Behaviour of Basalt Fibre Reinforced Polymer rods glued-in parallel to the grain in Low-Grade timber elements by Pullout-Bending tests

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Summary

Glued-in rod connections in timber possess many desirable attributes in terms of efficiency, manufacture, performance, aesthetics and cost. In recent years research has been conducted on such connections using fibre reinforced polymers (FRPs) as an alternative to steel. This research programme investigates the pull-out capacity of Basalt FRP rods bonded-in to low-grade Irish Sitka Spruce. Besides the diameter of rod used, embedded length is thought to be the most influential variable contributing to pull-out capacity of glued-in rods. Previous work has established an optimum embedded length of 15 times the hole diameter. However, this previous work considered solely the effects of axial stress on the bond using a pull-push testing system. This pull-push system may have given an artificially high pull-out capacity as bending effects, which are present in many applications of glued-in rods, were neglected. This paper gives a summary of an experimental programme that was undertaken to examine how the glued-in BFRP rods perform in low-grade timber, with the focus on how varying the embedded length of the rods influences pull-out strength.

1. Background

Since the late 1980s there have been many research projects commissioned on the use of glued-in rods in timber construction e.g. GIROD and LICONS. In spite of this, no universal standard exists for their design. There had been an informative annex in the pre-standard PrBS ENV 1995-2:1997 [1] which provided limited coverage of the design of glued-in rods using steel bars, however this document was replaced by BS EN 1995-2:2004 in which no guidance on glued-in rods is included. There are three key elements to be considered when designing glued-in rod connections: the timber, the rod and the adhesive. The following sections outline the timber, rod and adhesive materials used in this research programme.

1.1. Timber

The majority of research into glued-in rods to date has been steel rods glued-in to glued laminated (glulam) elements with lamellae of a high strength class timber. There has however been some degree of research on the behaviour of glued-in rods in lower grade timber e.g. glulam beams using laminations of low-grade Sitka Spruce, Spruce of strength class C16 in its sawn form, Pine beams and Beech laminated veneer lumber. This research investigates the use of locally sourced Irish Sitka Spruce. Sitka Spruce grown in Ireland has a fast growth time of approximately 30 to 40 years, as a result of this high growth rate the cell structure of the wood is less dense and therefore the timber generally has relatively poor strength and is of a low classification, typically C16. Although the strength classification of the timber in its sawn form is poor, low transportation costs relative to imported timber means that Irish Sitka Spruce can be a very cost-effective building material if its full potential is utilised. Class C16 Irish Sitka Spruce (Picea Sitchensis) of 75mm x 225mm sawn section was used. The C16 classification shows that the timber has a minimum bending strength of 16N/mm2.

1.2. Rod

As well as alternative timber types, rod materials other than steel are being investigated in

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recent years, namely Fibre Reinforced Polymers (FRPs). FRPs are composite materials made of a polymer matrix reinforced with different fibres. They are more corrosion-resistant than steel and so they will have a longer service life, with less maintenance and monitoring required. Even the weakest FRP is stronger in tension than steel and they are all much lighter, meaning that an equally strong joint can be formed with less material being required. Earlier studies investigated the use of glass fibre reinforced polymer (GFRP) as an alternative to steel while carbon fibre reinforced polymer (CFRP) has been used more recently. Despite its significant cost effectiveness compared to CFRP and its greater tensile strength compared to GFRP, basalt fibre reinforced polymer (BFRP) has only been touched upon in the literature with regards to its use in glued-in technology [2]. BFRP has a Young's modulus closer to timber than the more commonly used material, steel. It is also a much lower cost material compared to the other FRPs. 12mm diameter Basalt Fibre Reinforced Polymer (BFRP) rods were used in this experimental programme. These rods were found to have a tensile strength of 920 N/mm2 under a loading rate of 0.2kN/s [3]. Unlike steel or some other FRPs, no extensive cleaning of the rods is required prior to bonding as they are sand-coated which provides a good surface for adhesion.

1.3. Adhesive

Many investigations have been undertaken to determine which adhesive type is best suited to glued-in rod applications. The adhesive must have good gap-filling properties to ensure a good bond along the entire length of rod, good adhesion to both the rod material and the timber and higher shear strength and stiffness than the timber being used. In a number of studies it was determined that Epoxy adhesives had higher strength than phenol resorcinol and polyurethane alternatives and that epoxies are most suitable for glued-in rod applications [4], [5]. A two-part thixotropic gap filling epoxy was used. This adhesive only flows under shear so is ideal for applications such as overhead beam repair and jointing overhead.

1.4. Geometric Variables

In order to create a strong connection, a large surface area of the glue around each rod must be in contact with the timber. Variables that can be altered to increase this surface area include: thickness of the glue-line, length of rod glued (embedded length), number of rods used and rod diameter. Edge distance between the centre of the rod and the edge of the sample must also be considered to ensure the connection does not split prematurely. Embedded length, lb, was the variable examined in this piece of research. Embedded length is thought to be the most influential variable contributing to pull-out capacity after the diameter of rods used [6], [7].

1.5. Pull-out Test Methods

There are several test configurations seen in the literature that can be used to assess pull-out capacity of a rod bonded-in to timber. The five most common are pull-pull, pull-push, pull-pile foundation, pull-beam and pull-bending. Each test configuration has its own merits, however pull-pull was identified as the most representative test method, producing relatively higher pull-out strengths [9]. In applications such as a moment resisting timber connection it is highly likely that some bending forces would be acting on the bar rather than axial-only as in the pull-pull set-up. In order to include these bending effects a hinge system, based on the concrete beam test proposed by RILEM 1982 [10] can be used. This type of pull-out test is known as a pull-bending test. The pull-bending set-up allows the effects of bending forces to be taken in to consideration along with axial forces in what is essentially a modified pull-pull type test. The system allows bending strength of the glued-in rod connection to be evaluated by removing the timber in the section being loaded so that the only resistance is from the BFRP bars glued-in to the timber. This type of pull-out test has been used successfully in investigating the bond behaviour between glulam elements and GFRP [11], [12]. It is this system that was used in this research to establish pull-out capacity, with the set-up as shown in

Figure 1.

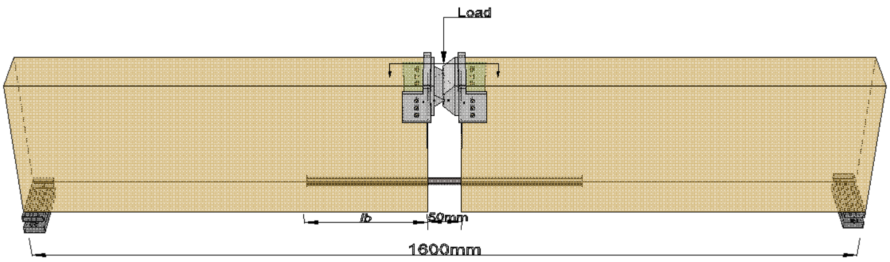

Fig. 1: Pullout-bending test set-up

2. Preliminary Results

Table 1: Sample Specification

Embedded length, l_b (mm)	Rod Diameter, *d* (mm)	Glueline Thickness, *t* (mm)	Edge Distance, *a* (mm)	Direction to gain	Moisture Content	No. Repetitions
80	12	2	30	Parallel	<12%	9
130	12	2	30	Parallel	<12%	9
180	12	2	30	Parallel	<12%	9
230	12	2	30	Parallel	<12%	9
280	12	2	30	Parallel	<12%	9
330	12	2	30	Parallel	<12%	7

Samples were prepared as per Table 1 and were loaded in 0.5kN increments to failure using the accurately calibrated 600kN capacity hydraulic actuator. Deflection at mid-span and net horizontal movement of the bar as the sample was loaded was recorded with data acquisition connected to transducers. Failure load was recorded when the sample could not take any additional load. The mode of failure was recorded also – percentage failure mode was then calculated for each bonded length. Each test was repeated a number of times due to the high variability of the timber used.

The most prevalent failure mode was a failure in shear of the timber with a total of 64% of all samples failing in this manner. This was as expected due to the timber being the weakest element in the bond. When splitting of the timber occurred the length of the split was often equal to the embedded length of rod. Tensile failure of the rod never occurred as the load required for the rupture of the rod was never reached.

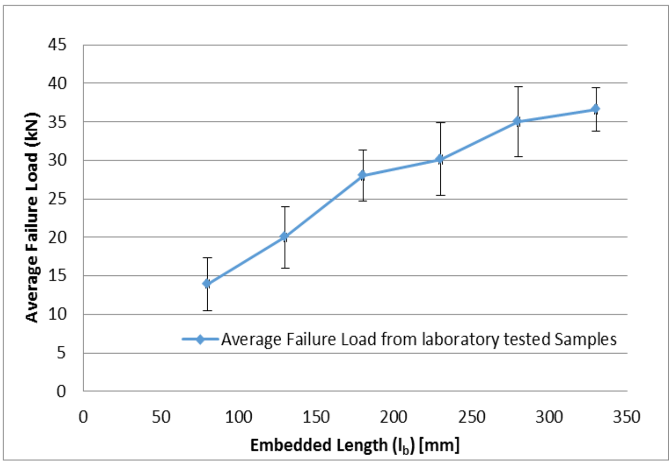

Fig. 2: Failure Loads of Samples

As shown in Figure 2, a clear increase in pull-out strength was observed with an increase in embedded length. An increase in pull-out capacity of 162% was observed between the shortest embedded length of 80mm and the longest length of 330mm. The overall relationship between embedded length and pull-out capacity was almost linear.

3. Conclusions

A clear increase in pull-out capacity was seen with increasing embedded length of the glued-in BFRP rods. It is planned that additional longer lengths are investigated to determine at which point the additional length becomes inactive. It is suggested also that an investigation where edge distance is increased is undertaken to determine if failure due to splitting of timber can be avoided.

4. Acknowledgements

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