

Briefing: Bonded-in technology for structural timber

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Bonded-in technology provides rapid and reliable solutions for the connection, reinforcement and repair of timber structures. This briefing describes how fibre-reinforced plastic pultruded rods are bonded into over-sized holes or slots in timber, using room-temperature cure epoxy adhesives, to achieve coherent timber-to-composite interfaces. The results of pull-out tests are reported which confirm the integrity of the pultruded rod-to-timber interface. Examples of timber connections, reinforced beams and the repair of timber bridges are examined, and a comprehensive list of research references are included which underpin bonded-in technology for structural timber.

1. INTRODUCTION

Conventional techniques for connecting together elements of timber structures include traditional carpenters' joints, bolts and nail plates and fasteners, such as nails and screws. Bonded-in connections, comprising rods or plates bonded into holes or slots machined into the structural elements, offer a rapid and economical method for facilitating timber construction. The reinforcement of timber structures, such as road bridges, may also be achieved by bonding reinforcement into routed grooves in existing structures, or by incorporating reinforcement into building elements, for example glue-laminated beams. A final application for bonded-in technology in construction is the repair of damaged or decayed timber, for example beam ends in heritage buildings. This briefing reviews examples of bonded-in technology for timber in construction with practical examples of work completed by Rotafix Ltd and research undertaken at the University of Bath.

2. MATERIALS

Bonded-in rods and plates are comprised of either steel, from standard steel stock, or, increasingly, pultruded fibre-reinforced plastics (FRPs). Pultrusion is a process whereby fibre tows, wetted with thermosetting adhesive, are pulled through dies to maximise fibre content and the adhesive system is cross-linked to allow the formation of continuous sections which can be cut to length. Thermoplastic-matrix FRPs are also available in rod and plate form with textured finishes. The relative merits of these materials are summarised in Table 1.

Although oak pegs are used as dowels to connect traditional timber structures, timber connectors are not used for bonded-in

structures because of their low modulus of elasticity and strength. One great advantage of bonded-in connections is that they are protected from direct moisture ingress and fire by the timber that surrounds them. FRP rods possess lower thermal conductivities than steel and conduct less heat into the connection.

Adhesives for bonding in plates and rods are generally room temperature cure epoxy systems such as Rotafix CB10T Slow Set. This adhesive system is formulated without organic solvents and is thixotropic such that it flows when sheared but then remains static when the shear force is removed. These characteristics enable the adhesive to be employed when repairing the underside of structures such as bridges because the adhesive cannot flow out of the joint.

3. BONDED-IN CONNECTIONS

Materials and design considerations for bonded-in connections are described in the recent literature for steel rods in softwood glulam^{1,2} and pultruded FRP rods in laminated veneer lumber.^{3,4} The resistance of bonded-in connections to static and dynamic loads are considered in these research papers and the design of moment-resisting joints is discussed. Bonded-in connections are shown to be capable of resisting fatigue loads, which might be caused by wind and vehicle loads acting on structures such as timber bridges.

The pull-out force required to de-bond rods from wood cubes along the grain has been measured as a function of adhesive type, glue-line thickness, bonded-in length and the surface preparation of rods. Failure modes for five glue-line thicknesses are illustrated in Fig. 1 and average failure loads are compared in Fig. 2. In static tests, thick glue-lines result in higher failure loads and failure moves from the rod to adhesive interface into the laminated veneer lumber away from the wood-to-adhesive interface as the glue line thickness increases. In tests perpendicular to the grain the pull-out force is very close to the value for pull-out along the grain.

The integrity of bonded rod to laminated veneer lumber interfaces is illustrated in Fig. 3, where two rods have been used to form an in-line connection between beam sections and the joint has been loaded in four-point bending. In this case the rods were 16 mm in diameter with a glue-line thickness of 4.5 mm. The laminated veneer lumber was 10 mm deep and 51 mm wide and the rod centres were located 25 mm from the top or bottom surfaces of the beam. On average 64% of moment transfer was achieved by this connection.

Connection material	Advantages	Disadvantages
Steel	Low cost, very high modulus of elasticity, ductile	High density, requires corrosion protection, high thermal conductivity (fire)
GFRP (glass fibre + thermosetting matrix)	Intermediate cost and density, high strength	Lower modulus than steel but compatible with timber
GFRP (glass fibre + thermoplastic matrix)	Intermediate cost and density, textured finish, compatible with timber	Matrix may be temperature sensitive
CFRP (carbon fibre + thermosetting matrix)	High modulus of elasticity, low density, high strength	Relatively high cost but only thin sections required

Table 1. Factors affecting choice of rod and plate materials for connections

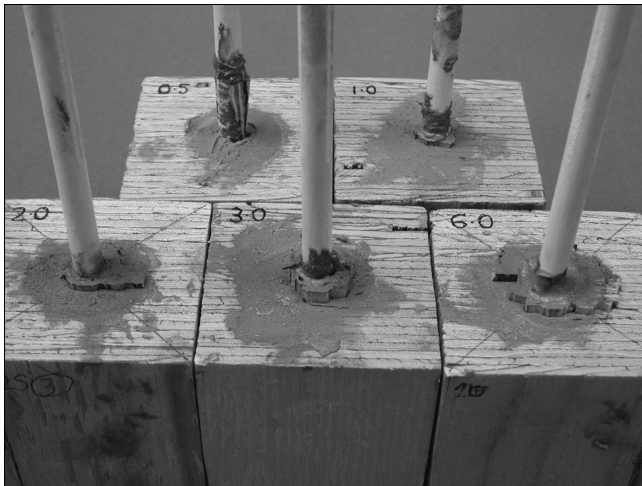


Fig. 1. Failure modes for GFRP rods in laminated veneer lumber for glue-line thicknesses of 0.5, 1.0, 2.0, 3.0 and 6.0 mm



Fig. 3. Failure of an in-line beam-to-beam connection tested in four-point bending

The effect of rate of loading on the pull-out strength of bonded-in rods⁵ is such that thin glue-lines are favoured for high rates of loading whereas at low rates of loading thicker glue-lines result in higher strengths. The performance of in-line joints⁶ and moment-resisting joints,⁷ based on bonded-in rods, has been evaluated in fatigue and these joints demonstrate a high capacity to dissipate energy, which is of relevance to earthquake zones.

4. BONDED-IN REINFORCEMENT

There is scope for upgrading the performance of timber by, for example, bonding reinforcement into the upper and lower faces

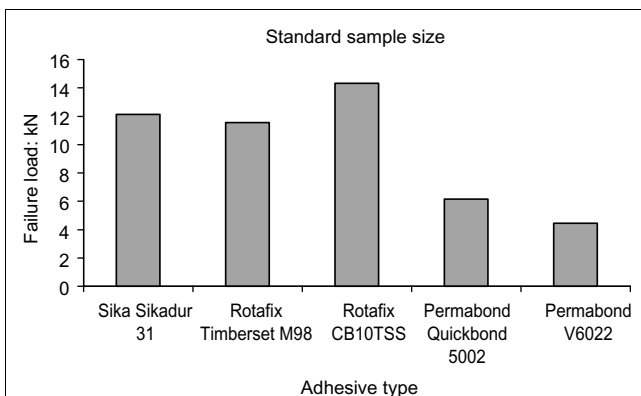


Fig. 2. Average failure loads as a function of adhesive for 2 mm thick glue-lines

of beams. Examples of reinforcement geometries⁸ are shown in Fig. 4. Finite-element techniques⁹ have been used to predict the performance of such reinforced beams as a function of reinforcement type and geometry.

Steel reinforcement offers a low-cost route for achieving significant improvements in flexural strength and stiffness.¹⁰ An example of the reinforcement of the underside of a Canadian bridge in situ is shown in Fig. 5.

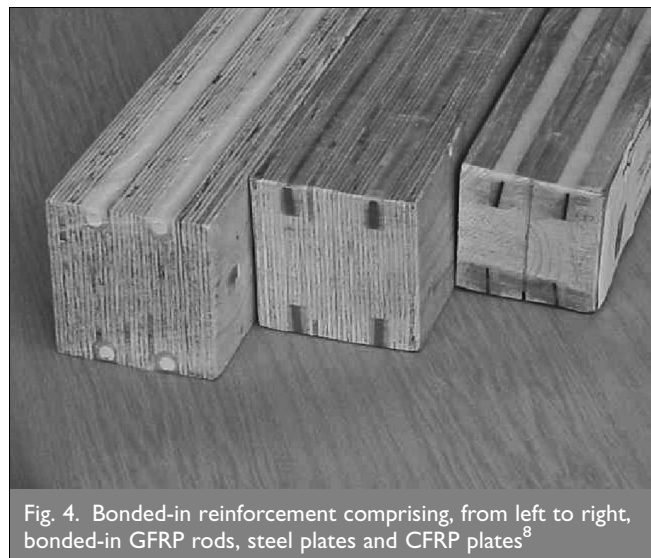


Fig. 4. Bonded-in reinforcement comprising, from left to right, bonded-in GFRP rods, steel plates and CFRP plates⁸



Fig. 5. Reinforcement of Tourand Creek Bridge, Canada. Rotaflex rods are being pressed into slots filled with Rotafix CB10T SS adhesive, © Rotafix Ltd



Fig. 6. CFRP plates being dry-fitted into slots before adhesive installation. The original beams are to the right and the new sections to the left, © Rotafix Ltd

The bridge deck was jacked up before the injection of adhesive and the insertion and bonding-in of continuous lengths of glass-fibre-reinforced plastic pultrusion. The ambient temperature at night dropped to as low as -35°C so the whole of the space beneath the bridge was enclosed with plastic sheeting and heating equipment was used to raise the ambient temperature to between 15 and 18°C . Following the complete cross-linking of the adhesive, the jacks were removed. Before reinforcement the bridge deck was loaded (using trucks containing wet concrete) and the deck deflections were measured. When the work was completed, the bridge was reloaded and reduced deflections of at least 30% were measured.

5. BONDED-IN REPAIR

The final application for bonded-in technology relates to the repair of timber structures. Such repair may be a response to long-term degradation, for example the decay of beam ends where they rest in apertures in the walls of heritage buildings. In the example shown in Fig. 6,¹¹ decayed sections have been removed and new sections positioned to allow end-to-end connection with the preserved central portion of the main structural floor beams.

In the photograph the carbon-fibre-reinforced plastic plates used in this restoration project to effect the repair are being aligned in position and the green peel ply is yet to be removed before the bonded-in repair is completed.

6. CONCLUSIONS

Bonded-in technology for timber in construction offers a wide range of versatile solutions for timber connection, reinforcement and repair. These repair and restoration solutions have paved the way for the introduction of bonded rod technology into new building construction. For example, a French company is manufacturing new timber-frame house kits with all bonded-in rod joints and Arup designed a prestige timber-framed swimming pool complex in Drogheda using bonded-in, moment-resisting joint technology. Standard methods for bonded-in technology for timber are also being developed for incorporation into codes and standards.

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