Aboveground Field Performance of Douglas-Fir Heartwood Subjected to Combinations of Glycerol, Boron, and Thermal Modification

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Abstract

The effect of pretreatment with either boron or glycerol followed by thermal modification on the durability of Douglas-fir heartwood was evaluated in an American Wood Protection Association ground proximity test in Hilo, Hawaii. Non–thermally modified samples were generally more heavily decayed than any of the modified woods, but there was no consistent effect of different thermal modification conditions on decay resistance. Thermally modified woods tended to perform better than untreated timbers but not as well as copper azole–treated Douglas-fir heartwood lumber in test at the same site. The results are discussed in relation to how the extreme site conditions might have made it difficult for thermally modified materials to perform.

Thermal modification is a long-established method for altering the resistance of timber to moisture uptake, thereby resulting in conditions that are presumably less conducive to fungal attack (Esteves and Pereira 2009).Thermal modification has been especially popular in Europe due to changing regulations related to traditional preservative-treated wood, and the cooler climatic conditions allow it to perform in uses such as cladding and decking wood. Elsewhere, the performance of thermally modified timbers has been more variable (Kamdem et al. 2002, Militz 2002, Vidrine et al. 2007, Korkut et al. 2008), but there have been relatively few field performance tests outside of Europe, especially under the more severe conditions present in subtropical or tropical environments.

As a part of a larger project to examine the potential for thermal modification to improve the heartwood durability of Douglas-fir from moderate to highly durable, a series of trials were established to examine the effects of thermal modification with varying times/temperatures or coupled with pretreatment with either disodium octaborate tetrahydrate (DOT) or glycerol on various wood properties (Yan and Morrell 2015, Conroy et al. 2019). Previous reports have described the effects of these processes on flexural properties, color, and laboratory mold/decay resistance (Yan and Morrell 2014, 2019). While laboratory trials suggested that the thermal modification processes did not markedly enhance decay resistance (Yan and Morrell 2015), field trials of the same material were also established at a test site near Hilo, Hawaii. This report describes the results of those studies after 57 months of exposure.

Materials and Methods

The full processes of thermal modification have been previously described elsewhere (Yan and Morrell 2014, 2015, 2019), but briefly Douglas-fir (*Psuedotsuga menziesii* (Mirb) Franco) heartwood lumber was cut into 300 blocks, 19 mm thick by 75 mm wide by 100 mm long, that were segregated into groups of 10 for treatment. Ten groups received no pretreatment, 10 groups were dipped in 10 percent DOT to produce an average loading of 0.556 percent (wt/wt) boric acid equivalent basis (pH = 8.3), and 10

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groups were vacuum treated with 20 percent glycerol (20 min of vacuum at 800 Pa). Boron was evaluated for its potential to provide supplemental insect and fungal resistance to the thermally modified woods, while glycerol was evaluated for its ability to accelerate the thermal modification process.

The boron-treated blocks were stored wet for 28 days at 5°C under nondrying conditions to allow the boron to become more evenly distributed in the wood. The samples were air-dried and then finally oven-dried (65°C). Glycerol-treated blocks were weighed after treatment to determine uptake (average glycerol uptake was 147% by weight) before being allowed to air-dry.

The wood in a given pretreatment group was then wrapped in foil to limit oxygen access before being subjected to heating to 160°C, 180°C, or 200°C for 2, 4, or 6 hours. One set of each pretreatment group received no thermal treatment. The samples were weighed after treatment to determine the effects of the various heating regimes on mass loss.

The samples were tagged and then placed on concrete blocks approximately 50 mm off the ground, and the blocks were covered with a permeable shade cloth that permitted moisture entry but limited ultraviolet light exposure as well as drying. The procedures followed those described in Standard E18 of the American Wood Protection Association (2017). The samples were periodically evaluated for degree of fungal decay on a scale from 10 (no decay) to 0 (complete failure) over a 57-month exposure period. The field site receives approximately 5 me of rainfall per year and has daily high temperatures ranging between 23°C and 30°C. The aboveground decay risk at the site is classified as extreme (>200) using the Scheffer Climate Index (Scheffer 1971).

Results and Discussion

There was little evidence of visible decay for the first 24 months of the test (Table 1). This likely reflects the moderate durability of Douglas-fir heartwood (Scheffer and Morrell 1998). Visible decay was detected on an increasing number of samples after 30 months of exposure, but the average ratings for all treatments, including the nontreated controls, were above 9.0. Sample condition continued to decline after 40 months. Standard E18 notes that a rating of 7.0 reflects the presence of advanced decay but considers the sample as still serviceable. For the purposes of our tests, we will consider this level as representing acceptable performance. Only two treatments had averages below 7.0 after 40 months of exposure, and both of these received a boron pretreatment (4 h at 160°C or 180°C). While boron is an excellent fungicide, it is also mobile and likely to be highly susceptible to leaching under the conditions present in the ground proximity test, especially at this site (Carr 1959). All the remaining samples were still serviceable, although only three treatments were still rated as 10 (glycerol at 200°C for 6 h and no pretreatment for 2 h at 180 or 6 h at 200°C). There were no discernible performance patterns in terms of pretreatment, modification temperature, or treatment time.

Average sample condition declined precipitously between 40 and 57 months of exposure. Control samples with no pretreatment or thermal modification had average ratings of 2.8 or less, indicating that they were no longer serviceable. Eleven of the 30 treatments had ratings between 5 and 7, suggesting the presence of advanced decay but not imminent failure, while the remaining samples were much more heavily degraded. The visible decay was entirely brown rot, which is a common failure mode for softwoods at the site.

One interesting observation was that many of the heavily decayed samples had curled as they decayed (Fig. 1). This phenomenon was not apparent at the 40-month inspection but was common at 57 months. It is unclear why this deformation occurred. One possibility is that the heating induced internal stresses that were released once the wood had decayed to a specific point. This deformation would be a major issue in service, although it occurred only at the advanced stages of decay, where the fungal damage would be a much greater concern.

The high standard deviations within individual treatments and the fact that these ratings are discrete and not continuous make it difficult to draw definitive conclusions concerning treatment efficacy. In general, there were no consistent trends with regard to wood condition for the various thermal modification conditions, which was interesting because the earlier study suggested that the longest time at the highest temperature produced the best dimensional stability (Yan and Morrell 2014).

Averaging the 57-month ratings for each pretreatment group (including all three temperatures and treatment times) provides a rough method for comparing the effects of the three pretreatments on decay resistance. The average values ranged from 3.9 for the glycerol pretreatment to 4.9 for the samples with no pretreatment prior to thermal modification. The non–thermally modified controls averaged 2.0, 2.0 and 2.8 for the untreated controls, the boron pretreated samples, and the glycerol pretreated samples, respectively. Thus, most of the pretreatment/thermal modification systems were associated with improved performance. These results differed from laboratory decay tests using matching materials (Yan and Morrell 2015), suggesting that laboratory tests did not provide an accurate measure of potential decay resistance. However, it is important to note that this performance is relative. Douglas-fir lumber samples commercially treated with copper azole to the UC3 retention for aboveground applications and exposed at the site for 72 months at the same time were still rating as 9.9, illustrating the benefits of a heavy-duty wood preservative (Konkler et al., 2020. Thus, while the processes improved durability, the effect was less pronounced than would be found with more traditional protective approaches.

It is important to consider the performance of thermally modified materials in context with the exposure conditions. Thermal modification processes are presumed to alter the hemicelluloses and thereby reduce hygroscopicity (Militz 2002, Esteves and Pereira 2009, Pfriem et al. 2010). This premise works well when materials are exposed under conditions that allow for periodic drying between precipitation events. This approach is analogous to the role of water repellents in outdoor exposure; they slow but do not completely prevent water ingress. Moisture ingress is inevitable under the prolonged precipitation conditions present at the test site. The site conditions in Hilo present a starkly different environment with repeated showers each day, providing relatively little time for drying under the shade cloth covers. This negates any water-repellent effect. In addition, the samples are exposed directly on concrete blocks that act to trap water on the underside of the test specimens. This creates an extreme aboveground exposure

Table 1.—Effect of various thermal modification processes in combination with glycerol or boron pretreatment on performance in an American Wood Protection Association Standard E18 ground proximity test in Hilo, Hawaii.

Pretreatment	Temperature (°C)	Time (h)	Sample condition[a]						
			0 mo	6 mo	12 mo	24 mo	30 mo	40 mo	57 mo
Glycerol	160	2	10	10	10	9.71 (0.39)	9.93 (0.19)	7.86 (0.19)	1.71 (2.14)
		4	10	10	10	10.00	10.00	9.00 (1.73)	3.50 (4.40)
		6	10	10	10	9.75 (0.29)	9.88 (0.25)	8.25 (1.50)	3.60 (3.51)
	180	2	10	10	10	10.00	10.00	8.20 (1.10)	4.50 (3.83)
		4	10	10	10	9.67 (0.29)	10.00	9.67 (0.58)	5.57 (2.07)
		6	10	10	10	10.00	10.00	8.20 (1.64)	2.50 (2.95)
	200	2	10	10	10	10.00	10.00	7.67 (1.15)	5.67 (3.72)
		4	10	10	10	10.00	10.00	8.00 (1.15)	3.22 (4.09)
		6	10	10	10	10.00	10.00	10.00	5.00 (3.74)
Boron	160	2	10	10	10	10.00	10.00	8.50 (1.00)	5.83 (2.86)
		4	10	10	10	9.75 (0.50)	9.83 (0.25)	5.75 (3.95)	2.29 (3.95)
		6	10	10	10	10.00	9.67 (0.52)	8.83 (1.7)	4.11 (3.66)
	180	2	10	10	10	9.80 (0.27)	9.60 (0.42)	7.80 (1.10)	4.50 (3.83)
		4	10	10	10	9.88 (0.25)	9.88 (0.25)	5.25 (4.27)	1.83 (2.99)
		6	10	10	10	10.00	9.80 (0.45)	9.60 (0.55)	3.67 (3.14)
	200	2	10	10	10	10.00	9.60 (0.42)	7.60 (7.60)	4.20 (4.38)
		4	10	10	10	10.00	9.67 (0.29)	8.67 (1.53)	3.14 (3.18)
		6	10	10	10	10.00	10.00	9.25 (1.50)	6.50 (2.83)
None	160	2	10	10	10	10.00	9.75 (0.29)	7.67 (1.15)	2.60 (3.97)
		4	10	10	10	10.00	9.88 (0.25)	7.67 (3.21)	2.33 (3.61)
		6	10	10	10	10.00	10.00	8.67 (8.67)	4.17 (4.17)
	180	2	10	10	10	10.00	10.00	10.00	5.38 (4.00)
		4	10	10	10	10.00	10.00	8.67 (1.53)	5.40 (3.51)
		6	10	10	10	10.00	10.00	9.00 (1.41)	5.57 (4.28)
	200	2	10	10	10	10.00	10.00	7.80 (1.10)	5.75 (3.65)
		4	10	10	10	10.00	10.00	8.67 (1.53)	5.83 (4.62)
		6	10	10	10	10.00	9.88 (0.25)	10.00	6.60 (3.91)
None	—	—	10	10	10	10.00	9.67 (0.58)	8.00 (1.15)	2.00 (2.31)
Boron	—	—	10	10	10	10.00	9.38 (0.8)	—	2.00 (2.31)
Glycerol	—	—	10	10	10	9.70 (0.45)	9.90 (0.22)	6.80 (1.79)	2.83 (3.60)

[a] Values represent means of 10 samples per treatment while figures in parentheses represent one standard deviation.

Figure 1.—Example of a thermally modified sample of Douglas-fir showing extensive curvature after 57 months of exposure in a ground proximity test in Hilo, Hawaii.

(Singh and Page 2020). Since thermal modification does not render the wood toxic to decay organisms, they can attack the wood once moisture conditions are suitable. The test results suggest that thermal modification slowed but could not completely protect the wood from moisture ingress and subsequent fungal attack under these more extreme conditions. Thus, these products might be best used in applications that are wetted but that are then allowed to dry, such as exterior cladding (siding) in more temperate climates.

Conclusions

Thermal modification alone or with a boron or glycerol pretreatment provided some protection to Douglas-fir heartwood in a ground proximity test, but the protection was less effective than a traditional preservative treatment. There were no consistent trends in improved durability with thermal modification temperature or time, suggesting that the lowest time/temperature treatment (2 h at 160°C) would be most preferable in terms of both cost and potential effects on other wood properties, although that treatment also produced the least improvement in dimensional stability.

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