PROTECTION OF WOOD WITH COATINGS

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Summary

Wood continues to play an important role as a structural material in today's society. As lumber and in reconstituted products, wood is commonly used for house siding, trim, decks, fences, and countless other exterior and interior applications. When wood is exposed to the weathering elements, particularly sunlight and moisture, special precautions must be taken in structural design as well as in the selection and application of any protective finish to minimize or prevent degradation. This paper describes the significance of the weathering process of wood, and physical and governmental changes affecting wood products and wood finishes today. Needed research in this rapidly changing area of wood and wood finish products is described and summarized.

1. Introduction

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 (Feist and Williams, 1993; 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 (Forest Products Laboratory, 1987). 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. 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 (Feist and Ross, 1995).

A further complication of the wood finish durability problem 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.

2. Wood Surface Treatments and the Wood Substrate

Surface treatments of wood (e.g. paints, stains, etc.), adhesion of wood composites, and chemical reactions with wood depend on understanding the surface chemistry of wood. This chemistry often differs for each wood/non-wood interface (Williams, 1994). Wood composite materials, paints and stains and chemical treatments have been developed empirically, over many years, without a thorough understanding of the interrelated chemistry. These products have served the consumer well, but traditional wood products and finishes are being replaced with alternates due to environmental considerations. Environmentally driven legislation is causing rapid change, and there is often little time for trial-and-error development of replacement products. The success of these replacements will depend on basic research focused on surface chemistry of wood to ensure that compatible materials are used with the wood.

The changing nature of wood and wood-based materials intended for exterior use presents a challenge for developing processes and formulating treatments that enhance wood-surface properties. These chemical and physical properties determine the interaction of the solid wood surface with liquids, both penetrating and film-forming finishes. This interaction is important whether the material is placed in service as is, or is subjected to further processing. In further processing, surface properties are important because good wetting of the wood surface by the treating liquid leads to optimum performance of the finished wood product. Finally, the surface properties of the finished wood product and the subsequent changes in these properties resulting from exposure in service need to be measured so that the processes that yield the best-performing products may be selected.

Basic studies of the interaction of liquids on the surface of solid wood or wood-based products and the relationship of these interactions will provide the key to developing compatible finishes, and other surface treatments for wood (Williams, 1998). The solutions to these problems will be beneficial to many user groups, including those involved in the wood, wood-preservation and wood-finishing industries, research and industry associations, federal and state agencies, architects, builders, highway engineers, scientists, and the general public.

3. Volatile Organic Compounds (VOCs)

A serious concern throughout the U.S. paint industry is compliance with volatile organic compound (VOC) emission legislation (Williams 1995). Many traditional wood finishes may no longer be acceptable because of this legislation (including oil-based semitransparent stains, oil- and alkyd-based primers and topcoats, solvent-borne water repellents and solvent-borne water-repellent preservatives).

Volatile organic compounds 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, NY; Dallas, TX; Fort Worth, TX; New Jersey; Arizona; and other areas, and legislation is pending in at least a dozen states. The VOC level attributed to architectural finishes used in California alone were reported as 195 tons (177 metric tons) per day in a June 1977 California Air Resources Board (CARB) report (Williams 1995).

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.

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.

3.1 Primer paints

Primers for wood must bridge two very different materials and are the link between a porous hydrophilic substrate and a hydrophobic film. The primer vehicle should penetrate into the surface of the wood to partially seal it. The pigment provides modest protection against UV degradation until the topcoats are applied. The primer provides a surface for the adhesion of subsequent topcoats. But the most unique function of a wood primer, both for interior and exterior applications, is an ability to block the migration of colored extractives in wood. These colored extractives are found in all wood species and give each of them their individual color and chemical properties. The most well-known are the water-soluble extractives in highly colored woods such as western redcedar and redwood. Alkyd or oil-based stain-blocking primers have been used for decades to block the diffusion of these extractives into the topcoat (Feist, 1996b). The VOC limitations for new primers may not be adequate to continue to meet these stain-blocking needs.

Manufacturers may need to do additional testing to ensure that new formulations continue to block extractive bleed, even on species not noted for problems with bleeding. As stain-blocking oil- or alkyd-based primers are replaced by water-borne (or latex) primers, this testing will become critical. It is also critical to test the blocking against other wood species. Even lightly colored woods can contain colored resins that can bleed through paints. This has been most obvious in recent years with bleed-through from some wood pieces in finger-jointed lumber. This bleed-through from portions of the board gives a good indication of the wide variability of wood properties, even within a single species. Testing should include a variety of wood species and be representative of both interior and exterior exposures. For example, even in interior uses, bleed-through can occur on painted white pine.

3.2 Topcoat paints

The trend to replace alkyd or oil-based topcoats with latex continues, and in many situations, the superior weathering characteristics of acrylic latex has improved paint service life. The higher ambient temperatures needed (50 deg F and above) to generate coalescing of the latex film may continue to limit use in cooler climates, however.

3.3 Oil- or alkyd-based semi-transparent stains

The levels of VOCs in semi-transparent stains should permit the continued availability of these critical finishes until the VOC levels decrease again in 2000 (Williams, 1995). Oil- or alkyd-based (solvent-borne) semi-transparent stains are widely used to finish rough-sawn or weathered siding, decks, log homes, and agricultural structures (Williams et al., 1996; McDonald, et al., 1996). These finishes are useful where penetrating finishes are necessary. They generally do not form a film and thus resist peeling. These stains are also quite useful for difficult-to-finish flat-grained wood. However, because the wood grain shows through semi-transparent stains, the wood substrate is partially exposed to sunlight and the resultant degrading effect of ultraviolet light (Feist, 1990, 1996b). As the semitransparent finish weathers with sunlight exposure, the wood substrate also weathers, but at a slower rate than unfinished or unprotected wood. The partial degradation of the wood substrate actually enhances the penetration of subsequent applications of oil-based semi-transparent stain, but this surface degradation limits the choice of subsequent finishes to oil- or alkyd-based semi-transparent stains.

3.4 Latex (water-borne) semi-transparent stains

Water-borne latex semitransparent stains do not penetrate wood as do their oil-based counterparts; the polymers in the latex are too large to penetrate the wood surface. Penetration into wood is limited to those chemicals having molecular weights below 3,000 Daltons (Williams, 1995). Even if micro-emulsion technology is used to prepare the latex finishes or the polymers are modified to dissolve in water, the polymers cannot absorb into the wood cell wall because their molecular weight is too high. Thus, they act like very dilute paints or solid-color stains and may not provide adequate protection to the finished wood surface.

3.5 Solid-color stains

Whether oil- or water-based, solid-color stains are used to achieve rustic finishes complementary to other film-forming finishes. These products usually give excellent service life when applied like other film-forming finishes; that is, over primers that are formulated to block extractive bleed and applied to give sufficient film build. Solid-color stains are often used over highly colored wood; therefore the wood should be primed with a stain blocking primer. This is most important when the latex solid-color stains are used. As with other latex finishes, the temperature requirements during and for 24 hours after application remain more stringent than the requirements for oil-borne solid-color stains.

3.6 Water repellents and water-repellent preservatives

Water repellents and water-repellent preservatives are generic terms for a broad range of clear and lightly pigmented penetrating finishes (Forest Products Laboratory, 1987). These finishes are not clearly identified in the various finish classifications within the proposed VOC regulations. The marketing names and nomenclature are rather confusing, and the addition of water-borne formulation has further complicated the nomenclature (Williams, 1995).

Solvent-borne water repellents are generally formulated with about 10 percent drying oil, alkyd or varnish resin, 1-3 percent wax or similar water repellent, and solvent (Forest Products Laboratory, 1987). If a mildewcide or preservative is added to the formulation, it becomes a water-repellent preservative. Until recently, solvent-borne formulations almost exclusively dominated the market for this type of finish. Now, with water-borne and lightly pigmented water-repellent preservatives, the formulation of these finishes is more complex, with a variety of cosolvents, pigments and emulsifiers used. Even with the same basic components, the characteristics of the formulation can change with the emulsion size. Little long-term research has been done on the efficacy of these new formulations, particularly with regard to penetration of the active ingredients and long-term durability of treated products.

4. Weathering of Wood

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, 1996b, Williams et al., 1996). Weathering is detrimental to the surface and appearance of wood. Thus, weathering must be taken into account when considering the preservation and 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.

The esthetic appeal and life expectancy of wood and the compatibility of the wood with potential finishes are greatly affected by the weathering process. This process, which modifies the molecular structure of wood, results from a complex combination of chemical, mechanical, biological, and ultraviolet and visible light-induced (photochemical) changes, all of which occur simultaneously and affect one another. In general, with 2 months of exposure to sunlight, all woods will turn yellowish or brownish, then gray. However, dark woods eventually become lighter and light woods become darker. Subsequently, surface checks, then cracks may develop. The grain raises and loosens; the boards cup and warp, pulling fasteners loose; and the wood surface becomes friable, with fragments separating from the surface. After the weathered gray surface has developed, usually in a year or two, further changes are very slow to develop. Once weathered wood turns gray, additional changes in the wood occur very slowly because the process affects only the surface of the wood. However, the wood surface slowly wears away in a process called erosion.

Outdoor weathering of unprotected wood can cause severe surface degradation. Wood siding and other wood products are often exposed to many weeks or months of weathering before being coated with paints, stains, or other finishes (coatings). This weathering before coating (hereafter called preweathering to differentiate it from weathering of the finished wood) can lead to chemical and physical changes on the wood surface that weaken the future coating/wood interface (Williams et al., 1990; Williams and Feist, 1994). This interface is crucial for adhesion of film-forming finishes and the performance of penetrating stains.

5. Precautions for Weathering Wood Before Finishing (Preweathering)

When wood or wood-based products are left outdoors to weather naturally, two factors should be carefully considered. First, wood left to weather naturally will likely develop mildew. In warm, humid climates typical in the South, mildew may be very unsightly and blotchy. Second, wood that becomes wet, even periodically, can eventually decay. To help guard against decay, which may take from one to several years to develop, all structures should be built so that exposure to both atmospheric and ground moisture is minimized and moisture is not trapped (Forest Products Laboratory, 1987). Furthermore, the naturally durable heartwood of certain species such as the western redcedar and redwood or preservative-treated wood should be chosen when the decay risk is high.

In the absence of adhesion failure, paint on wood exposed outdoors will gradually erode (Feist, 1996b). Degradation of a paint coating by this mechanism takes several years and the erosion rate depends on exposure to sunlight and moisture and the thickness and type of paint. During the time that paint is eroding, it still protects the wood substrate. Until this erosion proceeds to the point where the primer paint begins to show, the paint surface can easily be repainted with a topcoat. With timely repainting, painted wood can last for centuries.

If, however, the primer paint/wood interface fails, the paint film will degrade within a short time. This paint failure manifests itself as blistering, cracking, and peeling. It could result in damage to the substrate and more difficult and costly refinishing. One cause of interface failure is a degraded wood surface caused by weathering prior to initial priming with paint (Williams et al., 1990). Research at the Forest Products Laboratory as well as many studies at other laboratories all have led to the same conclusion. Whether wood is to be painted, stained, or finished in any manner, preweathering for as little as 4 weeks is detrimental to the service life of any film-forming finish.

Preservative-treated wood -- commonly treated with chromated copper arsenate (CCA) -- should also be finished as soon as possible after installation (Feist and Ross, 1995). For penetrating surface treatments, the only requirements are that the wood should be clean and dry on the surface. Even treated wood that is wet when it arrives at the construction site should be dry enough on the surface, to finish with a penetrating finish within a week or two of drying. However, treated wood (and any wood!) that is to be painted must be uniformly dry.

6. Wood Finishing Research at the Forest Products Laboratory

Wood finishing research at the Forest Products Laboratory (FPL) in Madison, Wis., began about 1920, and a program has been continuously maintained since that time (Gorman and Feist, 1989). The focus of the research at the Laboratory is to determine the basic mechanisms of wood and wood surface deterioration outdoors, investigate wood surface chemistry as it pertains to all types of surface treatments, adhesives, coatings, and composites, and develop procedures and treatments for improving outdoor wood surfaces as related to finishing and other performance characteristics (Williams 1994, 1998). The areas chosen for emphasis include the performance of coatings that are low in VOCs, and wood wetting relationships. Problems include:

- Performance of wood and finished wood products including tropical woods
- Environmental factors and materials properties that affect the durability of painted wood
- Multifunctional wood treatments.

Some highlights of recent FPL research are: Effects of weathering of factory applied primers on top coat service life; durability of water-borne WRPs and other low VOC WRPs; effects of moisture content on paint performance; determining the effect of wood and specimen properties on the Swellometer test; assessing the effect of preweathering of primers on the adhesion of top coats; continuing studies on back priming, surface roughness, application techniques, and deck finishes; interaction between water repellents and paints on ends and edges of siding; Modification of wood surface without solvents using plasma chemistry; Evaluation of lignocellulosic surfaces by inverse phase chromatography and atomic force microscopy.

7. Future needs and concerns

One important aspect of needed research on exterior wood finishes is the performance of VOC-compliant wood finishes (Williams 1995). There are many new, mostly untried VOC-compliant finish systems being introduced for exterior wood, and there is a great deal of misinformation and confusion about these materials. The VOC-compliant finishes need to be evaluated for their long-term performance and durability on a variety of wood surfaces. Studies must address basic materials science to define properties needed for selecting the best substrate/pretreatment/finish combinations for longest durability (Williams, 1998).

Future research should also be directed toward acquiring additional basic information on how weathering interactions affect the performance of wood and wood panel products used as outdoor siding for structures. Studies should evaluate the finishing and weathering characteristics of wood modified with preservatives, fire retardants, and other chemicals. Research should also address the dependence of finish performance (finish service life) on wood grain angle, particularly flat-grained wood, for a variety of species and should include studies on finish adhesion problems with smooth western redcedar (often referred to as mill glaze). Another important research need is the role of surface roughness in finish performance (Richter et al., 1995; Williams and Feist, 1994). This has long been overlooked and needs emphasis in light of the rapidly changing wood source.

Finally, research to develop new methods for treating wood surfaces for stability toward water, sunlight, microorganisms, and other causes of degradation must be continued. Emphasis should be placed on developing simple, economical, environmentally safe, and stable methods for protecting the wood surface and enhancing finish performance in outdoor exposure. Studies also need to be conducted on the finishing of heavily weathered wood and the refinishing of once-finished wood.

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