Glulam – Fibre Reinforced Laminated Wood Beam

1. History

The first articles that I have seen are already over 30 year old. Dr. Frederick F. Wandgaard wrote already in Forest Product Journal, June 1964 the following article *"Elastic Deflection of Woof-Fiberglass Composite Beams"*. He used unidirectional strands of fiberglass and epoxy resin. The fiberglass strands were 25 mm wide and 1.3 mm thick. He used 195 g/m^2 adhesive and the pressure was 0.12 Mpa. Pressure was maintained overnight at room temperature.

Also in Forest Products Journal February 1965 Mr. E. J. Biblis has written an article *"Analysis of Wood-Fiberglass Composite Beams Within and Beyond the Elastic Region".* He says that "The advantage of such composites from a design point of views lies in the possibility of placing the correct materials in their proper positions and hence improving structural efficiency. The purpose of his study is to test the validity of a novel (that time) theoretical analysis for wood-fiberglass composite beams in static bending.

Frank D. Spaun has studied the *"Reinforcement of wood with fiberglass"*

Prof. R. E. Rowlands has written an article in 1984, *"Fiber-Reinforced Wood Composites".* He studied ten adhesives (e.g. phenol-formaldehyde and resorcinol formaldehydes) and numerous types of fiber reinforcements. (glass, carbon and aramid). Glass-fiber reinforced Douglas-fir (18 % glass by volume) produced a 40 % stiffness enhancement and doubled the strength over similar unreinforced wood.

Prof. J. F. Davalos et al. had a presentation id 25th International SAMPE Technical Conference 1993. The title of the presentation was *"Interface Bond Strength of Laminated Wood-FRC Composite Beams"*. The outcome of this study was, that the results indicate that resorcinol formaldehyde (RF) resin is a promising wood adhesive that can be used for the production of Yellow-poplar Glulam-FRP beams. The RF adhesive provided an adequate bond strength and integrity for Yellow-poplar and E-glass-vinylester/polyester pultruded FRP profile.

Prof. Gardner et al. had an article *"Adhesive bonding of pultruded fiber-reinforced plastic to wood"* in Forest Products Journal in May 1994. In his research, combination of yellow-poplar and polyester- or vinylester-pultruded composites were bonded with resorcinol-formaldehyde (RF), epoxy, and emulsion polymer isocyanate adhesives.

Dr. D Tingley has developed High Strength Fiber Reinforced Plastic (FiRP) Glulam Technology.

In Wood Design Focus Vol. 4, Number 2, Summer 1993 Dr. Tingley has evaluated the cost of the Taylor Lake Bridge, where FiRP technology has been used. Some data: Bridge Span 24.38 m, width 1.829 m, live load 4.1 kPa and wind load 145 km/h. In the following table the a standard and FiRP technology is compared.

Item	Standard	FiRP	Saving	%
Cross-section (in)	8.75 ∗ 52.50	6.75 ∗ 46.50		-31.7
Weight/beam (lb)	10,846	7,411	3,435	-31.7
Cost of Beam ($)	8402	6187	2215	-26.3
Treatment Cost ($)	1531	1046	485	-31.7

Dr. Tingley is claiming when the total cost of the FiRP System is considered, the savings may reach 20-25%.

2. Concept

The concept is very simple – the ordinary glulam beam is reinforced with a composite laminate. The raw material of the laminate may be glass, aramid or carbon fibre. Today the price of the carbon fibre is decreasing so much that it is a realistic – cost wise – alternative.

The basic idea is to utilise good properties of the laminate and wood. The laminate is placed where it is most useful (where the most tensile stresses exists). Wood will take care of the compression and shear loads. The modulus of carbon fibre laminate is almost 10 times higher than the wood (or even more when HM carbon fibres are used).

The benefit of this concept that we can either reduce the size of the beam or with the same cross-section we are able to make longer beams. Also we are able to reduce the weight, so it will mean lower installation costs (smaller cranes, less transportation cost, faster installation etc.)

Below is the list of benefits of this concept:

- Same cross-section → bigger beams
- Same span → smaller cross-section, less wood
- Low quality wood can be used is the core part of the beam
- Lower transportation cost
- Lower installation cost

In our concept a standard resins should be used to bond wood to wood or wood to the pultruded laminate.

Different forms or reinforcement were studied (prepregs, fabrics, pultruded profiles, continuous lamination laminates).

3. New Offering

This concept was an old one, and also this idea were discussed in 70's. In the beginning we had an idea that we should develop a multimaterial laminated wood beam. One of the reasons was that Neste had phenolic resin production and also had very good connections to Exel Oy (Exel was earlier a part of Neste Composite Materials Group, but it was sold just before this project started).

The idea came from sales/marketing that could we use our resins as such in a glulam beam. R&D did first a feasibility study, where market size etc. was studied, before a technical project was started. The project had two phases, first a new feasibility one with small samples (shear tests) and after promising results a real project was started with much bigger effort.

Some remarks from the feasibility study, the market size was big enough, so sales were supporting the project.

4. Raw materials

4.1.Wood

In the project wood was almost constant, so used only high quality – strength classified wood for wood beams (classification LT40). All the samples were glued so that when samples dried the maximum strength was build (through thickness).

4.2 Resins

Because Neste is one of the biggest wood resin producers in the world, so Neste's phenolic and melamine resins were tested. Both resins could be used outdoors. Also some other adhesives were studied, for example epoxy and polyurethane.

Resins were also modified for example with silanes.

4.3 Surface treatment

Different surface treatments were studied (sand blasting, sanding, grindings, acetone cleaning etc.).

5. Project

5.1. Feasibility phase

In the feasibility phase market study were made, and first shear tests were made. In this phase we followed as much as possible real glulam manufacturing procedure (pressures, open and closed times, temperatures etc.).

Shear test results gave very promising results, because the wood failure was after few test samples in almost 100 %, so in acceptable level. Especially PRF resin gave good wood failure values, and that meant that our customer could use same resin for a standard and fiber reinforced laminated wood beams.

5.2. R&D Phase

In R&D phase bigger beams were made and also so-called delamination test were conducted. In R&D phase the maximum length of the beam that could be tested in our own lab was 3 m. So almost 20 beams with different height were made and tested.

The delamination test gave acceptable results after one week (two cycles).

In R&D also the glue amount were optimised (it should be same as in used in standard laminated wood beams).

The cross-section of the beam was from $145*180$ to $145*300$ mm^2, and the length was 3 m. Both glass-fiber and carbon fiber laminates were tested and tests gave the increase in the stiffness for 25 to 35 %. This value depends very much on the size of the beam, composite laminate thickness and raw material etc.

6. Manufacturing

The manufacturing process needs some modifications, and those modifications are acceptable according to the manufacturing experts.

7. Results and discussion

The project results show that the concept is viable. With this concept we are able to increase the stiffness by 25-35%, but it depends very much on the dimensions of the beam and also the reinforcement (alignment, raw material, fibre content).

Phenol-resorcinol-formaldehyde adhesive is a very good adhesive that bonds both wood to wood and also the carbon fibre reinforcement to wood.

The needed surface treatments is only decreasing (the laminate was already sanded).

Manufacturing process needs minor adjustments.

The project is ready in R&D point of view and the next step is commercialisation process.