Glued-In BFRP Rods as Moment Connections in Indigenous Low Grade Timber

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Project objectives and goals

Glued-in rods present a viable alternative to traditional timber connection methods, including mechanical fasteners, adhesives or carpentry connections. Suitable for use in a moment-resisting connection, glued-in rods transfer forces from timber to timber through the timber/adhesive and rod/adhesive interfaces. As well as their use in new build, glued-in rods have been used successfully for reinforcement and restoration of timber structures, for example in the renovation of roof and floor beams in buildings subject to decay. This repair method is favoured for renovation of historic structures in particular as it enables a stiff and strong hidden repair and allows the maximum possible portion of the original timber to be retained.

No universal standard exists for the design of glued-in rods despite many research projects being commissioned on their use since the 1980s. There had been an informative annex in the pre-standard PrENV 1995-2 (1997) which provided limited coverage of the design of glued-in rods using steel rods however this document was replaced by BS EN 1995-2:2004 and no guidance is included in this current document. It is expected that guidelines on the design of glued-in rods will be included in the next revision of Eurocode 5.

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. However other researchers have investigated the behaviour of glued-in rods in lower grade timber and with some fibre reinforced polymer (FRP) materials in place of the standard steel rods with the merits of these materials being reported in a recent state of the art report on the use of glued-in rods (Steiger et al, 2015). This research investigates the behaviour of Basalt Fibre Reinforced Polymer (BFRP) rods glued-in to indigenous Sitka Spruce which has relatively poor strength and is of a low classification, typically C16. Optimum embedded length of the rod and edge distance was determined through pull-out testing before durability performance was investigated. The research will conclude with glued-in rods being used as moment connections in full-scale frame corners, the testing of which will be used to validate the theoretical design developed.

Description of Method and Results

Pull-out capacity can be used as a measure of the strength of a glued-in rod. In order to represent the combination of axial and bending effects on a glued-in rod a pull-bending set-up was used to evaluate the influence of embedded length on pull-out capacity, see Fig 1. Results showed a clear increase in pull-out strength with an increase in embedded length with a 213% increase in capacity between the longest embedded length of 600mm and the shortest of 80mm. The most prevalent failure mode observed was a failure in shear of the timber with the majority of all specimens failing solely in this manner. Several specimens exhibited splitting along their tension face as a result of the build-up of stresses around the glueline before failure. Specimens where splitting occurred generally had a lower pull-out capacity as a result. As a means of preventing splitting edge distance was increased in steps of 1 rod diameter, an optimum edge distance of $3.5d_r$ was identified where pull-out strength remained at an optimum and splitting was less likely to occur.

'Fig. 1' Pull-bending test

Two ageing methods were used to assess the durability of the glued-in BFRP rods. A vacuum-pressure regime was used to simulate the deteriorative effects of long term moisture ingress. Specimens were soaked in a pressure vessel to saturation, dried and tested to failure where a 22% decrease in strength was observed after ageing. From observation of the failed specimens it was clear that some delamination had occurred by debonding of the epoxy and the BFRP bar. This vacuum-pressure regime is an extreme form of moisture cycling giving a worst case scenario representation. The second ageing method represented a more realistic exposure condition for structures designed for service classes 1 and 2. This was achieved by cycling relative humidity in a moisture chamber to mimic a typical Northern European annual relative humidity cycle. After three full cycles, when compared with similar specimens tested in ambient conditions no significant loss of strength was observed. Aged specimens had average failure strength of 74.47kN whereas non-aged specimens failed at an average of 75.44kN. Variation within the samples sets was similar confirming that ageing for a short time period does not have a detrimental impact on the bond strength.

Frame corner tests were designed to validate theoretical design guidelines that have been developed. These tests consisted of 600mm deep box beams connected to a post via glued-in rods on the back face embedded in to the post, see Fig. 2. Specimens were loaded in 1kN increments to failure with ultimate failure load and failure mode being recorded. At the time of writing results from these tests are being analysed and will be available in future publications by the author.

'Fig. 2' Frame corner test

Potential for Application of Results

The ultimate results from this research include a design method for glued-in rod moment connections. Looking towards the next edition of Eurocode 5, expected in 2020, the research presented here can provide information on the behaviour of Basalt Fibre Reinforced Polymer as a viable rod material and the design thereof.

References

RILEM TC, 1994, "RC 5 Bond test for reinforcement steel. 1. Beam test, 1982," in *RILEM Recommendations for the Testing and Use of Constructions Materials*, RILEM, Ed. E & FN SPON, pp. 213 – 217.

Steiger R., Serrano, E., Stepinac M., Rajčić V., O'Neill C., McPolin, D., Widmann, R.; 2015; Strengthening of timber structures with glued-in rods, Construction and Building Materials, Vol 97, pp. 90-105

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