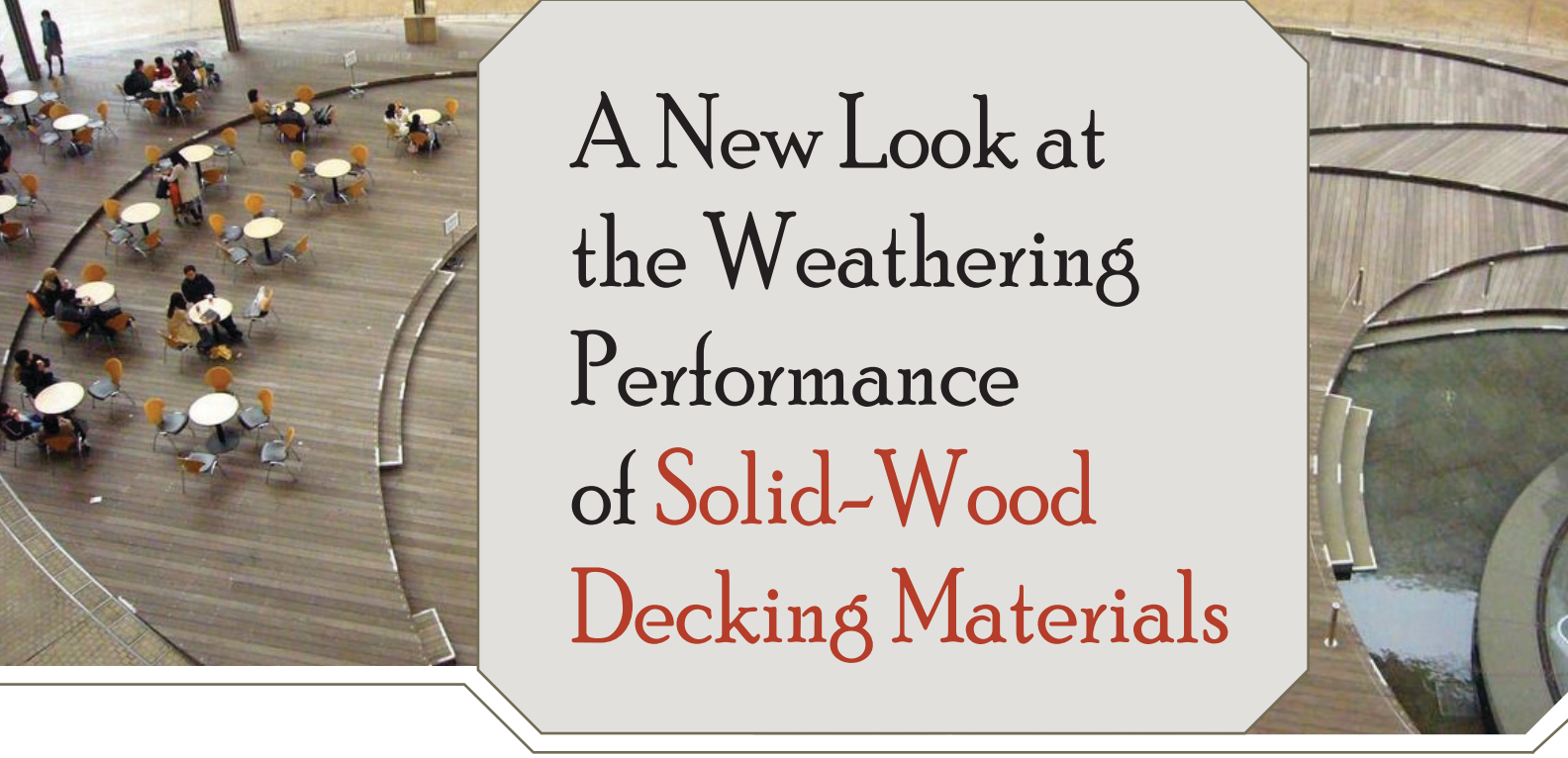

A New Look at the Weathering Performance of Solid-Wood Decking Materials

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Public awareness of resource scarcity and environmental protection has steadily increased during the past three decades. This awareness has been heightened by the public debate of issues such as global climate change, the impending end of the petroleum era, and the responsible management of old growth/native forest ecosystems. Heightened environmental responsibility has also been driving consumer preferences for building products that present a smaller ecological footprint. One material that has the potential to meet the demand for green building products is plantation-grown timber. This material is near carbon-neutral, is easily machined, and has aesthetic appeal.[1-3] However, one of the greatest drawbacks associated with wood is poor resistance to weathering when exposed outdoors. Wood is inherently sensitive to ultraviolet light and wet/dry cycling, and the much higher proportions of juvenile wood in the plantation resource exacerbates these problems.[4-5]

The chemical and anatomical changes that occur within wood exposed to ultraviolet light have been studied extensively.[4] Models indicate that the destruction of wood polymers is driven primarily by self-sustaining free radical reactions, leading to the preferential depolymerization of lignin, leaving behind a weak, disorganized surface of cellulose fibers, appearing white to gray in color.[6-8] Further, it is believed that the destabilization of the wood surface along with moisture cycling leads to the development of checks that mar the surface and create avenues for moisture collection and microbial growth.[5,9,10]

Controlling the undesirable consequences of exterior exposure has been extensively studied, yet few promising treatments that do not negatively alter the natural aesthetic appeal of the material have been forthcoming. One promising process developed during the 1970s was chromic acid treatment.[4,11] This treatment resulted in a very stable, albeit green-tinted surface.[12] However, concerns

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over the use of hexavalent chromium make this treatment impractical. Other treatments that have shown some promise include iron oxide-based chemistries and the grafting of UV absorbers onto the wood surface.[13,14] None of these methods completely prevents the degradation of both the lignin and the cellulose polymers.[15] Thus, if wood is to play a role in exterior applications, other treatments must be developed. The objective of this study was to evaluate the effects of selected water repellents and UV inhibitors on resistance of wood to exterior exposure in order to gain a basic understanding of how the properties of these treatments affect the weathering characteristics of wood.

METHODS

Water repellents, pigments, and organic UV-light inhibitors were chosen as the three major classes of compounds for this investigation. In an effort to examine some of the many variables within each group, a number of compounds with specific attributes of interest were chosen (*Table* 1). Clear, flat sawn southern yellow pine sapwood samples (10 mm thick, 85 mm wide, and 155 mm long) were prepared from nominal 1" x 4" stock. Two matched samples from each parent board were assigned to be treated with each compound of interest. This allowed for comparisons between chemical treatments across the natural range of wood characteristics. Stable treating solutions were formulated at the concentrations found in *Table* 1. The wood samples were weighed prior to being impregnated using a uniform vacuum/pressure cycle (*Table* 2). After treatment, the samples were weighed to determine chemical uptake and then reconditioned to a moisture content of 9% using a climate chamber set at 25°C and 50% relative humidity. The samples were end-sealed using a marine epoxy resin. Baseline colorimeter measurements were made on the exposed face using a Konica Minolta Chroma Meter and a jig to center the colorimeter over the samples.

Table 2—Vacuum and Pressure Conditions Used to Impregnate Southern Yellow Pine Sapwood with Various Compounds

Cycle	Time (min)	Pressure/ Vacuum
Initial vacuum	5	25 mmHg
Pressure	10	150 psi
Final vacuum	5	25 mmHg

Table 1—Compounds Used to Reduce the Effects of Weathering, the Reason for Inclusion, and Concentrations Used

Class	Compound	Purpose	Application Concentration (ppm)
Pigment	Red iron oxide suspension with a particle size of 700 nm	Baseline for particle size and crystal shape comparison	1000
Pigment	Red iron oxide suspension with a particle size of 190 nm	Particle size on surface discoloration	1000
Pigment	Yellow iron oxide suspension with a particle size of 190 nm	Crystal shape on surface discoloration	1000
Pigment	Titanium dioxide with a particle size of 130 nm	Compound and particle size on discoloration	1000
Pigment	Titanium dioxide suspension with a particle size of 195 nm	Compound and particle size on discoloration	1000
UV stabilizer	Hydroxyphenylbenzotriazole class	UV absorber	1000
UV stabilizer	Hindered amine light stabilizer (HAL)	Free radical scavenger	1000
Water repellent	Oil in water emulsion with a wax melt point of 34–38°C	Melt point and wax on water repellency	2000
Water repellent	Oil in water emulsion with a wax melt point of 54–58°C	Melt point and wax on water repellency	2000
Water repellent	Oil in water emulsion with a wax melt point of 65.5–75°C	Melt point and wax on water repellency	2000
Water repellent	Silicate with a particle size of 8–20 nm	Particle size and silicates on water repellency	1000
Water repellent	Silicate with a particle size of 20–100 nm	Particle size and silicates on water repellency	1000
Water repellent	Water dispersed acrylic polymer	Control water ingress by binding to the surface of the wood	4000
Biocide	DCOIT	Known to control mold and prevent biological discoloration	1000
Positive control	Chromic acid	Known to control surface discoloration	30000
Negative controls	Untreated	Baseline for checking and discoloration	NA

Figure 1—Samples mounted on 45° racks and pointed due south in Klamath Falls, Oregon, prior to the installation of the sprinkler heads.

Exterior Exposure

The samples were mounted on aluminum supports with the growth rings oriented concave face upwards. Each sample was secured to the rack by placing one 4.5 mm diameter screw into each corner of the sample. This limited cupping and warping, forcing stress relief to occur through check development.

Sixteen samples per treatment were exposed in the eastern Oregon high-elevation desert, at a site near Klamath Falls (Lat: 42.22, Long: –121.78, elevation of 1250 m) on racks pitched at 45° pointing due south (*Figure* 1). Solar irradiation data was collected daily from an AgriMet weather station operated by the Bureau of Reclamation located at the site. Natural precipitation was augmented with non-chlorinated irrigation water between August and the end of October by spraying the samples for 15 min per day at sunrise using sprinklers mounted to the upper edge of the racks. Approximately 0.668 m^3 of water was delivered to the samples per day. Two samples per treatment were harvested at the end of each 454 Mj/m^2 irradiation interval. This irradiation interval corresponded to the maximum amount of solar energy that the site received in the two weeks surrounding the summer solstice. One other set of samples was exposed to tropical conditions in Hilo, Hawaii (Lat: 19.72, Long: –155.07, elevation of 20 m). While the samples were exposed in the same manner, irradiation

Table 3—Irradiation Dose, Number of Days in the Field, and Climatic Conditions Experienced by Each Sample Set

Irradiation Period	Irradiation Dose (Mj/m^2)	Time in the Field (days)	Total Amount of Surface Wetting ($/m^2$)	Average Relative Humidity (%)
1	486.80	19	4.52	52.10
2	939.38	42	10.0	50.02
3	1363.52	78	17.18	57.64

Figure 2—Progression of checking and discoloration within southern pine samples exposed to 0, 486.8, 939.4, and 1363 Mj/m^2 of irradiation (left to right), respectively.

data was not available for this location. The Hilo samples were only exposed to natural precipitation; however, the site receives almost 2 m of rainfall per year. All of the Hilo samples were harvested after a six month exposure spanning from July 24 to January 23.

The harvested samples were reconditioned to a moisture content of 9% in a dark climate chamber. The conditioned samples were then scanned using a 600 dpi Canon color scanner. Each image was then stored as a .jpg file and the checking characteristics of the samples were analyzed using a custom software package developed by the University of British Columbia and updated by Mississippi State University.[16,17] Colorimeter measurements were taken using the Konica Minolta Chroma Meter and the results were compared with the baseline measurements made prior to exposure.

RESULTS AND DISCUSSION

Irradiation doses for all of the samples were centered on the targeted values, yet the length of time required to achieve the desired irradiation at the Oregon site increased with time due to the onset of winter *(Table* 3). Surface discoloration at the Oregon site occurred rapidly as predicted by Evans et al.,[18] while the low relative humidity (*Table* 3) kept biological discoloration of the surfaces to a minimum. The low relative humidity combined with the daily water sprays allowed for the rapid development of checks in all of the materials. Checks were predominately found in the latewood bands (*Figure* 2) and their number generally increased over time, while check length and width remained uniform. This may be explained by the greater stiffness of cell walls in the latewood portion of the growth ring, when compared to the thinner cell walls in the earlywood.

Checking and total color change results were analyzed by treatment class. Pigments provided the greatest fade resistance, while samples treated with either water repellents or UV stabilizers checked the least. The organic biocide (DCOIT) provided little or no protec-

Figure 3—Effects of pigments on total color change through time for southern pine samples exposed to sunlight. Untreated and samples treated with 3% chromic acid are included as negative and positive controls.

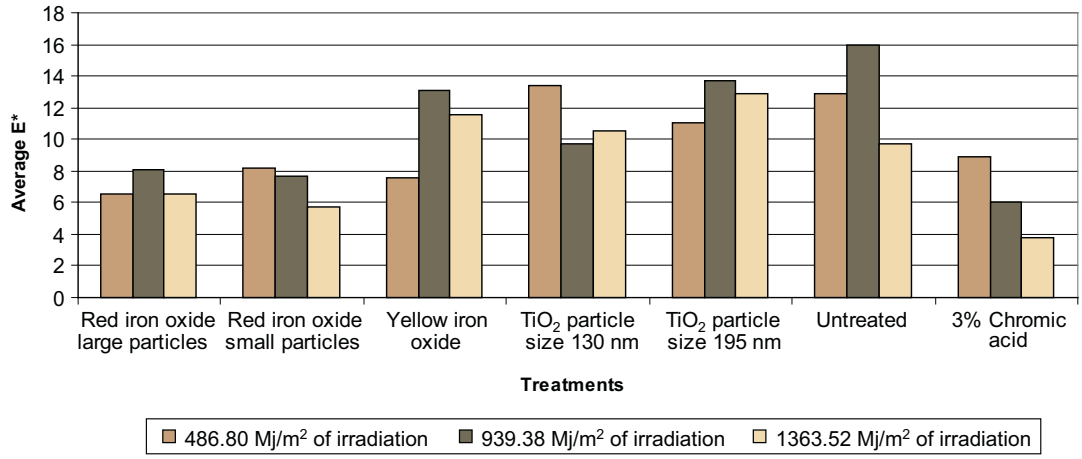


Figure 4—Effect of UV stabilization on total color change through time for southern pine sapwood exposed to sunlight. Untreated and samples treated with 3% chromic acid were included as negative and positive controls.

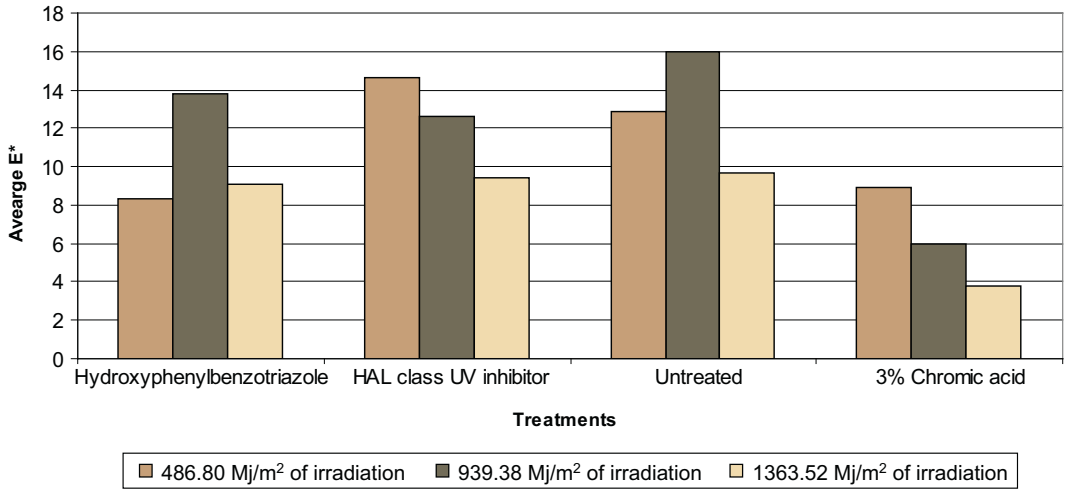


Figure 5—Effect of water repellent treatment on average number of checks through time on pine sapwood samples in an exterior exposure. Untreated and samples treated with 3% chromic acid were included as negative and positive controls, respectively.

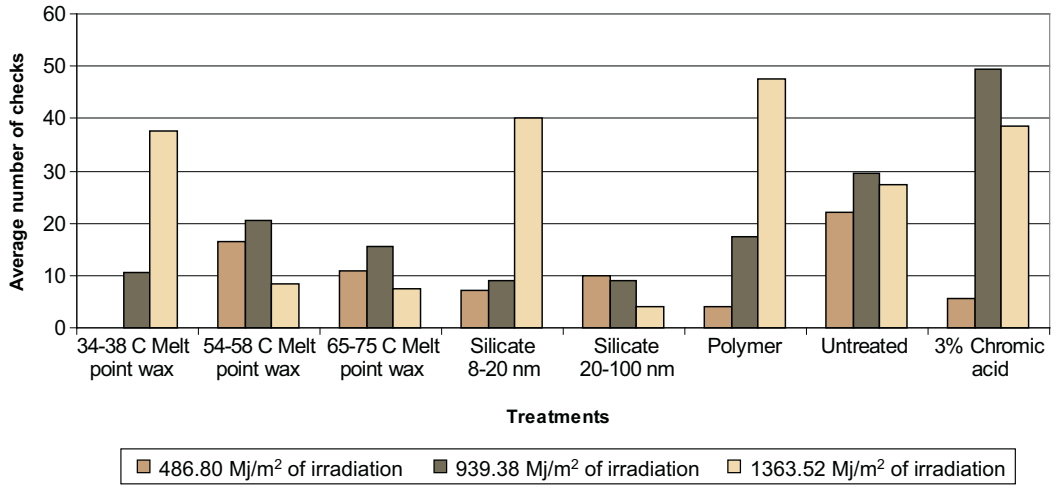
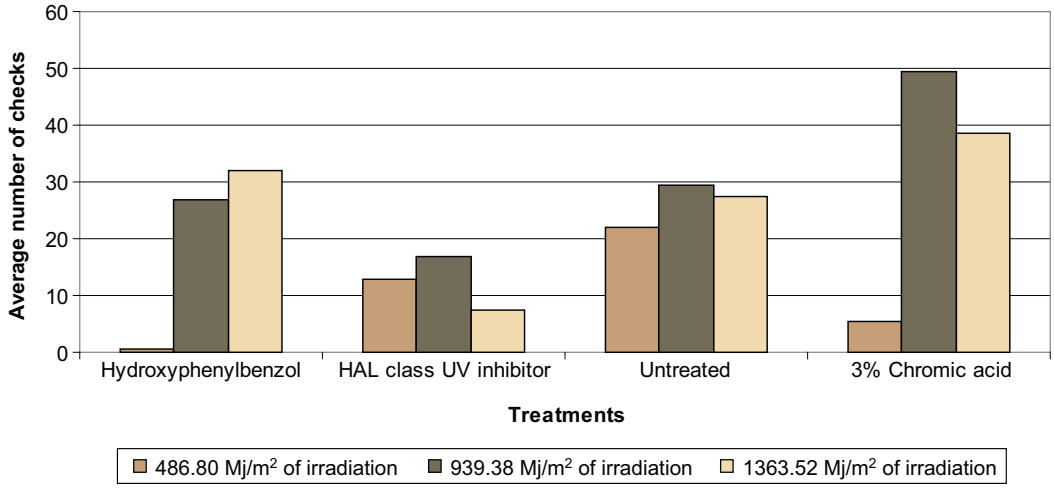


Figure 6—Effect of UV stabilization treatments on average number of checks through time on pine sapwood samples in an exterior exposure. Untreated and samples treated with 3% chromic acid were included as negative and positive controls, respectively.



tion against abiotic color change or checking; however, preliminary data from the samples exposed in Hawaii indicates that a biocide is essential for preventing significant biological discoloration.

The effects of each class of compounds were evaluated to gain an understanding of how the selected properties affected weathering. Samples treated with red iron oxide pigments experienced the least amount of color change within the pigments group (*Figure* 3). The results suggest that crystal shape plays an important role in preventing sun energy from reaching the wood surface. Particle size also appeared to play a role in preventing discoloration, perhaps because of preferential loading of larger particle size materials on the wood surface where the compound is needed. The larger particle size materials protected the substrate from a broader portion of the solar spectrum, thus reducing the amount of free radical reactions that can occur. Water repellents did not significantly affect color change, even though some protection would be expected from the silicate particles. It is likely that the silicate particles were too small to block a significant portion of the solar spectrum. The performance of UV absorbers indicates that it might be more fruitful to prevent solar energy from reaching the wood surface than to remediate the free radicals that are produced by

Figure 7—Effect of treatment on average check length for pine samples exposed to three levels of UV radiation.

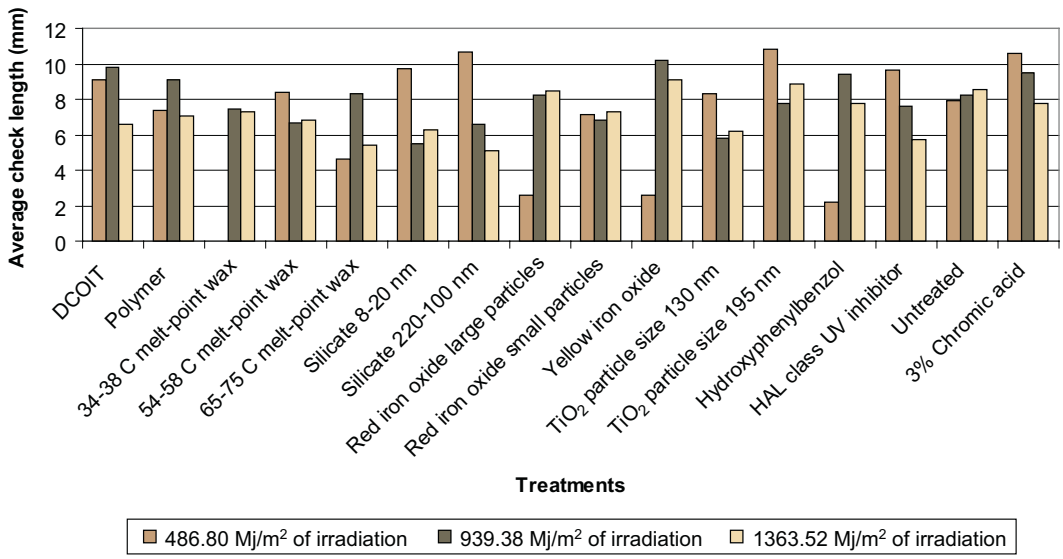
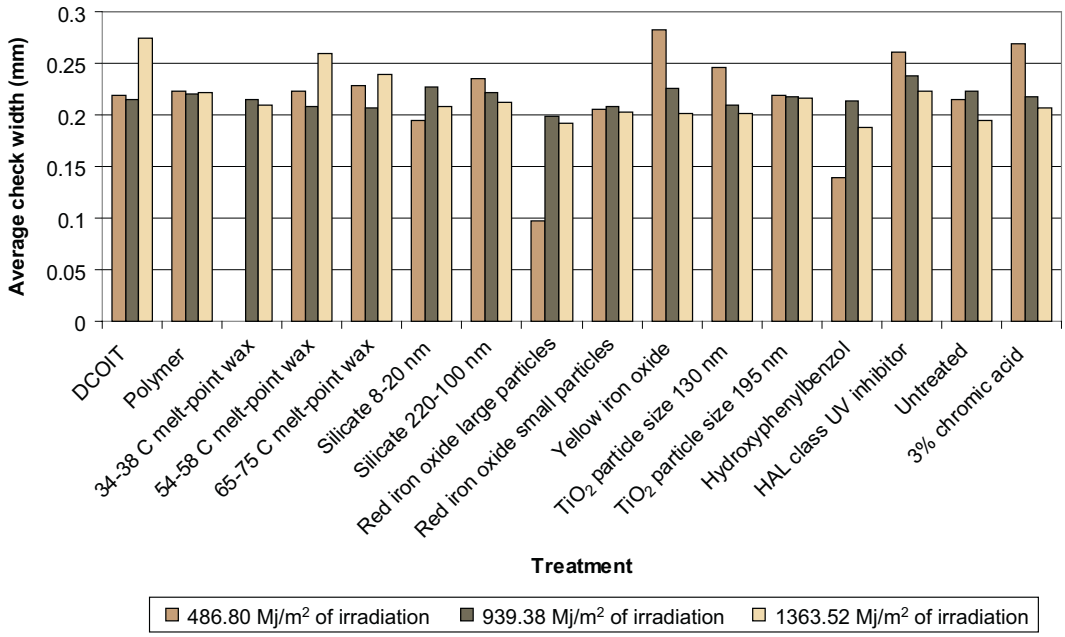


Figure 8—Effect of treatment on average check length for pine sapwood samples exposed to three levels of UV radiation.



it. This can be deduced from the data showing that hydroxyphenylbenzotriazole compounds imparted more protection than hindered amine light stabilizers (HALs) compounds (*Figure* 4).

Color change and checking were not strongly correlated during the first three sampling periods, suggesting that checking was controlled primarily by water ingress and moisture cycling rather than by surface weakening as a result of free radical reactions initiated by energy from UV light. Thus, water repellents had the greatest influence on checking.

Silicate water repellents produced a more hydrophobic surface than the wax-based systems (*Figure* 5). Yet within the silicates, particle size had little effect on overall performance. The melt point of the wax-based water repellents also affected performance. Initially, the low melt-point wax offered better protection against checking than the higher melt-point material, presumably because it melted and spread more evenly over the surface during conditioning. However, samples treated with the lower melt-point wax experienced more checking than those with higher melt-point waxes with continued exposure. Increased checking may be caused by the continued absorption of the low melt-point wax into the wood, moving it way from the surface where it is needed. Alternatively, the lower melting point may have been more sensitive to UV degradation. A linear progression in the number of checks over time was also detected within the samples treated with 4000 ppm of acrylic polymer. This treatment significantly reduced checking early in the exposure period, but then the number of checks increased rapidly, indicating that the material had broken down after exposure to sunlight or that it had been removed from the surface through water ingress. UV stabilizers did not greatly influence color change, but did limit checking, especially the HAL class of UV stabilizers. This may be caused by their oilborne nature, which would act as a water repellent.

Average check width and length were also investigated to measure differences between treatment effectiveness. However, neither check width nor length varied significantly after the first irradiation period, nor were there significant changes between treatments over time (*Figures* 7 and 8). The absence of effect may be due to the reconditioning process that is undertaken after the samples have been returned from the field.

CONCLUSION

While none of the treatments completely prevented discoloration or checking, some markedly reduced susceptibility to this damage. Pigments provided better fade resistance than the other treatments investigated while silicates produced the most hydrophilic surfaces. This increased hydrophobicity was associated with reduced checking. The results also highlighted the importance of individual properties within a group of treatments. This was most clearly illustrated with the

various iron oxide and wax water repellent treatments. Individual properties such as particle size and shape for the iron oxides or the wax melt point had dramatic effects on treatments performance. While no individual treatment provided complete protection, the results suggest that incorporation of carefully selected components can impart reasonable degrees of surface protection to wood. CT

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