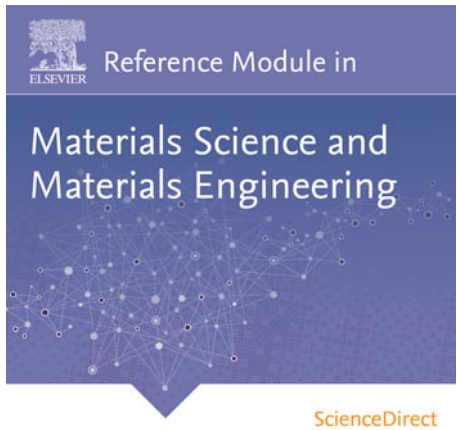

Feist W.C., and Abdullahi A.A, Wood: Finishes and Coatings. In: Saleem Hashmi (editor-in-chief), Reference Module in Materials Science and Materials Engineering. Oxford: Elsevier; 2016. pp. 1-5.

ISBN: 978-0-12-803581-8

Wood: Finishes and Coatings☆

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1 Introduction

The wide range of wood and wood-based materials and the variety of paints, stains, varnishes, and other finishes available provide a tremendous latitude and flexibility for protecting wood and wood structures (Feist, 1996; Williams *et al.*, 1996). Proper protection begins with good design of the structure, followed by good construction practices. The choice of materials must be made in concert with the design, good understanding of the wood materials being used, and knowledge about the weather conditions that will affect the structure (Feist, 1997).

Like other biological materials, wood is susceptible to environmental degradation. When exposed outdoors above ground, a complex combination of chemical, mechanical, and light energy factors contribute to what is described as weathering (Feist, 1990, 1996). Weathering is detrimental to the surfaces and appearance of wood (Williams *et al.*, 1996; Feist, 1996). Thus, weathering must be taken into account when considering the protection of outdoor wood. Weathering of wood is not to be confused with wood decay (rot), which results from fungal organisms acting in the presence of excess moisture and air for an extended period. Under conditions suitable for decay, wood can deteriorate rapidly, and the result is far different from that observed for natural outdoor weathering (Cassens *et al.*, 1995).

2 The Wood Resource

Wood is a natural biological material and as such its properties vary not only from one species to another but within the same species. Some differences can even be expected in boards cut from the same tree. The natural and manufacturing characteristics of wood are important influences on finishing characteristics and durability (Feist, 1990).

2.1 Wood Properties and Finish Durability

The properties of wood that can affect finish durability vary greatly from species to species are density, grain characteristics (presence of earlywood and latewood), texture (hardwood or softwood), presence and amount of heartwood or sapwood, and the presence of extractives, resins, and oils (Feist, 1996, 1997). The density of wood is one of the most important factors that affect finishing characteristics. Excessive dimensional change in wood constantly stresses a film-forming finish such as paint, varnish or

☆*Change History*: July 2015. A.A. Abdullahi added Abstract, Keywords, and expanded text with additional review materials. Text reorganized to have VOC under a single section for easy flow of discussion and understanding. Section 2.3 'Wood finish durability Problem' and Table 1 have been added; in addition, the Section 3.7 'Other Wood Finishes and Special Applications' is now combine as a section. Updated the list of references.

solid-color stain and may result in early failure of the finish. Density varies tremendously from species to species and it is important because high-density woods shrink and swell more than do low density woods. The finishability of various softwoods and hardwoods is directly related to the natural wood characteristics of density, presence of latewood, surface roughness, extractives, and texture, and to manufacturing characteristics such as ring orientation. The surface properties of wood materials can be enhanced easily by finishing with various coatings to provide different performance characteristics for individual applications, such as high hardness, impact resistance, suitable gloss, and chemical resistance (Chang and Lu, 2012; Forsthuber *et al.*, 2014; Xie *et al.*, 2006).

2.2 The Changing Wood Resource

In the United States, clear, vertical grain lumber from old-growth cedars, redwood, and baldcypress has traditionally been used for siding and house trim (millwork or joinery). These substrates provide good paintability and durability, and have been readily available for decades. Supplies are declining, however, and second- and third-growth timber is being cut in greater quantities (Williams, 1994; Williams *et al.*, 1996). Although supplies of this timber are abundant, the properties and performance characteristics of wood from these forests may not be the same as that from old-growth forests. For example, compared with wood from old growth, wood from second-and third-growth has more flat grain than vertical grain material, and more knots (Wood Handbook, 1998).

Siding is often cut thinner and siding boards are sometimes made from a series of end-glued (finger-jointed) pieces. This finger-jointed siding can have variable surface properties leading to different finish performance and durability. Because of the flat grain, knots, and finger joints, lumber from second- and third-growth trees may require additional care when finishing and may be prone to early failure (Williams, 1994). This is especially true for wood used as exterior siding, roofing, decking, and fencing.

Alternative wood species are also being used outdoors. These species include domestic softwoods, such as southern yellow pine, Alaska cedar, and Douglas fir; domestic hardwoods, such as yellow-poplar and sweet gum; and tropical hardwoods such as lauan and meranti. Other softwoods such as radiata pine may also be important species for exterior use. There are large differences in the performance of these alternate species compared to the performance of more traditionally used woods. These differences in wood characteristics are complicated by the increasing number of new wood-based materials being introduced, particularly reconstituted or composite wood panel products for which weathering characteristics and finish performance often have not been adequately tested. Preservative-treated wood is also often finished and may require special finish selection and application (Cassens *et al.*, 1995; Feist, 1996).

2.3 Wood Finish Durability Problem

Problem of wood finish durability is the rapid change taking place in the paint industry dictated by legislation that limits the amount of organic solvents and cosolvents that can be used to formulate wood finishes. Limiting the amount of these solvents – collectively called volatile organic compounds (VOCs) – in finishes may drastically change the performance of many wood finishes. Knowledge of the physical and chemical interactions of these new low-VOC finishes with wood materials and of the service life of these new finish systems is often lacking.

Finish durability problems on wood products are further compounded by many restrictions on traditional paint and stain systems, as well as by restrictions on some paint additives such as mildewcides, fungicides, and other preservatives. Also, changes in wood-based substrates, the use of VOC-compliant wood finishes, and the continued trend away from heavily pigmented paints to less-pigmented stains and clear finishes act in concert to make finished wood vulnerable to premature failure.

A serious concern throughout the US paint industry is compliance with VOC emission legislation (Feist, 1996). Many traditional wood finishes may no longer be acceptable because of this legislation (including alkyd- and oil-based semitransparent stains, alkyd- and oil-based primers and topcoats, solvent-borne water repellents and solvent-borne water-repellent preservatives).

VOC are those organic materials in finishes that evaporate as the finish dries or cures. These materials are regarded as air pollutants, and the amount that can be released for a given amount of solids or coloring pigments in the paints is now regulated in many areas. Many new regulations are currently being established. Legislation in California requires some wood finishes to have no more than 250 g of VOC per liter of finish. Similar legislation is in place in New York, Dallas, Fort Worth, New Jersey, Arizona, and other areas, and legislation is pending in at least a dozen states.

The result of this legislation is that all major paint companies have had to either change their paint formulation or market additional low-VOC formulations. The only manufacturers unaffected by the legislation already in place are those marketing their products in limited geographic areas outside those affected by the legislation. Many current wood finishes, including some latex-based materials, are being reformulated. These changes could affect the serviceability of different finishes and perhaps the method in which they are applied. The introduction of these new low-VOC finishes might also be complicated by changes within the wood industry that were previously discussed. In addition, the formulations and mixing such molecules to obtain a promising coating with lower toxicity than traditional systems is desired (Carteau *et al.*, 2014).

Many finishes being formulated to meet low-VOC requirements are those with low pigment levels such as semitransparent stains and penetrating clear finishes. These low pigment levels do not adequately protect the substrate against ultraviolet radiation in sunlight. To meet the VOC requirements, these finishes are being formulated with high solids content, reactive diluents, new types of solvents and/or cosolvents, or other nontraditional substituents. There is often little information about the way these new finishes interact with the substrate to protect the wood or about the degradation mechanisms of these finishes when exposed to various outdoor conditions.

3 Types of Exterior Wood Finishes

Protective finishes and coatings for wood used indoors can perform for many years without refinishing or severe deterioration. The durability of finishes on wood exposed to natural weathering processes, however, depends first of all on the wood itself. Other factors which contribute are the nature and the quality of the finish used, application techniques, the time between refinishings, the extent to which the surfaces are sheltered from the weather, and climatic and local weather conditions (Feist, 1996).

The primary function of any wood finish is to protect the wood surface from natural weathering processes (sunlight and water), and help maintain appearance. Weathering erodes and roughens unfinished wood. Wood can be left unfinished to weather naturally, and such wood can often provide for extended protection of the structure (Feist, 1990). Different finishes give varying degrees of protection from the weather.

The protection that surface treatment provides against light and water will be affected by the weather resistance of the bonding agents used in the finish (e.g., drying oils, synthetic resins, and latexes), as these agents are subject to some degree of photolytic degradation. The mechanism of failure of paints and other finishes methods have been described in great detail (Feist, 1996; Williams *et al.*, 1996) and will not be discussed further here. Protection of wood exposed outdoors by various finishes, by construction practices and by design factors to compensate for effects of weather has been addressed in great detail (Feist, 1996; Williams *et al.*, 1996; Wood Handbook, 1998).

A variety of finishes can be applied to outdoor wood. These include clear finishes, which reveal and accentuate the natural beauty of wood; stains, which impart a rustic appearance; and paint, which can be obtained in a multitude of colors. Finishes or coatings are applied to exterior wood surfaces for a variety of reasons. The particular reason will determine the type of finish selected and subsequently the amount of protection provided to the wood surface as well as the life expectancy for the finish. Finishes can be divided into two general categories: (1) film-forming opaque coatings, such as paints and solid-color stains; and (2) natural finishes, such as film-forming varnishes, and penetrating (non-film-forming) water repellents, water-repellent preservatives, oils, and semitransparent penetrating stains. An outline of the characteristics of finishes and their application on wood structure is presented in **Table 1** (Xie *et al.*, 2006).

3.1 Paints

Paints are common film-forming coatings used on wood that provide the most protection against surface erosion by weathering and against wetting by water (Williams *et al.*, 1996). They are also used for esthetic purposes and to conceal certain defects. Paints contain substantial quantities of pigments, which account for the wide range of colors available. Some pigments will essentially eliminate ultraviolet radiation degradation of the wood surface. Paint lifetimes up to 10 years are possible with good quality paints applied as two coats over a primer coat.

Oil-based paint films usually provide the best shield from liquid water and water vapor. However, they are not necessarily the most durable because they become brittle over time. No matter how well sealed, wood still moves with seasonal humidity, thus stressing and eventually cracking the brittle paint. On the other hand, latex paints, particularly the acrylic paints, remain more flexible with age. Even though latex paints allow some water vapor to pass through, they hold up better than oil-based paints by swelling and shrinking with the wood.

Table 1 Characteristics of finishes and their application on wood

Type	*Sikkens-system*	*Color*	*Solvent*	*Binder*	*Application*	*Wet amount (g m^{-2})*	*Film dry thickness (μm)*
Stain	Cetol WP 560/006	Brown	Water	Acrylic	Primer	71.2	54.8
	Cetol WF 780/006	Brown	Water	Acrylic	Topcoat	156.9	
Stain	Cetol WP 560/006	Brown	Water	Acrylic	Primer	73.1	47.22
	Cetol WF 950/006	Brown	Water	Acrylic	Topcoat	161.3	
Paint	Rubbol WP 176	White	Water	Acrylic	Primer	85.5	46.97
	Rubbol WF 380	White	Water	Acrylic	Topcoat	149.1	
Stain	Novatech/006	Brown	Organic solvent	Alkyd	Topcoat	153.3	46.51

Source: Reproduced from Xie, Y., Krause, A., Militz, H., Mai, C., 2006. Coating performance of finishes on wood modified with an n-methylol compound. Progress in Organic Coatings 57 (4), 291–300.

Paints perform best on edge-grained lumber of light-density species such as redwood and cedar. Paints are applied to the wood surface and do not penetrate the wood deeply. Rather, the wood grain is completely obscured and a surface film is formed. This film can blister or peel if the wood is wetted or if inside water vapor moves through the house wall and wood siding because of the absence of a vapor barrier. Original and maintenance costs are often higher for a paint finish than for a non-film-forming water-repellent preservative or penetrating stain finish.

3.2 Solid-Color Stains

Solid-color stains (also called hiding, heavy-bodied, or opaque stains) are opaque, film-forming finishes that come in a wide range of colors and are essentially thin paints. Solid-color stains are made with a higher concentration of pigment than are the semitransparent penetrating stains, but a somewhat lower concentration of pigment than that of standard paints. As a result, solid-color stains obscure the natural wood color and grain, and they can also be applied over old paints or solid-color stains. However, surface texture is retained and a flat-finish appearance normally results. Like paints, solid-color stains protect wood against ultraviolet radiation degradation. Lifetimes of three to seven years can be expected for two-coat applications. Solid-color stains form a thin film much like paint and consequently can also peel loose from the substrate. They are often used on textured surfaces and panel products such as hardboard and plywood. These solid-color stains are most effective when applied in two or three coats.

3.3 Varnishes and Varnish Stains

Clear coatings of conventional spar, urethane, or marine varnish, which are film-forming finishes, are not generally recommended for exterior use on wood unless the finished wood is protected by a suitable roof or overhang. Ultraviolet radiation from the sun penetrates the transparent film and degrades the wood under it. Regardless of the number of coats applied, the finish will eventually become brittle as a result of exposure to sunlight, develop severe cracks, and peel, often in less than two years.

A finish that forms a thin, erodable film is popular in Europe and has had some limited success in the USA. This finish is commonly called a varnish stain. The film of varnish stain is thicker than that provided by a semitransparent stain, but thinner than that provided by a film-forming varnish. Varnish stains contain a water repellent, special transparent iron oxide pigments, and mildewcides. The surface coating is designed to erode slowly and can be refinished easier than that provided by a conventional varnish. Varnish stains are usually applied initially as two- or three-coat systems and may last two to four years.

3.4 Water-Repellent Preservatives

A penetrating water-repellent preservative may be used as a natural wood finish. These finishes have minimal protection for wood and may last only one to two years depending on exposure. The treatment reduces warping and checking, prevents water staining at the edges and ends of wood siding, and helps control mildew growth. Paintable water-repellent preservatives may be used as a treatment for bare wood before priming and painting or in areas where old paint has peeled, exposing bare wood, particularly around butt joints or in corners. This treatment keeps rain or dew from penetrating the wood, especially at joints and on end grain, thus decreasing the shrinking and swelling of the wood. As a result, less stress is placed on the paint film, and its service life is extended. These treatments do not protect wood from water vapor.

3.5 Oils

Many penetrating oil or oil-based natural wood finish formulations are available for finishing exterior wood. The most common oils are linseed and tung. However, these oils may serve as a food source for mildew if applied to wood in the absence of a mildewcide. The oils will also perform better if a water repellent is included in the formulation. All these oil systems will protect wood, but their average lifetime may be only as long as that described for the water-repellent preservatives.

3.6 Semitransparent Penetrating Stains

Semitransparent penetrating stains have grown in popularity and are available in nearly all paint supply stores. These stains are moderately pigmented water repellents or water-repellent preservatives. Lifetimes may vary from three to six years depending on wood surface texture and quantity of stain applied. The solvent-borne stains (alkyd- or oil-based) penetrate the wood surface to a degree, are porous, and do not form a surface film like paint. Thus, they do not totally hide the wood grain and will not trap moisture that may encourage decay. As a result, the stains will not blister or peel even if moisture penetrates the wood. The alkyd- or oil-based penetrating stains may contain a fungicide (preservative or mildewcide), ultraviolet radiation stabilizer or absorber, or water repellent. Latex-based (waterborne) stains are also available, but they do not penetrate the wood surface as do their alkyd- or oil-based counterparts. Newer latex formulations are being developed that may provide some penetrating characteristics. A detail investigation of hydrophobic performance on the wood surfaces are carried out by researchers (Craven *et al.*, 2015; Hui *et al.*, 2015).

3.7 Other Wood Finishes and Special Applications

There are two other types of film-forming transparent coatings, but neither works well in exterior applications. Two-part polyurethanes are tougher and perhaps more ultraviolet radiation resistant than other transparent film-forming coatings, but they are difficult to use, and usually have as short a life as conventional varnishes. The second, lacquers and shellac, are *not* suitable for exterior application, even as sealers or primers, because these coatings have little resistance to moisture. These finishes are also normally brittle and thus crack and check easily. However, specialty pigmented knot sealer primers based on shellac are available for specific exterior applications.

Although general wood-finishing procedures are applicable to typical situations, some applications deserve special attention. These include the application of finish to decks and porches (McDonald *et al.*, 1996), fences, wood roofs, log structures, and structures in marine environments (Williams *et al.*, 1996). Wood used in all of these applications is usually exposed to particularly harsh weathering conditions. Special consideration must be given to finish selection and application. Log structures need special consideration because of the large amounts of end grain exposed and the deep checking associated with large timbers as well as small, round logs.

4 Preservatives

Although not generally classified as wood finishes, preservatives do protect wood against weathering and decay, a great quantity of preservative-treated wood being exposed without any additional finish (Cassens *et al.*, 1995). There are three main types of wood preservative: (1) preservative oils (e.g., coal-tar creosote), (2) 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 (Feist, 1996).

5 Acidic Deposition

The attention given to acid deposition (acid rain) during the 1990s prompted interest in the effect of acids on wood finish durability and on wood weathering (Williams, 1991). It has been shown that in the summer, the decisive factor in wood weathering is the intensity of solar radiation, whereas in the winter, it is the increased amount of sulfur dioxide in the surrounding air (central Europe exposure). The effects of acid rain on painted materials can be seen in the degradation of the coating and substrate. The type of pigment and extenders used in paint formulations has a direct bearing on paint performance in an acid environment. The degradation of the substrate also has a direct bearing on coating performance, and may induce different coating failure mechanisms.

References

Cassens, D.L., Johnson, B.R., Feist, W.C., De Groot, R.C., 1995. Selection and Use of Preservative-treated Wood Forest Products Society Publication. No. 7299, Madison, WI.

Carteau, D., Vallée-Réhel, K., Linossier, I., *et al.*, 2014. Development of environmentally friendly antifouling paints using biodegradable polymer and lower toxic substances. Progress in Organic Coatings 77 (2), 485–493.

Chang, C.-W., Lu, K.-T., 2012. Natural castor oil based 2-package waterborne polyurethane wood coatings. Progress in Organic Coatings 75 (4), 435–443.

Craven, J.M., Swithenbank, J., Sharifi, V.N., *et al.*, 2015. Hydrophobic coatings for moisture stable wood pellets. Biomass and Bioenergy 80, 278–285.

Feist, W.C., 1990. Outdoor wood weathering and protection. In: Rowell, R.M. (Ed.), Archaeological Wood, Properties, Chemistry, and Preservation, Advances in Chemistry Series 225. Washington, DC: American Chemical Society Washington, pp. 263–298.

Feist, W.C., 1996. Finishing Exterior Wood. Federation Series on Coatings Technology. Blue Bell, PA: Federation of Societies for Coatings Technology.

Feist, W.C., 1997. The challenges of selecting finishes for exterior wood. For. Prod. J. 47 (5), 16–20.

Forsthuber, B., Müller, U., Teischinger, A., Grüll, G., 2014. A note on evaluating the photocatalytical activity of anatase tio2 during photooxidation of acrylic clear wood coatings by ftir and mechanical characterization. Polymer Degradation and Stability 105, 206–210.

Hui, B., Li, Y., Huang, Q., *et al.*, 2015. Fabrication of smart coatings based on wood substrates with photoresponsive behavior and hydrophobic performance. Materials & Design 84, 277–284.

McDonald, K.A., Falk, R.H., Williams, R.S., Winandy, J.E., 1996. Wood Decks: Materials, Construction, and Finishing. Madison, WI: Forest Products Society.

Williams, R.S., 1991. Effects of acidic deposition on painted wood: A review. J. Coat. Technol. 63 (800), 53–73.

Williams, R.S., 1994. Thinking ahead: Research at forest products lab sets sights on the year 2000. Am. Paint Coat. J., Convention Daily 79 (11), 29.

Williams, R.S., Knaebe, M.T., Feist, W.C., 1996. Finishes for Exterior Wood: Selection, Application, and Maintenance. Madison, WI: Forest Products Society. Publication No. 7291.

Wood Handbook: Wood as an Engineering Material, 1998. Madison, WI: Forest Products Society.

Xie, Y., Krause, A., Militz, H., Mai, C., 2006. Coating performance of finishes on wood modified with an n-methylol compound. Progress in Organic Coatings 57 (4), 291–300.