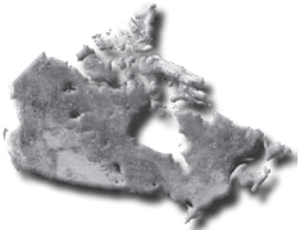

Performance of posts laminated with blue-stained mountain pine beetle lodgepole pine

Frank Lam, Jianzhong (James) Gu
and Igor Zaturecky

Mountain Pine Beetle Initiative
Working Paper 2005–5

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2005

Abstract

Performance of laminated posts produced from mountain pine beetle-infested wood which could potentially compete with Douglas-fir posts in the California market is studied. Based on nondestructive vibration modulus of elasticity (MOE) test data of 38 mm x 140 mm (nominal 2 in. x 6 in.) mountain pine beetle-infested wood specimens, a 152 mm x 152 mm post (true 6 in. x 6 in.) was designed to compete with 140 mm x 140 mm (nominal 6 in. x 6 in.) Douglas-fir posts. The Canadian Forest Product (CANFOR) Research Centre further processed the wood to produce 60 2.26-metre-long (89 inches) glued laminated posts for structural testing. After non-destructive tests, four 76.2 mm x 76.2 mm x 251 mm (3 in. x 3 in. x 9-7/8 in.) short columns were obtained from each original specimen and tested in compression parallel to grain. The results showed that the 152 mm x 152 mm posts laminated with blue-stained lodgepole pine exhibited good structural performance compared to 140 mm x 140 mm select structural Douglas-fir posts.

Key words: Mountain pine beetle, Dendroctonus ponderosae, blue stain, laminated posts, structural performance, wood products, lodgepole pine, Pinus contorta, Douglas-fir, Pseudotsuga menziesii

Résumé

La présente étude examine la résistance des poteaux lamellés fabriqués à partir de bois infesté par le dendroctone du pin ponderosa sous l'angle d'une concurrence éventuelle avec les poteaux en Douglas taxifolié commercialisés en Californie. D'après des coefficients d'élasticité obtenus par essais non destructifs de vibrations sur des éprouvettes de bois infesté par le dendroctone du pin ponderosa mesurant 38 mm x 140 mm (nominal 2 po x 6 po), un poteau de 152 mm x 152 mm (réel 6 po x 6 po) a été conçu pour concurrencer le poteau en Douglas taxifolié de 140 mm x 140 mm (nominal 6 po x 6 po). Le centre de recherche de la société de produits forestiers Canfor a poussé le traitement du bois et produit 60 poteaux lamellés collés de 2,26 mètres (89 po) de long pour faire des essais de résistance. Après les essais non destructifs, quatre courtes colonnes de 76,2 mm x 76,2 mm x 251 mm (3 po x 3 po x 9 ⅞ po) ont été produites à partir de chaque éprouvette originale et soumises à des essais de compression parallèle au fil. Les résultats ont démontré que la résistance structurale des poteaux lamellés collés de 152 mm x 152 mm obtenus à partir de bois de pin tordu latifolié bleui était bonne par rapport à celle des poteaux en Douglas taxifolié de 140 mm x 140 mm de catégorie « select structural ».

Mots clés : dendroctone du pin ponderosa, Dendroctonus ponderosae, bleuissement, poteaux lamellés, résistance structurale, produits ligneux, pin tordu latifolié, Pinus contorta, Douglas taxifolié, Pseudotsuga menziesii

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Introduction

The volume of lodgepole pine lumber from British Columbia's (BC) forestlands that is infested by mountain pine beetle is projected to exceed the annual harvest by a significant margin. For example, the infested volume on Canfor's forestlands is estimated at nine million cubic meters per year; Canfor's annual harvest is seven million cubic meters. As lodgepole pine comprises a significant share of the spruce–pine–fir (SPF) species group, the percentage of blue-stained lumber within the group from sawmills in the province's interior will remain high for the foreseeable future.

Technologies capable of converting blue-stained lumber into market-acceptable products are required to reduce the impact of the growing volume of stained lumber on the profitability of forestry in BC. Green Douglas-fir 140 mm x 140 mm (nominal 6 in. x 6 in.) members are commonly used in California as posts and columns to support structures such as sundecks or porches. Laminated posts using blue-stained lodgepole pine lumber represent a potential application in the California market. The objective of this paper is to evaluate the appearance and structural performance of glued laminated posts produced from the blue-stained lodgepole pine lumber.

The structural capacity of posts is governed by the compression strength parallel to grain, modulus of elasticity (MOE) of the material, member geometry, and end fixity. Lamination can improve appearance and performance of the product through distribution of defects. The cost of manufacturing, including cutting and gluing, must be weighed against the benefits of the improvements, and is outside the scope of this research.

Much research on the subject of glued laminated posts is available. An application of this technology was reported by Wright et al. (1988 and 1990). Zahn and Rammer (1995) reported research on the c-value in the design formula in the code for glued laminated posts. Harries et al. (2000) studied the performance of glued box-timber columns. There is no information on posts laminated with blue-stained lumber.

Materials and methods

38 mm x 140 mm (nominal 2 in. x 6 in.) No.2 and better grade blue-stained lodgepole pine lumber was sampled from a British Columbia sawmill. The material was shipped to Canfor's research facilities, and non-destructively evaluated for MOE. Using the preliminary test results, structural analysis with a commercial finite element program (ANSYS; Swanson Analysis Systems 2002) was conducted to design a 152 mm x 152 mm (true 6 in. x 6 in.) laminated lodgepole pine post with capacity comparable to that of a 140 mm x 140 mm (nominal 6 in. x 6 in.) Douglas-fir post.

Based on the recommended size, attempts were made to use the most severely stained lumber in the core and to orient the laminae with the lowest degree of staining on the exposed face. The non-destructively tested members and some additional 38 mm x 184 mm (nominal 2 in. x 8 in.) members were processed and glued together to construct 60 prototype pieces.

In Phase Two of the study, the posts were shipped to the Timber Engineering and Applied Mechanics (TEAM) Laboratory at the University of British Columbia (UBC). The MOE and short column compression strength parallel to grain were tested to determine the axial capacity of the posts. The short column strength gives the crushing capacity and the MOE is required for a slenderness adjustment factor in the column formula.

Dynamic MOE tests of the raw materials

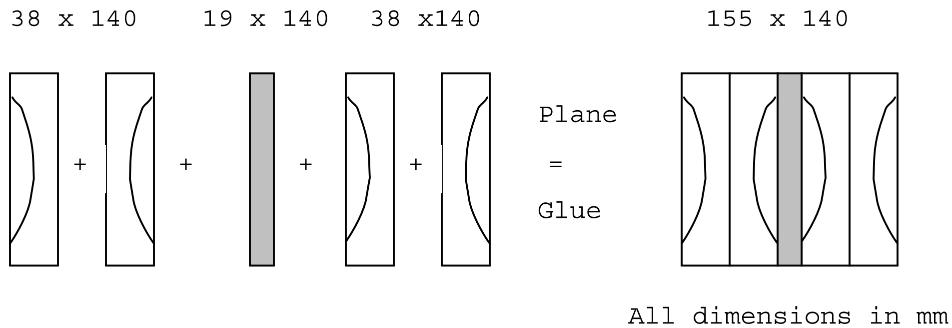
The dynamic MOE for each 38 mm x 140 mm (nominal 2 in. x 6 in.) member was determined using a Metriguard Model 340 Transverse Vibration E-Computer. The E-Computer determines MOE based on resonant vibration frequency and density. Each member was positioned flatwise and supported at the two ends as a beam, and the specimen was set into vibration by gently tapping it near the centre of the span. A load cell measured the vibration frequency and board weight, and the E-Computer calculated MOE for each of the 378 specimens.

Lay-up and construction processes

The requirement of making a 152 mm x 152 mm (true 6 in. x 6 in.) cross-section from the 38 mm x 140 mm (nominal 2 in. x 6 in.) sample material created manufacturing issues. Procedures involved two stages of gluing and pressing. The initial face bonding was completed during the first pressing stage; lamination into the final size occurred with the second pressing phase.

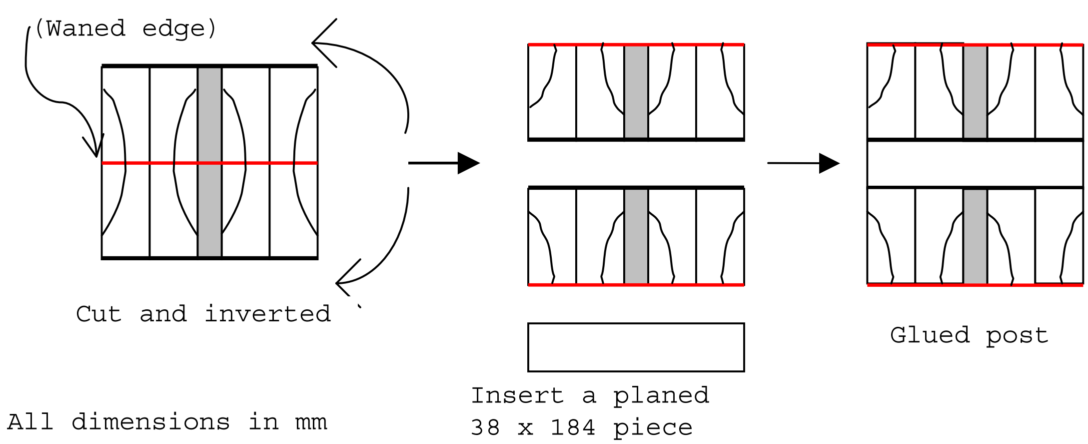
To make the initial block, four pieces of 38 mm x 140 mm (nominal 2 in. x 6 in.) pieces were glued together, with an additional 19 mm x 140 mm (¾ in. x 5½ in.) piece placed in the middle for symmetry. The additional piece was made by ripping a 38 mm x 140 mm (nominal 2 in. x 6 in.) member into small sizes. Grain orientation was chosen to increase strength and minimize amount of visible stain, as illustrated in Figure 1. The press machine was LV-4016, made by Kallesoe Company of Denmark, with a press opening of 150 mm x 1600 mm x 4000 mm (6 in. x 63 in. x 157 in.). The initial blocks were pressed under 827 kPa (120 psi), with a temperature of 90º C, for 25 minutes.

Figure 1. Creating the initial block



After the initial face gluing, the block was cut in half and inverted to hide the wane. Then a planed 38 mm x 184 mm (nominal 2 in. x 8 in.) member was inserted and glued in the middle to create the final desired dimensions. Dimension after gluing was 156 mm (6-1/8 in.), and final dimension was 152 mm (6 in.) after planing (see Figure 2). A custom-made edge-gluing–laminating press device with pneumatic top pressure and hydraulic side pressure was used. The pressure was 689 kPa (100 psi), and lasted for 30 minutes. Two heaters were used to heat the press table from the bottom. The adhesive was a mixture of PRF resin 4001-5 and catalyst H-1003, made by Dynea. The spread rate was 0.293 kg/m^2 (60 lbs/1000 ft^2) for all gluing.

Figure 2. Creating the final block



Bending tests of posts

After cutting and sanding, the posts were 2.26 m (89 in.) long and had a net cross-section of 152 mm x 152 mm (6 in. x 6 in.). The materials were then shipped to the UBC TEAM Laboratory and stored in a conditioning chamber at 20° C and 65% relative humidity prior to testing. Moisture content was measured with a Delmhorst analog two-pin moisture meter. Third-point loading tests (Figure 3), to a load level of 11.12 kN (2500 lb), were conducted as per ASTM D198 (American Society for Testing and Materials

1995). The span-to-depth ratio was chosen to be 14:1. The test machine was under displacement control with a rate of cross-head movement of 0.0339 mm/sec (0.08 inch/min). The data were acquired through a PC-based data acquisition system with a sampling frequency of 2 Hz. Each specimen was tested twice, once when loaded in cross-directions with respect to the central layer (Figure 4, left), and once when loaded in the parallel direction (Figure 4, right). Two yokes were used to measure the deflection: a short yoke measured relative deformation between mid-span and loading point (Figure 5); a long yoke measured deformation between mid-span and reaction point (Figure 6). The tests were conducted with a MTS 810, equipped with a PC-based data acquisition device. The capacity of the universal test machine is 245 kN (55000 lb).

Figure 3. Third-point loading tests

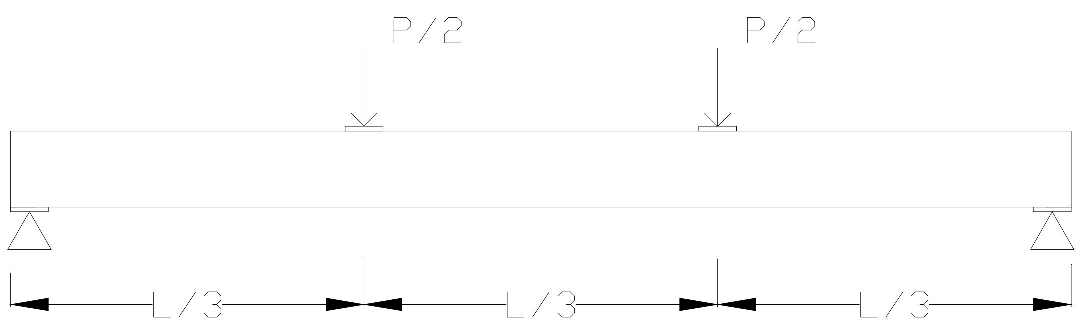


Figure 4. Load directions in bending tests

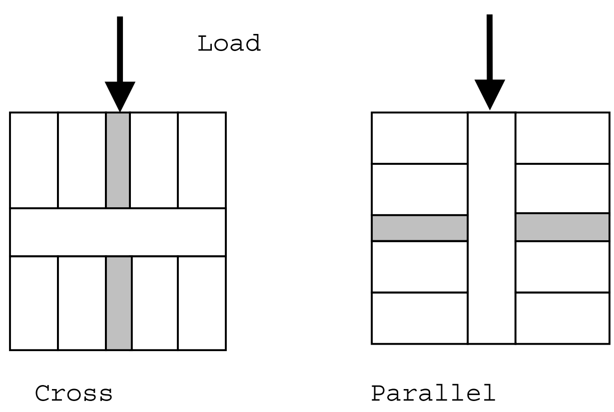
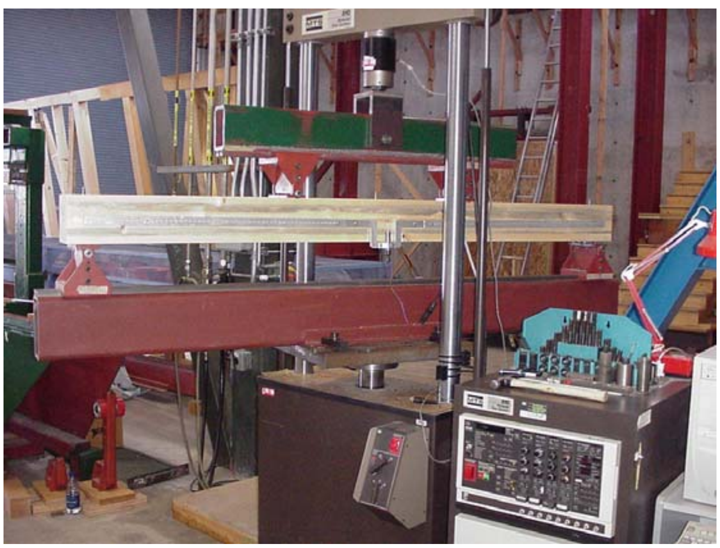


Figure 5. Short yoke for bending tests

Figure 6. Long yoke for bending tests



Compression strength parallel to grain tests

After the non-destructive bending tests, a short 251-mm-long (9-7/8 in.) column was cut from each of the 60 original specimens. Due to limited machine capacity, the 60 short columns were sliced into four equal quarters, which were then sanded to the dimension of 73.6 mm x 73.6 mm x 250.8 mm (2.9 in. x 2.9 in. x 9.875 in.). The length-to-width ratio was approximately 3:4. All quarters were numbered to track the original specimen (Figure 7). All members were tested with the MTS 810 machine as per ASTM D198

(ASTM 1995). The load ratio was 0.00487 mm/sec (0.0115 in/min), and the sampling frequency was 2 Hz (Figure 8).

Figure 7. Numbering the quarters for compression parallel to grain strength tests

Figure 8. Compression parallel to grain strength tests

Results and Discussion

Dynamic MOE results for raw material

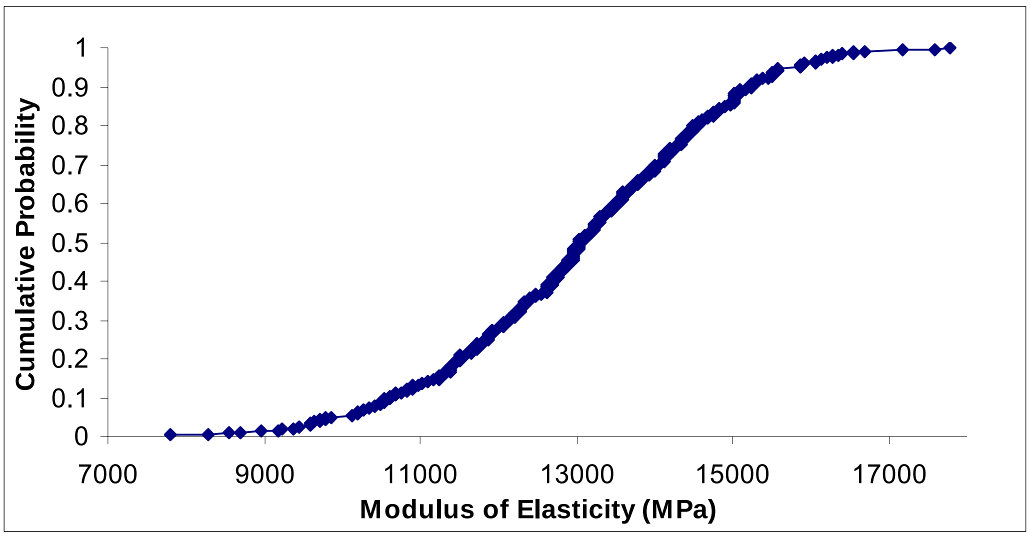
The results from the dynamic MOE tests are summarized (Table 1). A graph of cumulative distribution is presented (Figure 9). The mean dynamic MOE value is 13 030 MPa (1.89 x 10^6 psi). The coefficient of variation and the fifth-percentile values are 13.5% and 9791 MPa (1.42 x 10^6 psi), respectively. These results are very encouraging, as the MOE of Select Structural post- and timber-grade Douglas-fir is specified as 12 000 MPa (1.74 x 10^6 psi) (CSA 2001).

Table 1. Dynamic statistical MOE value of the raw 38 mm x 89 mm members

	Dynamic MOE
Average (MPa)	13 030
Median (MPa)	13 031
5th percentile value (MPa)	9 791
Standard deviation (MPa)	1 759
COV	13.50%
Min (MPa)	7 791
Max (MPa)	17 788

1 MPa = 145 psi

Figure 9. Cumulative distribution of dynamic MOE test results of raw 38 mm x 89 mm members



Bending test results

Moisture content (MC) was measured during static bending tests. The average MC was 12%, with a coefficient of variation of 7%. Table 2 lists the test results summary.

Table 2. Moisture content of specimen before testing

Average (%)	12.33
Median (%)	12.45
Standard deviation (%)	0.866
COV	7.0%
Min (%)	10.0
Max (%)	14.5

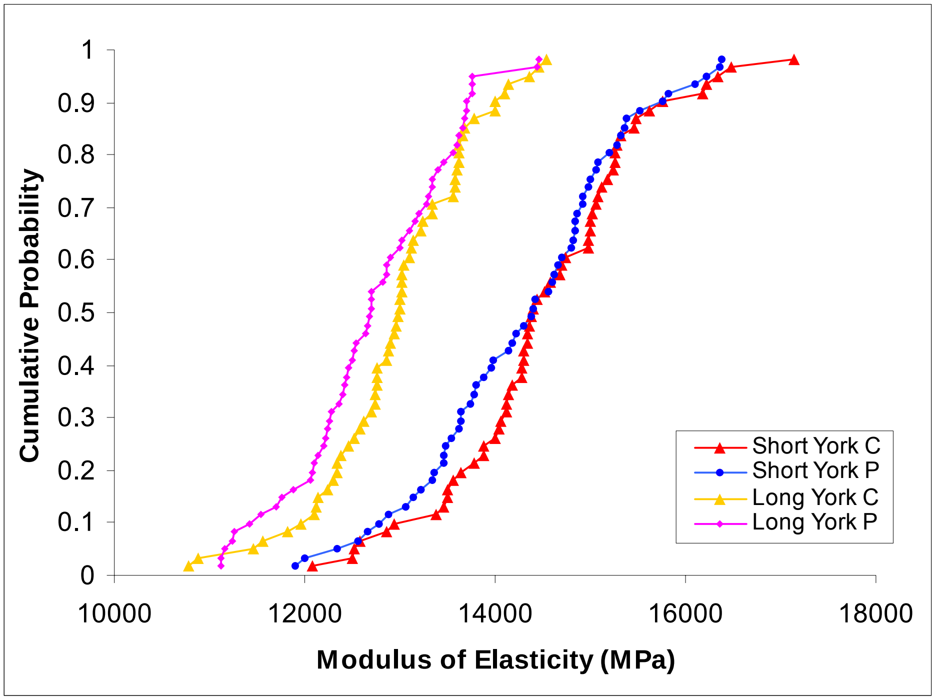
Table 3. Summary of MOE test results

	Short-yoke results		Long-yoke results	
	Parallel	Cross	Parallel	Cross
Average (MPa)	14 287	14 496	12 704	12 951
Median (MPa)	14 391	14 389	12 687	12 986
5^{th} percentile value (MPa)	12 352	12 531	11 167	11 472
Standard deviation (MPa)	1 069	1 024	817	796
COV	7.49%	7.06%	6.43%	6.15%
Min (MPa)	11 902	12 082	11 118	10 779
Max (MPa)	16 379	17 134	14 466	14 539

The MOE was calculated from the slope with the load ranging between 2 224 N (500 lbs) and 8 896 N (2000 lbs). The summary of results is listed in Table 3. Figure 10 shows the cumulative probability distribution of MOE.

From Table 3, the average MOE values from the short-yoke tests (true MOE) are 14 287 MPa (2.072 x 10^6 psi) in parallel direction and 14 496 MPa (2.103 x 10^6 psi) in cross-direction. The average MOE values from long-yoke tests (the apparent MOE) are 12 704 MPa (1.843 x 10^6 psi) in parallel direction and 12 951 MPa (1.878 x 10^6 psi) in cross-direction, respectively. The values are about 12% smaller than the true MOE. Compared with the MOE of Select Structural and No. 1 post- and timber-grade Douglas-fir, specified as 12 000 MPa (1.74 x 10^6 psi) and 10500 MPa (1.52 x 10^6 psi), respectively (CSA 2001), the apparent MOE of glued laminated lodgepole pine post is 5.8% and 20% higher. All coefficients of variation are smaller than 7.5%. Results from both parallel and cross-directional tests are very consistent, which indicates that orientation of cross-section is not important for construction.

Figure 10. Cumulative distribution of MOE test results



Compression strength parallel to grain results

Results of tests measuring compression strength parallel to grain are summarized in Table 4. Probability distribution is plotted in Figure 11. Of the 240 specimens tested, 26 specimens did not fail before the test machine reached its load capacity of 245 kN (55 000 lbs). Figure 12 shows the typical failure modes observed in the short-column compression parallel to grain tests.

The fifth-percentile values of specimen test results range from 31.0 MPa (4 497 psi) to 33.3 MPa (4 823 psi). In order to obtain conservative results, the minimum of the four strength values from each post was considered the post's compression strength parallel to grain (Table 4, Figure 11). The post's fifth-percentile compressive strength parallel to grain is therefore 28.4 MPa (4 113 psi).

Specified strength values for compression strength parallel to grain (F_c) can be obtained according to equation 1:

$$F_c = FC \times Kr = 23.8\,MPa \qquad (1)$$

where FC = characteristic compression parallel to grain strength = 28.4 MPa

and Kr = 0.84 for coefficient of variation ~ 10%–14%

Compared with the compression strength parallel to grain of Select Structural post- and timber-grade Douglas-fir, specified as 13.8 MPa (2001 psi) (CSA 2001), the strength value of the glued laminated lodgepole pine post is 72% higher than that of Select Structural post- and timber-grade Douglas-fir.

Table 4. Summary of compression strength parallel to grain test results

	Quarter a	Quarter b	Quarter c	Quarter d	Minimum[a]
Average (MPa)	40.3	39.7	39.3	39.3	36.4
Median (MPa)	41.9	40.4	40.4	39.3	36.6
5^{th} percentile value (MPa)	33.3	31.0	32.6	31.3	28.4
Standard deviation (MPa)	3.3	3.5	3.9	3.4	4.2
COV	8.1%	8.9%	9.9%	8.8%	11.5%
Min (MPa)	32.0	27.4	25.0	29.2	25.0
Max (MPa)	43.7	43.8	43.6	43.9	42.8
Unbroken member	5	7	3	11	N/A

[a]: Minimum refers to the smallest value among four quarters from the same post.

Figure 11. Cumulative distribution of compression parallel to grain strength test results

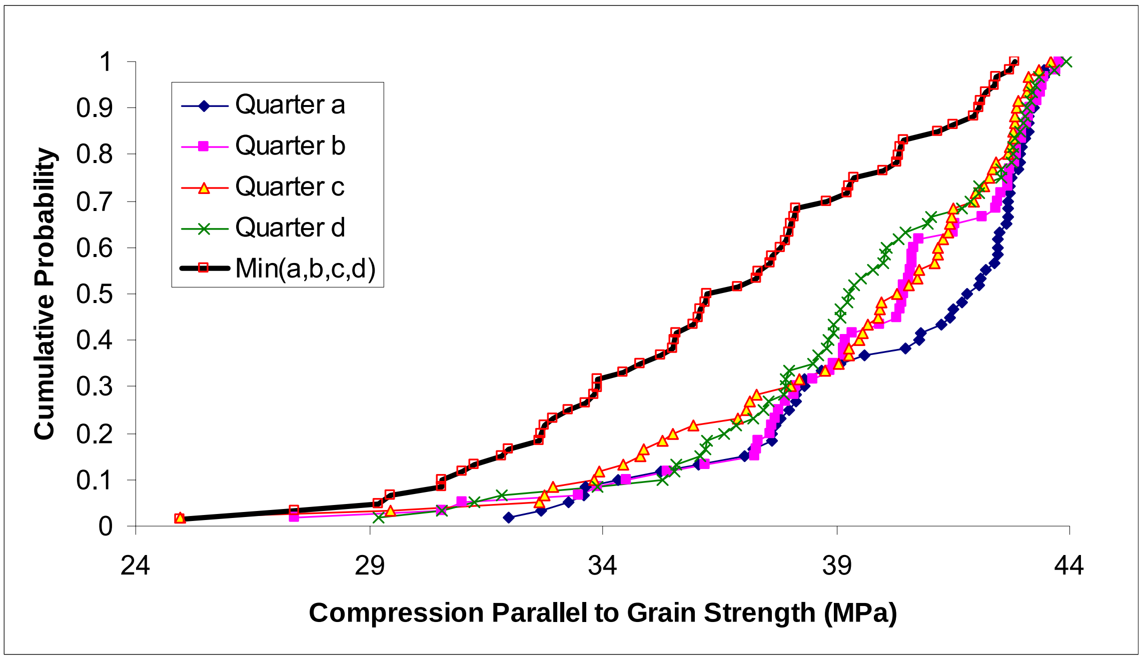
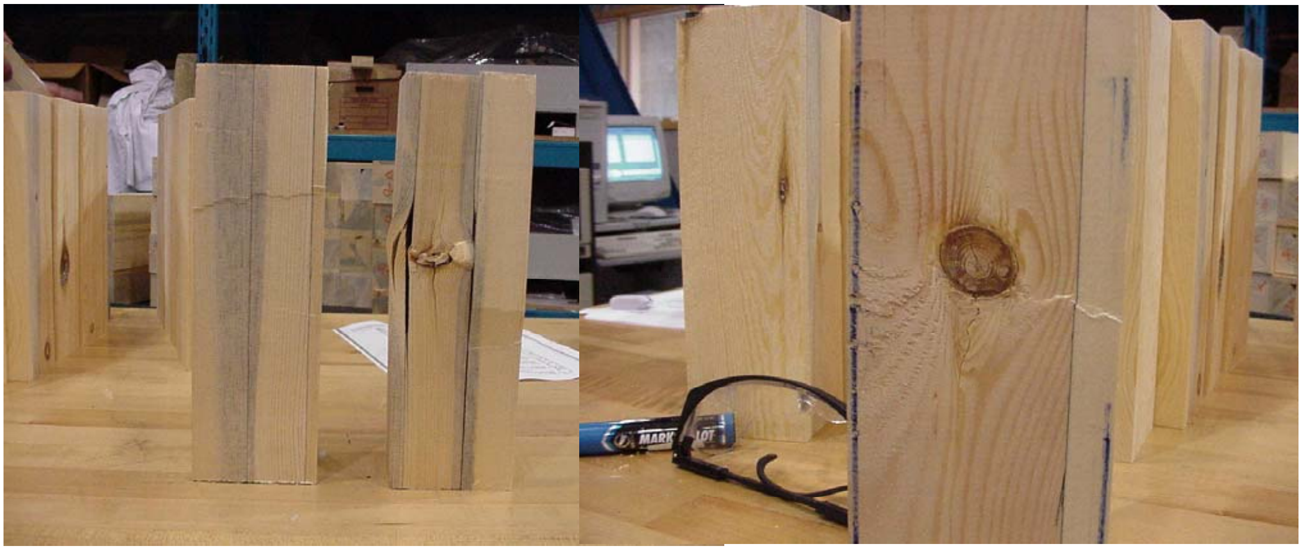


Figure 12. Typical failure mode of compression parallel to grain strength tests



Analytical results

To determine the dimension of glued laminated posts, the commercial finite element program, ANSYS, was used to predict MOE. The original trial cross-section was chosen as that in Figure 13. Material properties came from Jessome (1977) and Forest Product Laboratory (199p9), as follows:

$$E_L = 11400\,\text{MPa},\ E_R = 0.102E_L,\ E_T = 0.068E_L$$

$$G_{LR} = 0.049E_L,\ G_{LT} = 0.046E_L,\ G_{TR} = 0.005E_L$$

$$\nu_{LR} = 0.032232, \nu_{LT} = 0.023596, \nu_{RT} = 0.3127$$

Grain-orientation angles were selected so that the member would experience maximum deflection. The deformed shape is plotted in Figure 14.

Figure 13. Model used in predicting the dimension of cross-section

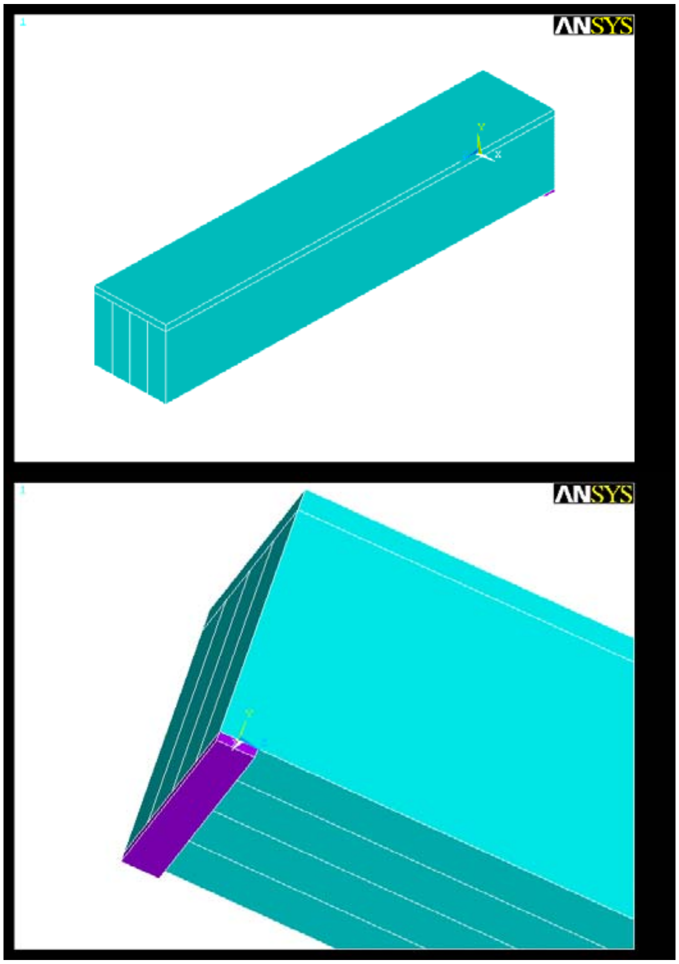
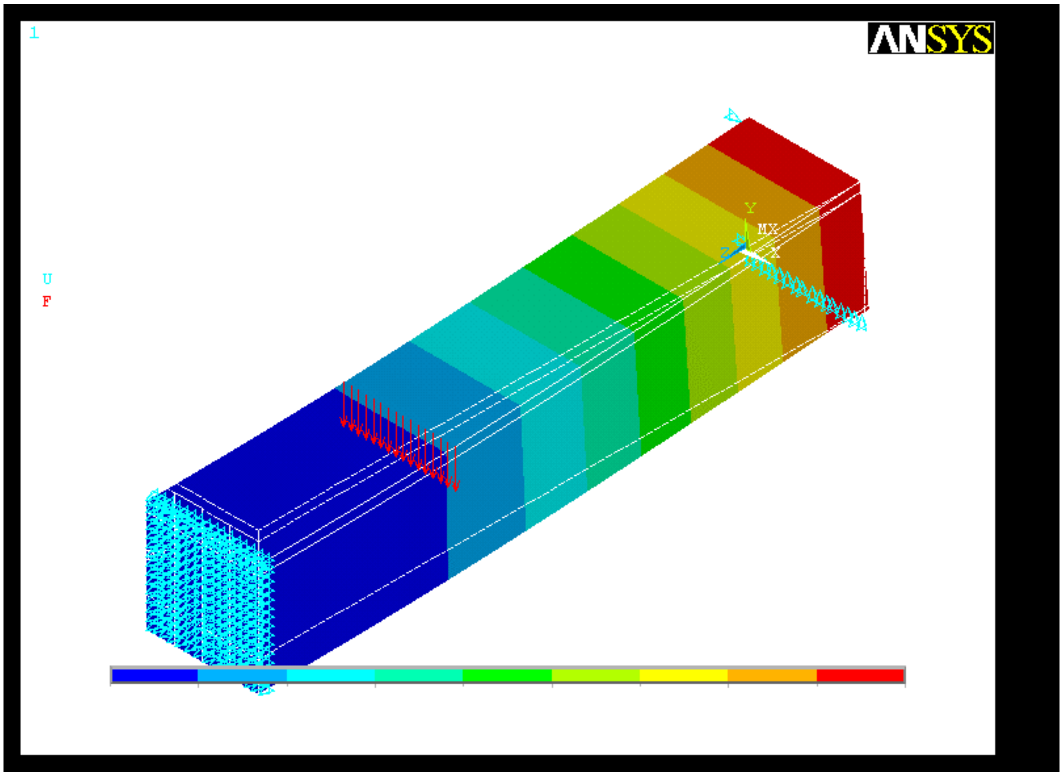


Figure 14. Deformed shape in simulating bending test

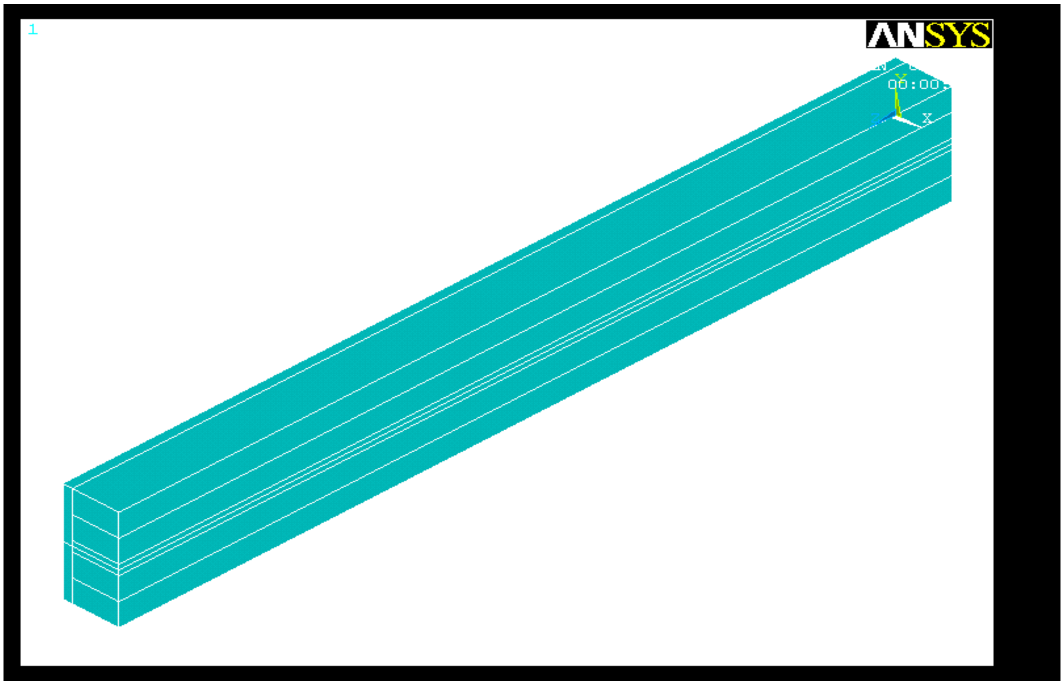


Another model for solid sawn lumber was also established to provide comparison. For it, properties of materials were chosen as (Jessome 1977; Forest Product Laboratory 1999):

$$E_L = 13600\,\text{MPa},\ E_R = 0.068E_L,\ E_T = 0.050E_L\ \ G_{LR} = 0.064E_L,\ G_{LT} = 0.078E_L,\ G_{TR} = 0.007E_L$$
$$\nu_{LR} = 0.019856, \nu_{LT} = 0.02245, \nu_{RT} = 0.11183$$

Based on the calculated deformation from both models, the cross-section of 152 mm x 152 mm (6 in. x 6 in.) was selected.

Figure 15. Model used in buckling analysis



After bending tests, another model similar to the tests with real posts was established to analyze buckling load. Figure 15 shows the model for analysis. The MOE values are the same as above. Analysis gave a buckling load of 911.2 kN.

Conclusions

Sixty 152 mm x 152 mm (6 in. x 6 in.) specimens were constructed to evaluate the performance of glued laminated mountain pine beetle-infested blue-stained lodgepole pine products. These posts exhibited acceptable appearance performance. Both MOE and compression strength parallel to grain of these posts are superior to Select Structural post- and timber-grade Douglas-fir posts. This implies that, in terms of structural performance, it may be possible to substitute Douglas-fir posts with glued laminated blue stained mountain pine beetle lodgepole pine posts.

The MOE test results in the two orthogonal directions did not show a significant difference; thus, orientation of cross-section is not important for construction. Based on the tested MOE and compression parallel to grain strength values, the design load for any length of posts can be determined from the buckling design curve in the codes, such as that listed in NDS code (national design specification; AFPA 2001).

Acknowledgements

This project is funded by the Government of Canada through the Mountain Pine Beetle Initiative, a six-year, $40 million program administered by Natural Resources Canada, Canadian Forest Service. Publication does not necessarily signify that the contents of this report reflect the views or policies of Natural Resources Canada, Canadian Forest Service.

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This publication is funded by the Government of Canada through the Mountain Pine Beetle Initiative, a program administered by Natural Resources Canada, Canadian Forest Service (web site: mpb.cfs.nrcan.gc.ca).

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