New Opportunities for Fiber Reinforced Glued-Laminated Beams

By Paul C. Gilham, S. E. and Thomas Williamson, P. E.

Fiber reinforced glued-laminated (glulam) beams have been in use since the early 1990s. With this technology, high-strength fiber-reinforced polymers, commonly referred to as FRP, are adhesively bonded to glulam timber beams to increase the bending strength and stiffness of the product. The addition of a relatively small percentage of FRP results in beams that are less expensive, use less wood resource and have lower strength and stiffness variability than conventional un-reinforced glulam members. Today, there is increased interest in using this technology within the laminating industry. Recent developments include the adoption of an ASTM standard for establishing strength and stiffness values for the product, and an Acceptance Criteria that defines the procedures for developing design values for the product. These two documents will greatly simplify the ability of laminators to obtain an International Code Council (ICC) evaluation report.

History of Development

Reinforced glulam beams were developed by Daniel Tingley, P. Eng. in the early 1990s. Tingley teamed with American Laminators of Drain, Oregon and Oregon State University to develop the design model for FiRP® GLULAMS. This development included issuance of ICBO Acceptance Criteria AC102 in 1994. More than 700 beams were tested to failure in accordance with the acceptance criteria, culminating in the issuance of the ICBO evaluation report ER 5100 in September 1995. With this report, reinforced GLULAM beams have been designed and installed in more than 300 timber bridges and buildings. American Laminators continues to produce these reinforced beams with the technology covered under ER 5100.

Shortly after ER 5100 was issued, competing technologies began to be developed at several universities including West Virginia University, the University of Wyoming and the University of Maine. The new ASTM standard, D7199, defines the requirements for calculating characteristic values for the strength and stiffness for each new technology based on the use of mechanics-based modeling. Today, the technology developed at the University of Maine, in conjunction with APA – The Engineered Wood Association, is being evaluated by several laminators in anticipation of pursuing ICC Evaluation Reports.

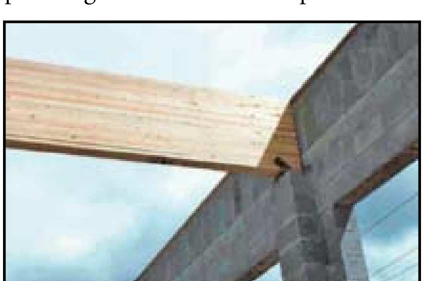

Figure 1: Reinforced glulam used in a roof beam of a commercial building

Description of FRP Glulam Beams

In a FRP glulam beam, one or more panels or layers of fiber-reinforced polymer are adhesively bonded into the beam in the zones stressed in tension. The panels are typically manufactured to the same widths as conventional glulam members. These panels have high tensile strength and very high stiffness compared to the wood in the beam. For example, an aramid-reinforced panel has a tensile strength of 143,000 psi and a modulus of elasticity of 10,500,000 psi. This compares with a modulus of rupture of 12,400 psi and a modulus of elasticity of 1,950,000 psi for small clear samples of Coast region Douglas fir.

The addition of roughly one percent of a fiber reinforced polymer panel to a glulam beam increases the overall stiffness of the member based on the transformed section. More importantly, the bending strength is significantly enhanced because the FRP panel contains no strength-reducing growth characteristics. Strength-reducing growth characteristics, such as knots and slope of grain along with end-joints in the laminations, significantly affect the strength of glulam beams. The addition of the reinforcing panel(s) allows much higher stresses to develop in the tension zone of the beam before failure. The reinforcing can be seen in the beam in *Figure 1* between the bottom and second lamination. It typically appears as a wide glue line.

Advantages of Using FRP Glulams

As stated earlier, there are significant advantages to using FRP reinforced glulam when compared to conventional glulam beams. One key advantage is lower cost. A reinforced glulam beam is smaller than an equivalent conventional member. Typically, the reinforced member can be one width narrower and several laminations shallower than the conventional beam of the same design capacity and carry the same load. Most often, the decrease in the amount of wood fiber used more than offsets the cost of the reinforcing added to the member.

The use of FRP glulams makes even more sense when considering the "green" building implications. By using these members, the amount of timber resource needed to complete a project is reduced significantly. This is an important consideration for sustainable construction. Currently, FRP glulams are not recognized by the organizations that accredit green building such as the LEED or Green Globes certification programs. However, as they become more common, it follows that they will be recognized and encouraged by these organizations.

And, from an engineering perspective, the FRP reinforced glulam members have significantly lower variability than conventional glulam beams, leading to more predictable performance. The addition of the fiber reinforcement adds enough strength in the tension zone to significantly reduce the number of initial failures in the tension zone of the beam. The manufacturing of the reinforcing panel is highly controlled so that the strength of the material is uniform along its length. With a moderate amount of reinforcing, the tension failures are precluded and the failure in the beam is a compression failure. With compression failures, the fibers in the beam buckle in compression, resulting in a ductile failure mode, which is preferable to a more brittle failure mode as would typically be associated with a tension failure.

continued on next page

	Beam Size (inches)	Weight	Cost (less freight)
Main Gym – Six girders 106 feet long, 28 feet on center			
Conventional Beam	14¼ x 90	33,040 lbs. each	$15,430 each
FRP Beam	10¾ x 75	20,770 lbs. each	$12,665 each
Small Gym – Three girders 78 feet 6 inches long, 26 feet 6 inches on center			
Conventional Beam	12¼ x 70½	16,475 lbs. each	$7,835 each
FRP Beam	10¾ x 57	11,690 lbs. each	$7,130 each
Natatorium – Three girders 91 feet 6 inches long, 27 feet on center			
Conventional Beam	12¼ x 81	22,070 lbs. each	$10,490 each
FRP Beam	10 ¾ x 64½	15,420 lbs. each	$9,400 each

Table 1: Comparison of conventional and FRP beams at WWU Student Recreation Center

Finally, since the moment capacity of the beam is increased, the governing design limit often becomes deflection. This adds safety to the member because if an overload condition occurs, the result is a potential deflection in excess of the design limit (a serviceability deign limit) as opposed to a bending overstress, which is a strength design limit.

Case History at Western Washington University

A good example of the benefits of using a reinforced glulam beam can be found at the Student Recreation Center constructed at Western Washington University in Bellingham, Washington in 2002. The facility required large clear-spans for the two gymnasiums and the natatorium. The largest gymnasium required six main girders with a span of 107 feet 6 inches. The second gymnasium and the natatorium had smaller spans. *Table 1* shows the differences between using a reinforced member and a conventional beam for each of these beams.The total cost savings on this job was nearly $22,000 for the beams alone. The reduction in weight reduced the freight by six truckloads. This added an additional savings of close to $6,000, since these were over-length loads requiring special permits and pilot car escort. And, since the beams are lighter, additional cost savings in foundations may also result.

Reinforced glulam girders at WWU main gymnasium. Courtesy of KPFF Consulting Engineers.

Recent Developments

ASTM recently issued Standard D7199, Establishing Characteristic Values for Reinforced Glued Laminated Timber (Glulam) Beams Using Mechanics Based Models. This standard allows a developer of a reinforcement technology to calculate the characteristic values for bending strength and stiffness using a mechanics-based model. The standard also provides the minimum test requirements needed to validate the model. The developer will be able to establish design values for their product from the characteristic values obtained using the standard. This is a significant achievement, since there are several technologies available to manufacture these beams. The ASTM standard creates a unified approach to establishing the characteristic values for each technology. This document also describes the minimum durability requirements for reinforced glulams. This is a major step in gaining code approval for the product.

A second development was the completion of the ICC Acceptance Criteria AC280. This document prescribes the method for a laminator to establish design values for the reinforced beams based on their own mechanics-based model. The document also includes the procedures for qualifying a reinforcement. Based on the application of the principles of this document, the laminator will be able to obtain an ICC evaluation report.

Since there are many types of FRP reinforcements and different mechanics-based models, it is important that all developers of this technology meet an industry agreed-upon set of conditions when obtaining the necessary code approvals. With these two documents, the industry has established a clear pathway for developers of the technology to obtain a code approval that meets the consensus requirements of the timber industry.

Future Possibilities

The glulam industry will be able to use this technology in a number of ways. Currently, FiRP® technology is used to design custom beams. With this technology, each beam is designed to meet the load requirements of the structure. The amount and placement of the reinforcement is calculated for the required load cases. This method is analogous to the design of a reinforced concrete beam. The amount of FRP reinforcement can be increased or decreased, depending on the strength and stiffness requirements for the beam much like reinforcing steel can be added to a concrete beam to increase its capacity.

A second option is to use the technology to develop a series of high-strength beam lay-up combinations that would prescribe the grade of lumber and inherent design properties of the FRP to be used, and thus preclude the need to custom design each lay-up. For example, a beam with a bending strength of 3000 or 3200 psi and a modulus of elasticity of 2.0 x 10^6 or 2.1 x 10^6 psi can be used to compete with the structural composite lumber beams currently on the market and more readily compete with steel beams. And even higher bending strengths are foreseeable as the FRP industry evolves and new products reach the marketplace.

Finally, the technology can be used to develop beams comparable to conventional glulam members while using less expensive, lower-grade lumber. In this scenario, lumber from weaker species, such as Spruce-Pine-Fir, can be reinforced to provide equivalent strength and stiffness as a Douglas Fir 24F-V4 or Southern Pine 24F-V3 member, both commonly specified glulam lay-ups.

Conclusion

Fiber-reinforced glulam beams have been in use for more than a decade. With this technology, Fiber Reinforced Polymer (FRP) panels are integrated into glulam beams to provide increased strength and stiffness. Reinforced beams are smaller and cost less than an equivalent conventional glulam, particularly when compared to the large beams commonly required in commercial building construction and bridge applications. Recent completion of ASTM standard D7199 and ICC Acceptance AC280 pave the way for increased acceptance of these beams in the marketplace.▪

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