FINISHING WOOD FOR EXTERIOR USE

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Abstract

Hardwoods, like all woods exposed outdoors without protection, undergo: (1) Photodegradation by ultraviolet light; (2) leaching, hydrolysis, and swelling by water; and (3) discoloration and degradation by staining and decay micro-organisms. Unfinished wood surfaces exposed to weather without any finish change color, are roughened by photodegradation and surface checking, and erode. The appearance of unprotected wood exposed outdoors changes markedly in a few months; then the wood remains almost unaltered for years. In the absence of decay, wood exposed to the weather can last many years. Although physical as well as chemical changes occur due to weathering, these changes affect only the surface of the exposed wood. Wood a few millimeters under the surface is essentially unchanged and unaffected.

Hardwoods exposed to the weather can be protected by paints, stains, or varnishes. Paints provide the most protection to exposed hardwood surfaces, since they are generally opaque to the degradative effects of ultraviolet light and protect wood to some degree against wetting. Paint performance may vary greatly on different hardwoods. Pigmented stains also provide durable, easily refinished finishes for hardwoods exposed outdoors. Varnishes generally do not perform satisfactorily and require frequent refinishing.

The performance of hardwoods in exterior use will be greatly affected by species, by finishes, by construction practices, and by the degree of protection from prolonged wetting.

Introduction

When wood is exposed outdoors, above ground, a complex combination of chemical, mechanical, and light energy factors contribute to what is described as weathering (25). Weathering is not to be confused with decay, which results from decay organisms (fungi) acting in the presence of excess moisture and air for an extended period of time (21). Under conditions suitable for the development of decay, wood can deteriorate rapidly and the result is far different than that observed for natural outdoor weathering.

Outdoor Weathering Process

In outdoor weathering of smooth wood, original surfaces become rough as grain raises and the wood checks, and the checks grow into large cracks; grain may loosen, boards cup and warp and pull away from fasteners (Figs. 1 and 2). The roughened surface changes color, gathers dirt and mildew, and may become unsightly; the wood loses its surface coherence and becomes friable, splinters, and fragments come off. All these effects, brought about by a combination of light, water, mechanical forces, and heat, are covered in one word--weathering (25).

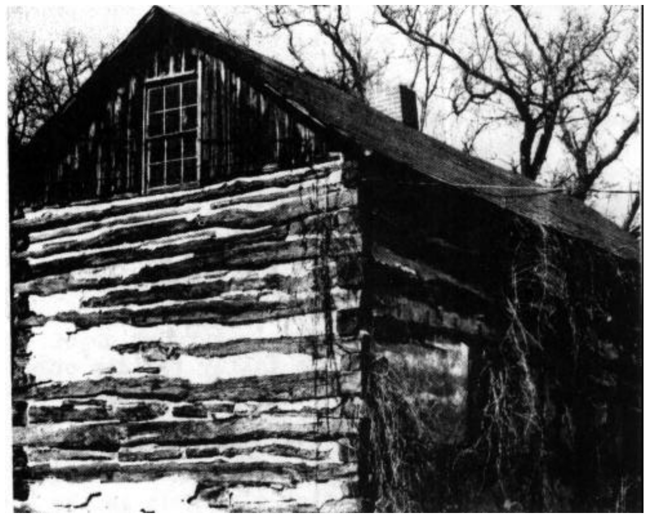

Figure l.--White oak log cabin near Middleton, Wis., constructed around 1845 and never painted or finished.

Weathering Factors

Moisture. One of the principal causes of weathering is frequent exposure of the wood surface to rapid changes in moisture content. Rain or dew falling upon unprotected wood is quickly absorbed by capillary action on the surface layer of the wood, followed by adsorption within wood cell walls. Water vapor is taken up directly by the wood by adsorption under increased relative humidities, and the wood swells. Stresses are set up in the wood as it swells and shrinks due to moisture gradients between the surface and the interior. These induced stresses are greater the steeper the moisture

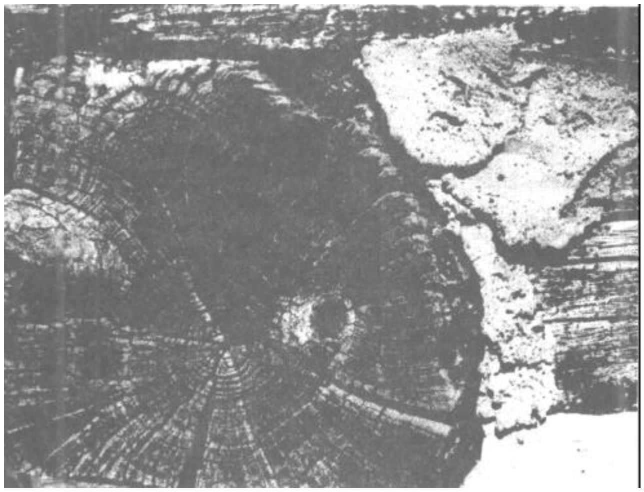

Figure 2.--Close-up view of weathered white oak logs in Figure 1.

gradient, and are usually largest near the surface of the wood. Unbalanced stresses may result in the surface warping, cupping, and face checking. Grain raises when dull planes are used in wood processing, and subsequent differential swelling and shrinking of summerwood and springwood occurs when the wood is wetted.

Light. The photochemical degradation of wood due to sunlight occurs fairly rapidly on the exposed wood surface. The initial color change of wood exposed to sunlight is a yellowing or browning which proceeds to an eventual graying. These color changes can be related to the decomposition of lignin in the surface wood cells and are strictly a surface phenomenon. These changes occur only to a depth of 0.05 to 0.5 mm (25) and are a result of sunlight, particularly ultraviolet (UV) light which initiates photodegradation. Such photodegradation by UV light induces changes in chemical composition, particularly in the lignin, and subsequent color changes.

It is important to note here that the two most important elements of weathering--sunlight and water--tend to operate at different times. Exposed wood can be irradiated after having been wet by rain or when surface moisture content is high from overnight high humidity or from dew. Time of wetness, therefore, is important in relating climatic conditions to exterior degradation. The action of the combined elements can follow different degradation paths, with irradiation accelerating the effect of water or the converse.

Other Factors Temperature is not as critical a factor as UV irradiation or water but, as the temperature increases, the rate of photochemical and oxidative reactions increases. Freezing and thawing of absorbed water can contribute to wood checking. Abrasion or mechanical action, such as wind, sand, and dirt, can be an important factor in the rate of surface degradation and removal of wood. Small particles such as sand can become lodged in surface checks and, through swelling and shrinking, weaken fibers in contact with it. Solid particles in combination with wind can have a sandblasting effect.

Property Changes

From information on the chemical changes occurring during outdoor weathering of wood, it can be concluded that absorption of UV light by lignin at the wood surface results in preferential lignin degradation as described earlier. In the graying of wood, most of the solubilized lignin degradation products are washed out by rain. Fibers, high in cellulose content and whitish to gray in color, remain on the wood surface and are more resistant to UV degradation (25).

Color. The color of wood exposed outdoors is affected very rapidly. Generally, all woods change toward a yellow to brown due to the chemical breakdown (photo-oxidation) of lignin and wood extractives. This yellowing or browning occurs after only several months of exposure in sunny, warm climates. Woods rich in extractives may first become bleached before the browning becomes observable. In the absence of micro-organisms, wood can weather to a soft, silver gray as a result of the leaching of decomposition products of wood lignin.

Changes in wood color reveal chemical changes in wood during weathering. Only those parts of the wood close to the exposed surface are affected. Initial browning penetrates only 0.01 to 2 mm into the wood (25). As rain leaches the brown decomposition products of lignin, a silver gray layer 0.08 to 0.2 mm thick, consisting of a disorderly arrangement of loosely matted fibers, develops over the brown layer. The gray layer is composed chiefly of the more leach-resistant parts of the wood cellulose. This surface color change to gray is observed when the wood is exposed to intense irradiation of the sun in cooler climates with little precipitation. This would also occur on structures with large roof overhang, which protects the wood underneath from rain and sun. However, another mechanism of surface graying of weathered wood--fungal action--usually predominates, particularly in the presence of moisture.

All modern studies on the weathering of wood conclude that the discoloration (graying) of woods in the presence of moisture is practically always due to growth of fungi on the surface of the wood (16,20). The most frequently observed fungus species is *Aureobasidium pullulans* (*Pullularia pullulans*) which under favorable conditions grows not only on wood surfaces, but also on the surface of coatings and various organic and inorganic materials. This fungus is commonly referred to as mildew. The ecological requirements of this fungus and related fungi are modest, the most important condition for its growth being the sporadic supply of bulk water. The fungus is otherwise relatively resistant and adaptable.

Sell (20) found that _A. pullulans_ grows on infested finished as well as untreated softwood and hardwood surfaces. He concluded that discoloration of unfinished wood by mildew is more general than commonly believed. Fungal infection was the result of a temporary or lasting wetting of the wood surface with water. Sell and Leukens (21) subjected 20 European and non-European softwood and hardwood species of widely differing density and mechanical strength properties to unprotected outdoor weathering of 45° inclined to the south in Switzerland. While behavior among the different species was initially distinctly different, this gradually changed, and photochemical and mechanical deterioration as well as intensity of attack by the blue stain fungi evened out. After only 1 year's weathering, all wood surfaces had a uniformly weathered and gray appearance.

Color changes on the wood surface are very rapid during outdoor exposure. These changes may occur even when the wood is well dried and protected from the weather. Light-colored woods tend to turn yellow or brown, and dark woods sometimes bleach noticeably (23). The degree of color change was evaluated in experiments made at the Forest Products Laboratory by exposing 19 different hardwoods outdoors (15). The panels were laid flat and covered at night and during rainy weather to prevent discoloration by moisture. Removal of a chip from the surface of each specimen permitted close comparison between a fresh surface and the exposed surface.

Many of the 19 freshly planed wood surfaces showed noticeable color changes after 16 hours' exposure to summer sunlight, or about the interval between sunrise and sunset in June in the latitude of Madison, Wis. Woods in which color changes were not apparent after 16 hours were basswood, white oak, willow, and sweetgum. After 32 hours, changes could be detected in all woods.

The 19 woods were classified as to change in color after exposure to 160 hours of sun (Table 1). In black walnut and willow heartwood, the change consisted of a slight bleaching of the exposed surface. The remaining woods yellowed or browned in varying degrees. Light-colored woods did not necessarily discolor more than darker ones. Basswood, one of the whitest woods, changed color much less than did chestnut. In the same wood, light-colored or sapwood samples generally showed a more decided color change after exposure than darker or heartwood samples.

Physical Changes. In addition to chemical and color changes of wood on outdoor

Table 1.--DEGREE OF COLOR CHANGE OF SOUTHERN HARDWOODS[1] AFTER 20 DAYS' EXPOSURE OUTDOORS

Wood	Heartwood	Sapwod	Degree of color change[2]
Basswood		X	1
Beech	X		1
Birch	X	X	1
Sweetgum	X		1
Sycamore	X		1
Blackgum		X	2
Maple, hard, soft		X	2
Oak, white	X		2
Cottonwood		X	3
Elm		X	3
Hickory	X	X	3
Walnut, black	X		3
Willow	X		3
Ash		X	4
Chestnut	X		4
Magnolia		X	4
Oak, red	X	X	4
Yellow-poplar	X	X	4

[1]Information from Technical Bulletin No. 1267 (15).

[2]l--Slight; 2--slight to medium; 3--medium; 4-medium to large.

weathering, mechanical damage occurs on the exposed wood surface. Decomposition of wood surface due to the combined action of light and water causes surface darkening and leads to formation of macroscopic to microscopic intercellular and intracellular cracks or checks. Strength of cell wall bonds is lost near the wood surface. As weathering continues, rainwater washes out degraded portions and further erosion takes place (Figs. 2 and 3). Because of different types of wood tissue on the surface, erosion and checking differ in intensity, and the wood surface becomes increasingly uneven. Hardwoods erode more slowly than do softwoods.

The rate of outdoor weathering has been estimated from erosion data obtained by controlled accelerated weathering of several hardwoods (Table 2). Specimens were exposed to a high-intensity xenon arc light in an accelerated weathering chamber. Exposure was cycles of 20 hours of light followed by 4 hours of distilled water' spray. Erosion measurements were made microscopically (16). The results show that the hard, dense hardwoods erode at a rate similar to that observed for the summerwood of softwood species (estimated at 3 mm/century compared to 6 mm for softwoods). The higher the density. generally the less the erosion rate. Lower density woods such as basswood wear away (erode) at a higher rate than woods such as the oaks, but less than the springwood of the softwood, southern pine.

Thus the physical loss of wood substance from the wood surface during weathering depends on the species of wood, density, amount of irradiation, rain action, wind, degree of exposure and, generally, climate. Because of differences in erosion on the surface, weathered wood generally assumes a corrugated or serrated appearance (Fig. 3). The effect is less in hardwoods than in softwoods. Accompanying the loss of wood substance are the swelling and shrinking stresses set up by fluctuations in moisture content. All these result in surface roughening, grain raising, differential swelling of springwood and summerwood bands, and the formation of small checks or cracks. Larger and deeper cracks may develop and cupping and warping may result.

Strength Changes. The various weathering effects (physical, chemical, etc.) have been reported to have little influence upon modulus of rupture, modulus of elasticity, and compressive strength of wood (16). Only toughness and abrasion resistance are materially reduced as a result of penetrating thermal effects. This apparent lack of change in strength properties is undoubtedly due to the fact that weathering is essentially a surface effect (Fig. 3). In the absence of decay and extremely large cracks, little

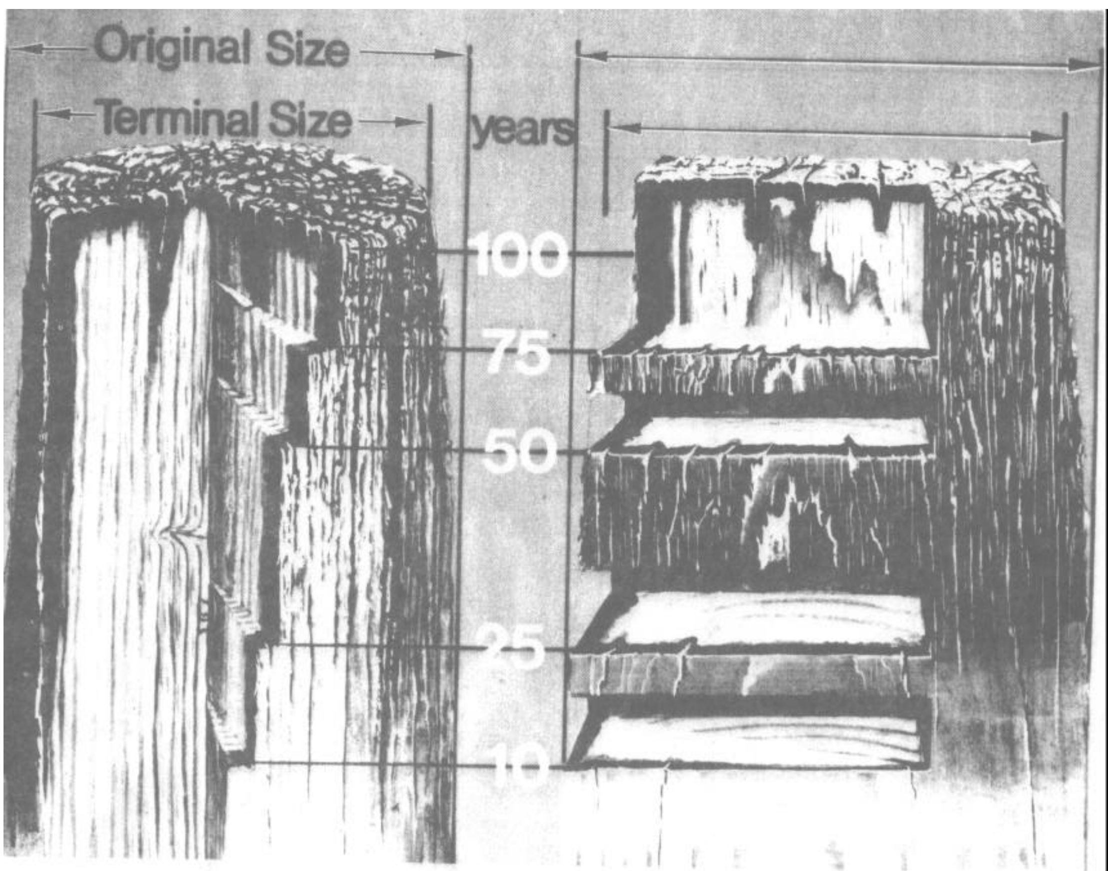

Figure 3.--Artist's representation of the weathering of poles and posts showing surface phenomenon of the weathering process.

Table 2.--EROSION OF WOOD SURFACES AFTER ACCELERATED WEATHERING[1]

Species	Specific gravity	Erosion in microns after exposure to light — Hours: 600	1,200	1,800	2,400
	g/cc				
Hardwoods					
White oak					
Heartwood	0.641	65	105	135	180
Red oak					
Heartwood	.566	75	135	150	200
Maple, hard					
Heartwood	.572	95	175	200	240
Maple, soft					
Heartwood	.450	85	160	195	250
Basswood					
Heartwood	.370	130	195	320	385
Yellow-poplar					
Heartwood	.449	115	170	260	305
Birch, yellow					
Heartwood	.555	100	200	245	300
Softwood					
Southern pine					
Heartwood	.459				
Earlywood	.30[2]	135	325	465	600
Latewood	.70[2]	40	70	125	175

[1]Except for southern pine, values represent latewood erosion. Earlywood erosion was only slightly greater.

[2]Estimated values.

change occurs in the overall physical properties of wood.

Weathering of Wood-Based Materials

The weathering process described thus far has been that observed for solid wood. The introduction of another variable, the adhesive, in the weathering of wood-based materials such as plywood and particleboard creates additional complications. Wood substance is still exposed to the elements in these reconstituted products, and deteriorates in a manner similar to that for solid wood. The wood-adhesive bond is the new element in exposure.

Plywood. The weathering of plywood is directly related to the quality of the veneer exposed and to the adhesives used. Water resistance of the adhesive is of great importance. Because of its tendency to check, most exterior plywood is protected with a finish or with overlay material. Finished or overlaid plywood weathers and performs similarly to solid wood (1,16,23).

Strength change studies on both naturally and artificially weathered plywood have been reported (16). For unfinished plywood, rapid surface checking occurs in the early weathering stages. Water absorption increases and percent shrinkage and swelling parallel to the fiber direction decrease slightly. Shear strengths vary greatly with the type of adhesive.

Reconstituted Panel Products. As in the case of plywood, durability of reconstituted panel products such as hardboard and particleboard (waferboard, chipboard) in outdoor weathering depends very much on wood species, and on the amount and nature of resin (binder, adhesive) use in preparing the board. In outdoor weathering of unprotected particleboards, for example, outer layers are subjected to greater wear and tear. As long as the outer cover layers are intact, inner layers are protected from the elements of weathering. When outer layers of exposed boards deteriorate and loosen, shrinking and swelling of inner layers result due to exposure to changes in moisture content. Accelerated deterioration of inner layers generally results, cohesion is lost, and boards may fail under mechanical loads (23). Only 1 or 2 years of weathering can cause significant strength loss and increased swelling (16). Deterioration of particleboard during outdoor weathering takes place because of the combined effects of springback from compression set, deterioration of resin, and differential shrinkage of adjacent wood particles during moisture content change. Phenolic resins appear to give the best overall performance. Additional related studies have reported on the effect of natural outdoor and artificial accelerated weathering on durability and strength properties of particleboard and' related materials.

Protection of exterior reconstituted panel products (in particular particleboard) by surface coatings, treatments and overlays, and subsequent weathering performance, has received considerable attention. Painted and overlaid board are much more durable than unfinished boards. Addition of wax as a water repellent is beneficial in performance of the boards, but does not protect against water vapor (16,20).

Results from outdoor weathering experiments with different surface treatments indicate that lasting protective effects of surface treatment, and protection of board edges against moisture, are the most important prerequisites for long-term functioning of coating systems. Complementary construction measures are necessary for good performance (23), and it is generally concluded that waterproofing and sealing of the wood surface is imperative. Above a minimum value, the gradient of water vapor diffusion of the coating is only of secondary importance. The visual state of the board and thickness swelling are considered the best criteria for evaluating the protective effect of surface treatments. Surface stability is recognized as one of the most important criteria in retaining finish and maintaining satisfactory protection and appearance (20).

Protection Against Weathering

Paint and other coatings (finishes) on wood used indoors can protect and last for many decades without refinishing or severe deterioration (4,8). The durability of finishes on wood exposed outdoors to the natural weathering process, however, depends first on the wood itself. Wood properties that are important in finishing are moisture content; density and texture; resin and oil content; width and orientation of growth rings; and defects such as knots, reaction wood, and fungi-infected (diseased) wood (9). Other contributing factors are the nature and the quality of the finish used, application techniques, pretreatments, the time between refinishings, the extent to which the surfaces are sheltered from the weather, and climatic and local weather conditions.

The primary function of any wood finish is to protect the wood surface from the natural weathering process (sunlight and water) and help maintain appearance (23). Where weathering does not matter, wood can be left unfinished to weather naturally and such wood can often provide for extended protection of the structure (7,23). Different finishes give varying degrees of protection to the weather (13).

Protection that surface treatment provides against light and water will be affected by the weather resistance of the bonding agents of the finish (drying oils, synthetic resins, latexes, etc). These bonding agents are subject to photolytic degradation to some degree. The mechanism of failure of paints and other finishes has been described (4,19), and will not be discussed further here. Wood exposed outdoors is protected from the effects of weather by various finishes, by construction practices, and by design factors; these have been addressed in detail (2,6,13,20,23,24) and will be summarized in a subsequent section.

Two basic types of finishes (or treatments) are used to protect wood surfaces during outdoor weathering: (1) Those that form a film, layer, or coating on the wood surface, and (2) those that penetrate the wood surface leaving no distinct layer or coating. Film-forming materials include paints of all description, varnishes, lacquers, and also overlays bonded to the wood surface. Penetrating finishes include preservatives, water repellents, pigmented semitransparent stains, and chemical treatments. Natural finishes are important in wood protection as are finishing practices.

Film-Forming Finishes

Paints. Film-forming finishes such as paint have long been used to protect wood surfaces. Of all the finishes, paints most protect wood against erosion by weathering and offer the widest selection of colors. A nonporous paint film will retard penetration of moisture thereby reducing problems of paint discoloration by wood extractives, paint peeling and checking, and warping of the wood. Proper pigments will essentially eliminate UV degradation of the wood surface. Paint, however, is not a preservative; it will not prevent decay if conditions are favorable for fungal growth. The durability of paint coatings on exterior wood is affected by variables in-the wood surface and the type of paint.

Paints are commonly divided into the oil-base or solvent-borne systems and the latex or waterborne systems (4,10). Oil-base paints are essentially a suspension of inorganic pigments in an oleoresinous vehicle that binds the pigment particles and the bonding agent to the wood surface. Latex paints are suspensions of inorganic pigments and various latex resins in water, and form porous coatings. Acrylic latex resins are particularly durable, versatile materials for finishing wood and wood-related materials. Latex paints are used to a greater extent than are oil-base paints for finishing wood, particularly for exterior use because of their better durability, ease of application, and ease of cleanup.

Varnishes and Lacquers. The most natural appearance for wood is obtained by use of clear varnishes or lacquers. Other treatments either change wood color or cover it up completely. Unfortunately, clear varnish finishes used on wood exposed to sun and rain require frequent maintenance to retain a satisfactory appearance. The addition of colorless UV light absorbers to clear finishes has found only moderate success to help retain the natural color and original surface structure of wood. It is generally recognized that opaque pigments found in paints and stains provide the most effective and long-lasting protection against light. Even using relatively durable clear synthetic resin varnishes, the weatherproof qualities of the wood-varnish system are still limited because UV light penetrates the transparent varnish film, and gradually degrades the wood under it. Eventually, the varnish begins to flake and crack off, taking with it fibers of the wood which have been degraded photochemically. Durability of varnish on wood under action of the weather is limited and many initial coats are necessary for reasonable performance. Maintenance of the varnish surface must be carried out as soon as signs of breakdown occur. This may be as little as 1 year in severe exposures. Lacquers and shellacs are usually not suitable as exterior clear finishes for wood because of water sensitivity and ease of cracking or checking of their rather brittle films.

Penetrating Finishes

Water Repellents. A large proportion of the damage done to exterior woodwork (paint defects, deformation, decay, leakage, etc.) is a direct result of moisture changes in the wood and subsequent dimensional instability (23). Water repellents (WR) and water-repellent preservative (WRP) treatments are used to protect wood from moisture and decay (17). Such treatments reduce absorption of water and retard growth of decay organisms. Pretreatment of wood with WR or WRP is an important step in the finishing of wood (such as millwork) for exterior uses (23).

Stains. When pigments are added to WR or WRP solutions or to similar transparent wood finishes, the mixture is classified as a pigmented penetrating stain (sometimes referred to as an impregnating paint) (1,5,13). Addition of pigment provides color and greatly increases the durability of the finish because UV light is blocked. The semitransparent pigmented penetrating stains permit much of the wood grain to show through; such stains penetrate the wood to a degree without forming a discrete, continuous layer. Therefore, they will not blister or **peel** even if excessive moisture enters the wood. The durability of any stain system is a function of pigment content, resin content, preservative, water repellent, and quantity of material applied to the wood surface. Their performance during outdoor exposure has received a great deal of attention (5,18,22).

Penetrating stains are suitable for both smooth and rough-textured surfaces; however, their performance is markedly improved if applied to roughsawn, weathered, or rough-textured wood (18) because more material can be applied to such surfaces. They are especially effective on lumber and plywood that does not hold paint well, such as flat-grained surfaces or dense species. Penetrating stains can be used effectively to finish such exterior surfaces as siding, trim, exposed decking, and fences. Stains can be prepared from both solvent-base resin systems and latex systems, however, latex systems do not penetrate the wood surface. Commercial finishes known as heavy-bodied, solid color, or opaque stains are also available, but these products are essentially similar to paint because of their film-forming characteristics. Such "stains" do find wide success when applied on textured surfaces and panel products such as hardboard. They can be oil-based or latex-based.

Preservatives. Although not generally classified as wood finishes, preservatives in wood do protect against weathering in addition to decay and a great quantity of preservative-treated wood is exposed without any additional finish. There are three main types of preservative: (1) The preservative oils (e.g., coal-tar creosote), (2) the organic solvent solutions (e.g., pentachlorophenol), and (3) waterborne salts (e.g., chromated copper arsenate). These preservatives can be applied in several ways, but pressure treatment generally gives the greatest protection against decay. Greater preservative content of pressure-treated wood generally results in greater resistance to weathering and improved surface durability. The chromium-containing preservatives also protect against UV degradation (18).

Natural Finishes

Some of the wood finishes just described often find application as so-called natural finishes for wood. Each finish system offers various advantages and disadvantages for this use. These systems can be classified as film-forming or penetrating finishes. The penetrating finishes can be subdivided further into transparent, semitransparent, and waterborne salts.

Film-Forming

Varnishes are the primary transparent film-forming materials used for natural wood finishes, and their use greatly enhances the natural beauty and figure of wood. Varnishes lack exterior permanence unless protected from direct exposure to sunlight, and varnish finishes on wood exposed outdoors without protection will generally require refinishing every 1 to 2 years (16).

Penetrating

The penetrating finishes are the second broad classification of natural wood finishes. These finishes do not form a film on the wood surface and are further divided into (1) transparent or clear systems, (2) pigmented or semitransparent systems, and (3) waterborne salts.

Transparent. Water-repellent preservatives (WRP) (17) are the most important of the transparent penetrating natural finish systems. Treating wood surfaces with WRP will protect wood exposed outdoors with little change in appearance. A clean, golden-tan color can be achieved with most wood species. The treatment reduces warping and cracking, prevents water staining at edges and ends of wood siding, and helps control mildew growth. The first application of WRP may protect exposed wood surfaces for only 1 to 2 years, but subsequent reapplications may last 2 to 4 years because the weathered boards absorb more of the finish.

Semitransparent. The semitransparent stains (5) are the second of the penetrating natural wood finishes. These stain finishes provide a less natural appearance because they contain pigment which partially hides the original grain and color of the wood. They are generally much more durable than are varnishes or WRP's and provide more protection against weathering. With these stain systems, weathering is slowed by retarding the alternate wetting and drying of wood and the presence of pigments on the wood surface minimizes the degrading effects of sunlight. The amount of pigment in the semitransparent stains varies considerably, and different degrees of protection against ultraviolet degradation and masking of the appearance of the original wood surface can be achieved.

Latex stains are also described as semitransparent. These pigmented "natural" finishes are generally nonpenetrating and retain the surface texture of the wood but completely obliterate the natural wood color.

Waterborne Salts. Waterborne inorganic salts (18) are a special group of penetrating finishes. These surface treatments result in a natural finish related to the semitransparent penetrating finishes, because they change the color of the wood and leave a surface deposit of material similar to the pigment found in the semitransparent stains.

Opaque Stains

Solid color or opaque stains are another classification of finishes sometimes inaccurately described as natural wood finishes. These finishes are high in pigment content and completely mask the color and figure of the wood. Surface texture is retained and these generally nonpenetrating finishes yield a flat appearance. They do protect wood against ultraviolet degradation, but tend to perform more like paints in that they do not penetrate the wood surface to any degree.

Finishing Practices

Many requirements, suggestions, and recommendations for good painting and finishing practices have been described in detail in several publications (1,4,5,13,14,17,23,24,26). Additional information is available from manufacturers, trade associations, and local county extension agents.

Interactions of Weather, Construction Variables, and Finishes

Satisfactory performance of wood finishes is realized when full consideration and attention to detail is given to the many factors that affect finishes. These factors include the effect of the wood substrate (wood properties), the properties of the finishing material, details of application, and severity of exposure to elements of the weather. Even when the best paints and painting procedures are used, coatings remain serviceable much longer on some woods than on others. Because of their variation, woods can be classified as to ease of painting and paint performance.

Wood Properties

Wood surfaces that shrink and swell the least are the best for painting. For this reason, vertical- or edge-grained (quarter-sawed) surfaces are far better than flat-grained (plain-sawed) surfaces of any species, especially for exterior use where wide ranges in relative humidity and periodic wetting can produce wide ranges in swelling and shrinking (9).

Classification of Hardwoods for Painting. For reasons explained below, the hardwoods as a class are less satisfactory than the softwoods for purposes of exterior painting (6, 8,23). From the point of view of painting, woods can be classified into five groups (8) (Table 3). The best woods for exterior painting, and easiest to keep painted, consist entirely of softwoods. The best of the hardwoods fall into group III indicating intermediate ease of keeping painted.

The hardwoods of group III can be painted with ordinary house paints in exactly the same way as is customary with softwoods. If properly painted (6,7,8) with top quality paints, the group III hardwoods should hold paint well. These woods perform reasonably well when cut into the siding patterns often used with lighter softwoods (6). Even when left exposed to the weather without paint, hardwoods of group III perform at least as well as softwoods of group III or IV because these hardwoods generally have less tendency to split than the softwoods and the hardwoods do not have the tendency for latewood bands to shell out as the softwoods do (8).

Hardwoods of group IV can be painted with house paints (Table 3) according to customary practice but the durability of the paint is a year or more shorter (6,7). The form of paint failure is such that repainting may be difficult and uncertain unless all old paint is removed first.

On the hardwoods, paint tends to scale off in rather large flakes having no observable relation to the grain of the wood underneath. On the softwoods of group IV, paint usually flakes at first from the latewood bands.

Hardwoods of group V (lowest rank for ease of keeping well painted) contain pores so large that they are not filled and leveled off properly by ordinary house paints. The pores then become foci for early paint failure and the failure is inclined to be in large flakes. Proper painting should begin with the operation of filling the pores with a paste wood filler intended for exterior use. Filler must be brushed on and, shortly after, wiped off with rags. Generally, this is not practicable for house painting.

Hardwoods of groups IV and V, when exposed to the weather without paint or with inadequate paint protection, or if water gets behind them, have a very marked tendency to warp or cup and pull away from fastenings. The hardwoods need to be nailed firmly but, if firmly nailed, the boards may split. Thin boards cup and warp worse than thick ones from surface wetting and drying. For these reasons 1/2-inch siding of heavy hardwoods is impracticable. Boards for exterior exposure should not be thinner than 3/4 inch at any point and preferably no wider than 6 inches.

Construction Factors and Finish Performance. When ordinary iron nails corrode, they stain many hardwoods (and some softwoods) badly because iron rust or dissolved iron reacts with tannin in the wood to form a dark-colored substance. Corrosion-resistant nails minimize such trouble. Paint over the nail heads cannot be relied upon to prevent corrosion of nails. Stainless steel, aluminum, and top-quality galvanized nails generally work best.

If rainwater seeps into joints between painted boards of some hardwoods, colored substances from the wood may be streaked over the paint (11). Walnut, the oaks, and chestnut are known to be troublesome in this way. Condensation behind siding may have the same result at joints. Painting the edges of boards joined together and backs of boards where there is danger of condensation minimizes the trouble but adds to the expense of the job. Careful attention to the design of structures, and good carpenter work during erection to avoid joints into which water can penetrate, are the best and cheapest ways of avoiding streaking of this kind.

Quarter-sawed boards of hardwoods hold paint slightly better than plain-sawed boards but the difference is comparatively small in contrast to softwoods where the difference in favor of edge-grain over flat-grain boards is considerable.

Rate of growth is not known to be a factor in paint holding by hardwoods, though among softwoods, slow-grown wood holds paint appreciably better than fast-grown wood. Among both hardwoods and softwoods, paint is held longer by lower density wood.

Where hardwoods of groups III and IV (Table 3) are used for exterior coverings of buildings, consideration should be given to alternative decorative procedures to avoid use of paint:

- Where practicable, let the wood weather naturally but use thick boards, well nailed with corrosion-resistant nails. It is appropriate to use sawed (unplaned) boards for such uses.

- For good performance and ease of refinishing, consider using semi-transparent penetrating stains or solid color acrylic latex stains. These stains will perform better on roughsawn or weathered boards than on new, smooth wood. The semi-transparent stain cannot be used over painted surfaces.

Cooper (14) made several recommendations for the use of yellow-poplar or red oak siding, and a semitransparent stain finish:

1. For maximum weather tightness use full-length, vertical tongue-and-groove siding, dip-treated in WRP, and installed back side out (unplaned side).

2. Use accurately milled boards to insure even thickness if rough vertical board-and-batten or horizontal clapboard siding is preferred.

3. To insure tight joints, use boards dressed on both sides (sacrificing stain-holding characteristics).

Controlling Effects of Light

Finishes always weather fastest on the sides of a building that receive the most sunlight. In the degradation of surfaces by photo-oxidation, the UV portion of the light spectrum, which is the high-energy portion, is the most damaging. Clear coatings become embrittled and check. After checks develop, rain and dew have ready access to the wood substrate, Subsequent cycles of wetting and drying produce serious water staining of the wood under the coating and in time, flaking of the clear coating from the wood. In paint, pigment particles serve as effective UV absorbers, so paint degrades more slowly than clear coatings. During degradation, very shallow checks develop which gradually loosen

Table 3.--CHARACTERISTICS OF WOODS FOR FINISHING AND WEATHERING[1]

Wood[2]	Shrinkage from green to ovendry moisture content[3]		Ease of painting and paint holding[4]		Weathering	
	Radial	Tangential	Unfilled	Filled	Resistance to cupping[5]	Conspicuousness of checking[6]
	%	%				
Hardwoods						
Ash	4.4	7.3	V	III	4	2
Aspen	3.4	7.3	III		2	1
Basswood	6.6	9.3	III	--	2	2
Beech	5.5	11.9	IV	--	4	2
Birch, yellow	7.3	9.5	IV	--	4	2
Chestnut	3.4	6.7	V	III	3	2
Cottonwood	3.5	8.3	III	--	4	2
Elm	4.8	9.2	V	IV	4	2
Hickory	7.4	11.3	V	IV	4	2
Magnolia	5.1	7.9	III	--	2	--
Maple, soft, hard	3.9	8.4	IV	--	4	2
Oak, red, white	4.9	10.2	V	IV	4	2
Sweetgum	5.3	10.2	IV	--	4	2
Sycamore	5.0	8.4	IV	--	--	--
Tupelo	4.7	8.2	III	--	--	--
Walnut, black	5.5	7.8	V	III	3	2
Yellow-poplar	4.6	8.2	III	--	2	1
Softwoods						
Cypress	3.8	6.2	I	--	1	1
Douglas-fir	4.8	7.6	IV	--	2	2
Pine, southern	4.8	7.4	IV	--	2	2
Pine, white	2.1	6.1	II	--	2	2
Redwood	2.6	4.4	I	--	1	1
Western redcedar	2.4	5.0	I	--	1	1

[1]Information from Wood Handbook (23).

[2]Flat-grain specimens except for cypress, redwood, and western redcedar which are vertical-grain.

[3]Average of values in Wood Handbook (23).

[4]I--Easiest or best; V--worst or most exacting.

[5]l--Best; 4--worst.

[6]l--Least; 2--most.

and cause chalking or erosion of the paint surface. Chalking of colored and tinted paints is a common cause of fading (12).

The photodegradation and weathering of wood is important in subsequent finish performance. Wood which has weathered badly before painting will have a degraded surface which is not good for painting, and a paint coating is likely to crack over more degraded areas. However, weathering of the wood surface iS beneficial when a penetrating finish (such as semitransparent oil-base stain) is employed. Weathering permits the wood to adsorb and retain much more of the preservative or pigment stain, so the finish is generally more durable (18).

In addition to light's degradative effects, it also produces heat. Absorption of radiant energy in dark-colored coatings may produce surface temperatures of 100° C or higher under favorable conditions. High temperatures will result in moisture gradients. When the wood surface is hotter than the rest of the board, moisture in the wood substrate moves away from the surface; when the surface is cooler, moisture moves toward it.

Heat of absorbed radiant energy causes a problem in the application of paint, particularly dark-colored paint. If paint is applied too thickly on a cool surface which is subsequently warmed by the sun, blisters may form in the paint due to rapid volatilization of paint thinners. The blistering can be avoided by spreading the paint in only moderate thicknesses and on a surface which has already been warmed by the sun (12).

By Pigmentation. Adverse effects, particularly the photodegradation effect of sunlight on wood, can be readily retarded in many ways. Addition of pigment to clear coatings effectively protects both wood and coating. This technique is used to great advantage in plastic overlays made of polymers which are transparent to UV light. Because the polymers are transparent and do not absorb UV, they have long life out of doors. When applied to wood, such clear polymers permit UV light to attack the wood surface under the coating; this leads to early separation of clear coating from the wood. Addition of pigment to a W-transparent polymer can fully protect the wood from breakdown by sunlight.

By Construction Factors. The feature most widely employed in construction to protect wood from sunlight is roof overhang. When a 4-foot-wide overhang is provided, approximately two-thirds of a conventional one-story side wall is protected from exposure to full sunlight. If clear natural finishes are desired, such as on exterior doors, they must be protected by either recessing the entrance or by porch construction. Gable-end constructions can be utilized on the north side of the buildings while hip-roof construction provides protection on all sides of a house. A-frame designs generally also give good protection.

Vertical siding patterns may also be beneficial in reducing the effects of light and weathering. Water drains better off vertical boards than off horizontal boards. Vertical siding is also slightly more resistant to sunlight than beveled horizontal siding because the angle of incident sunlight is smaller and UV light effects are reduced.

Controlling Effects of Outside Water

Rain and dew account for large volumes of water which come in contact with exterior wood surfaces. This kind of wetting can produce cracking and peeling failure in paint and clear coatings. Water can pass through cracks in the coating and produce peeling. Leaks in the roof, inadequate drainage of water from valleys on steep roofs, or the formation of ice dams on the roof also allow outside water to enter side walls and damage the paint (3). Decay can develop where excessive penetration of water occurs in joints of untreated wood that have a low natural resistance to decay (23).

The discoloration of paint by the water-soluble extractives found in some woods may be evidence of outside water damage (11). When the discoloration is a rundown or streaked pattern, it indicates water is getting behind the horizontal siding and running down at breaks in the lap joint. This kind of discoloration is commonly caused by ice dams in northern climates. An overall diffused pattern of discoloration, on the other hand, indicates penetration of rain and dew through thin layers of porous paint.

Discoloration can further be produced by fungal growth (mildew) on the surface (11,23). This failure also is associated with the dew pattern of the house.

Most exterior water problems resulting from rain are eliminated with properly designed roofs, valleys, gutter, and overhang (3). Proper use of metal flashing in critical areas is most important. Flashing should be used at the junction of a roof and a wood or masonry wall, at chimneys, over exposed doors and windows, at siding material changes, in roof valleys, and other areas where rain or melted snow may penetrate into the house. Wide overhangs are most effective in reducing the amount of rain and dew that wet exterior side walls.

Where coating failure is associated with ends of boards and joints between boards, or when extractive discoloration is present, the best precautionary step is to apply WRP before painting (13,23). Window and door trim of a wood species susceptible to decay should be factory treated with WRP. If not, they should be treated liberally on the site before painting. After treating, prime the surface with nonporous paint. Larger cracks and openings should be talked after treating and priming. Painting untreated sapwood and species low in decay resistance may enhance the possibility of decay because moisture may be more readily trapped behind the paint film.

Formation of ice dams on horizontal roof edges and valleys on houses in north temperate zones can be largely eliminated by providing insulation in the attic floor to arrest heat losses. In addition to insulation, the attic space should be properly vented (3).

Controlling Effects of Inside Water

Water from inside a building can cause paint failure on the outside by diffusing through the walls. Paint will not adhere to wet wood. The water can come from such faulty conditions as leaks in plumbing, or shower spray on 'a bathroom wall that is not properly sealed. Or it may result strictly from conditions of high humidity (3,23).

Inside the building many gallons of water evaporate daily. In the winter time, in cold northern climates, and some mid-South climates, this moisture diffuses toward the cold surfaces of the outer walls. If the outer walls have no vapor barrier or an improperly installed one, water vapor passes into the walls and condenses to liquid in the sheathing and siding. In very cold weather, it may condense into frost, and later be melted by the warm spring sun. The condensed water vapor soaks into the siding and wets the paint. This problem is called cold-weather condensation and is a common cause of paint blistering and peeling (12). Discoloration patterns can also occur from the movement of water-soluble extractives out to the surface of paint (11).

Controlling Effects of Organisms

Fungal organisms are a common cause of discoloration on wood and paint surfaces, particularly in the south (23). Such growth usually does no serious damage to either house or finish system but it does detract from the appearance. It is also evidence that moisture and temperature conditions may be favorable for the growth of other fungi which could cause decay. Many times it is difficult to distinguish between fungal staining and dirt collection. Usually an identification by microscopic examination is required to be certain of the fungal growth (11).

Fungi are most likely to grow on surfaces that remain wet for long periods of time. For this reason, it is not uncommon to see fungal growth on exterior house paint which has been wetted by dew. These areas are usually the exterior surfaces between studs where the surface cools quickly by radiation, while insulation in the wall between the studs prevents warming the surface with heat from inside the house. The painted area over studs and around nails, however, usually remains free of fungal growth because the area is warmed by heat from within.

Control of fungal staining and decay problems is achieved through either the selection of wood species that have a high natural resistance to decay or by use of wood treated with a fungicide or WRP. Where greater resistance is needed, liberal brush treatment or even pressure treatment with a preservative may be advisable. Exterior wood trim, such as windows and doors, should always be treated with WRP before painting or staining. Treatment not only retards fungal growth in the paint but also reduces penetration of water at joints which accelerate paint peeling and decay in wood. Not all hardwoods may respond effectively to the treatment though.

Fungal growth in finishes is controlled also by the addition of fungicides (mildewcides) to the finish. The use of fungicides in latex and flat alkyd-base paints is quite important because these paints, being porous, will hold water on the surface, which favors fungal growth. In severe conditions, paints which contain zinc oxide and mildewcides are recommended to control fungal growth.

Finishing of Special Items

Hardwoods are sometimes used in outdoor situations where special treatments and finishes are required for proper protection and best service use. These situations involve the need for protection against decay (rotting), fire, and harsh exposures such as marine environments.

Treated Wood

Hardwoods which have been pressure treated for decay or fire resistance sometimes have special finishing requirements. All the common pressure preservative treatments (creosote, pentachlorophenol, water-repellent preservatives, and waterborne) will not significantly change the weathering characteristics of hardwoods (16,23). Certain treatments such as waterborne treatments containing chromium may even reduce the degrading effects of weathering (16,18). Except for esthetic or visual reasons, there is generally no need to apply a finish to most preservative-treated woods. If needed, oil-base, semitransparent penetrating stains can be used but only after the preservative-treated wood has weathered for 1 to 2 years depending on exposure. The only preservative-treated woods which can be painted immediately after treatment and without further exposure are those containing the waterborne preservatives (23). Manufacturers generally have specific recommendations for good painting and finishing practices for these preservative-treated woods.

The fire-retardant treatment of hardwood does not generally interfere with adhesion of decorative paint coatings, unless the treated wood has an extremely high moisture content because of its increased hygroscopicity (23). It is most important that only those fire-retardant treatments specifically prepared and recommended for outdoor exposure be used for that purpose. These treated woods are generally painted according to recommendations of the manufacturer rather than being provided with a natural finish because the treatment and subsequent drying often darkens and irregularly stains the wood.

Many commercial fire-retardant coating products are available to provide varying degrees of protection of wood against fire. These paint coatings generally have low surface flammability characteristics and "intumesce" to form an expanded low-density film upon exposure to fire, thus insulating the wood surface below from heat and retarding pyrolysis reactions. The paints have added ingredients to restrict the flaming of any released combustible vapors. Chemicals may also be present in these paints to promote decomposition of the wood surface to charcoal and water rather than forming volatile flammable products.

Most fire-retardant coatings are intended for interior use, but some are available for exterior application. Conventional paints have been applied over the fire-retardant coatings to improve their durability. Most conventional decorative coatings will in themselves slightly reduce the flammability of wood products when applied in conventional film thicknesses (23).

Boats and Marine Uses

The marine environment is particularly harsh on hardwoods. The earlier discussion on wood weathering indicated that the natural surface deterioration process occurs slowly. Marine environments speed up the natural weathering process to some degree and wood is often finished with paint or varnish for protection. Certain antifouling paints are also used for protection against marine organisms on piers and ship hulls.

For best protection, wood exposed to marine environments above water and above ground should be treated with WRP, painted with a suitable paint primer, and topcoated (at least two coats) with quality exterior products (13,24). Any wood in contact with water or the ground should be pressure treated to specifications recommended for inground or marine use (23). Such treated woods are not always paintable. As indicated earlier, the waterborne-preservative-treated woods are clean and paintable.

Natural finishes (varnishes) for marine-exposed hardwoods need almost constant care and refinishing. Varnishes should be applied in three- to six-coat thicknesses for best performance.

Many specific recommendations and suggestions for maintenance and finishing of hardwoods used in marine exposures can be found in reference 26.

Summary

Hardwoods, like all wood exposed outdoors without protection, undergo: (1) Photodegradation by ultraviolet light; (2) leaching, hydrolysis, and swelling by water; and (3) discoloration and degradation by decay micro-organisms. Unfinished wood surfaces change color when exposed to weather, are roughened by photodegradation and surface checking, and erode or wear away slowly. The appearance of unprotected wood exposed outdoors changes markedly in a few months; then the wood remains almost unaltered for years. In the absence of decay, wood exposed to the weather can last for centuries. Although physical as well as chemical changes occur due to weathering, these changes affect only the surface of the exposed wood, Wood only a few millimeters under the surface is essentially unchanged and unaffected.

Film-forming finishes, such as paint, provide the most protection for hardwoods against sunlight and offer the widest selection of colors. A nonporous paint film is needed to retard the penetration of moisture and to reduce discoloration by wood extractives, paint peeling, and checking. Paint is not a preservative and will not prevent decay if conditions are favorable. Because paint forms a coating on the surface, failures by cracking, blistering, and peeling are possible for a paint finish. To achieve optimum performance, both the substrate and coating must be carefully selected and used on well-designed and constructed structures that reduce the exposure of coating to a minimum of sunlight, moisture, and fungal organisms. Hardwoods vary in their paint-holding characteristics. Varnishes are generally short-lived as outdoor natural finshes.

In contrast to the film-forming finishes, the penetrating-type finishes do not form a film or coating on the surface and there is no failure of these finishes by cracking, peeling, or blistering. Quality of the substrate is not critical; it can be rough, smooth, weathered, knotty, flat-grain, dense, porous, and of any species. The penetrating preservative and pigmented oil-base stains are easily maintained, essentially troublefree, and durable. Further, because peeling and blistering failures have been eliminated, the dependence of the finish on design and construction factors has been decreased.

Construction practices and techniques can play a large role in determining the performance of hardwoods used for outdoor exposure. Improper practices can cause early substrate and finish failure.

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