

Effects of Postlayup Borate Treatment on Appearance and Flexural Properties of Douglas-Fir Glued Laminated Beams

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Abstract

Preservative treatments are required whenever glued laminated beams are exposed outdoors. Treatments can be either water-based systems applied to individual laminations prior to layup or organic solvent-borne systems applied after the beams are fabricated. Water-based systems are not recommended for posttreatment because of concerns over checking and the potential for reductions in flexural properties, but there are few data on the effects of these treatments. The effects of pressure treatment with disodium octaborate tetrahydrate (boron) on flexural properties, glue-line shear, and visual appearance were investigated using Douglas-fir (*Pseudotsuga menziesii*) glued laminated beams. While treatment did result in the presence of drying checks on some beams, boron treatment followed by air seasoning or mild kiln drying did not produce any significant effects on modulus of rupture, modulus of elasticity, or glue-line shear. The results indicate that boron treatment does not affect load-bearing properties.

Glued laminated beams are widely used in a diverse array of residential and industrial applications where long, clear spans are required. These materials are typically used under dry conditions with little risk of biological deterioration, but they can be subjected to wetting under some applications or they may be used where there is a risk of termite attack. As a result, some local building codes require preservative treatments for laminated timbers because of the risk of insect attack, particularly termites. For example, the building codes for the City of Honolulu, Hawaii, require that all structural members in a building be preservative treated because of the extreme risk of attack by the Formosan termite (*Coptotermes formosanus*; Anonymous 2009).

The current American Wood Protection Association (AWPA) standards specify two approaches to preservative treatment of laminated material. The lumber used in the laminations can be treated and dried prior to lamination, or the finished beams can be pressure treated after layup. Pretreatment of laminations is typically used for waterborne treatment of southern pine, but it is less suitable for Douglas-fir because the material must be planed between treatment and lamination, and this process removes a substantial proportion of the treated zone. Beams of any species can be treated after lamination, but these processes have typically been limited to solvent-based preservatives because of concerns about potential for water-based treatments to cause excessive checking and delamination. Despite these concerns, a number of wood treating facilities along the West Coast of the United States currently treat laminated beams with water-

based systems, and the purchasers accept the risk of checking. APA—The Engineered Wood Association does not recommend waterborne treatments for glued laminated beams because of the risk of reducing properties due to both the potential interactions between the wood and the treatment chemicals as well as the potential for additional checking during drying (Anonymous 2006).

Previous flexural tests of laminated beams treated with ammoniacal copper zinc arsenate (ACZA) showed that treatment produced no significant negative effects on flexural properties or on glue-line shear strength, although the process was associated with some checking damage (Vaughn and Morrell 2012). While ACZA is an excellent preservative, some users object to the greenish color and, instead, specify borates for treatment.

Borates have a long history of successful use in Europe and Australasia both as an initial and remedial treatment. Borates are especially attractive for treating laminated beams because they impart little or no color to the finished product, and the dried, treated surface can be easily painted or coated. Borate treatment will, however, result in increases

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in postfabrication moisture content that can lead to surface checking as the beams recondition to a stable moisture content. Borates are also only suitable where the wood is continually protected from wetting, limiting the product to interior applications where insects pose the primary risk of damage. While borates have a well-known negative effect on veneer bonding (Kreber et al. 1993), their potential effects on the properties of fabricated beams were not known. The objective of this research was to determine the effects of postlayup pressure treatment with borates on the flexural properties of glued laminated beams as well as the effects of treatment on glue-line shear strength.

Materials and Methods

Twenty-eight Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) glued laminated beams (175 mm wide by 150 mm deep by 9.3 m long) were fabricated with a resorcinol resin according to APA EWS (Engineered Wood Systems) Y117 (Anonymous 2010). The beams were ripped longitudinally to create two sets of beams (78 mm wide by 150 mm deep and 87.5 mm wide by 150 mm deep). The faces exposed by ripping were not further processed. The beams were then cut into three equal 2.1-m lengths, and each section was numbered for later identification. One section of each dimension from an original beam was then allocated to one of three treatment groups. One group was left untreated and was stored under cover until flexural testing began, while the other two groups were pressure treated with 10 percent solution of sodium octaborate tetrahydrate (boron oxide basis) using a 30-minute initial vacuum followed by a 15-minute pressure period at 1 MPa. Although the AWWA standards require incising of glue laminated Douglas-fir prior to treatment, the beams were not incised since most architects waive this requirement because of concerns over appearance (AWPA 2009a). The target retention was 6.72 kg/m³ (as boron oxide) in the 0- to 15-mm assay zone.

One treated beam of each dimension from the original section was then set aside and allowed to air dry, while the other treated sections were kiln dried to a target moisture content of 17 percent using a 4-day kiln cycle with a relatively narrow wet/dry bulb depression (20°C) to minimize possible checking and strength effects (Winandy 1995).

Visual assessment

Since waterborne treatment can increase the risk that the wetting and drying processes induce checking, the untreated and treated beams were visually assessed for degree of checking. These results are somewhat subjective, but they may help architects and engineers assess the benefits of waterborne treatments in term of costs versus the potential negative visual impacts of checking. The lengths and widths of checks on the wide face of each beam were assessed, and the checks were qualitatively categorized as 0 = no checking or splitting, 1 = mild checking, 2 = moderate checking, or 3 = severe checking (Fig. 1).

Flexural testing

The conditioned beams were tested to failure in third point bending on an MTS Universal Testing Machine following procedures described in American Society for Testing and Materials (ASTM) Standard D198 (ASTM International 2008a). Load was applied at a rate of 12.5 mm/min, and load/deflection data were continually collected using LabVIEW. Failure mode was noted, as were any defects in the failure zone. Load deflection data were used to calculate

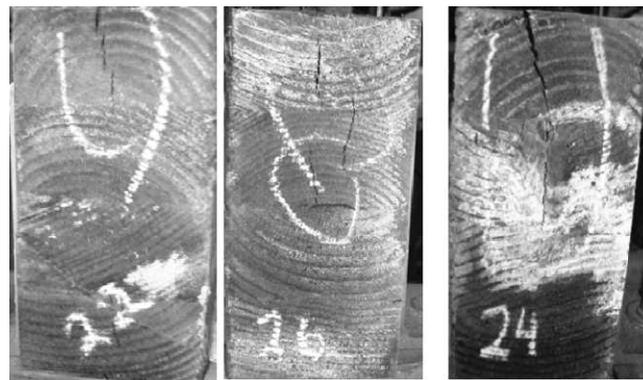


Figure 1.—Examples of mild, moderate, and severe checking (left to right) at the ends of glued laminated beams following amononical copper zinc arsenate (ACZA) treatment and kiln drying.

modulus of rupture (MOR) and modulus of elasticity (MOE). Data for treated and untreated beams for each property were compared using paired *t* tests at $\alpha = 0.05$.

Preservative treatment assessment

Increment cores were removed at three locations along the length of each lamination in a given beam. Preservative penetration was visually assessed on each core by spraying the surface with a curcumin indicator that turned red in the presence of boron. The outer 15 mm of each core was removed and the segments from a given beam were combined before being ground to pass a 20 mesh screen. This ground sample was then divided into replicate samples, which were analyzed for boron by hot water extraction followed by spectrophotometric measurement using the azomethine H method according to procedures described in AWWA Standard A2-16 (AWPA 2009c). A total of 112 assays were run for each set of boron-treated beams.

Shear testing

Wetting and drying of the beams creates the potential for glue-line damage. In order to assess this potential, shear blocks were cut after flexural testing from zones approximately 610 mm from either end of the original beam, away from any evidence of failure. One shear block (81.25 by 75 by 75-mm blocks with a 25 by 37.5-mm-long notch cut at the glue line) was tested from each end of a beam. The blocks were conditioned to constant weight at 20°C and 65 percent relative humidity, prior to testing to failure on a University Testing Machine configured with a special jig to apply load parallel to the glue line in a modification of ASTM Standard D1037 (ASTM International 2008b). Load/deflection data were collected and used to calculate shear strength as compressive stress at maximum load. The failure zone was also examined to determine whether the failure occurred in the wood or the resin. Shear test data were averaged for the two subreplicates for each beam, and then data for treated and untreated beams were compared using paired *t* tests at $\alpha = 0.05$.

Results and Discussion

Visual assessment

None of the untreated control beams had any evidence of surface checking, reflecting the fact that these sections had not been subjected to wetting and drying. Kiln-dried beams

Table 1.—Effect of borate treatment coupled with air seasoning or kiln drying after treatment on flexural properties and glue-line shear (compressive stress at maximum load) of Douglas-fir glued laminated beams.^a

Treatment	MOR (MPa)		MOE (MPa)		Compressive stress at maximum load (MPa)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Control	46.3 (11.5)	29.7–74.4	16,400 (1,344)	12,645–19,105	8.16 (2.58)	3.29–13.62
Borates/air dried	45.7 (9.5)	23.9–70.7	17,788 (1,427)	14,513–21,084	7.40 (2.05)	1.68–11.85
Borates/kiln dried	46.1 (10.4)	30.6–69.4	17,975 (1,779)	17,975–1,779	7.82 (2.36)	2.58–11.78

^a Values represent means of 56 pieces, while figures in parentheses represent 1 SD.

were also virtually free of checking, reflecting the mild kiln cycle used. Small checks were evident on most of the air-dried beams (80%). These beams had been placed in a kiln and subjected to rapid air movement, which was intended to simulate summer drying conditions in western Oregon. Checking is to be expected when wood is subjected to wet/dry cycles, and the data illustrate the risk that specifiers take when opting for a waterborne treatment. None of the air-dried beams had checks that would rate beyond a mild rating. The results indicated that borate treatment and the subsequent drying had no substantial negative effect on appearance of the beams.

Treatment results

The minimum penetration required for treatment of lumber in AWWA Standard T1 is 10 mm, and this value was used for assessing treatment quality in the laminated timbers (AWWA 2009b). Preservative penetration varied widely among the samples, reflecting both the treatment of heartwood and the absence of incising. While incising is required for treatment of glued laminated Douglas-fir, it is often waived by architects because of appearance concerns. Boron penetration in air-dried beams averaged (\pm SD) 8.8 ± 2.3 mm, while penetration averaged 7.0 ± 2.7 mm in the kiln-dried samples. The results suggest that drying method had little effect on boron penetration. Boron retentions in the beams averaged 9.28 ± 5.11 kg/m³ for the kiln-dried beams and 10.08 ± 4.79 kg/m³ for the air-dried samples. Both easily exceeded the 6.72 kg/m³ required in the AWWA standards and indicated that drying method did not adversely affect retention in the assay zone.

Shear tests

Shear tests showed that treatment had no significant effect on glue-line integrity, nor was there any evidence of increased resin versus wood failure in the specimens (Table 1). In general, failures occurred in the wood, which is typical for a well-formed bond. There was no evidence that treatment or drying method significantly affected shear strength ($P = 0.31$ and $P = 0.48$ for air-dried and kiln-dried beams, respectively).

Flexural properties

Examination of MOR and MOE values for the two slightly different sized beams showed that they did not differ significantly from one another; therefore, the data were combined for a given treatment prior to analysis.

Subsequent analysis using paired *t* tests showed that MOR values were similar for all treatments and that treatment followed by either air or kiln drying had no significant negative effect on MOR ($P = 0.68$ and $P = 0.94$ for air-dried and kiln-dried beams, respectively; Table 1). Results were similar for MOE and indicated that borate treatment followed by drying had no significant negative effect on either dynamic or flexural properties of the beams.

Conclusions

Pressure treatment of Douglas-fir glued laminated beams with boron to the current AWWA standard for interior aboveground use had no significant negative effect on checking, glue-line shear strength, modulus of elasticity, or modulus of rupture.

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