Enhancing Low Grade Sitka Spruce Glulam Beams with Bonded-in BFRP Rods

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Summary

The reinforcement of timber elements using fibre reinforced polymer (FRP) rods or plates is widely accepted as an effective method of increasing the stiffness of members, while at the same time reducing the variability in properties. There are many options to choose from in relation to the FRP material and one of the least documented is basalt fibre reinforced polymer (BFRP). BFRP is the reinforcement chosen in this project due to its superior properties over more commonly used FRPs. Twenty low-grade Irish glued laminated beams are reinforced with two near surface mounted BFRP rods. They are tested in four-point bending in both their unreinforced and reinforced state and the percentage increase in bending stiffness is calculated. The average increase in local bending stiffness is 16.30% with a standard deviation of 1.65%. In addition, the variability in the bending stiffness of the beams is reduced after reinforcement.

1. Introduction

This paper focuses on the short-term stiffness testing of reinforced and unreinforced glued laminated beams constructed from low-grade material. These short-term experiments form the basis of a more substantial project examining the long-term effects of such reinforced timber beams. The most common structural grade produced by Irish grown Sitka spruce is C16 grade. This low-grade Irish timber has been reinforced successfully in previous studies [1, 2] using glass fibre reinforced polymer (GFRP). The effect of externally bonded GFRP plate reinforcement and near surface mounted GFRP rod reinforcement has been shown to enhance the flexural properties of low-grade Sitka spruce. Kelly [3] examined the positive effect of BFRP reinforcement on Irish Sitka spruce glued laminated beams. Her results demonstrated the potential of BFRP as a possible substitute for GFRP. These studies on Sitka spruce show promising results, however, the long-term effects on these reinforced beams has received less attention and must be examined. In order to evaluate long-term effects such as duration of load effects and moisture effects, a comprehensive experimental programme was created. In total, thirty six glued laminated beams (98 mm x 125 mm x 2300 mm) were manufactured from Irish grown Sitka spruce. Subsequently twenty of these beams were reinforced using two 12 mm diameter BFRP rods centred 30 mm from each edge on the bottom tensile laminate. Prior to creep testing of the beams, non-destructive short-term flexural testing of the beams was carried out to provide baseline data. In this paper, results of these short-term bending tests on the unreinforced beams and reinforced beams are presented and the percentage increase in stiffness properties due to the reinforcement is reported.

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2. Glued laminated beam manufacture

2.1 Unreinforced glulam manufacture

The manufacture of each glued laminated beam began by grading each laminate in a mechanical grading machine. Each laminate was strength graded and ranked accordingly. It was desirable to manufacture thirty six beams of equal properties to create matched groups for comparative studies of long-term effects at a later stage. The beam lay-up was designed by arranging each laminate based on the strength graded data. Laminates were bonded together using a waterproof 1:1 phenol resorcinol formaldehyde adhesive chosen due to its suitability for timber structural applications [4]. The final beam consisted of four laminations giving an overall depth of 125 mm. To ensure a solid bond at the timber-timber interface, each laminate was knife planed in order to achieve a surface free from irregularities and torn grain in accordance with EN 14080 [5]. The planing decreased the thickness of each laminate from 34 mm to 31.25 mm on average. The adhesive was applied using a rubber roller to each surface ensuring an even spread of 350 g/m². The beams were then clamped into a rig applying a minimum pressure of 0.6 N/mm² as seen in Fig. 1. The beams were allowed to cure under pressure for a duration of 24 hours. They were subsequently placed in a conditioning chamber for 5 weeks at a temperature of 20 ± 2°C and at a relative humidity of 65 ± 5% prior to short-term testing.

Fig. 1 Clamping rig

2.2 Reinforced glulam manufacture

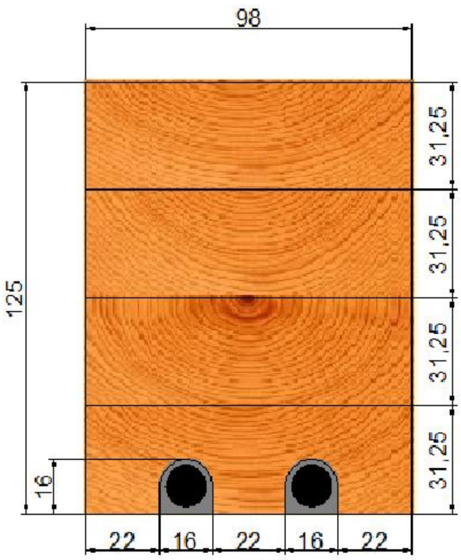

Fig. 2 Reinforcement detail

Twenty beams from the total were selected for reinforcement with BFRP rods. BFRP is a relatively new FRP material that has been shown to demonstrate superior properties when compared to GFRP [6]. When comparing GFRP and BFRP, Lopresto et al.[6] showed that BFRP has a 35-42% higher elastic modulus as well as better compressive strength and flexural performance. Basalt is one of the most common types of rock on earth, and this makes basalt fibres an excellent and sustainable alternative to FRPs such as GFRP. Two 12 mm diameter BFRP rods were inserted into two circular grooves routed the whole length of the bottom tensile laminate and centred 30 mm each edge as shown in Fig. 2. Circular grooves were chosen due to the reduced stress concentrations and improved mechanical performance [2]. This configuration accumulates to a percentage reinforcement of 1.85%. To guarantee a secure bond, each routed groove was cleaned using compressed air to ensure a dust/impurity free surface. A two-part thixotropic epoxy adhesive was used to bond the reinforcement to the timber as it is specially formulated for the bonding of FRP to timber

[7]. The groove was filled to approximately two-thirds of the routed depth using an injection gun. The BFRP rod was then inserted into the groove forcing excess adhesive around the rod ensuring complete coverage on the bottom and sides. Additional adhesive was applied on top to complete the 2 mm glue line. Small rubber rings were placed at 300 mm centres to ensure that a uniform 2 mm bond line was achieved. These beams were then placed in a conditioning chamber for a period of 3 weeks to cure at a temperature of 20 ± 2°C and at a relative humidity of 65 ± 5%.

3. Experimental procedure

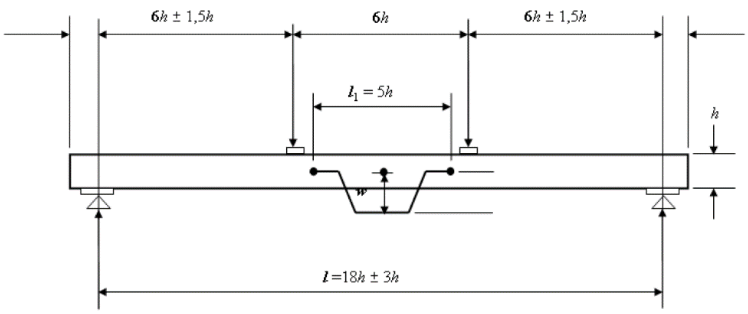

Fig. 3 Beam bending set-up (EN 408, [2])

The bending test set-up was in accordance with EN 408 [8] as seen in Fig. 3. The beams were loaded at a constant cross head rate of 0.15 mm/s (< 0.003 x h limit) to a maximum stroke of 15 mm to ensure the deflection does not exceed the elastic limit. The deflection at mid-span was measured using a linear variable displacements transducer (LVDT) fixed centrally on the top surface of the beam in order to determine the global bending stiffness. A local deflection measurement was acquired from a LVDT located centrally on a hanger. The hanger was fixed between the two loading heads with a span of 5 x h, where h is equal to the total beam height. In order to avoid indentation and inaccurate deflection measurement, steel plates were placed under each support and each load head. Polytetrafluoroethylene (PTFE) strips and packing were used as a precaution to support the beam and avoid lateral torsional buckling. The recorded local and global deflection measurements were plotted against the applied load to determine the stiffness of each beam. Eq. (1) and Eq. (2) were used to obtain the values for local and global stiffnesses, respectively.

$$(EI)_{m,local} = \frac{a{l_1}^2(F_2 - F_1)}{16(w_2 - w_1)} \tag{1}$$

$$(EI)_{m,global} = \frac{l^3(F_2 - F_1)}{12(w_2 - w_1)}\left[\left(\frac{3a}{4l}\right) - \left(\frac{a}{l}\right)^3\right] \tag{2}$$

In Eq. (1) and Eq. (2), $\boldsymbol{a}$ is the distance between the load head and the nearest support, $\boldsymbol{l_1}$ is equal to the gauge length (5 x h) of the local modulus hanger and $\boldsymbol{l}$ is the span between the supports. $\boldsymbol{F_1}$ and $\boldsymbol{F_2}$ are the loads corresponding to 10% and 40% of the ultimate load $\boldsymbol{F_{max}}$, respectively. Similarly $\boldsymbol{w_1}$ and $\boldsymbol{w_2}$ are the deflections corresponding to 10% and 40% of the ultimate load $\boldsymbol{F_{max}}$, respectively. This test was performed on thirty six unreinforced glued laminated beams. Twenty of these glued laminated beams were subsequently reinforced and retested in the same apparatus.

4. Results

GROUP	Average Local EI Increase (%)	Average Global EI Increase (%)

1	15.30%	6.54%
2	17.86%	14.14%
3	14.51%	8.15%
4	17.54%	6.36%
Average	16.30%	8.80%

Table 1: Increase in Bending Stiffness

Each beam was subjected to four-point bending in its unreinforced state to determine the bending stiffness and elastic modulus. From these results, six matched groups of five beams were created. Four of these matched groups were subsequently reinforced with two near surface mounted BFRP rods as seen in Fig. 2. The percentage increase in bending stiffness was compared between beams in their unreinforced and reinforced state. The average increase in bending stiffness of each reinforced group can be seen in Table 1 and Fig. 6. The average increase in local bending stiffness is 16.30% with a standard deviation of 1.65%. There is an average increase in global bending stiffness of 8.80% with a standard deviation of 3.65%.The elastic modulus is measured locally and globally. Once reinforced, the local elastic modulus of all beams had a mean value of 10727 N/mm² and global elastic modulus had a mean value of 9307 N/mm². As seen in Table 1, the increase in global bending stiffness of group 2 is significantly larger than that realised in other groups. This may be due to the lower initial global stiffness of group 2 in its unreinforced state. The lower the initial stiffness, the greater the effect of FRP reinforcement. The addition of reinforcement has resulted in reduced variability within each group as seen in Fig. 4.

5. Conclusion

The short term bending tests on unreinforced and BFRP reinforced glued laminated beams are presented. This has enabled the formation of six matched groups for comparative studies in future work to establish the long-term behaviour of these beams. The results of the non-destructive four-point bending tests revealed that significant increases in stiffness can be achieved when reinforcing low-grade Sitka spruce. The modest percentage reinforcement of 1.85% resulted in a local bending stiffness increase of 16.30%. A reduction in the variability of properties was observed after reinforcement.

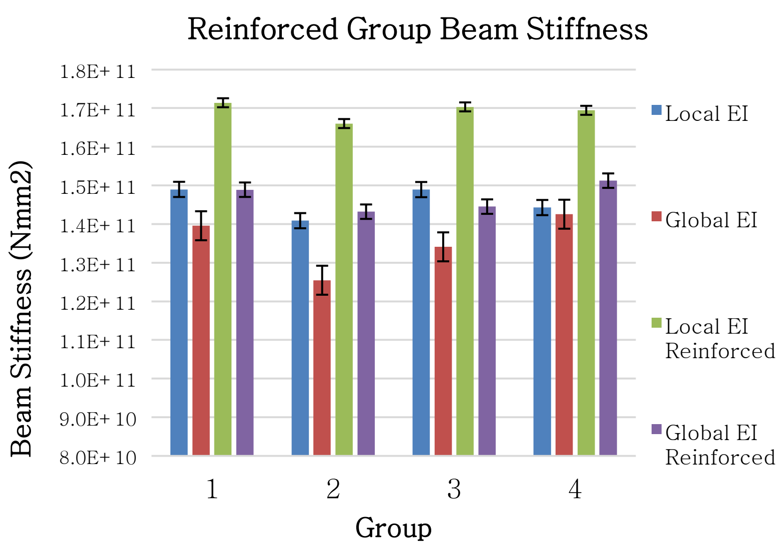

Fig. 4 Reinforced group beam stiffness

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