Commercialization of FRP reinforced glulam beam technology
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ABSTRACT
Thin laminates made of high-strength pultruded fiber reinforced polymers (FRP) have been developed to reinforce glue-laminated timber (glulam) beams. The FRP reinforced glulams are significantly stiffer, stronger, and have less variation in bending strength than a conventional (unreinforced) glulam of equal size. Following the technical development and model building code approval of design procedures, a commercialization effort focused primarily in North America and Europe has been undertaken. The commercialization process of this new FRP reinforced glulam has had mixed success. This paper describes the recent experiences that both helped and hindered FRP glulam commercialization. The discussion includes the effect of exclusive agreements and the negative price perception that has resulted, differences in the way North American and European glulam markets operate and the subsequent effect on FRP reinforced glulam penetration. Commercial acceptance of this new product has been easier in Europe compared to North America, and reasons for this are explored.

INTRODUCTION
Thin laminates made of high-strength pultruded fiber reinforced polymers (FRP) are increasingly being used to reinforce glue-laminated timber (glulam) beams, creating a new composite glulam significantly stronger and stiffer than a conventional (unreinforced) glulam of equal size. The FRP laminates are composed of tensioned high-strength pultruded synthetic fibers embedded in a polymer matrix, resulting in a thin FRP panel of appropriate width and length suited for glulam manufacture using traditional gluing and clamping procedures. These FRP panels are typically used as tensile reinforcement, similar in concept to steel rebar used to reinforce concrete beams. The FRP panels are much stronger than wood and even steel. The design tensile stress of FRP panels about 18-70 times greater than that of wood, and the tensile modulus of elasticity is about 4-10 times greater than that of wood. Furthermore, FRP-wood composites have overcome material compatibility problems that metal-wood composites have had, and the resulting composite member is less variable in bending strength. Thus, from a structural engineering standpoint the FRP reinforced glulam has many advantages over its conventional (unreinforced) counterpart.

Commercialization efforts using the FRP reinforcement technology have been underway for the past five years in North America and Europe and this paper will discuss those efforts, from initial technological development to current commercialization successes and failures.

DEVELOPMENT OF FRP REINFORCED GLULAMS
The inventor of the FRP reinforced wood technology is Dr. Dan Tingley. Tingley has conducted extensive research into the many aspects of FRP reinforced wood, particularly with glulams (1994; 1996; 1997) and owns over 24 patents worldwide and the FiRP® Trademark.

After more than 65 years, the economic and strength factors that have made glued-laminated timber (glulam) a popular engineered wood composite have been significantly improved upon. Glulam reinforced with FRP is a new form of the glulam product. In North America the FRP reinforced glulam is manufactured commercially under the trade name FiRP® Glulam by American Laminators, Inc. and Duco-Lam, Inc. both of Drain, OR, and Structurlam Products, Ltd. of Penticton, B.C. Other glulam manufactures are now qualifying their plants for use of this new technology. The FRP

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reinforced glulams are certain to have an impact on the future of the glulam industry as well as the use of wood composites in infrastructure and building construction.

As the FRP reinforcement technology developed, it became clear to the project staff that the test data would support a major change in design philosophy. The new FRP design method is compression-based, similar to that used for reinforced concrete, and thus is a radical departure from that conventionally used for timber, which is tensile-based. Evolution of the FRP technology led to the development of a worldwide first-of-a-kind method for establishing and monitoring allowable design values for high-strength fiber-reinforced plastics. This method is now approved by the International Conference of Building Officials Evaluation Service (ICBO ES), and is detailed in Evaluation Report (ER) number 5100 (ER-5100).

Through their cooperative efforts, a consortia of academic, manufacturing and engineering partners led by Tingley and the Wood Science & Technology Institute, Ltd. successfully brought the FRP technology from concept through prototype testing, refinement, submission to and approval from ICBO. The code approval process was accomplished in 12 months from the date of the first approval of an acceptance criteria (AC102) to ICBO to issuance of ER-5100, upon approval by ICBO ES staff. The approved evaluation protocol, developed to demonstrate the design method as well as the technology, required the testing of more than 700 full-sized glulam beams. These beams represented the major commercial wood species in the U.S. and Canada and the complete range of anticipated sizes and reinforcement strategies.

The FRP reinforcement technology has gained recognition in numerous civil engineering publications such as *ASCE News*, *High-Performance Composites*, and *Civil Engineering*. This technology also has been discussed in a variety of technical papers and forums, such as the 1994 Pacific Timber Engineering Conference, 1994 Western Bridge Engineers’ Seminar, 1995 Structures Congress XIII, the 1995 10th International Conference on Composites Materials, the 1997 International Conference on Engineering Materials, the 1998 Structural Engineers World Congress, and many others (Leichti et al., 1994; Tingley, 1994; 1996, Tingley et al. 1997). On February 5, 1996, FRP reinforced glulams were awarded the CERF (Civil Engineering Research Foundation) Charles Pankow Award for Innovation in Washington, DC at its International Research Symposium: *Engineering and Construction for Sustainable Development in the 21st Century*. In the spring of 1997 the Construction Innovation Forum (CIF) awarded the FRP glulam technology the NOVA award. In addition the B.C. Technologist Association awarded an innovation award to Tingley for the FRP technology in the spring of 1997.

The FRP technology applies to a wide range of structural composite lumber (SCL) members including laminated veneer lumber (LVL), I-beams, and structural solid sawn lumber. Reconstituted wood fiber structural products such as Parallam® can also be reinforced. Many structural products, representing nearly 400 billion U.S. dollars in sales annually worldwide can be reinforced using FRP Technology. Currently various SCL production applications for the FRP technology are being developed and licensed around the world.

**APPLICATION AND DEVELOPMENT OF FRP REINFORCED GLULAMS**

**Applications**
The FRP reinforced glulams have many potential structural applications, i.e., residential, commercial, and infrastructure uses, and are particularly well suited to structures wherein dead load is a large component of the total design load, i.e., bridges and domes. Another growing application of FRP reinforcement is to upgrade load capacity or retrofit existing under-designed or decayed structures.

**Low variability**
The FRP reinforced glulams are less variable in stiffness and strength, and thus can be considered more reliable than conventional glulams. This consistency gives the design engineer increased comfort with the design application and improves the construction process. The uniformity of stiffness means that girders can be expected to behave similarly. For example, at Clallam Bay, WA, on Route 112, an HS-25 rated highway bridge with two 24.7-m (81-ft) spans was constructed in 1996 using FRP reinforced glulam girders. Once the girders were set in place, the initial deflections of the six main girders differed by less than 2.5 mm (1/10-inch). This consistency resulted in less time being spent by the construction crew installing and adjusting the members. Ultimately, this uniformity should also benefit the wear surface because the bridge will flex more uniformly.
Improved utilization of the wood resource
The supply of timber for high-grade tensile laminae used in the manufacture of glulams has decreased significantly in recent years with a corresponding price increase. The FRP reinforcement used to reinforce glulam beams has had and will have an impact on the wood products industry with the potential to affect the wood framing market in the same way that reinforcing rebar changed the concrete industry.

The FRP reinforced glulam is designed with single grade lay-ups of lower grade materials, substantially diminishing the weight and, therefore, requiring fewer chemicals for preservative treatment (when necessary), lowering transportation costs, reducing superstructure weight and minimizing foundation requirements.

The FRP reinforced glulam has the potential to extend the use of raw materials through enhanced use and performance. This offers increased productivity, performance and reliability. In addition, the FRP reinforced glulam uses between 25 and 40 percent less wood and lower grades of wood, leading to substantial savings. This results in a major environmental advantage as the beams are produced from a renewable resource coming from forests that are being replanted at a rate of 6 million trees daily, assuring that the supply will never be exhausted. It also reduces waste in wood fiber, pollution, and energy usage. The FRP reinforced glulam does all this as well as having the ability to carry the same loads as conventional glulams, using smaller sections, fewer materials and lower grades.

With its favorable economics and excellent performance, it is reasonable to believe that FRP reinforced glulam will become the conventional glulam of the industrialized nations in the near future.

COMMERCIAL SUCCESS OF FRP REINFORCED GLULAMS
Commercial success of the FRP reinforced glulam has been hindered by an early exclusive marketing agreement, and a complicated glulam supply-distribution process involving many different and separate entities that are unwilling and economically unable to change the current process. Since the acceptance of FRP reinforced glulams has been so different in North America and Europe, a comparison of the general North American and European glulam supply process is warranted.

The effect of exclusive agreements
Prior to 1997, an exclusive agreement for using and manufacturing the technology existed in North America with one company. In the early stages of the FRP reinforced glulam development the exclusivity was needed to justify the high cost of application development necessary to enter the structural products marketplace. The effect of this exclusivity, led to pricing of the FRP reinforced glulams marginally under the cost of conventional glulams, to maximize profits. Thus, the industry has come to believe that the cost competitiveness of FRP reinforced glulams was marginal. Secondly it led to a lack of interest in developing alternative less costly wood lamination stock and thereby continuing to drop FRP reinforced glulam cost and subsequent market price.

North American supply process
In the current North American system, there was not an easy entrance for FRP reinforced glulams. The current North American system, as shown in Figure 1, shows the many different entities required in completion of a project. The early approach to marketing FRP reinforced glulam technology was to go directly to the glulam manufacturers to encourage the use of FRP reinforcement technology, but most manufacturers do not have engineers on staff and do not see the projects until bid stage. Even though FRP reinforced glulam can compete with steel prices, by the time a project has been tendered; the building material has already been selected and designed. Because of this the owners were not willing to pay additional money to redesign the building with less expensive material, due to the increase in time and additional engineering costs. Additionally, projects that could be built less expensively using FRP reinforced glulams were not necessarily less expensive using conventional glulams and therefore were never seen by the glulam manufacturers.

In order to market FRP glulams more effectively the marketing strategy required a pull through approach versus a push through. Thus, FRP glulams are currently being marketed down the supply chain, for example to the roof erectors with much greater success.
Roof erectors usually have the opportunity to redesign the roof with a system that is cheaper and easier to construct. They can provide value engineering, meaning the owner and the roof erectors split the savings in cost between the two roof systems, FRP glulam and steel or FRP glulam and conventional glulam. This is important because many roof erectors prefer to construct FRP reinforced glulam roof systems as opposed to steel systems because they can use less skilled labor, the members are typically lighter and easier to handle, and the members can be easily altered on the job site.

Naturally, the ideal way to get FRP reinforced glulams into the market is through the owner, who best appreciates the cost savings, but in most cases the owner is not interested in the building material, and is left unaware of FRP reinforced glulams. Another way into the market is to have the original design completed using FRP reinforced glulam. However, many engineers are not aware or are unsure of the existence of FRP reinforced glulams or how to design them. To raise engineer awareness many design seminars to teach engineers how to design FRP reinforced glulams have been conducted. These design seminars have resulted in mixed success since engineers do not yet see the value and supply availability of FRP glulams. Thus creating awareness and use in the marketplace for FRP glulams is difficult and complicated.

The typical North American process from start to finish of a structure involves many different entities as shown in Figure 1, who are usually unaware of FRP reinforced glulams, or are resistant to trying something new because the change requires effort and involves risk.

**European supply process**

Recently, FRP reinforced glulam introduction to the marketplace is having more success in Europe than it has in America. The success in Europe is due to their simplified delivery system for glulam beams that is more flexible and efficient. In Europe, it is common for one company to perform the duties of the engineer, contractor, and the glulam manufacturer, and erector as shown in Figure 2. This European process allows the projects to be designed initially with FRP reinforced glulams more easily. This same company can then provide expert labor and materials as necessary.

The level of engineering expertise within this one stop supply chain is significantly more advanced than that in North America. Thus, the FRP glulam technology is easily adopted. Further, additional value added uses are quickly identified e.g. connector benefits from FRP reinforcement panels.

Low-grade wood consumption is more important in Europe since the commercial species have lower strength and stiffness values than popular North American glulam species e.g. European Spruce vs. Douglas fir. These lower grade species such as spruce tend to have higher yield-point strain values in tension allowing greater economic advantage to be achieved with a FRP reinforcement panel.
CONCLUSIONS

The technical development of the FRP reinforced glulam, has shown that a new composite glulam can be made, that is significantly stronger, stiffer, and has less variation in strength, compared to a conventional unreinforced glulam. Furthermore, this new FRP reinforced glulam provides these significant performance increases while using lower grades of wood, and/or less wood. Since the structural performance is enhanced so significantly, while using less desired and more easily available wood material, the commercial success is not far away.

Commercialization of FRP reinforced glulams has had mixed success so far in North America, and several reasons are now identified. Exclusive agreements that have been granted have prevented price competition; thus prices were set just below the cost of conventional glulams to maximize profits. These “high” prices have allowed many in the industry to see only a marginal cost benefit by using FRP reinforced glulams.

The North American glulam design and supply process involves many different entities, which in itself makes change (i.e. using FRP reinforced glulams) difficult. It necessitates a pull through marketing program versus push through. In contrast, the European design build process involves fewer separate entities, making implementation of FRP reinforced glulams easier and allowing a push through marketing program to be more effective. The commercial growth rate of FRP reinforced glulams in Europe is surpassing that in North America.

REFERENCES


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