Factors effecting paint performance on wood siding

Christopher G. Hunt*, cghunt@fs.fed.us, R. Sam Williams, Mark Knaebe, Peter Sotos, Steven Lacher. US Forest Service Forest Products Laboratory, Madison, WI USA.

Abstract

Several different studies are compared to assess the effectiveness of commercial water repellent preservatives (WRP's) in the late 1990's on vertical and horizontal siding. Besides WRP, variables included wood species, exposure location (Wisconsin or Mississippi), and solid color stain vs. primer + paint. Data on substrate checking and paint flaking are presented.

Painting end grain of vertical siding was universally helpful. Appropriate WRP's on end grain universally improved performance, even when end grain was primed and painted. WRP applied to entire boards had mixed results. Any system with a primer coat significantly outperformed solid color stain applied directly to the wood.

These data suggest that appropriate WRP's and paint should be applied to end grain of wood in outdoor exposure. WRP's can improve or harm performance on flat surfaces, however. Some products sold with the claims of being water-repellent preservative provided no positive benefit, even on end grain drip edge. The general public has no effective way to determine which WRP's are effective and which are not.

Introduction

Paint specialists have long advocated for the use of water repellent preservatives on end grain of wood in exterior applications. FPL has even published information on how to formulate your own WRP. Today, however, the consumer cannot access the ingredients to make their own WRP and must rely on commercial products. There is no good way for a consumer to evaluate these products. This paper discusses WRP effects from several studies, originally designed to look at various effects, all of which apply WRP's under paint or stain.

Problems with finishes on wood siding related to water

Most service problems in wood siding are related to water. Decay is typically not an issue unless wood is saturated with water [1]. Wood checking is often a result of stresses from swelling and shrinking, as wood expansion is linearly related to moisture content (MC) between 0 and 30% MC. Moisture differences between the core and face [2] are especially problematic. For example, a dry core and wet face results in face tension, which tends to enlarge surface checks. Paint flaking, on the other hand, is a commonly a result of adhesive failure. Water commonly causes flaking via bondline stress from swelling and shrinking of wood, normal forces from trapped vapor caused by solar heating of wet wood, and by supporting biological growth and decay. Soluble extractives can also be transported by water through the finish to the surface, causing discoloration when no or a low-quality primer is used.

Mechanism of Water-Repellent Preservatives (WRPs)

As the name implies, WRP has two functions: water-repellent and preservative. Preservative helps paint performance after prolonged wet exposure by preventing growth of microbes that would decay the wood substrate. The water-repellent helps wood and paint by preventing liquid water from entering the wood. Because of the many ways that water degrades wood and paint, keeping the wood dry is far better than allowing it to wet while preventing decay.

Natural extractives can decrease the acidic character of wood (K_a) and the enthalpy of water desorption [3]. Conversely, we expect the hydrophobic molecules added to the wood to reduce the acidic character of the wood and its affinity for water. As the acidic component of wood is a major contribution to total surface energy, further discussion will simply refer to surface energy.

Water repellents contain hydrophobic components such as paraffin, mineral oil, alkyd polymers, naphthenic acid, etc. which deposit on the wood and reduce surface energy. The problem with reducing the surface energy of wood is that the force of adhesion between the wood and a coating is proportional to surface energy of the wood [4, 5]. Therefore WR treatment impedes paint adhesion to some extent, which can effect performance: adhesion strength of freshly applied paint has been correlated with service life [6]. A 1% wax content in water-repellent is the traditional balance point between repelling water and minimal loss of paint adhesion [7]. Any hydrophobic molecule added to the wood is likely to have a similar tradeoff: reduce surface energy to repel water but do not reduce it so much that paint adhesion is seriously compromised.

Previous experience with WRP

Paint companies commonly void warranties when wood is pretreated with water-repellents (WR). This is not completely unreasonable, because water-repellents do typically degrade paint adhesion. Over application of water-repellent could seriously degrade finish performance. Copper naphthenate pretreatment has also been implicated in increased resin bleed [8], probably from the addition of solvent, and not leaving enough time for primer to dry before top coating. Also, some commercially available water-repellents provide little benefit. Despite these problems, in some applications WPs and WRPs are very helpful. Norton [9] observed that WRP outperformed primer on end grain in wooden joints exposed outdoors. WRP application extended rot-free performance by up to 7 years. Feist [10] showed improved paint performance on woods with poor paint-holding characteristics after 9 years outdoor exposure.

Experimental

Water-Repellent Preservatives and Coatings

All coatings were from commercial sources. White solid color stains (alkyd and latex), white primer (alkyd and latex), and white latex topcoat were all high quality. The copper naphthenate (CuN) product contained mineral spirits as a solvent, 15% mineral oil, and 33% copper naphthenate (8% copper and 25% naphthenic counter ion). The IPBC product contained 0.5% IPBC (3-iodo-2-propynyl butyl carbamate) and ~5% nondrying oil, and was labeled as a WRP. Waterborne WRP (WbWRP) was a 10.5% solids emulsion containing alkyd polymers, paraffin wax, surfactant, and IPBC.

Previous work has shown that as little as one week of sunlight exposure prior to painting can have a measurable detrimental effect so all treatments were done prior to outdoor exposure [6]. CuN was allowed to dry one week before application of further coats.

Vertical Siding:

Boards 13×5× ½ in. were installed vertically on an upright (90º) fence with southern exposure, as shown in Figure 1. Three replicate boards were glued to a plywood frame with silicone caulk. All boards had one primer coat and one high-quality white latex topcoat. In a full factorial design, the three boards

- were Southern Pine (SP), ponderosa pine (PP), and western red cedar (WRC),
- were exposed in Madison, Wisconsin, or Gulfport, Mississippi,
- received a WRP (none, CuN, or IPBC),
- were primed with either alkyd or latex primer,
- had the bottom drip edge primed and painted with and without pretreatment, and
- had the primer coat washed after cure to remove surfactants.

Horizontal Siding:

Alaska yellow cedar (AYC) or baldcypress (BC) siding 47x5 in. were exposed horizontally on an upright fence with Southern exposure. Six different finish systems were applied to each board. The left and right half of each board had different WRP's applied. The 3 panels on each side of the board had 1, 2, or 3 coats of finish. These could be 1, 2, or 3 coats of solid color stain (SCS), or 1 topcoat directly on the wood, primer+topcoat, and primer +2 topcoats. The three replicate boards of each condition:

- were baldcypress or Alaska yellow cedar,
- were exposed in Madison WI, or Gulfport, MS,
- received a water-repellent preservative (none, CuN, IPBC, or waterborne WRP),
- were either alkyd SCS, latex SCS, or latex primer + latex paint topcoat.

Observations

Substrate checking and paint flaking were rated annually on a scale from 1 to 10 using ASTM methods D772 and D 661, respectively, where 10 is perfect, 9 shows some small blemish, 5 is time to repaint, 1 is complete failure. Five and 9-year field exposure values are discussed here. "Significant" indicates a *t*-test *p* value of 0.05 or less.

The layout of vertical siding sections and their ratings are shown in Figure 1.

Figure 1: Layout of vertical siding specimens+ ratings at 12 years. Top: SYP, unpainted drip edge+CuN. Subtrate (L to R) 8,9,10: Flake 9,9,9. Bottom: SYP, unpainted drip edge, no CuN. Substrate 9,6,7: Flake 8,7,7

Results

Water-Repellent Preservative

Vertical siding – WRP

Figures 2-4 show the checking performance of vertically oriented siding. A clear, consistent improvement is evident with copper naphthenate (CuN) treatment (green, center values). Performance of IPBC is mixed and not statistically significant.

There is not a strong difference in checking between exposure in Wisconsin (left of each WRP group) and Mississippi.

Progressing from Southern Pine, a wood prone to checking and paint flaking (Figure 2), through ponderosa pine (medium), to western red cedar (resistant to checking and flaking, (figures 3 and 4) the improvement in checking performance of the control specimens is obvious.

Particularly in PP and WRC, the improvement from priming and painting the drip edge (open circles) is obvious.

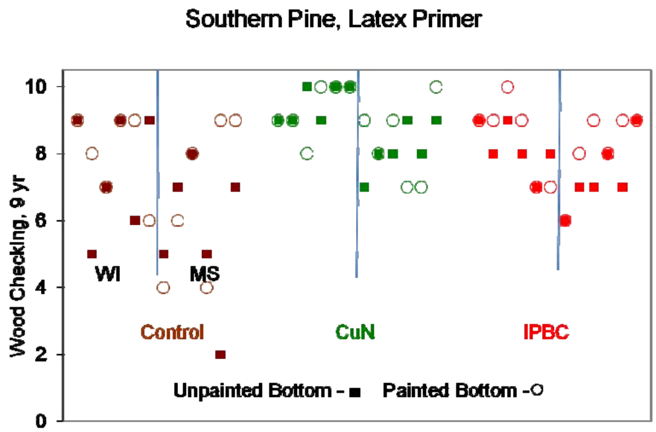

Figure 2: Wood checking observations on vertically oriented Southern Pine. Higher numbers indicate less checking.

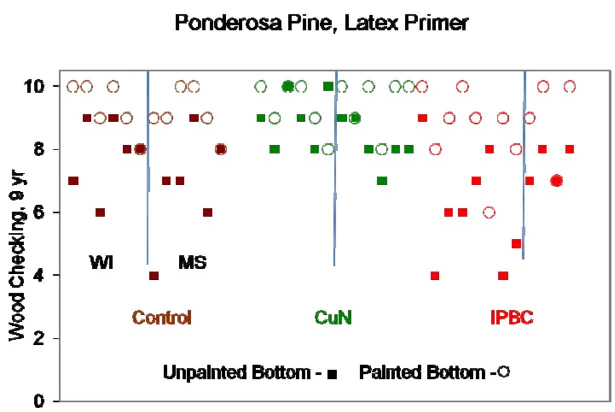

Figure 3: Wood checking observations on vertically oriented ponderosa pine.

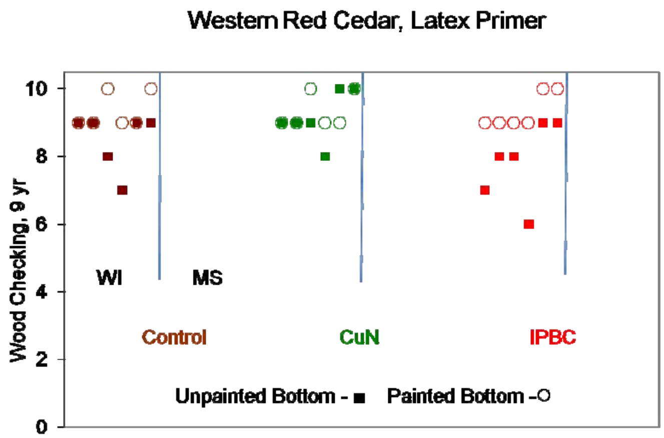

Figure 4: Wood checking observations on vertically oriented ponderosa pine. Higher numbers indicate less checking.

Figures 5 and 6 show the average checking of both locations and primer systems. The effects of CuN and species are statistically significant. Also, improvement seen by painting end grain and applying WRP are significant. After 5 years, painting provides better substrate performance than WRP on all three species. After 9 years, however, Figure 6 shows that CuN is even more effective than painting the end grain of SYP, while painting is more effective for the PP and WRC. In all cases, applying CuN *and* priming and painting the end grain gives the best results. Statistical *p* values for SYP, PP, and WRC comparing paint vs. paint + CuN were 0.00, 0.47, and 0.11, respectively.

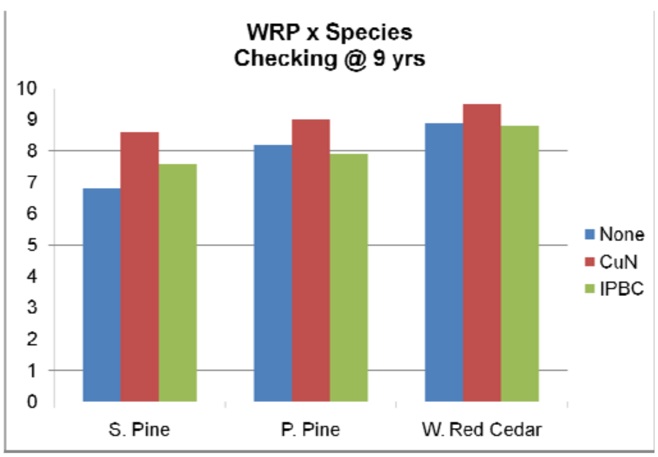

Figure 5: Wood checking observations on vertically oriented siding. Average of all conditions.

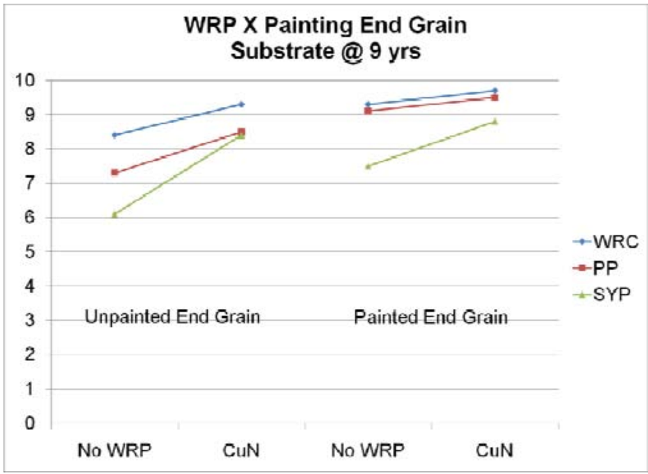

Figure 6: Impact of CuN and painting end grain on checking at 9yrs. All primers and locations on vertical siding.

Flake performance (Figure 7) followed the general trends of checking performance, but typically the results were not as dramatic. Nine-year flake values were significantly improved by painting PP and WRC, whereas CuN significantly improved with unpainted edge for SYP and WRC. The combination of treatments did not make a significant difference.

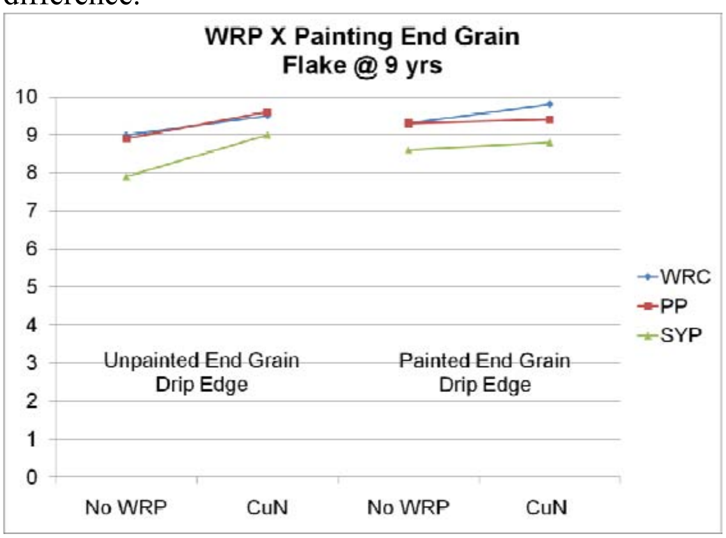

Figure 7: Flaking after 9 years. All primers and locations on vertical siding.

Horizontal siding CuN

Results of primer+topcoat checking on horizontal baldcypress (BC) siding are shown in Figure 8. No significant effects are observed, and in every case the siding is still serviceable. Alaska yellow-cedar (AYC) was in even better condition, with 83% of observations scoring 10.

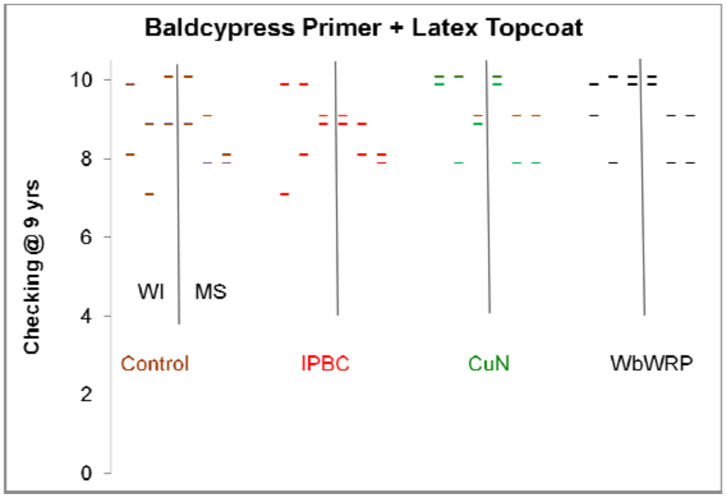

Figure 8: Horizontal BC siding – checking with primer+paint.

As opposed to primer+paint, two coats of solid color stain showed severe degradation after only 9 years. Under these conditions it is possible to see a difference between WRP treatments (Figures 9 and 10). CuN significantly improved flake in AYC, and the WbWRP provided significant improvement in flake and substrate in AYC.

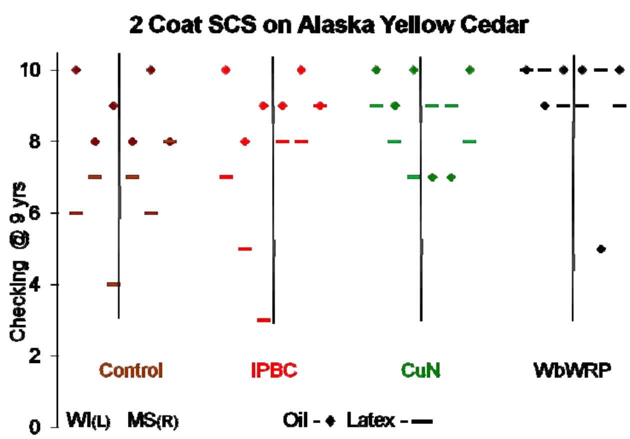

Figure 9: Horizontal AYC siding. Checking with 2 coats SCS.

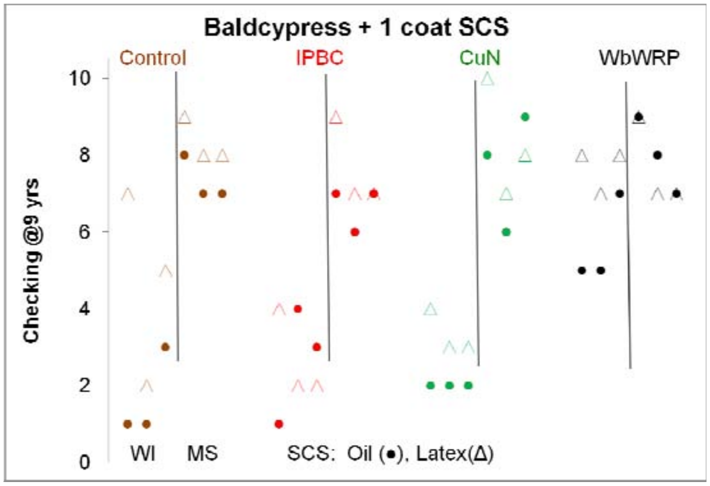

Figure 10: Horizontal baldcypress siding – checking with one coat SCS.

CuN in other applications

Because of the interesting difference in behavior between CuN in these two geometries, we surveyed other studies containing CuN on our test fence in Madison, Wisconsin. We found the CuN helped flaking performance at 7 years on SYP and radiata pine, with both alkyd and latex primer and white topcoat.

We also found several examples of worse flaking with CuN treated siding after 7 years exposure. For example, the same study where SYP and radiata were helped, blue latex SCS exhibited more severe flaking. Flaking was also worse on WRC siding with one blue latex topcoat, and radiata pine siding with blue SCS. SYP and radiata with CCA, ACQ and CA preservative (chromate copper arsenate, alkaline copper quaternary ammonia, and copper azole) all flaked more when CuN was applied before primer or SCS.

Discussion of WRP effects

CuN treated vertical siding with horizontal end grain showed consistently better performance in checking after 9 years. Flaking of boards in this study generally followed the trends of checking but damage was less severe. These improvements are consistent with what has been previously observed with WR treatments [10]. Checking of wood and paint flaking can result from decay (loss of strength), but are more commonly a direct result of moisture in the wood. Therefore it appears that at least in the early stages, the CuN treatment was helpful because of its water repellent properties, more so than its role as a preservative. The fact that IBCN treatment was not helpful, even though we observed biocide activity, further supports the conclusion that it is the water repellent, rather than the preservative, which is important in this case.

In other studies, however, CuN has little effect or was detrimental to finish properties. CuN applied to horizontal siding (baldcypress, Alaska yellow cedar, SYP and radiata) with white solid color stain or white primer/paint had a slight beneficial effect on checking and flaking, occasionally statistically significant after 9 years.

In our survey of other, yet unpublished, studies on our test fence, we saw that in general blue paints and stains had more flaking with CuN compared with untreated controls. Also finish on treated woods flaked much more with CuN pretreatment.

We will not analyze the details of these other studies but simply make the point that CuN pretreatment can cause problems in finishes. However in the situation where end grain is a horizontal surface, CuN, and presumably other products with similar action, such as the WbWRP used in the horizontal siding studies, can help.

In this work, we showed that CuN was especially helpful when end grain sat in a horizontal orientation (board vertical), maximizing the likelihood of liquid water sitting on end grain. CuN significantly improved flaking and checking with every wood substrate when end grain was unpainted. Even when CuN was applied under primed and top coated end grain, it improved checking performance for every wood substrate, though in western red cedar it was not quite significant. The water repellency contributed by the high mineral oil content and the hydrophobic naphthenic salts likely slowed the flow of water into the end grain, while the preservative prevented microbial attack. Inspection of the end grain shows fungal fruiting bodies on some of the Southern pine drip edges (both painted and unpainted) when no WRP was used (Figure 11). These are mostly absent in CuN and ICBN treated specimens, as expected.

Figure 11: Drip edge of SYP boards at 12 years. From top: +paint+CuN, +paint–CuN, -paint+CuN, -paint-CuN. Note dark fruiting bodies pushing through paint from latewood of second board.

The dramatic improvement in end grain (vs. horizontal siding) treated with water-repellent makes sense because the end grain of wood absorbs water typically 10 times faster than the radial or tangential face. In addition, maximum swelling and lowest strength are perpendicular to the end grain, so moisture driven dimensional changes are more likely to cause checking in end grain than on the radial or tangential face.

In areas that fail because liquid water enters the wood and causes checking (and paint cracking), decay, or paint blistering because of excessive moisture, water-repellents will help. Because all areas of end grain are prone to paint failure from liquid water absorption, all end grain should be treated with a water-repellent. If there is concern about excessive moisture for extended periods, then we, like many before us, suggest a good WRP[10].

Though it appears that a good WRP is very effective in improving finish performance, the commercial WRP we called IPBC had little if any effect. Our opinion, based on recent experience and discussions, is that much of the WRP sold today does not provide the long lasting benefits of water-repellency that we observed with the CuN and WbWRP discussed in this work. Clearly, care needs to be taken in choosing an effective WRP. Despite the shortcomings of the Window & Door Manufacturers Association swellometer test [12], it does indicate initial water-repellency effectiveness. Yet very few commercial product labels even have this rudimentary information, much less anything more useful, for a consumer to evaluate the product effectiveness.

Non-performing water repellents likely result in premature failure of paint systems and a declining reputation for wood as a building material. It would seem that paint producers could improve service life, and therefore customer satisfaction, by providing a high quality WRP recommended for use with their paint systems on end grain in exterior applications. Another alternative would be to advertise the results from a standard test method for water repellent efficacy. Alternatively, producers of quality water-repellent preservative could differentiate themselves from the ineffective competition by clearly labeling the composition of their products.

Paint vs. Solid Color Stain

As previous studies have shown, if two coats of finish were applied, a primer + paint topcoat far surpassed two coats of solid color stain (SCS) in every case. Solid color stains can be a useful in some specific applications. In our opinion, however, SCS performance is so inferior to primer/paint that it gives painted wood a bad reputation, and its use should be strongly discouraged.

Conclusions

While water-repellents and water-repellent preservatives can diminish paint adhesion, in some specific applications this loss is more than offset by the gain in preventing liquid water from entering the wood. In this work, the benefit of a good water repellent preservative was seen in horizontal end grain. Statistically significant improvements in ponderosa and southern pine checking were seen even when the end grain was also primed and painted. We also observed one WRP that had no effect at all. We suggest that any end grain would likely benefit from a good water-repellent.

The consumer, however, is faced with an array of products claiming to be water repellent or water-repellent preservative, some of work well and some which give no long-term benefit. With little information on the label, it is very difficult for consumers to choose the effective products. Paint producers have the ability to solve this problem by producing and marketing an effective product that will make their paint systems last longer, or by promoting their superior performance in standard tests.

Disclaimer

References

1. Highley, T., *Biodeterioration of Wood*, in *Wood handbook - Wood as an engineering material*, USDA, Editor. 1999, USDA Forest Service, Forest Products Laboratory: Madison, WI.
2. Simpson, W., *Drying and control of moisture content and dimensional changes*, in *Wood handbook: Wood as an engineering material*, USDA, Editor. 1999, USDA Forest Products Laboratory: Madison, WI.
3. Tshabalala, M.A., A.R. Denes, and R.S. Williams, *Correlation of water vapor adsorption behavior of wood with surface thermodynamic properties.* Journal of Applied Polymer Science, 1999. **73**(3): p. 399-407.
4. Pizzi, A., *A brief, non-mathematical review of adhesion theories as regards their applicability to wood.* Holzforschung und Holzverwertung, 1992. **44**(1): p. 6-11.
5. Kendall, K., *Adhesion and Surface Energy of Elastic Solids.* Journal of Physics D-Applied Physics, 1971. **4**(8): p. 1186-&.
6. Williams, R.S. and W.C. Feist, *Durability of Paint or Solid-Color Stain Applied to Preweathered Wood.* Forest Products Journal, 1993. **43**(1): p. 8-14.
7. Feist, W.C. and E. Mraz, *Wood finishing: Water repellents and water-repellent preservatives*, USDA, Editor. 1979, FPL.
8. Dawson, B.S.W., et al., *Resin bleed after painting from radiata pine boards treated with tributyltin naphthenate (light organic solvent preservative) or copper, chromium and arsenic compounds (water-borne preservative).* Holz als Roh - und Werkstoff, 2002. **60**(1): p. 18-24.
9. Norton, J. and L.P. Francis, *Effect of surface-applied treatments on the above-ground performance of simulated timber joinery.* Australian Forestry, 2008. **71**(2): p. 100-106.
10. Feist, W.C., Weathering Performance of Painted Wood Pretreated with Water-Repellent Preservatives. Forest Products Journal, 1990. 40(7-8): p. 21-26.
11. Williams, R.S. and W.C. Feist, *Water Repellents and Water-Repellent Preservatives for Wood*, USDA, Editor. 1999, FPL.
12. WDMA, TM-2-99 (06) Swellometer Test: Test method to determine the water-repellent effectiveness of treating formulations. 2006. WWW.WDMA.com

Hunt, C., R. S. Williams, M. Knaebe, P. Sotos and S. Lacher (2009). Factors effecting paint performance on wood siding. 3rd International Coating Wood and Wood Composites Charlotte, NC, National Paint and Coatings Association (NPCA/FSCT).