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Behaviour of Glued-in BFRP Rods under combined Axial Force and Bending Moment

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ABSTRACT

Glued-in rods (GiR) present a viable alternative to traditional steel moment connections in both new build and retrofit of timber structures. A simplified experimental set-up was developed to study the behaviour of the glued-in rod system under a combination of axial force and bending moment. The testing method allowed controlled adjustment of embedded length and edge distance to assess their influence on performance of the system.
A clear increase in pull-out strength was observed with an increase in embedded length. An increase in pull-out capacity of 213% was observed between the shortest embedded length of 80mm and the longest length of 600mm. Increasing edge distance did not significantly affect failure strength however a difference in behaviour was observed with a shift to a more favourable failure mode with increased edge distance.
For axially loaded systems the stress distribution along a GiR is generally considered to show a peak at the loaded end with dissipation of the stress occurring along the length of the rod. At a fixed loading rate it appears that for short embedded lengths the entire length of the rod reaches peak stress at once whereas at longer embedded lengths failure is more gradual, with one end reaching peak stress before the other leading to a higher failure load and lower peak stress. This research aims to determine if this assumption of stress distribution is valid also for systems under a combination of axial and bending forces.
Electrical Resisting Strain gauges and Draw Tower Grating fibre optic sensors were used to capture the stress profile along the length of the GiR. Embedded length and edge distance were varied to investigate the effect of these variables on stress distribution. Specimens were tested under a pull-bending test set-up. Generally, a linear increase in strain was observed at each measured location along the glued length until failure. In all specimens, the loaded end recorded the maximum strain. This proves that failure initiates primarily at the loaded end. This paper presents the full results of this experimental program.

1. INTRODUCTION

The development of lightweight, corrosion resistant and sustainable moment resistant timber connections using glued-in rods would facilitate the adoption of timber elements in large construction projects. However the basic principles of behaviour under both axial force and bending moment must first be established.

Glued-in rods (GiR) present a sustainable, aesthetically pleasing alternative to the cumbersome conventional steel moment connections that are often encountered in timber construction. Not only do connections with bonded-in rods look better than conventional connections, they also have enhanced fire protection as the rods which transfer moment are embedded inside, and are therefore protected by, the timber.

Glued-in rods have great potential in a wide range of both new build and restoration projects. Successful renovation has been carried out in roof and floor beams in buildings subject to decay (Smedley et al. 2006; Schober & Rautenstrauch 2005). In new build, five areas were identified where glued-in rods may be used for connections: frame corner, beam-post connection, beam-beam joint, supports and hinged joints (Gehri 2010).

Since the late 1980s there have been many research projects commissioned on the use of bonded-in rods in timber construction e.g. GIROD and LICONS (Broughton & Hutchinson 2004; Bainbridge & Mettem 1999). 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 which provided limited coverage of the design of bonded-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.

Considerable research can be found in the literature on the behaviour of such connections however, the majority of this research is focused on

steel rods under purely axial loading. In service, these moment resisting connections will be subject to a combination of axial and bending forces rather than exclusively axial force.
Performance of glued-in Basalt Fibre Reinforced Polymer (BFRP) rods under combined axial and bending was appraised by considering both the joint performance in terms of strength, failure mode and deflection and the nature of the stress distribution along the joint interface. This was achieved by altering both embedded length and edge distance in a controlled manner and monitoring the effect this had on performance. Joint performance was determined by measuring the force, deflections and strain as well as observing behaviour during loading and failure mode.

The stress distribution along a GiR is generally considered to show a peak at the loaded end with dissipation of the stress occurring along the length of the rod as suggested by Steiger et al. (2006) for axially loaded systems. At a fixed loading rate it appears that for short embedded lengths the entire length of the rod reaches peak stress at once and hence fails at a relatively low load and with high peak stress. At longer embedded lengths failure is more gradual, with one end reaching peak stress before the other leading to a higher failure load and lower peak stress. This research aims to determine if this assumption of stress distribution is valid for pull-bending mechanisms; that stresses are not distributed evenly along the embedded length of a GiR and that failure arises at the loaded end due to a peak in stress concentration at this location.

2. Test Procedure

Materials

Class C16 Irish Sitka Spruce (Picea sitchensis), sourced from Balcas Sawmill in Northern Ireland with a size of 75mm x 225mm sawn section was used. Material testing revealed that this timber had a 5th percentile bending strength $f_{m,k}$= 16.8N/mm^2 , shear strength $f_{v,k}$=8.7N/mm^2 and a density ρ_k= 381kg/m^3.

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/mm^2 under a low loading rate of 0.2kN/s (Tharmarajah 2010). 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.

A two-part thixotropic gap filling epoxy was used. This adhesive only flows under shear so is ideal for GiR applications such as overhead beam repair or jointing overhead.

Test set-up

Pull-out capacity can be used as a measure of the strength of a glued-in rod. The pull-out test system used was a pull-bending set-up, as pictured in Figure 1. 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.

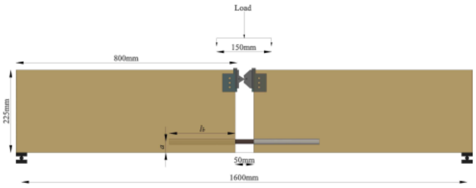


Figure 1. Pull-bending test set-up

Stress in the rod was monitored by means of an electrical resistance strain (ERS) 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). A flat plate was clamped at mid-span to allow measurement of overall slip of the rod.

Embedded length (l_b) was varied to assess its impact upon the performance of the glued-in rod. Embedded length is thought to be the most influential variable on pull-out capacity of a glued-in rod. Embedded length ranging from 80mm to 600mm was investigated.

Two methods were employed to obtain the stress profile along the length of the GiR: Electrical Resisting Strain (ERS) gauges and Draw Tower Grating (DTG) fibre optic sensors. The sensors were attached directly on to the BFRP rod on one specimen in each tested set to assess the how stresses were distributed along the glued length after being transferred through the timber and adhesive.

Samples 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 the transducer. 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 nine times due to the high variability of the timber used.

3. Results

Failure mode

All specimens failed in a sudden, brittle manner. Two primary failure modes were identified and are pictured in Figure 2: a timber plug pull-out indicative of shear failure in the timber and a 'clean' pull-out signifying a failure of the rod/adhesive interface. The most prevalent failure mode observed was a pull-out failure in shear of the timber with a total of 67.6% of all samples failing in this manner. This was as expected due to the timber being the weakest element in the connection. Rod/adhesive failure was thought to have occurred due to the sand coating on the BFRP rod not adhering sufficiently well to the adhesive. The BFRP rod never failed as the force required for the rupture of the rod was never reached.

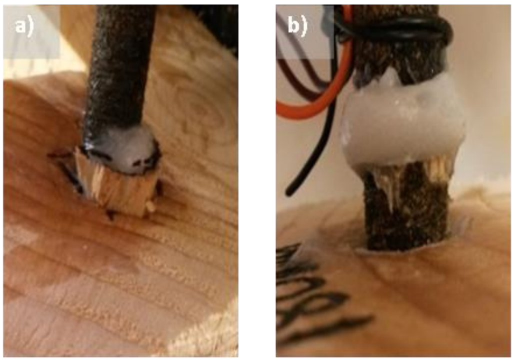


Figure 2. Failure modes observed a) shear in timber, b) rod/adhesive failure

Splitting was evident in 28% of all specimens. Splitting occurred as a consequence of the build-up of stresses approaching failure. When splitting of the timber occurred the length of the split was often equal to the embedded length of the rod. When the timber split the capacity of the section was reduced resulting in a lower failure load, this is evidenced in Figure 3 where strength of specimens without splitting is compared to those where splitting did occur.

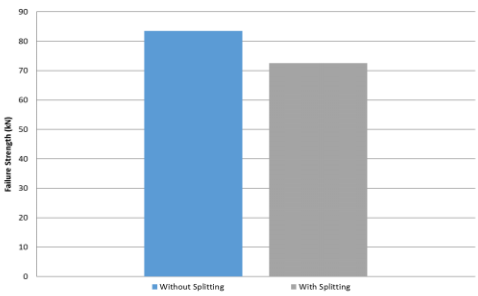


Figure 3. Comparison of failure strength of specimens with and without splitting

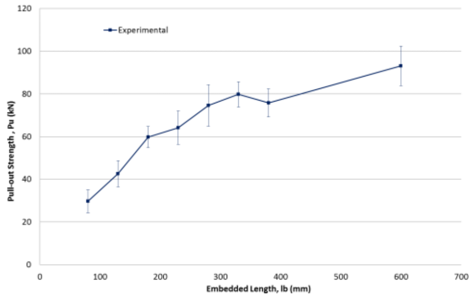
In an attempt to alleviate this issue and optimise the specimen capacity, edge distance was increased. This principal is similar to increasing the cover to reinforcement in a concrete beam. Splitting was significantly reduced with increasing edge distance with no significant impact upon failure strength. However, as edge distance increased the lever arm was reduced. Thus, moment capacity of the section decreased with increasing edge distance since moment capacity is a function of the force and lever arm.

Influence of embedded length

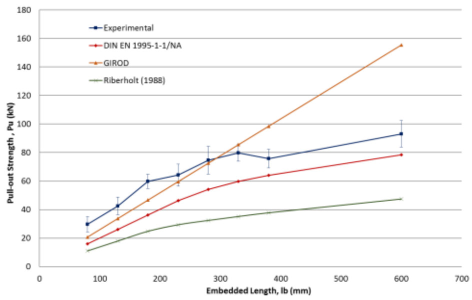
A clear increase in pull-out strength was observed with an increase in embedded length as illustrated in Figure 4. An increase in pull-out capacity of 213% was observed between the shortest embedded length of 80mm and the longest length of 600mm. This was as expected since the larger interface area with each increase in embedded length provides additional resistance to the applied loading.

Figure 4. Pull-out strength with increasing embedded length

Comparing the experimental data obtained in this research to the three most used design guidelines,



it can be seen that the data follows the same trend as both the DIN and Riberholt design equations (Figure 5). The experimental strengths are significantly stronger than both the DIN and



Riberholt predictions however this is to be expected since the guidelines are designed to give a safe prediction of strength. The GIROD prediction gives a completely linear behaviour. While this is conservative at shorter embedded lengths compared to the experimentally derived data, beyond an embedded length of 330mm the design prediction is significantly higher than the experimentally obtained strengths and therefore unsafe.

Figure 5. Comparison of experimental data with commonly used theoretical predictions

Stress distribution along glued length

Generally, a linear increase in strain was observed at each measured location along the glued length until failure. As shown in Figure 6 and Figure 7, in all specimens, the loaded end (0mm) recorded the maximum strain. This proves the presumption that failure occurs primarily at the loaded end.

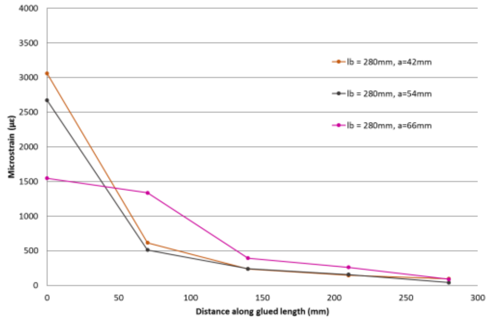


Figure 6. Stress distribution along glued length with increasing edge distance at a load of 10kN

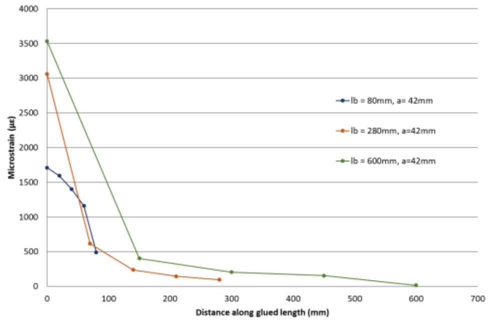


Figure 7. Stress distribution along the glued length with increasing embedded length at a load of 10kN

In a typical specimen stresses were distributed in a triangular fashion with the start of the bond length having the highest stress concentration and this dissipating along the bonded length to a minimum concentration at the unloaded end. Further along the glued length it was observed that behaviour became more linear. This suggests that bending has less of influence on performance of the GiR further along the glued length. As loading increased stresses increased at each location along the rod

Increasing edge distance tended to result in a reduction of stresses at each measured point. Increasing embedded length had the opposite effect, with higher stresses being recorded at each point along the rod, suggesting that forces are more effectively being transferred through the timber to the connection element when a longer embedded length is used.

4. Conclusions

- A clear increase in pull-out capacity with increased embedded length of the glued-in BFRP rods was seen, which appears to be reaching a plateau as failure is occurring in the timber as opposed to in the bond.
- Increasing edge distance is an effective method of reducing instances of splitting without sacrificing pull-out capacity.
- Stress distribution along the length of a glued-in rod under combined axial and bending force is not linear, with the loaded end reaching failure first and this then propagating along the glued length of the rod.
- Further work is suggested to assess the performance of such a connection method as a moment connection in a portal frame application.

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References

Bainbridge, R. & Mettem, C., 1999. Bonded-in rods for timber structures: a versatile method for achieving structural connections. *The Structural Engineer*, Volume 77(Issue 5), pp.p24–27.

Broughton, J.G. & Hutchinson, A.R., 2004. *LICONS Task 2-Sub tast 2.2*,

Gehri, E., 2010. High Performing Jointing Technique Using Glued-in Rods. In *11th World Conference on Timber Engineering 2010, WCTE 2010.* Trentino, Italy.

Schober, K.U. & Rautenstrauch, K., 2005. Experimental Investigations on Flexural Strengthening of Timber Structures with CFRP. In *Proceedings of the International Symposium on Bond Behaviour of FRP in Structures (BBFS 2005)*. pp. 457–464.

Smedley, D., Alam, P. & Ansell, M., 2006. George Street, St. Albans, UK–a case study in the repair of historic timber structures using bonded-in pultruded plates. *… of 9th World Conference on Timber …*, (2006).

Steiger, R., Gehri, E. & Widmann, R., 2006. Pull-out strength of axially loaded steel rods bonded in glulam parallel to the grain. *Materials and Structures*, Vol. 40(8), p.p 69–78.

Tharmarajah, G., 2010. *Compressive Membrane Action in Fibre Reinforced Polymer (FRP) Reinforced Concrete Slabs*. Queen’s University Belfast.