Basalt Fibre Reinforced Polymer Rods for glued connections in Low Grade Timber

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ABSTRACT

Glued-in rods offer a wide range of applications such as connecting timber sections, as reinforcement and for restoration of timber structures. The research presented in this paper focuses on their use as connectors. The pull-out capacity of glued-in Basalt fibre reinforced polymer (BFRP) rods in indigenous Sitka spruce sections was investigated. Influence on pull-out capacity of the embedded length of the bar and the end distance were determined using a pull-bending hinged test method. This pull-bending method allowed the effects of bending forces to be taken in to consideration along with axial forces in a pull-out test.

An experimental programme was conducted where pull-bending tests were carried out on specimens of 12mm diameter BFRP bars with a 2mm glueline thickness and embedded lengths between 80mm and 600mm glued-in to low-grade timber with an epoxy resin. Nine repetitions of each were tested. A clear increase in pull-out strength was observed with an increasing embedded length. The longest length had a pull-out capacity 213% greater than that of the shortest embedded length. In an effort to reduce instances of failure by splitting in the timber end distance was varied. It was found that increased end distance had minimal impact upon overall pull-out capacity and that premature failure after splitting was reduced significantly.

INTRODUCTION

Glued-in rods (GiR) present a sustainable, aesthetically pleasing alternative to the conventional steel moment connections that are often encountered in timber construction. GiR are also likely to be more cost effective than specially fabricated steel connections. Furthermore GiR have enhanced fire protection as the rods which transfer moment are embedded inside, and are therefore protected by, the timber.

Glued-in rods have a wide range of uses in both new build and restoration projects. Successful renovation has been carried out in roof and floor beams in buildings subject to decay [1; 2]. In new build, five areas were identified where GiR rods may be used for connections: frame corner, beam-post connection, beam-beam joint, supports and hinged joints [3].

No universal standard exists for the design of GiR despite many research projects being commissioned on their use since the 1980s. There had been an informative annex in the pre-standard PrBS ENV 1995-2:1997 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 and no guidance is included in this current document.

There are three key elements to be considered when designing glued-in rod connections: the timber, the rod and the adhesive. The most significant challenge in the development of a standard design method is the many varying approaches to defining each of these joint properties.

THEORETICAL BACKGROUND

Materials

The majority of research done in this area to date comprises steel rods glued-in to glued laminated (glulam) elements with lamellae of a high strength class timber. There has however been some limited research on the behaviour of glued-in rods in lower grade timber eg. [4] and [5].

This research investigates the use of indigenous Sitka Spruce which has a fast growth time of approximately 30 to 40 years [6], as a result 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 [7]. However, low transportation costs relative to imported timber and a ready supply means that indigenous timber can be a very cost-effective building material if its full potential is utilised.

While GiR are often steel other types have been studied, namely Fibre Reinforced Polymers (FRPs). Earlier studies investigated the use of glass fibre reinforced polymer (GFRP) as an alternative to steel [8–10] while carbon fibre reinforced polymer (CFRP) has been used more recently [11]. Despite its significant cost effectiveness compared to CFRP and its greater tensile strength compared to GFRP, basalt fibre reinforced polymer (BFRP) has only been investigated in a very limited manner for use in glued-in technology [12]. BFRP has a modulus of elasticity closer to timber than the more commonly used material, steel. It is also a much lower cost material compared to the other FRPs. These advantages resulted in BFRP being selected for use in this research.

Many investigations have been undertaken to determine which adhesive type is best suited to glued-in rod applications. The adhesive must be capable of acting as a gap-filler to ensure a good bond along the entire length of rod by filling the void between the rod and the timber. This will help achieve 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 [13; 14]. A two-part thixotropic gap filling epoxy was used for the purposes of this research. This adhesive only flows under shear so is ideal for applications such as overhead beam repair and jointing overhead.

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 timber does not split resulting in premature failure. In this report the effect of embedded length on strength and edge distance on failure mode are presented.

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 glued-in to timber. The five most common are pull-pull, pull-push, pull-pile foundation, pull-beam and pull-bending. In a moment resisting timber connection, such as a frame corner in a portal frame structure, it is highly likely that some bending forces would be acting on the glued-in rod rather than axial-only as in the pull-pull and pull-push set-ups. In order to include these bending effects the pull-bending set-up should be used. This involves a use of a hinge apparatus based on the concrete beam test proposed by RILEM 1982 [15].

The pull-bending 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 [16; 17]. It is this system that will be used in this research to establish pull-out capacity.

Embedded Length, l_b

Embedded length is thought to be the most influential variable contributing to pull-out capacity after diameter of the rods used [18], [8]. Following a series of pull-out testing of BFRP rods glued in to glulam elements with an epoxy resin, it was found that the ultimate pull-out capacity would be reached at a rod embedment length of 15*d* i.e. 15 times the rod diameter [19]. However, the test set-up used in that study only considered the effects of axial stress using a pull-push testing system which may have given an artificially high pull out capacity as bending effects were neglected.

Edge Distance, *a*

A minimum edge distance, i.e. the cross-sectional distance between the centre of the bar and the bottom edge of the timber, must be prescribed in order to prevent the timber from splitting and causing premature failure. Additionally, it has been stated that small edge distances can result in a lesser bond strength and a decrease in average pull-out capacity [20]. Most of the latest design approaches use an edge distance of *2.5d* [21]; [22]. However, there has not been a significant amount of research in this area to date.

TESTING

Specimen Details

Class C16 indigenous Sitka spruce (Picea sitchensis), sourced from Balcas Sawmill, Co. Fermanagh of 75mm x 225mm sawn section was used. Laboratory classification showed that the timber had a 5th percentile bending strength of 16.9N/mm^2 and a mean density of 381kg/m^3.

12mm diameter Basalt Fibre Reinforced Polymer (BFRP) rods were used with a tensile strength of 920 N/mm^2 under a low loading rate of 0.2kN/s [23]. Unlike steel or some other FRPs, no extensive cleaning of the rods was required prior to bonding as they are sand-coated which provides a good surface for adhesion. These rods were glued-in with a two-part thixotropic gap filling epoxy.

Specimen fabrication

Moisture content of each sample was recorded during sample preparation and before testing using a handheld moisture meter. Moisture content was found to range from 9% to 11%, which corresponds to Service Class 1 (EC5, Part 1-1).

An auger drill bit was used to drill holes of 16mm diameter, thus producing a glueline thickness of 2mm all around the 12mm diameter rods. Guide blocks were used to ensure the holes were drilled accurately. Drilled lengths varied from a minimum of 80mm to a maximum of 600mm. For embedded length tests holes were drilled 30mm in from the specimen edge; this corresponds to an edge distance *a =2.5d* where *d* is rod diameter. Edge distance was then varied between 2.5*d* and 5.5*d* for the second phase of testing with embedded length remaining constant at 280mm in these specimens.
In summary, nine of each test variables as listed below were fabricated:
Embedded lengths: 80mm, 130mm, 180mm, 230mm, 280mm, 330mm, 380mm and 600mm
Edge distance: 2.5*d* (30mm), 3.5*d* (42mm), 4.5*d* (54mm) and 5.5*d* (66mm).

The surface of the timber around the drilled hole was sealed with candlewax to ensure that any glue overspill would not penetrate the sample and result in a false increase in strength around the hole. Holes were then 2/3rds filled with glue and the rods twisted into place allowing any trapped air to be expelled and ensuring the glue fully coated the surface of the rods.

A temporary support was used to hold the sample in place to maintain the 2mm glueline all around the rod whilst drying. When the glue had hardened the steel hinges joining the specimen at the top and strain gauges at mid-span on the exposed rod were fitted. The specimens were then left until the glue had a minimum of 7 days to cure fully before testing.

Testing Set-up

A pull-bending test set-up was used as it more closely imitates the forces which a glued-in rod connection would be under in a real application. This test required a hinge system to be developed to transfer load through the sample such that the GiR is under bending forces as well as axial forces. The pull-bending test set-up is illustrated in Figure 1 below.

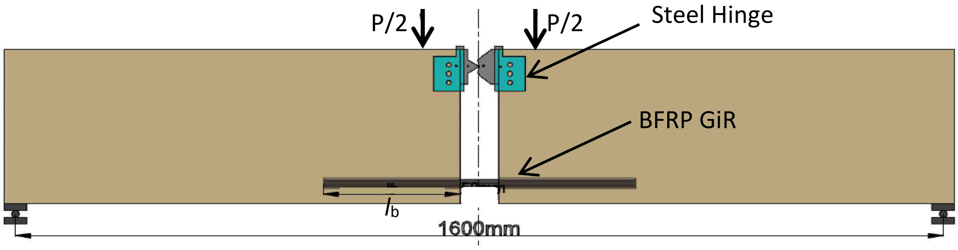

Figure 1: Pull-Bending Test Set-up

Stress in the rod was monitored via a strain gauge placed at mid-span on the exposed BFRP rod on each sample. Vertical deflection at mid-span and slip of the rod were recorded with linear variable differential transformers (LVDTs), as shown in Figure 2. A flat plate was clamped at mid-span to allow measurement of overall slip of the rod.

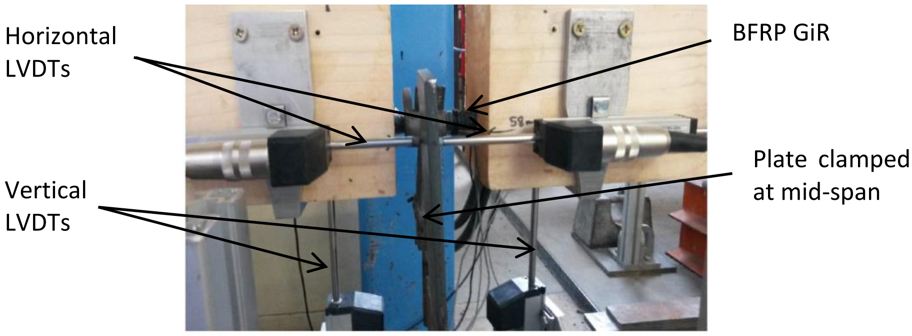

Figure 2: LVDT Set-up

Samples were loaded at a rate of 0.015mm/sec to ultimate failure using a calibrated 600kN capacity hydraulic actuator. Failure load and mode of failure were recorded when the sample could not take any additional load. Each test was repeated with nine specimens due to the high variability of the timber used. The results presented in the next section are an average of the nine specimens in each set.

RESULTS

All specimens failed in a sudden, brittle manner. Three primary failure modes were identified and are shown in Figure 3: shear failure in timber, rod/adhesive failure and premature failure due to timber splitting. The most prevalent failure mode observed 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.

Figure 3: Failure modes observed: a) Shear in timber; b) Rod/Adhesive Failure; c) Timber Splitting

Influence of Embedded Length on Pull-out Strength

A clear increase in pull-out strength was observed with an increase in embedded length. Figure 4 shows this relationship. Pull-out load was calculated from recorded strain on the bar at mid-span. An increase in pull-out capacity of 213% was observed between the shortest embedded length of 80mm and the longest length of 600mm. It was observed that pull-out strength increased at a lesser rate at higher embedded lengths, suggesting that strength was approaching a plateau as stress capacities were being reached.

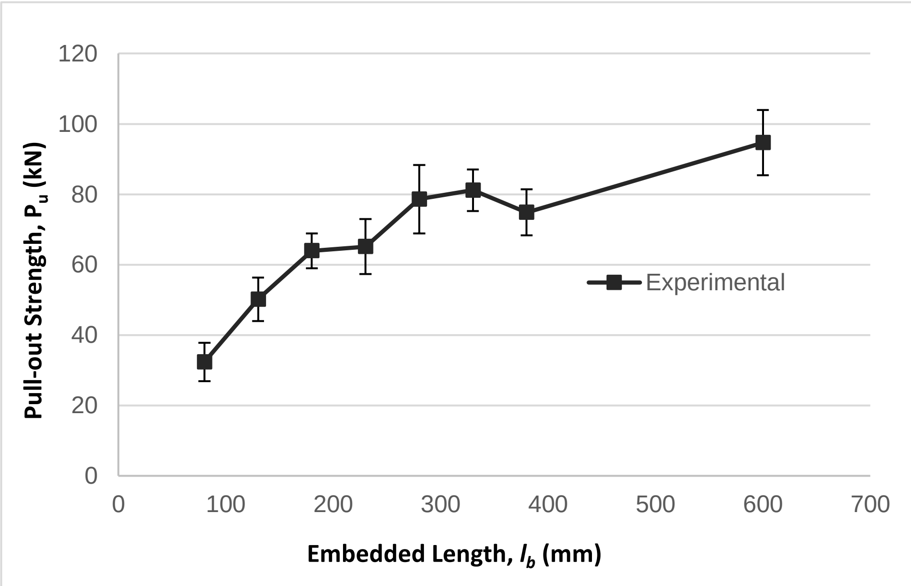

Figure 4: Pull-out strength with increasing Embedded Length

With increasing embedded length failure mode noticeably shifted from mainly failing in timber shear in the shortest embedded length to a mixture of other failure modes in the longest embedded length. This is a result of shear stress at the timber/adhesive bond decreasing with increasing embedded length, as detailed in Figure 5. Shear stress at the timber/adhesive bond exhibited a general decrease with increasing embedded length.

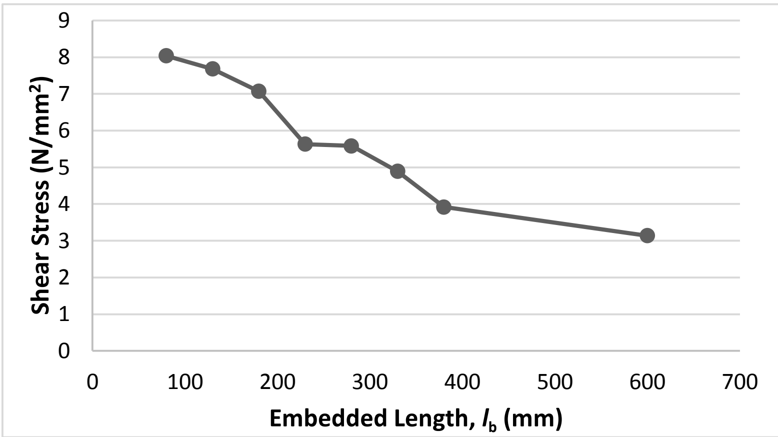

Figure 5: Peak Shear Stress at Timber/Adhesive Interface

Influence of increasing edge distance on failure mode

As detailed in Table 1 the majority of specimens with the minimum edge distance exhibited splitting. Splitting was significantly reduced with increasing edge distance. No specimens in the sets with largest edge distances exhibited splitting. Pull-out strength was not affected by increasing edge distance with no significant increase or decrease being observed. As the edge distance increased it can be observed that the failure mode altered from timber failure to interface failure. This is important as it determines the minimum edge distance that can be used that will cause damage to the timber elements of the connection. This can then be used to determine the maximum number of GiR that can be used within a given cross-section.

Table 1: Percentage of Failure Modes Observed

	Splitting	**Shear in timber**	**Rod/adhesive failure**
2.5*d*	44%	44%	11%
3.5*d*	11%	78%	11%
4.5*d*	0	89%	11%
5.5*d*	0	67%	33%

CONCLUSIONS

- Increasing embedded length increases pull-out capacity. Experimental values for strength obtained in this study fall between conservative and enhanced predictions from previous research.
- Increasing end distance has no significant benefit on pull-out capacity but leads to a change in failure mode.
- GiR as frame corner moment-resisting connections will be tested. Timber buildings using these GiR connections are lightweight and sustainable. Applications of such buildings include construction in poor ground conditions, rapid construction and low energy buildings.

ACKNOWLEDGMENTS

This research is funded by the Department of Agriculture, Food and the Marine of the Republic of Ireland under the FIRM/RSF/COFORD scheme as part of 'Innovation in Irish timber Usage' (project ref. 11/C/207). The authors would also like to thank the technical staff in QUB for their assistance in the lab.

REFERENCES

1. Smedley, D., Alam, P., Ansell, M., George Street, St. Albans, UK–a case study in the repair of historic timber structures using bonded-in pultruded plates, presented at the *9th World Conference on Timber Engineering*, Portland, OR, USA, August 6-10, 2006.
2. Schober, K.U., Rautenstrauch, K., Experimental Investigations on Flexural Strengthening of Timber Structures with CFRP. In: *Proceedings of the International Symposium on Bond Behaviour of FRP in Structures,* Hong Kong, China, December 7-9, 2005.
3. Gehri, E., High Performing Jointing Technique Using Glued-in Rods, presented at the *11th World Conference on Timber Engineering*, Trentino, Itlay, June 20-24, 2010.
4. Raftery G.M., Whelan C., Low-grade glued laminated timber beams reinforced using improved arrangements of bonded-in GFRP rods. *Construction and Building Materials,* **52**, 209–220, 2014.
5. Alam P., Ansell M.P., Smedley D., Mechanical repair of timber beams fractured in flexure using bonded-in reinforcements. *Composites Part B: Engineering,* **40** (**2**), 95–106, 2009
6. Irish Forestry and Forest Products Association. *An overview of the Irish forestry and forest products sector*., Ibec Ltd. Dublin: 2012.
7. UNECE, *Timber Committee Market Report for Ireland,* Dublin, 2011
8. Harvey K., Ansell M.P., Improved timber connections using bonded-in GFRP rods. In: *Proceedings of 6th World Conference on Timber Engineering,* Whitsler, British Columbia Canada, July 31 - August 3, 2000.

9. Madhoushi M., Ansell M.P., Experimental study of static and fatigue strengths of pultruded GFRP rods bonded into LVL and glulam. *International Journal of Adhesion and Adhesives*, **24** (**4**), 319–325, 2004
10. Ansell M., Smedley D., Briefing: Bonded-in technology for structural timber. *Proceedings of the ICE-Construction Materials,* **160** (**3**): 95–98, 2007.
11. Juvandes F.P., Barbosa R.M.T., Bond Analysis of Timber Structures Strengthened with FRP Systems. *Strain*, **48** (**2**): 124–135, 2012
12. Yeboah D., *Rigid Connections in Structural Timber Assemblies*. PhD Thesis, Queen's University Belfast, 2012.
13. Serrano E., Glued-in rods for timber structures — a 3D model and finite element parameter studies. *International Journal of Adhesion and Adhesives,* **21**(**2**): 115–127, 2001.
14. Broughton J.G., Hutchinson A.R., Adhesive systems for structural connections in timber. *International Journal of Adhesion and Adhesives*, **21**(**3**), 177–186, 2001.
15. RILEM TC. *RC 5 Bond test for reinforcement steel. 1. Beam test, 1982. In: RILEM (ed). RILEM Recommendations for the Testing and Use of Constructions Materials.* E & FN SPON, p213 – 217. 1994.
16. Sena-Cruz J., Branco J., Jorge M., Barros J.A.O., Silva C., Cunha V.M.C.F., Bond behavior between glulam and GFRP's by pullout tests. *Composites Part B: Engineering,***43** (**3**), 1045–1055, 2012.
17. Sena-Cruz J.,, Barros J.A.O., Faria R., Assessing the embedded length of epoxy-bonded carbon laminates by pull-out bending tests, presented at the *International Conference of Composites in Construction,* October 10-12, Porto, Portugal, 2001.
18. Steiger R., Gehri E., Widmann R., Pull-out strength of axially loaded steel rods bonded in glulam parallel to the grain. *Materials and Structures*, **40** (**8**): 69–78, 2006.
19. Yeboah D., Taylor S., McPolin D., Gilfillan R., Pull-out behaviour of axially loaded basalt fibre reinforced polymer (BFRP) rods bonded parallel to the grain of glulam elements. *The Structural Engineer*, p42–51, May 2012.
20. Tlustochowicz G., Serrano E., Steiger R., State-of-the-art review on timber connections with glued-in steel rods. *Materials and Structures*, **44** (**5**), 997–1020, 2011.
21. Widmann R., Steiger R., Gehri E., Pull-out strength of axially loaded steel rods bonded in glulam perpendicular to the grain. *Materials and Structures*, **40** (**8**): 827–838, 2007.
22. Serrano E., Steiger R., Lavisci P., *Core Document of the COST Action E34 "Bonding of Timber." In: Lignovisionen 18,* University of Natural Resources and Applied Life Sciences, Vienna; 2008.
23. Tharmarajah G., Compressive Membrane Action in Fibre Reinforced Polymer (FRP) Reinforced Concrete Slabs, PhD Thesis, Queen's University Belfast, 2010