Technical Note

# Properties of Bamboo–Wood Hybrid Glulam Beams

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## Abstract

Bending and shear characteristics of bamboo–wood hybrid glulam (BWHG) beams were investigated to evaluate the possibility of using laminated bamboo lumber (LBL) as a lamstock for glulam beams in structural application. Moreover, two different resin types were also evaluated for bamboo–wood bond strength. Isocyanate-based resin performed better in terms of bond performance and resulted in higher bending strength and comparable stiffness to that of phenol-resorcinol-formaldehyde resin. The BWHGs performed better than the reported values on Douglas-fir (*Pseudotsuga menziesii*) glulam beams. Initial results indicate there is potential for LBL to be used as lamstock for glulam beams, which should be investigated further.

Bamboo has gained popularity in the green building community because it is a renewable, natural, biodegradable, and fast-growing material with low embodied energy (van der Lugt et al. 2006). Bamboo in its natural form is a hollow tubular structure and is highly efficient in resisting bending forces due to its high moment of inertia per unit cross-sectional area. However, this is also the largest impediment to the use of bamboo in engineered construction because it causes difficulty in making connections. To mitigate this difficulty, laminated bamboo lumber (LBL) was introduced. LBL resolves the identified deficiencies in the natural shape of bamboo because it is formed in rectangular sections that are more suitable for use in traditional structural applications. LBL involves gluing together bamboo strands in various forms to create rectangular cross sections that are similar to conventional lumber in shape and size. The processing of LBL is covered in more detail in Lee et al. (1998) and Nugroho and Ando (2001). Studies have reported higher bending and tensile properties of LBL compared with most softwoods (Madhavi et al. 2011, Sinha et al. 2013). The higher tensile and bending properties of LBL present an opportunity for them to be used as tension and compression laminates in a glulam beam. In this study, to investigate the possibility of using LBL in softwood glulam beams, properties of hybrid glulam beams were studied. Moreover, two different resin types were used to manufacture the hybrid glulam, and their performances were investigated.

## Materials and Methods

Laminated bamboo lumber with dimensions of 38 by 142.5 by 2,464 mm was procured from a manufacturer in China. The species of bamboo used to make the LBL was Moso (*Phyllostachys pubescens* Mazel ex J. Houz). LBL is made by gluing together strands of bamboo to form rectangular cross sections similar in shape and size to conventional lumber. This is a four-step process. First, tubular bamboo sections are ripped through the length to form strands, which are then passed through a planer. Second, the strands are edge glued into small rectangular sections called slats using emulsion polymer isocyanate. The slats are typically 6.4 by 19 by 2,464 mm. Slats are then laminated either horizontally or vertically to form a row. In this study the slats were laminated vertically. Finally, two rows are laminated together to form a 38 by 142.5 by 2,464-mm LBL (nominal 2 by 6-in. LBL) void of end joints. The specific gravity of LBL was 0.69. No butt or finger joints were used to produce the LBL. Three L2 grade Douglas-fir (*Pseudotsuga menziesii*) studs measuring 38 by 142.5 mm (nominal 2 by 6 in.) and two pieces of LBL were laminated together in such a way that top and bottom laminates were LBL while the core laminates were Douglas-fir. As a result, the LBLs made up the compression and tension lam for a bamboo–wood hybrid glulam (BWHG). Two of those beams were laminated using phenol-resorcinol-formaldehyde (PRF) resin (5210J resin with 6310L hardener produced by Momentive Glue Company), while an additional two beams were laminated using a formalde-

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Forest Prod. J. 62(7/8):541–544.

Table 1.—Bending and shear properties of bamboo–wood hybrid glulam beams tested with two different resin types.[a]

| Specimen details | | | Bending properties | | Shear characteristics | | | |
|---|---|---|---|---|---|---|---|---|
| Specimen | Resin type | Length (mm) | MOE (GPa) | MOR (MPa) | Shear strength (MPa) | % bamboo failure | % adhesive failure | % wood failure |
| H1P | PRF | 2,464 | 10.00 | 58.12 | 6.61 | 5 | 10 | 85 |
| H2P | PRF | 2,464 | 9.93 | 68.12 | 6.32 | 5 | 15 | 75 |
| H3F | ISO | 2,464 | 9.72 | 74.52 | 9.96 | 0 | 0 | 100 |
| H4F | ISO | 2,464 | 9.93 | 71.40 | 7.61 | 10 | 5 | 85 |
| H5F | PRF | 4,880 | 11.93 | 45.76 | 6.94 | 0 | 10 | 90 |
| H6P | ISO | 4,880 | 11.51 | 51.94 | 10.00 | 0 | 10 | 90 |

[a] MOE = modulus of elasticity; MOR = modulus of rupture; PRF = phenol-resorcinol-formaldehyde; ISO = isocyanate.

hyde-free isocyanate resin (GT20 with a GT205 hardener produced by Purbond). Both these adhesives met AITC 405-2005 (American Institute of Timber Construction 2005) requirements for use in glulam application. These beams were manufactured using a static pressure of 690 kPa for 6 hours at a glulam manufacturing facility in Eugene, Oregon. After pressing, the beams were planed to dimensions of 133.5 by 190 by 2,464 mm. Two additional BWHGs 4,880 mm long were manufactured using PRF resin for lamination. The dimension lumbers were finger jointed to achieve the requisite length. The finger joints were staggered throughout the length of the beam. Beams were conditioned in a standard room (20°C and 65% relative humidity) for 4 weeks until the variation in weight for the beams stabilized. The beams were tested at an average of 11 percent moisture content.

## Bending test

All the BWHGs were tested in third-point bending using ASTM D198 (American Society for Testing and Materials 2009) to characterize their flexural properties and identify failure patterns. The span-to-depth ratio was 13:1 for the beams 2,464 mm long, while a 21:1 span-to-depth was used for 4,880-mm-long beams. Table 1 identifies the type of beams tested and the resin system used to manufacture those beams. A 220-kN StrainSert universal load cell calibrated to ±1 percent accuracy was used to measure load. Load was applied at a constant rate of 6.5 mm/min with an average time to failure of 7 minutes. The loading heads were equipped with a load evener, and both reaction-bearing plates were able to pivot. The bearing plates were 152.4 mm wide for both long-span and short-span tests. For short-span tests, the load heads at the third points were 76.2 mm wide. No compression failures were noted at the third reaction points. On the other hand, for the long-span tests, the load heads were 178 mm wide. Both tests used a full span deflection bridge placed on one side of the beam at the neutral axis. The deflections were measured using a calibrated high-resolution linear variable differential transformer to compute the slope in the load-deflection data over the initial region, i.e., 10 to 25 percent of the maximum load.

## Shear test

Specimens from the BWHGs were cut and tested for adhesive bond strength properties using compressive loading following ASTM D905 (2011a). Specimens were cut from the end of the BWHGs tested in flexure from either end and prepared with a bond line area of 63.5 by 76 mm between bamboo and wood. As a result, two specimens were obtained from each BWHG for shear test. Specimens were conditioned for 7 days at 20°C and 65 percent relative humidity. All bond line areas were measured with digital calipers accurate to ±0.001 inch. Specimens were loaded at a rate of 5 mm/min using a 100-kN load cell calibrated to ±1 percent accuracy using a shear block setup. The average moisture content at the time of testing of the specimens was 11 percent. Shear failure was evaluated following ASTM D5266 (2011b) and characterized as adhesive failure, bamboo failure, and wood failure.

## Results and Discussion

Table 1 shows the bending and shear properties of the BWHGs tested. The shear properties are the average of two tests for each BWHG specimen obtained from either end. The modulus of elasticity (MOE) for BWHG beams with both resin types was comparable. However, the modulus of rupture (MOR) was higher for BWHG with isocyanate resin. Figure 1 shows the load-deflection diagram for PRF resin as well as isocyanate resin. The constitutive behavior depicted in Figure 1 reinforces the fact the both types of beams had similar MOE, while the MOR for isocyanate resin was higher. These results are only suggestive, because statistical significance cannot be evaluated with the sample size at hand for this study. Corresponding shear strength of an isocyanate bond was considerably higher than that of a PRF bond (Table 1). Higher shear strength of the isocyanate bond is accompanied by less visible adhesive failure and a higher percentage of wood failure in the tested bond line. The

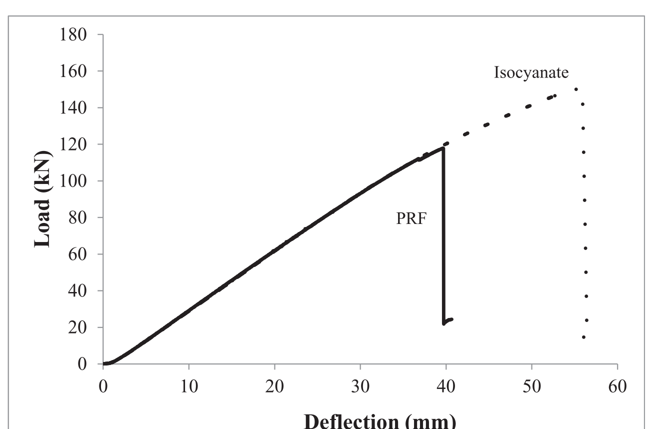


Figure 1.—Load-deflection diagram for bamboo–wood hybrid glulam beams laminated using two different resin types: phenol-resorcinol-formaldehyde and isocyanate.

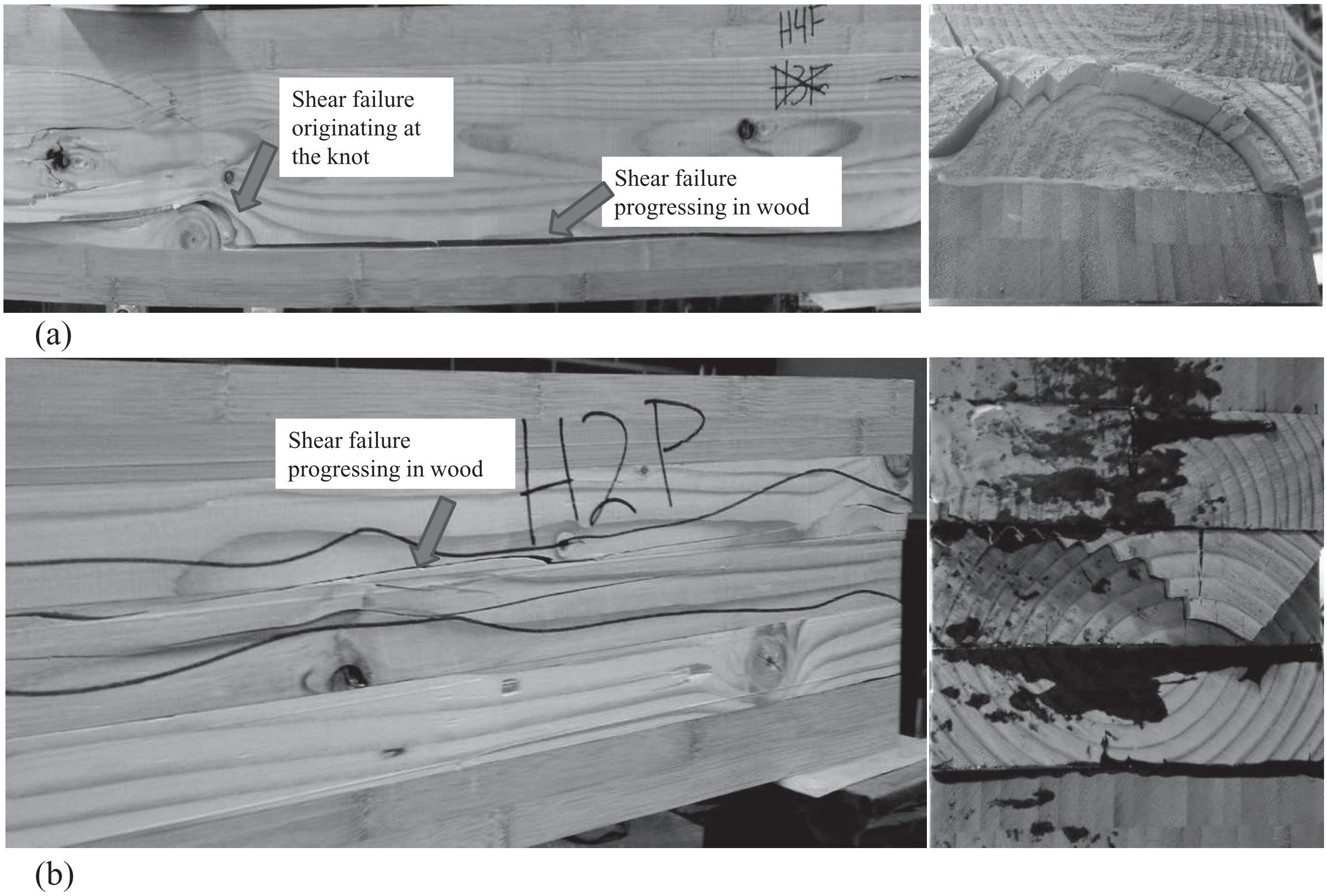


*Figure 2.—Typical failure pattern dominated by shear in wood in bamboo–wood hybrid glulam beams. (a) Shear failure in bamboo wood hybrid glulam (BWHG) with isocyanate resin; (b) shear failure in BWHG with phenol-resorcinol-formaldehyde resin.*

results indicate that the isocyanate resin performed better than PRF resin in a bamboo–wood bond for stress transfer between two laminates. The higher capability of stress transfer resulted in higher strength of BWHGs manufactured using isocyanate resin. A similar trend was observed in the longer span BWHGs. The isocyanate bond performed better than the PRF bond as demonstrated by its higher average shear strength (Table 1) with similar failure patterns (90% wood failure). Similarly, the MOR for longer span BWHG manufactured using isocyanate resin was higher than that of BWHG manufactured using PRF resin.

The bending characteristics of softwood glulam (Douglas-fir) beams are reported as average MOE and MOR of 13.6 GPa and 40.7 MPa, respectively, in Chapter 12 of the *Wood Handbook* (Cai and Ross 2010). All the BWHGs tested in this study, irrespective of the resin type, had a higher strength than that of their softwood counterpart. However, the MOE values were lower than the reported softwood glulam MOE values. Comparing the bending characteristics of shorter and longer beams, it is observed that the shorter BWHGs had a higher MOR than the longer ones. This is expected because the longer the beam, the greater the probability of a strength-limiting defect being present in the beam. Further, the short span-to-depth ratio on a couple of occasions led to failure in longitudinal shear. The longer BWHGs were manufactured with a finger joint in the Douglas-fir lamina because the available raw material comes in 2,440-mm lengths. The finger joints are not necessarily defects, but they reduce the strength of a beam considerably (Bustos et al. 2003). The MOE values for the longer beams are higher than those of the shorter BWHGs. The reason for this discrepancy could be the span-to-depth ratio used in testing the shorter BWHGs (13:1). This span-to-depth ratio induces higher shear force and increases the deflection due to shear. Following the recommendation of Cai and Ross (2010) to add 10 percent for shear correction in MOE values, we observe the values for both longer and shorter BWHGs are comparable.

The higher shear induced in the shorter BWHGs was also illustrated by their failure method, which was predominantly shear within the wood. In most cases shear caused failure to begin near a defect in wood and then propagated to cause entire BWHG failure. A few examples of shear failure in wood in shorter BWHGs are presented in Figure 2. As an example, in Figure 2a, a shear failure originated at a knot in the wood and then propagated toward the ends causing the BWHG beam to fail. For the longer beams, one of the longer BWHGs failed first in the LBL at nodes in individual slats, then progressed into shear failure along the Douglas-fir–LBL interface, and then propagated into Douglas-fir typically at a finger joint. The second longer BWHG also failed first at a finger joint in wood, and then the failure propagated throughout the wood in shear.

## Conclusions

This study investigated properties of BWHGs in order to gain insights into the potential application of laminated bamboo lumber in glulams. The BWHGs performed very well strengthwise when compared with its all-wood counterparts. In contrast, the MOE values were lower than those of wooden glulam beams. There were indications that the isocyanate resin performed better than PRF resin in bonding wood and bamboo and subsequently influenced the strength values of the glulam beams. The results indicate that there is a tremendous potential for using LBL as a lamstock in glulam beams. However, more testing is needed to ascertain its effect on other crucial properties and long-term performance.

## Acknowledgments

The support of Mike Pullen of Bamboo Revolution is immensely appreciated. Furthermore, the authors would like to thank Danny Way for his help in the laboratory.

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