checks. Like all wood checks, they will tend to open when dry and close when moist. Fillers should be flexible so that they stay bonded to the wood during these movements.

Loss of Gloss and Fading

Loss of gloss and fading was a significant problem with traditional oil-alkyd finishes. Although modern acrylic-based latex finishes do not give the high gloss of an oil-alkyd, they maintain gloss much longer. Some pigments fade more than others; check with the paint manufacturer to ensure that the colors will last. White is always a safe choice. Another advantage of light colors is the lack of solar heating and associated moisture gradients in the wood. Many dark-colored finishes may fade to give unacceptable performance long before the finish fails.

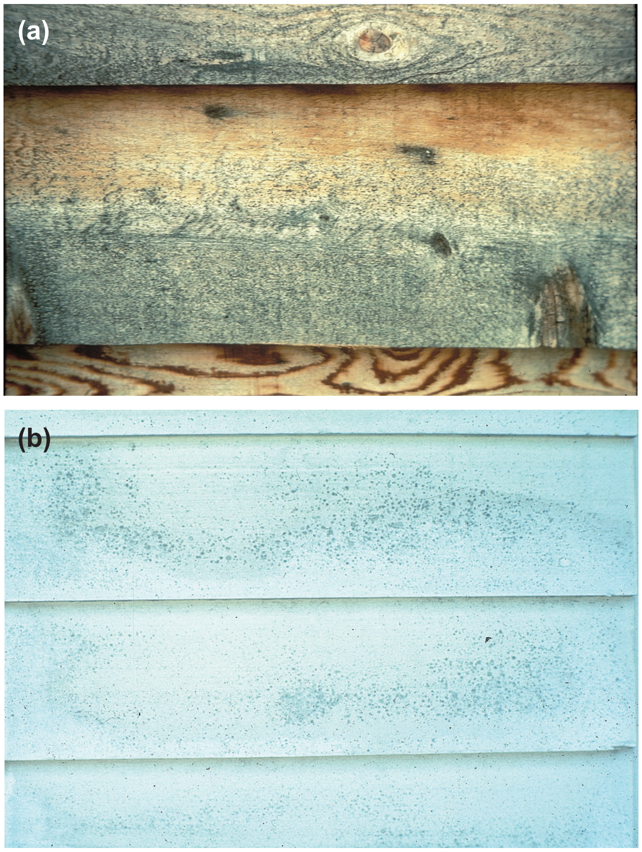

Figure 16–28. Mildew is most common in shaded, moist, or protected areas (a) on wood and (b) on painted wood.

Mildew

After peeling and flaking, mildew is probably the most common complaint with finishes. Mildew is the term for fungi that infect surfaces such as wood (Fig. 16–28a) and painted wood (Fig. 16–28b). These fungi can live on any surface that supplies a food source from either within the material or from air or liquids that contact the surface, such as dirt. Although this type of fungi cannot decay wood, they can metabolize some of the extractives in wood and natural oils (such as linseed oil) in finishes, as well as dust. They usually discolor wood or finishes with black deposits and often grow in combination with algae (usually green discoloration).

Mildew may be found anywhere on a building but is most common where moisture stays longest—out of the sun and where air does not move, such as near tall plants. Mildew may also be associated with dew patterns of structures. Dew forms on parts of structures that cool rapidly, such as eaves, soffits, and ceilings of carports and porches. The dew provides a source of water for mildew.

Mildew can sometimes be distinguished from dirt by examining it under a microscope. In the growing stage, when the surface is damp or wet, the fungus has threadlike growth. In the dormant stage, when the surface is dry, the fungus may have 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 (5% sodium hypochlorite) to the discolored area. The dark color of mildew will usually bleach out in a few seconds. Surface discoloration that does not bleach is probably dirt, extractives bleed, or iron stain. Mildew can grow through a surface coating or under a clear finish. In these cases, it may be difficult to test for or to clean the mildew; the finish protects the mildew from the cleaning solution.

To remove mildew, use a commercial cleaner or a dilute solution of household bleach with detergent. Oxygen bleaches are likely to do less damage to the wood than chlorine-based bleaches. When using bleach, use as dilute a solution as possible. One part household bleach to five parts water should be adequate. In no case should a mixture stronger than one part bleach to three parts water be necessary. A little powdered detergent can help remove the dirt. Do not use liquid detergent because it may contain ingredients that react with bleach to give toxic fumes. Gently scrub the surface with a bristle brush or sponge and rinse thoroughly. Rinse using a garden hose, keeping the water stream pointed down to avoid flooding the back side of siding with water. If using a power-washer, keep the pressure low to avoid damaging the wood and, as with the garden hose, keep the water stream pointed down. Refinish the cleaned surface as soon as it has dried using a finish containing a mildewcide.

Household bleach mildew remover
- 1 part (5%) sodium hypochlorite (household bleach) (1 gal)
- 3 to 5 parts warm water (3–5 gal)
- A little powdered household detergent (1/4 cup)

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

Mill Glaze

A condition known as “mill glaze” (also called planer’s glaze) is sometimes reported to cause paint failure. Controversy exists over the exact cause of this condition, and many people use it as a catch all for unexplained paint failures. They attributed the paint failure to dull planer blades or excessive heat during planing. However, investigations of reported mill glaze by FPL scientists showed that other factors caused finish failure; scientists were unable to duplicate mill glaze in the laboratory. FPL scientists found three causes for paint failures that others had attributed to mill glaze: (1) raised grain under a thin film, particularly on smooth flat-grain lumber (see Grain Raise), (2) wood weathering prior to application of film-forming finishes (see Sunburn), and (3) moisture (see Peeling and Flaking). These factors often occurred together.

Peeling and Flaking

Peeling and flaking (adhesion failure between wood and primer) can have several causes: water, wood weathering, difficult surfaces, and dimensional change of wood. Flaking often follows cracking; small cracks in paint allow water to enter. Flaking is similar to peeling—small pieces of finish peel from the surface usually along a boundary between earlywood and latewood. Flaking often occurs with cracking parallel to grain and usually occurs with thin films. It can occur with thinly applied film-forming finishes and with penetrating stains if they form a film (such as if too heavily applied). Water is the main cause, but other factors can also be involved. Water speeds the failure by other causes.

Peeling and flaking are often worst at the ends of boards because of water more easily entering end grain and more extreme wet–dry cycling. This problem can be greatly reduced by priming or otherwise sealing all end grain and preventing water from sitting in contact with end grain.

One cause of peeling and flaking is weathering of wood prior to primer application (see Sunburn). Protect wood from the weather prior to installation and paint it as soon as possible after (or before) installing it. Leaving smooth-planed lumber exposed to the weather for as little as a week decreases its paint-holding properties. If wood was exposed more than a week, check adhesion with the tape test and consider sanding prior to painting. Paint applied to weathered wood often fails over large areas and sometimes wood fibers are attached to the back of the film, clearly showing the grain of the wood.

Grain raise is also a source of peeling, because of the crack formed at the EW/LW boundary during springback (see Grain Raise).

LW is often more prone to peeling and flaking than EW (Fig. 16–29). One reason is that LW moves more with the same change in MC than EW. Another is that EW often presents a lot of microscopic surface area for contact with the primer, whereas LW can sometimes be very smooth (Fig. 16–30). Some research has suggested that sanded LW surfaces gave a better surface for paint adhesion than planed surfaces.

Sunburn

Exposing wood to UV light for as short as a week before applying a film-forming finish measurably reduces the service life of the coating (see Effect of Weathering on Finishes—Sunburn).

Figure 16–29. Typical peeling and flaking over latewood.

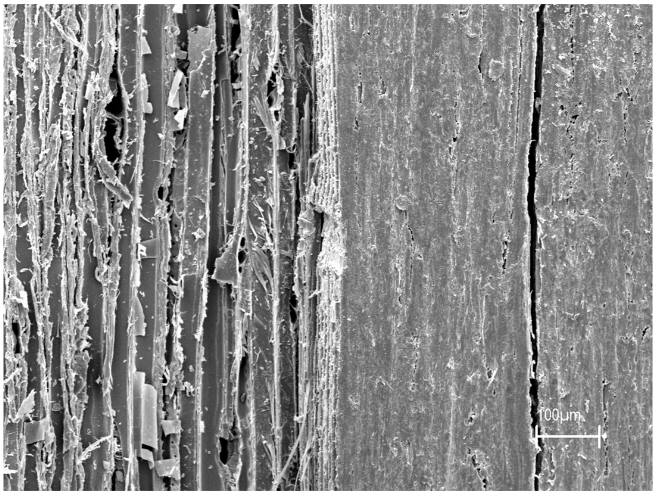

Figure 16–30. High magnification image (1 mm wide) of the boundary between earlywood and latewood on the surface, as delivered, of a southern pine deck board. The low-density earlywood cells on the left provide a textured surface, whereas the latewood on the right is smooth and the cell walls crushed. The multiple cell walls close together in the center are likely a series of collapsed earlywood cells.

Water Blisters

Water blisters (also called moisture blisters) are bubble-like deformation of paint films (Fig. 16–31). As the name implies, these blisters usually contain water when they form. Water blisters form between the wood substrate and the primer. After the blisters appear, they may dry out and collapse. Small blisters may disappear completely, and large ones may leave rough spots; in severe cases, the paint peels. Oil-based paint is much more prone to blisters than latex paint.

Minimizing water absorption into wood is the only way to prevent water blisters. Water blisters may occur on siding and trim where rain enters through improperly flashed doors, windows, and vents; they are common near unsealed end grain of siding and trim. Water from ice dams and overflow from blocked gutters can also cause water blisters. Movement of water vapor from the inside of a structure to siding and trim may also cause water blisters. Plumbing leaks, humidifiers, and shower spray are sources of inside water. Minimizing water absorption not only prevents blisters, but also prevents decay (rot), warping, and checking of wood.

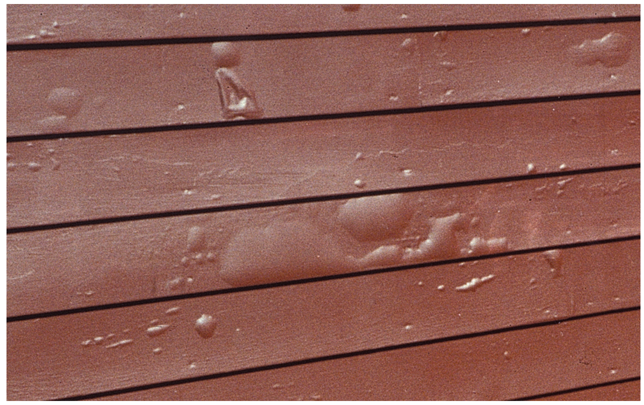

Figure 16–31. Water blisters (also called moisture blisters) caused bubble-like deformation of paint film. Dark colors are more susceptible than light colors because they get hotter in the sun.

Finishing Interior Wood

Many finishes and finishing methods are used indoors because of the breadth of wood products and uses—from wood floors to cutting boards. This section includes general information on a few common products used for interior wood finishing and brief subsections on finishing wood floors and kitchen utensils. Many finishing methods exist for just furniture. Factory finishing of furniture is often proprietary and may involve more than a dozen steps. Methods for furniture finishing are not included in this chapter, but most public libraries contain books on furniture finishing. Product literature for furniture finishes often contains recommendations for application. Interior wood products require less protection against water and UV radiation than do exterior wood products, and finishes usually last for decades. However, interior wood products have more exacting standards for appearance and cleanability than do exterior wood products.

As with wood used outdoors, wood changes color as it ages indoors, whether unfinished or finished. In general, dark wood gets lighter and light wood gets darker. Color change is natural aging of newly cut wood and is primarily caused by visible light, as opposed to sunburn, which is primarily caused by UV radiation. If removing a picture from paneling shows a color difference (shadowing by the picture), correct it by leaving the wood exposed to light. The color will usually even out within several months, though cherry takes exceptionally long. To avoid shadowing, keep all paintings and other wall coverings off paneling until most color change has occurred (usually 2 to 3 months, depending on the light intensity). Check under rugs on newly installed floors after a few weeks to see if color change is occurring. If so, remove or move the rugs periodically to avoid sharp lines.

High gloss finishes can be beautiful but require more attention to the surface because gloss accentuates imperfections such as planer marks, hammer marks, raised grain, and joints in the wood. Planer and hammer marks can be sanded smooth, as can raised grain after it has been released (see Raised Grain). However, joints, especially if seen in direct sunlight (Venetian blinds, for instance), are especially challenging to hide under high gloss coatings. This is because the two pieces of wood will change thickness as their moisture content changes with humidity levels. To keep two pieces of wood perfectly matched in thickness, they must have the same grain angle and swelling characteristics, requiring exacting attention to detail.

Types of Finish and Wood Fillers

Interior Paint

Smooth surfaces, consistent color, and a lasting sheen are often desirable for interior woodwork, especially trim. Therefore, high-gloss or semi-gloss enamels are more common than flat paints.

Extractive stain can also be a problem in interior wood. Extractives can discolor finishes, particularly in humid environments such bathrooms and kitchens (Figs. 16–20, 16–24). Pieces of wood for finger-jointed lumber commonly used in trim often come from different trees having different amounts of extractives. When painting (but not with clear finishes) finger-jointed lumber, or over knots, a stain-blocking primer is often used to minimize discoloration.

Fillers and Sealers

Sometimes hardwood vessels (especially in ring porous species) are so large that they need to be filled to obtain a smooth finished surface. Hardwoods such as ash, hickory, oak, and walnut are known for large vessels, whereas aspen, cherry, and maple have small vessels (see Chap. 2). Softwoods have no vessels. Filler may be a paste or liquid, natural or colored. After filling and wiping off excess, it is common to lightly sand before finishing.

Sealers are thinned clear coats used to prevent bleeding of stains into surface coatings or to prevent over-absorption of stain or coating.

Sometimes wood is not structural, and so filling in a rotten section is much easier then replacing the entire board. In this case, adding a filler or consolidant to the remaining wood can stiffen it or hide the imperfection. Fillers should be flexible when cured to accommodate movement of the wood with changes in moisture.

Stains

Stains accentuate wood grain by absorbing differently into EW, LW, knots, vessels, and flaws. Stains can color EW more than LW, reversing the typical color gradation. Many beautiful effects can be accomplished with skillfully applied stain. A penetrating sealer (“wash coat”) is sometimes applied before the stain to even out the color. These work by partially filling the void spaces in wood, impeding stain absorption.

Figure 16–32. Number 2 grade of hickory with a transparent finish to accentuate the beauty of the various colors, knots, and grain pattern of this species.

If stain absorbs into wood unevenly, causing a blotchy appearance, the cause might be infection by blue-stain fungi (Fig. 16–21) or bacteria before the lumber was dried. These infections can make the wood very porous, allowing it to soak up large quantities of thin liquids such as stain. Although blue stain is usually easy to see, there are fungal and bacterial infections that produce the same result but do not change the wood color. These infections occur across grain boundaries. This problem is not very common, but should it occur, it cannot be fixed once the stain is applied. Schofield (2008) describes how to check lumber before using it by applying a stain or denatured alcohol to identify infected areas.

Transparent Finishes

Transparent film-forming finishes, often called varnish, can give excellent performance on wood indoors (Fig. 16–32). There is no fundamental reason a clear finish cannot last essentially forever in an indoor environment, as there is no danger of sunburn. However, as with high-gloss finishes, transparent finishes accentuate surface blemishes. Remove all blemishes, such as planer marks and raised grain, before finishing.

Smooth film-forming finishes, such as varnish, are generally easier to clean and better at preventing wood from getting dirty, compared with penetrating finishes such as oils that leave the surface texture intact. Films, especially when thicker, can also protect the wood from scratches and dents. Films often get worn away by repeated cleaning or by abrasion. Thicker, harder films are needed for high wear applications such as floors.

The nomenclature around clear finishes and stains is quite confusing, in part because manufacturers do not adhere to a standard set of definitions for their products. A good explanation of the different products on the market in 2010 is provided in *Understanding Wood Finishing* (Flexner 2010).

Food-Contact Finishes

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 water repellent finish helps keep wood dry, which makes it less prone to check or crack. Finished wood is easier to clean than unfinished wood. Dishwashers are very hard on any kind of wooden object, no matter what finish is used.

Sealers and drying oils penetrate wood and cure (dry) to form a barrier to liquid water. Many commercial sealers are similar to thinned varnish (such as polyurethane or alkyd-modified polyurethane). Drying oils such as tung, linseed, and walnut can also be used as sealers. Sealers and drying oils give a surface that is easy to clean and resistant to scratching. Sealers are easy to apply and cure quickly. Drying oils may require several weeks to cure.

Nondrying oils (vegetable and mineral oils) penetrate wood but do not cure. As with sealers and drying oils, they improve water resistance. Vegetable oils (such as olive, corn, peanut, and safflower) are food for microorganisms such as mildew or bacteria. Vegetable oils also can become rancid and may impart undesirable odors or flavors to food. Mineral (or paraffin) oil is a nondrying oil from petroleum. Paraffin wax is similar to paraffin oil but is solid at room temperature. Paraffin oil and wax do not become rancid, do not support microbes, and have not ill effects on humans. Also known as candle wax, paraffin wax is one of the simplest ways to finish wood food items, especially cutting surfaces (countertops, butcher blocks, and cutting boards). Gentle warming of the wood item to the melting point of the wax makes it easy to apply.

Finishes that form a film, such as varnish or lacquer, are generally the easiest to clean because of the smooth surface. These finishes are also generally more resistant to staining than the oils or sealers. However, eventually the finish may crack, chip, and peel. Minimizing water exposure prolongs finish life. Historically, lead was put in varnish to help cure it, but that practice ended long ago in the United States and Europe, so clear film-forming finishes are generally safe as well.

> **Note:** Whatever finish is chosen for wood utensils used to store, handle, or eat food, it is recommended to look for products that are food grade.

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 active ingredient in many of these products is sodium percarbonate ($2Na_2CO_3 \cdot 3H_2O_2$). Sodium percarbonate is bleach, but it is oxygen based rather than chlorine based, typical of laundry bleaches (sodium hypochlorite and calcium hypochlorite). Oxygen bleaches remove mildew and have been reported to be less likely to damage wood surfaces than chlorine-based bleaches, particularly with low-density woods like western redcedar, Alaska yellow-cedar, and redwood. However, it is difficult to compare the advantages and disadvantages of the two types of cleaner (oxygen and chlorine) because of the wide range of active ingredient concentrations in the cleaners, additives in the cleaners, bleach consumption by unintended chemical targets, and various wood substrates that have been used for evaluating the cleaners. Some commercial products contain chlorine-based bleach. Commercial cleaners usually have a surfactant or detergent to enhance the cleansing action.

At the other extreme from the reported gentle bleaching action of sodium percarbonate are those cleaners containing sodium hydroxide. Sodium hydroxide is a strongly alkaline chemical that pulps wood and is used in some paint strippers. These cleaners may be necessary where mildew is imbedded in a surface finish; however, they should be used only as a last resort.

Manufacturers of some cleaners and brighteners report that their products restore color to wood. Cleaning wood does not add color. Removing mildew reveals the original color. Wet wood always has more, and richer, color because the optical effects let you see deeper into the wood. Brightening the wood may make it appear as if it has more color. Weathered wood has a silvery gray appearance because weathering removes colored components from the surface. If you want to restore color, stain the wood. Some commercial cleaners pulp the wood surface and subsequent power washing removes the pulped surface. In this case, the color is “restored” because the surface of the wood was removed. Sanding would give the same result.

Some brighteners contain oxalic acid. Oxalic acid removes extractives bleed and iron stains, but it is not effective for removing mildew.

Paint Stripping

Removing paint and other film-forming finishes from wood is a time-consuming and often difficult process. Finish removal is necessary if a finish has extensive cracking or peeling. Stripping can be done mechanically (including heating), chemically, or in combination. Chemical strippers soften paint, as does heat. Mechanical stripping is sanding and scraping. Products that are effective at stripping paint tend to pose health risks. The smaller range of chemicals allowed by regulation and the more complex latex formulations are making chemical stripping a harder task than it once was. When dealing with strippers, consult product literature for additional information on appropriate uses and safety precautions. Regardless of the method used to strip paint, sand the wood prior to applying new finish.

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, paint over the lead-based paint to seal in the lead (see Lead-Based Paint).

Note: Dust caused by mechanical stripping methods and fumes given off by chemical strippers can be toxic. Use effective safety equipment, including a respirator, even if the paint does not contain lead (see Lead-Based Paint). Dust masks sold in hardware stores do not block chemical fumes and some are not effective against dust.

Mechanical Methods

Scraping, sanding, wet or dry sandblasting, spraying with pressurized water (power washing), and using electrically heated pads, hot air guns, and blowtorches are mechanical methods for removing finishes.

Scraping is effective for removing loosely bonded paint or paint that has already partially peeled from small areas of the structure. If possible, sand weathered surfaces and feather edges of paint still bonded to wood. Do not sand if the old paint contains lead (see Lead-Based Paint).

If paint has partially debonded on large areas of a structure, contractors usually remove the finish by power washing. This method works well for paint that is loosely bonded. If paint is tightly bonded, complete removal can be difficult without severely damaging wood. The pressure needed to debond tightly bound paint from wood can easily cause deep erosion of wood. If high pressure is necessary to remove paint, the paint probably does not need to be removed prior to refinishing. Power washing erodes less dense EW more than dense LW, leaving behind ridges of LW, which are difficult to repaint. Power washing is less damaging to wood than is wet or dry sandblasting, particularly if low-pressure power washing is used. If more aggressive mechanical methods are required, wet sandblasting can remove even tightly bonded paint. Dry sandblasting is not suitable for removing paint from wood, because it severely erodes wood along with the paint and it tends to glaze the surface. Power washing and wet and dry sandblasting are not suitable for paint containing lead.

Power sanders and similar devices are available for complete paint removal. Some 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. Planers and sanders cannot be used unless the fasteners are counter sunk. 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 softened using electrically heated pads, hot air guns, or blowtorches, then removed by scraping it from the wood. Heated pads and hot air guns are slow methods and cause little damage to the wood. Blowtorches have been used to remove paint, but they are extremely hazardous; the flame 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. Heated pads, hot air guns, and blowtorches are not suitable for paint containing lead. These methods volatilize lead at their operating temperatures. Lead fumes are released at approximately 370 °C (700 °F).

Note: Removing paint from wood with a blowtorch is not recommended.

Chemical Methods

Efficient paint removal may involve mechanical and chemical methods. Stripping paint chemically has the following steps: apply paint stripper, wait, scrap off the softened paint, neutralize the stripper (if necessary), wash the wood, and sand the surface to remove wood damaged by the stripper and raised grain caused by washing. Chemical paint strippers, although tedious to use, are sometimes the most reasonable choice. 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, how safe a product is and how fast it removes paint seem to be inversely correlated.

Solvent-Based Strippers

Fast-working paint strippers usually contain methylene chloride, a possible carcinogen that can burn eyes and skin. Methylene chloride was banned from noncommercial uses by the European Union in 2011 and the U.S. EPA in 2019. When using this paint stripper industrially, eye and skin protection and a supplied-air respirator are essential. Paint strippers having methylene chloride can remove paint in as little as 10 min and do not hurt the wood. Some paint strippers are formulated using other strong solvents because of concerns with methylene chloride; do not assume that because it does not contain methylene chloride, it is safe. Consult product literature and strictly observe safety precautions.

Alkali-Based Strippers

As an alternative to strong solvents, some paint strippers contain strong bases (alkali). As with solvent-based paint strippers, alkali-based strippers require eye and skin protection. Follow manufacturers’ recommendations concerning use of a respirator. Although alkali-based paint strippers soften paint rather slowly, they are strong chemicals and can severely damage wood. Strong alkali pulps the wood surface. After paint removal, neutralize the surface with mild acid. Unfortunately, balancing the acid and base concentrations is difficult. If excess alkali remains in the wood, it may degrade the wood and subsequent paint coating. Excess acid can also damage wood. Alkali strippers are often left on painted wood a full day or overnight and are usually covered to slow evaporation. These covered types of products have the advantage of containing the paint stripper and paint quite well, an important consideration when removing paint containing lead. Do not let alkali chemicals dry on the surface, particularly on those finishes containing lead, because the dry chemicals contain lead dust.

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 usually needs to be sanded before repainting.

Avoidance of Problems

Avoid finish failure subsequent to removing the old finish by using methods that do not damage wood. The best way to remove paint may involve a combination of methods. For example, use power washing to remove as much loosely bound paint as possible. Then, use a chemical paint stripper on tightly bonded paint. Avoid using excessive amounts of chemical stripper. Applying too much stripper or leaving it on painted wood too long can damage wood. Use less paint stripper and reapply it rather than trying to remove all the paint with one application and risk damaging wood.

The range of wood species and finishes and the possibility of finishes containing lead complicate paint removal. Companies may optimize paint stripper formulation without considering the effects on wood. Removing paint from wood is only half the task. Getting a paintable surface is the 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 old paint, particularly paint that contains lead. Lead paint is hazardous waste; follow all regulations, national and local, during the removal, storage, and disposal of all paint, especially paint containing lead (see Lead-Based Paint). For leftover paint in a can, letting it dry and disposing in solid waste is the typical disposal method.

Lead-Based Paint

Lead-based paint was widely used in residential structures in the United States until the early 1940s, and its use continued to some extent, for the exterior of dwellings, until 1976. Prior to any paint restoration on U.S. structures built prior to 1976, check paint for lead. Check for lead using a solution of 6% to 8% sodium sulfide in water and look for black or brown precipitate that forms with lead or other ions. A positive result warrants further testing, such as use of a commercial test kit. Test kits should be available in most paint and hardware stores. Be certain to check all paint layers, because the older ones are more likely to contain lead.

Lead-based paint is still manufactured for special applications, such as paint for metal products, particularly those made of steel. Lead is also widespread in household paints sold in the developing world and has even been reported in high levels in products labelled "lead free." Studies have shown that ingestion of even minute amounts of lead can have serious effects on health; lead causes hypertension, fetal injury, damage to the brain, kidneys, and red blood cells, partial loss of hearing, impairment of mental development, growth retardation, and inhibited metabolism of vitamin D. The American Academy of Pediatrics regards lead as one of the foremost toxicological dangers to children.

Lead-based paint on the exterior of structures weathers to give flakes and powder. The degraded paint particles accumulate in the soil near the structure. Lead-based paint used on interior surfaces can also degrade to produce lead-containing dust. Sanding coatings prior to repainting generates lead dust. Sanding the exterior of a structure without proper equipment can cause lead contamination inside the structure.

Methods used to remove lead 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. Micron-sized lead dust particles can remain airborne for substantial periods and cannot be completely removed by standard cleaning methods. When working on old painted surfaces, assume that one or more of the paint coats contain lead. Take precautions accordingly.

Check with the U.S. Department of Health and Urban Development (HUD), U.S. Environmental Protection Agency (EPA), or American Coatings Association for the latest regulations and guidelines for remediating lead-based paint.

Caution: Remodeling or refinishing projects that require disturbing, removing, or demolishing portions of structures coated with lead-based paint pose serious health risk. The consumer should seek information, advice, and perhaps professional assistance for addressing these risks. Contact HUD for the latest information on removal of lead-based paints. Debris coated with lead-based paint is hazardous waste and must be disposed of in accordance with federal and local regulations.

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Wood Handbook

Wood as an Engineering Material

Forest Products Laboratory | United States Department of Agriculture Forest Service | Madison, Wisconsin

Abstract

Summarizes information on wood as an engineering material. Presents properties of wood and wood-based products of particular concern to the architect and engineer. Includes discussion of designing with wood and wood-based products along with some pertinent uses.

Keywords: wood structure, physical properties (wood), mechanical properties (wood), lumber, wood-based composites, plywood, panel products, design, fastenings, wood moisture, drying, gluing, fire resistance, finishing, decay, preservation, wood-based products, heat sterilization, sustainable use

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