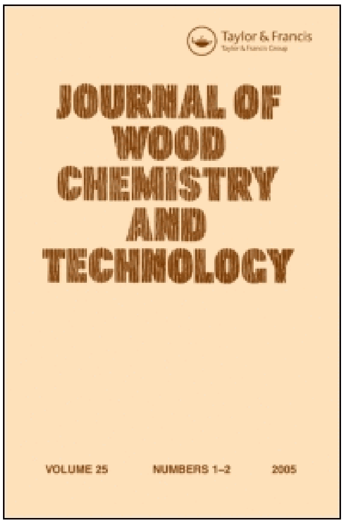

Journal of Wood Chemistry and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597282

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Joseph Dahlen[a]; Darrel D. Nicholas[a]; Tor P. Schultz[a]
[a] Forest Products Department, FWRC, Mississippi State University, Mississippi State, Mississippi, USA

To cite this Article Dahlen, Joseph , Nicholas, Darrel D. and Schultz, Tor P.(2008) 'Water Repellency and Dimensional Stability of Southern Pine Decking Treated with Waterborne Resin Acids', Journal of Wood Chemistry and Technology, 28: 1, 47 — 54

To link to this Article: DOI: 10.1080/02773810801916472
URL: http://dx.doi.org/10.1080/02773810801916472

Journal of Wood Chemistry and Technology, 28: 47–54, 2008

ISSN 0277-3813 print/1532-2319 online
DOI: 10.1080/02773810801916472

Water Repellency and Dimensional Stability of Southern Pine Decking Treated with Waterborne Resin Acids

Joseph Dahlen, Darrel D. Nicholas, and Tor P. Schultz
Forest Products Department, FWRC, Mississippi State University,
Mississippi State, Mississippi, USA

Abstract: Many residential consumers prefer that wood used in above-ground exterior applications be protected by environmentally benign biocide systems and have good dimensional stability. To help achieve these two properties we are employing resin acids, a by-product from the kraft pulping of pines, in a waterborne formulation. In an extremely harsh above-ground exterior exposure, two sets of decking boards treated with the resin acid system had water repellent properties that were still effective after up to two years of exposure. The increased water repellency reduced the moisture gain following summer rainstorms by about one-third compared to untreated matched samples, and this was sufficient to significantly reduce splitting by about half and cupping by one-third. A wide variation in moisture gain following rain was observed for the untreated sapwood flatsawn decking, with the moisture gain positively and significantly correlated to the extent of checking. The optimal use of resin acids may be to provide some limited dimensional stability and, in combination with antioxidants and organic biocide(s), as a benign wood preservative system.

Keywords: Dimensional stability, resin acids, tall oil rosin (TOR), water repellency

Funding for this project was provided by the USDA-CSREES Wood Utilization Program and the state of Mississippi. Approved for publication as Journal Article No. FP 445 of the Forest and Wildlife Research Center, Mississippi State University.
Address correspondence to Tor P. Schultz, Forest Products Department, FWRC, Mississippi State University, Mississippi State, MS 39762-9820, USA. E-mail: tschultz@cfr.msstate.edu

INTRODUCTION

Wood products are used in residential construction and other outdoor applications where the wood can be biodegraded by many fungi and insects. To prevent deterioration, non-durable wood products can be treated with biocides. Wood preservation has recently undergone dramatic and rapid changes worldwide due to a demand for environmentally benign residential wood preservative systems. Wood is also a hygroscopic material that in above-ground exposure such as decking will swell unevenly when wetted and then shrink as it dries. This dimensional instability often leads to undesired checking and warping in treated lumber.[1–3]

To address the aforementioned problems we have been working on developing environmentally benign organic wood preservative systems and water repellents.[4–7] The wood preservative systems combine organic biocides with non-biocidal, benign, and low-cost additives that enhance the biocides' efficacy, specifically antioxidants and metal complexing compounds. These additives were selected based on the fungal decay mechanisms and the properties of heartwood extractives. Specifically, extractives in naturally durable heartwood have excellent antioxidant and metal chelator properties,[6] and antioxidants and metal complexing compounds interfere with the wood-degrading free radicals generated by fungal metal-mediated reactions.[4,8–10] Thus, our approach mimics natural durability. Furthermore, some extractives, such as terpenoids, are very hydrophobic and thus water repellents. Water repellents enhance the durability of wood products by reducing the decay potential and extent of biocide leaching of treated wood, and further improve the dimensional stability of treated wood.[2,11]

We identified a non-leachable, economical and stable antioxidant, butylated hydroxytoluene or BHT, that was effective in laboratory and outdoor studies.[4,6] A suitable metal complexing compound proved more difficult to select but we recently reported that resin acids give enhanced efficacy when combined with organic biocides.[12] Furthermore, when formulated into a waterborne system enhanced water repellency is obtained.[7] Resin acids are a by-product from the kraft pulping of pines, are benign and inexpensive.

The objective of this study was to determine the change in moisture content over time in two sets of southern pine decking boards that had been treated with waterborne resin acids, then exposed in a harsh above-ground environment for at least a year. One set consisted of commercial nominal 5/4 flatsawn decking, and the second was laminated quartersawn samples of the same thickness. We are examining ways to produce quartersawn decking because it has good dimensional stability and fewer tendencies to check than flatsawn lumber. Because we sought to reduce undesired dimensional changes, we measured the moisture content changes during the hot summer months in Mississippi where extremely high temperatures and often low humilities alternating with short thunderstorms cause above-ground lumber to undergo rapid wet and dry cycles.

MATERIALS AND METHODS

The preparation and treatment of the southern pine samples were as previously described.[7] Briefly, one sample set was cut from commercial flatsawn 5/4 defect-free, untreated sapwood decking, each 112 cm long, 2.5 cm thick, and 14 cm wide, which were then cut into two matched 65 cm long samples, one treated and one control. A total of 12 replicate sets were prepared. The samples were then weighed and the moisture content determined using a Wagner dielectric moisture meter so that the oven-dry weight could be estimated for later determination of the moisture content when outdoors. The second set consisted of quartersawn laminated samples made by gluing defect-free southern pine flatsawn sapwood lumber together, then sawing the billets into 2.5 cm thick by 14.6 cm wide laminated quartersawn boards that were then cut to give three replicate samples each 33 cm long. These samples were divided into three matched sets of 12 samples each. Each individual sample was then weighed and the moisture content measured as described earlier.

One set of the flatsawn decking samples were treated with a 3% resin acid waterborne solution using a full-cell process. The Pamite 90™ resin acid employed was a commercial by-product from pulping, tall oil rosin commonly known by the acronym TOR, provided by Eastman Chemical Company. The waterborne formulation was made using 0.95 equivalents of NaOH and 6% isopropanol, as described earlier (Schultz et al. 2007). The matched set of control samples was untreated. The three matched sets of quartersawn samples were treated by a full-cell process with either waterborne 3% TOR, 3% paraffin wax in toluene for the positive controls, or the untreated negative control samples untreated. As these samples were relatively short the samples were end-coated with a phenolic-resorcinol adhesive after air drying.

The samples were installed on exterior roofs at Mississippi State University, with the roofs slanted south to maximize the sunlight and heat exposure, with the flatsawn samples all bark-side up. During the summer months the shade temperature will often rise to around 38°C, but on a sunny August day the roof temperature was measured at 72°C and the wooden samples 57°C using a Westward Infrared non-contact thermometer. The flatsawn samples had been in this outdoor exposure for 22 months prior to the start of the experiment and the quartersawn samples 12 months to ensure that the water repellent system was durable. During the approximately 10 weeks that this exposure study was conducted, from the end of July to the beginning of September when the Mississippi temperatures are the highest, the samples were periodically weighed before predicted rain, right after and then one or two days later. One unusually heavy storm with 8 cm of rain over 12 hours occurred during this period as the remnants of a hurricane came through, but most storms were less then 1 hour with 1 to 3 cm of rain, with a few light sprinkles also occurring. The extent of checking was measured at the end of the experiment on the flatsawn samples using a scale of 0 to 4, where a "0" is no checking, "1" light checking, up to a "4" where the checking was so bad that the board could be bent by hand. The quartersawn samples were also inspected for checking, but as the splits often occurred in the laminated joint the extent of cupping was measured instead.

RESULTS AND DISCUSSION

Moisture Content Variation

The average moisture content (MC) over time of the flatsawn test boards during the study period is shown in Figure 1. Considerable variation in the MC change among individual untreated sapwood samples was observed. For example, for the last rain in this study the MC gain for the control boards ranged from a low of 22.3 to a high of 42.0%, with an average of 30.9% We expected the wide variability based on our prior studies on the inherent permeability and hydrophobic extractive variations in southern

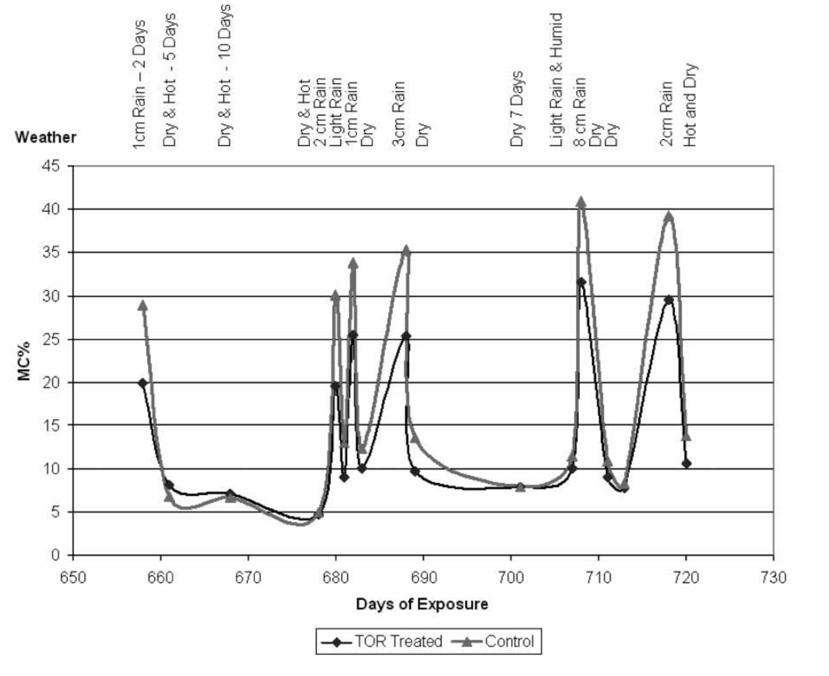

Figure 1. Average moisture content over the period of study for the matched flatsawn decking samples that were untreated or treated with 3% tall oil rosin (TOR) in response to the weather conditions that are indicated on the top of the graph.

pine sapwood.[7,13] These large and rapid MC changes in the untreated decking lead to stresses and subsequent poor dimensional stability. For example, starting at about 680 days of exposure three short-duration rains occurred over an eight-day period causing rapid increases in the MC of the untreated samples followed by rapid drying, which would led to multiple and rapid swelling and shrinking cycles. Interestingly, the average MC of the untreated decking following rain was not highly dependent on the amount of rain, with average MCs after rain ranging from approximately 30% to 40% after summer rains of 1 to 3 cm, and an average MC of only 41% measured after an unusual eight cm of rain over 12 hours. During a prolonged period of hot and dry weather the MC dropped to as low as 4% MC.

When comparing the average MC of the TOR- versus untreated samples, it can be seen from Figure 1 that the treated boards gained less moisture following rain but then dried to about the same MC as the untreated boards within only a few summer days. Thus, we conclude that the TOR treatment did impart some water repellency to the decking. For days 718 to 720, the average MC gain for the untreated flatsawn samples (26.1%) was significantly different than the TOR samples (18.9%) (p-value = .0016). Furthermore, because these samples had been in outdoor exposure for almost two years prior to the start of this study, it appears that the TOR treatment is effective over long periods.

The average MC of the quartersawn samples is shown in Figure 2, with a similar pattern as observed in Figure 1. Both sets equilibrated to similarly low MCs with both treated and untreated samples; however, untreated and TOR-treated quartersawn samples attained a higher MC than the flatsawn samples after the same rain exposure. In comparing the MC of the untreated, TOR-treated, and wax-treated quartersawn boards, it is apparent that the paraffin wax provides extremely good water repellency, as expected. The amount of wax employed in this study was much greater than that used in commercially treated water-repellent decking. While the TOR treatment was not as effective as the wax it did reduce the amount of moisture gained by rain by about one-third, as was also observed in the flatsawn decking. For days 423 to 425, the average MC gain for the three treatments were significantly different (p-value = $<$.0001), with untreated quartersawn samples having an average MC gain of 33.4%, TOR samples 26.2%, and paraffin wax samples 5.2%.

Dimensional Stability

As discussed earlier, the reduction in MC gained by the TOR-treated flatsawn samples following rain was about one-third relative to the untreated controls. The average checking for the flatsawn control samples was 3.2, with one sample having a low "1" while seven of the 12 controls had the severest "4" ranking. This was significantly greater than the TOR-treated flatsawn samples that had an average 2.1 ranking, which ranged from three "1's"

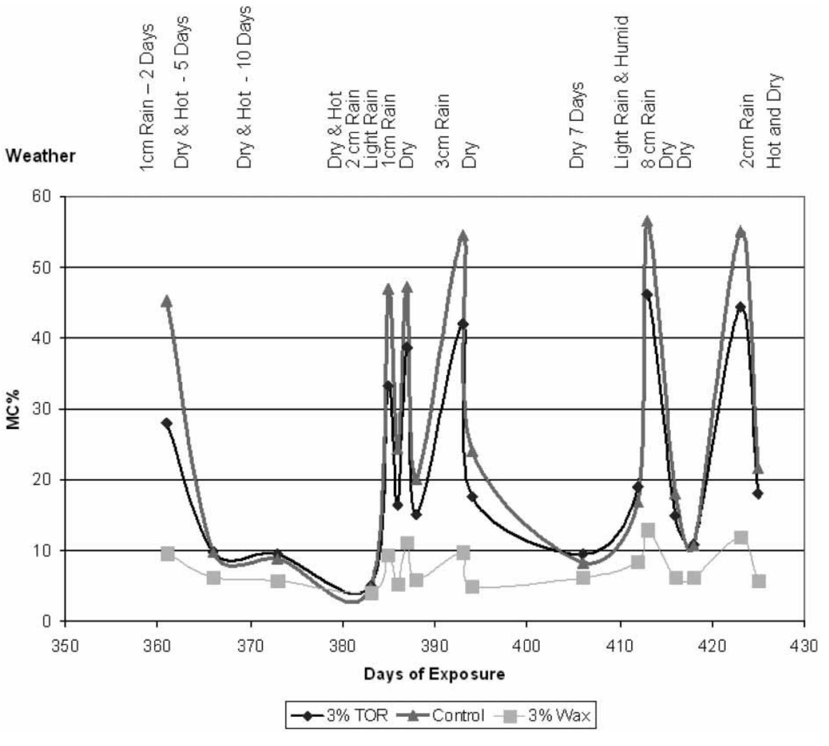

Figure 2. Average moisture content over the period of study for the matched quartersawn decking samples that were untreated, treated with 3% tall oil rosin (TOR), and treated with 3% wax in response to the weather conditions that are indicated on the top of the graph.

(light checking) to four samples with moderately severe "3" rankings (p-value = .01). A regression model was fitted for the two flatsawn treatments with MC gain as the independent variable and the average checking rating as the dependent variable. For the untreated flatsawn samples, the change in MC explained 40% of the variability in the splitting rating ($R^2 = 0.4$). For the TOR-treated samples, the change in moisture content explained 50% of the variability in the splitting rating ($R^2 = 0.5$). For the quartersawn treatments, the paraffin wax treatment had significantly less cupping (1.3 mm) than the untreated (4.2 mm) and TOR-treated (3.4 mm) samples (p-value = $<.0001$).

Although not a study objective, 5 of the 12 control quartersawn samples had fungal decay at the end of the study. The samples with decay all had higher MCs following rain than the average overall MC of the untreated boards. The higher MC is likely due to a lower level of hydrophobic extractives (resin acids, fatty acids, and monoterpenes)[7,13] in the decayed untreated sapwood samples compared to the non-decayed controls. Furthermore, as resin acids are known metal complexing agents and, thus, would provide some decay resistance to wood,[6,12] a relatively low level of resin acids may result in sapwood being more susceptible to decay. We therefore suspect that the five samples with decay have relatively low inherent levels of resin acids, and are currently studying the effect of both natural and added resin acids on the decay resistance of pine sapwood.

Based on this study, it may be possible to employ renewable and economical resin acids to enhance the dimensional stability of lumber. Furthermore, if naturally present resin acids are found to enhance the dimensional stability and decay resistance, it may be possible to genetically select trees to provide lumber with these desirable properties.[14]

CONCLUSIONS

Flatsawn and quartersawn southern pine sapwood decking samples treated with a low-cost waterborne resin acid system and exposed to a harsh above-ground environment for up to two years had enhanced water repellency compared to the untreated samples. A wide variation in moisture gained after a rain was observed for the untreated flatsawn decking, which was significantly and positively correlated to the extent of splitting. Although the amount of water gained was only reduced by about one-third for the TOR-treated boards compared to the untreated boards, this significantly lowered the splitting and cupping. We are continuing these studies and plan to report in the near future on the possible enhanced fungal protection obtained by resin acids alone or combined with organic biocides.

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