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MANUFACTURE OF BORATE-TREATED GLULAM – A NEW PRODUCT RESISTANT TO TERMITES, MOLD AND DECAY

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Abstract

The commercial manufacture of borate-treated glulam, a new structural engineered wood product that is resistant to termites, mold and decay is now a real possibility.

Using a PRF adhesive, a Forintek resin modifier and a commercial glulam manufacturing process, it was demonstrated that it is feasible to laminate borate-treated lodgepole pine lumber (bluestained or non-stained) and meet the requirements of the Canadian standard CSA 0177-06. It was also found that borate-treated laminating stock can be produced using a commercial radio-frequency finger-joint process. The resulting bond quality is not adversely affected by the borate treatment.

It was discovered that the borate treatment caused 12% - 23% loss of tensile strength of either the solid lumber or the finger-joint lumber whether they are non-stained or bluestained but there was no reduction of MOE in the treated lumber.

Key Words: glulam, borate, termite, mold, decay

1. Introduction

Glulam is being used in environments where it may be exposed to fire and biological attacks such as mold, termite, beetles, decay, etc. There is a need for glulam that has improved fire-retardant and/or biological-resistant properties. Using borate as a wood preservative is known to provide the needed biological resistance for wood-based materials. At higher loading levels, borate also provides fire resistance. Borate is considered to have minimal environmental impact and low mammalian toxicity. The successful utilization of borate as a wood preservative can conceivably open new markets for the use of glulam.

Glulam as a structural wood composite product is commercially produced by bonding lumber with a phenol-resorcinol-formaldehyde (PRF) resin at ambient temperatures. Borate-treated glulam is highly desirable because of its mold and termite-resistant properties. However, bonding borate-treated lumber with a PRF resin at ambient temperatures is difficult and usually results in high glue line failure and high delamination after water soaking. Therefore, no successful process of producing borate-treated glulam with PRF resin is commercially known. If a low-cost solution can be found to ensure good bonding quality between borate-treated lumber and a PRF resin, the applications and market size of glulam can be expanded. A resin modifier discovered by FPInnoavtions - Forintek Division has provided a solution to the problem. This technology provided sufficient bond quality improvement to enable the use of an existing commercial PRF resin for laminating borate-treated lumber at ambient temperatures.

A mill trial was conducted in 2007 to demonstrate the feasibility of commercial production of borate-treated glulam using lodgepole pine lumber, a PRF resin and the resin modifier.

2. Materials and Methods

Material Preparations

Sourcing and Grading of Lumber

Thirteen thousand fbm of high grade 2100 MSR (B or C+) lodgepole pine lumber (nominal dimension: 2”x6”x12’) were obtained from a saw mill in British Columbia, Canada for this mill trial. The lumber was sorted into two main groups: bluestained and non-bluestained. All of the lumber was E rated for stiffness and visually graded for bluestain. The average moisture content was 13% to 14%.

Two hundred boards of non-stained wood (as used in groups A and C) and 200 boards of bluestained wood (as used in groups B and D) were selected according to E rating. Each group of 200 was then divided into 2 sub groups such that the E rating of the boards in each sub group of 100 would be equivalent. One hundred of the sorted AC boards and 100 of the sorted BD boards were borate treated while the corresponding 100 AC and 100 BD boards were retained as controls for tensile strength tests. In the same manner an additional 100 boards of each type were sorted and separated to provide stock for finger-joint tests and laminating. This resulted in 4 groups: non-stained control; bluestained control; borate-treated non-stained; borate-treated bluestain.

Borate Treatment

An aqueous Timbor® (disodium octaborate tetrahydrate) solution of 5.6% (wt./vol.) was used for the lumber treatment. The initial working barrel temperature was approximately 20ºC. The wood was placed under a vacuum of -25 to -26 inHg for 30 minutes and then at a pressure of 150 psi for 4 hours. The lumber was stored for borate diffusion in heated space for several weeks before mild kiln drying (maximum temperature 70ºC) to less than 12% moisture content.

Glue Preparations

A total of 14 gallons of LT5210J adhesive (liquid PRF resin manufactured by Hexion Specialty Chemicals) was mixed with 2.0 % resin modifier (based on liquid resin weight). The modified resin mixture was stored overnight before use.

Finger-jointing and Lamination

The trimmed lengths were finger-jointed continuously to 56-foot lengths using the radio frequency process in an end-to-end fashion, followed by planing to 1.38 inches in thickness. The glue used for the RF accelerated finger-joint process was a mixture of RS254D resin and FM 316MB catalyst, both of which were manufactured by Hexion Specialty Chemicals. The 56-foot lengths were then chopped into about 7.5-foot sections having one central finger-joint in each.

The face lamination experiment involved making 4 glulam beams of 8 laminations for each of the 4 test groups. The 2 untreated groups (bluestained and non-bluestained) used the unmodified PRF resin (LT5210J), and the 2 borate-treated groups (bluestained and non-bluestained) used the modified PRF resin. A total of 32 pieces of each of the two treated groups (C & D) and the control groups (A & B) were end trimmed and then finger-jointed to 12-foot length and planed prior to face laminating into a total of 16 glulam beams of 8 lamellas and 12 feet long.

The glue mix used for the face lamination of the borate-treated lumber was a mixture of modified LT5210J PRF resin and FM6210 slurry catalyst in a weight to weight ratio of 2.5 to 1 (resin to catalyst). The glue application used an inline mixing system, where the PRF resin and the catalyst (in slurry) were mixed immediately prior to glue mix spread. The adhesive application, beam lay-up and clamping and adhesive curing followed the normal operating procedures in the mill.

Product Tests

Evaluation of the glulam beams and the finger-jointed test specimens followed the Canadian Standards for Structural Glued Laminated Timber (CSA-0122-06 for quality control and CSA-0177-O6 as qualification code for manufacturers). These standards were designed for untreated glulam only. For this study three beams of each type were evaluated for dry block shear and vacuum/pressure cyclic delamination, while the fourth beam has been saved for the purpose of demonstration. Test specimens were cut from each beam according to the requirements of the numbers of test replicates in CSA-0177-06.

Delamination Tests

Four specimens were cut from each of the 3 beams of each category (A, B, C & D) to create 12 specimens to be tested for each of the 4 wood groups. A total of 48 specimens were processed through 3 vacuum-pressure and dry cycles according to the requirements of the CSA-0177-O6 standard. These samples were subjected to 2.5 hours of vacuum-pressure followed by 72 hours of drying at 27+/-2°C for each of the 3 cycles and then measured for delamination of each glue line when the samples reached their original starting moisture contents after the third drying cycle.

Block Shear Tests

All glue lines were evaluated from the three ‘test beams’. Eight sample sections were cut from each of the three test beams giving 24 block shear sections (with 7 glue lines each) from each type of glulam beam. A total of 168 block shear tests were performed on each beam type (total 672). Each beam was sampled at different locations along the length of the beam and all 7 glue lines were tested at each location. The samples were tested dry with shear load recorded and wood failure tabulated.

Tensile Strength & Finger-joint Tests

Tensile strength tests were performed on the 100 selected pieces of lumber from each of the 4 groups. Tensile tests were also performed on 40 - 50 pieces of finger-jointed lumber produced from each group (90 treated and 88 untreated boards). The resulting tensile and finger-joint test data were normalized for moisture contents. Tension testing was carried out on the lumber using a 2-foot gauge length to maximize stress on the finger-joint.

Borate Content Analysis

Boric acid equivalent (BAE%) was determined for 2 samples taken from each of the 20 borate-treated tensile test specimens of blue-stained and non-stained wood following standard borate retention procedures. One sample was obtained from the flat face and one from the edge of these specimens to approximate sap and heart borate retention evaluation.

The BAE level of the material was analyzed by the Mannitol method. The samples were ground to pass a 60 mesh screen, carefully weighed and then immersed in distilled water heated to 95ºC for a minimum of 4 hours. The samples were then neutralized and an excess of Mannitol added to the sample to convert the borate compounds to boric acid. The boric acid was then titrated with an aqueous potassium hydroxide solution and the quantity of boric acid calculated and expressed as the percentage of boric acid equivalent (% BAE) in the sample.

3. Results and Discussion

This mill trial overall went smoothly according to the trial plan. No process change was required by the glulam plant except for pre-mixing the PRF resin with the Forintek resin modifier for face lamination. Borate-treated pine lumber was finger-jointed using a radio frequency heating process in the same manner as untreated pine lumber. A total of 16 glulam beams were manufactured in the mill, of which 12 beams were tested. The evaluation data are summarized in Table 1. These data showed that:

- All lumber (bluestained and non-stained) used as starting materials were high grade materials with MOE values exceeding the requirement of the CSA-0177-O6 standard. Their E-ratings were fairly similar.
- The borate-treatment process lowered the tensile strength of the solid lumber.
- The borate-treatment process lowered the tensile strength of the finger-joint lumber.
- All glulam beams manufactured in this mill trial passed the dry block shear strength and wood failure requirements of the CSA-0177-O6 standard by very large margins.
- Five out of 6 treated glulam beams and 5 out of 6 untreated glulam beams passed the requirements of the CSA-0177-O6 standard. Both beams that failed the delamination test were derived from non-stained lumber. In each case, only 1 of the 7 glue lines failed. It is not understood why one beam failed in the case of either treated or untreated glulam product.

Table 1. Summary of test results for untreated and borate-treated lumber, finger-joint lumber and glulam beams

Property	Sample Size	Borate-Treated Lumber/ Fingerjoint/Glulam	CAN / CSA-O177-06 Requirement	Status
Modulus of Elasticity (MOE) Test				
Minimum MOE (psi)			1.6 x 106	
Bluestained untreated	100	1.78 x 106		Pass
Bluestained treated	100	1.78 x 106		Pass
Non-stained untreated	100	1.78 x 106		Pass
Non-stained treated	100	1.75 x 106		pass
Solid Lumber Tension Test				
UltimateTensile Strength (psi)				
Lower 5% limit (75% confidence)				
Bluestained untreated	98	3715		
Bluestained treated	98	2824		
Non-stained untreated	98	4418		
Non-stained treated	98	3815		
Finger-joint Tension Test				
UltimateTensile Strength (psi)1				
Lower 5% limit (75% confidence)2				
Bluestained untreated	40	4321		
Bluestained treated	40	3896		
Non-stained untreated	40	5223		
Non-stained treated	40	3960		
Dry Block Shear Test				
Shear Strength (psi)				
Average			888	
Bluestained untreated	168	1740		Pass
Bluestained treated	168	1719		Pass
Non-stained untreated	168	1623		Pass
Non-stained treated	168	1562		Pass
Minimum			444	
Bluestained untreated	168	1014		Pass
Bluestained treated	168	843		Pass
Non-stained untreated	168	956		Pass
Non-stained treated	168	957		Pass
Wood Failure (%)3				
Average			80	
Bluestained untreated	168	93		Pass
Bluestained treated	168	94		Pass
Non-stained untreated	168	95		Pass
Non-stained treated	168	93		Pass
Delamination Test				
Maximum Delamination (%)			10	
Any single glueline				
Bluestained untreated				
Beam no. 1	4			Pass
Beam no. 2	4			Pass
Beam no. 3	4			Pass

Property	Sample Size	Borate-Treated Lumber/ Fingerjoint/Glulam	CAN / CSA-O177-06 Requirement	Status
Bluestained treated				
Beam no. 1	4			Pass
Beam no. 2	4			Pass
Beam no. 3	4			Pass
Non-stained untreated				
Beam no. 1	4			Pass
Beam no. 2	4			Fail
Beam no. 3	4			Pass
Non-stained treated				
Beam no. 1	4			Fail
Beam no. 2	4			Pass
Beam no. 3	4			Pass

1 Low-stress data with Mode Type 6 failure were culled.
2 Based on ASTM D 2915 standard.
3 Wood failure of specimens with defects, such as knot, were not determined.
No retest was made for specimen with less than 50% wood failure.

Initial Lumber Grading

MOE measurements were performed for all of the lumber. They are summarized in Table 2. These data suggested that all of the lumber (bluesatined or non-stained) used as starting materials for this mill trial had very similar E-ratings.

Table 2. ***Average initial MOE values of bluesatained lumber and non-stained lumber***

Lumber Group	Untreated Non-stained (106psi)	Untreated Bluestained (106psi)	To Be Treated Non-stained (106psi)	To Be Treated Bluestained (106psi)
For Finger-joint	1.973* (0.112)**	1.966 (0.122)	1.944 (0.131)	1.976 (0.173)
For Tensile Test	1.954 (0.104)	1.975 (0.112)	1.953 (0.120)	1.973 (0.221)

* All of these MOE values are based on data obtained at Western Archrib.
**Values in parenthesis are standard deviations.

Borate Treatment and Retention Levels

Twenty tensile test specimens of bluestained lumber and 20 specimens of non stained lumber were analyzed for % boric acid equivalent. Each specimen was evaluated on the face of the board and on the edge. There was significant variation within each set and significant difference between face and edge. Table 3 is a summary of the average values of these analysis data and their standard deviations. BEA retention levels in the face were similar between bluestained and non-stained wood specimens. However, the BEA retention level of the bluestained lumer was significantly higher than the non-stained lumber. The variability in data between face and edge was expected due to the predominant presence of sapwood on the edges of the lumber and the occurrence of heartwood on the faces. This resulted in higher overall BEA retention levels for the bluesatined lumber.

Table 3. Borate Analysis (as % BAE) of Treated Wood Specimens

Location White Wood	% BAE*	Location Bluestained	% BAE
Face	1.10 (1.06)	Face	1.24 (1.42)
Edge	1.46 (0.82)	Edge	2.35 (0.90)
Overall	1.28 (0.95)	Overall	1.79 (1.30)

* The % BEA values are averages with standard deviation in parentheses.

Solid Lumber MOE and Tension Tests

Two groups of untreated solid lumber (bluestained and non-stained, 100 pieces each) and 2 groups of borate-treated solid lumber (bluestained and non-stained, 100 pieces each) were subjected to MOE analysis and tension tests. This allowed a comparison of the stiffness and the tensile strength before and after the borate treatment and subsequent drying. The test data showed that the borate treatment and the subsequent drying did not lower the MOE or the stiffness of the lumber whether it was bluestained or non-stained. However, the data clearly showed that the borate treatment and/or the subsequent drying did lower the average tensile strength of the bluestained by about 20% and non-stained lumber by about 12% (after corrected for the effect of moisture).

The above observations are supported by ANOVA statistical analysis. The analysis concluded that the borate treatment had a significant effect on the tensile strength of the lumber at the 99% level of significance ($0.00 < 0.01$). On the other hand, bluestain in lumber had no effect on the tensile strength at the 95% level of significance ($0.065 > 0.05$). In the lumber, the effects on tensile strength of treating with borate and being bluestained were not related at the 95% level of significance ($0.116 > 0.05$).

It was also noted that the treated lumber had lower moisture contents than the untreated lumber, probably as a result of attention paid to the drying process of the treated lumber after the borate treatment.

Finger-joint Lumber MOE and Tension Tests

Two groups of untreated finger-joint lumber (bluestained and non-stained, 40 pieces each) and 2 groups of borate-treated finger-joint lumber (bluestained and non-stained, 40 pieces each) were subjected to MOE analysis and tension tests. The data showed that the borate treatment and the subsequent drying did not lower the MOE or the stiffness of the finger-joint lumber whether it was bluestained or non-stained. However, the data clearly showed that the borate treatment and/or the subsequent drying did lower the average tensile strength of the bluestained lumber by about 14% and non-stained lumber by about 23% (after corrected for the effect of moisture). The failures occurred almost completely as wood failure. Very little glue failure was observed.

The above observations are again supported by ANOVA statistical analysis.

Glulam Beam Tests

Four glulam beams were produced from each type of finger-joint lumber (treated/untreated bluestain and treated/untreated non-stain). A total of 16 glulam beams were manufactured. Delamination and block shear tests were performed on 3 beams of each type according to the requirements of CSA 0177-06 standard.

Delamination test

The 3-cyclic delamination test showed delamination along individual glue lines. In the case of bluestained wood, the borate-treated and untreated glulam beams passed the delamination test. In the case of non-stained wood, 2 of the 3 treated glulam beams and 2 of the 3 untreated glulam beams that passed the delamination test. Delamination test results of borate-treated non-stained glulam beams showed that beam #1 failed the test in glue line # 5 but the rest of the glue line in this beam passed. Delamination test results of untreated non-stained glulam beams showed that beam #2 failed the test in glue line # 4 but the rest of the glue line in this beam passed.

Block Shear Test

The block shear strength requirement according to the CSA 0177-06 is an average shear of 3.5 times the specified strength in longitudinal shear, which is 1.75 MPa for Lodgepole pine assuming dry service conditions (Table 6.3 in CSA O86.1-94). The minimum shear required is 1.75 times the longitudinal shear value. This translates to an average of 888 psi and a minimum of 444 psi. All glue lines exceeded the requirements for average shear strength and none of the glue lines had any individual shear value below the minimum required shear. All of the glue lines showed wood failure above the required average wood failure of 80%. Therefore, all test beams passed the dry block shear requirements of the Canadian standard.

4. Conclusions

Based on the test data, the following conclusions are made:

1. Using the Forintek resin modifier and an existing commercial glulam manufacturing process, it is feasible to laminate borate-treated lodgepole pine lumber (bluestained or non-stained) at boric acid equivalent levels of 1.1% - 2.4% to create new glulam products. This type of laminated beams would meet the requirements of CSA 0177-06 standard.

2. Radio frequency curing method is capable of producing borate-treated finger-joint lumber that meet the strength requirements of CSA 0177-06 standard.

3. After the borate treatment, there was no reduction on lumber MOE.

4. The borate treatment caused 12% - 23% loss of tensile strength of either the solid lumber or the finger-joint lumber whether they are non-stained or bluestained. It is not certain whether this strength loss is due to the chemical or the treating process but other treating processes such as CCA treatment also result in tensile strength loss of lumber.

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6. Literature

CSA. 1994. Engineering Design in Wood (Limit States Design). CSA 086.1-94 standard, Canadian Standard Association.

CSA. 2006. Structural Glued-laminated Timber. CSA 0122-06 standard, Canadian Standard Association.

CSA. 2006. Qualification Code for Manufacturers of Structural Glued-laminated Timber. CSA 0177-06 standard, Canadian Standard Association.