Construction and Building Materials 97 (2015) 90–105

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Strengthening of timber structures with glued-in rods

René Steiger [a,*], Erik Serrano [b,1], Mislav Stepinac [c,2], Vlatka Rajčić [c,3], Caoimhe O'Neill [d,4], Daniel McPolin [d,5], Robert Widmann [a,6]

[a] Empa, Swiss Federal Laboratories for Materials Science and Technology, Structural Engineering Research Laboratory, Ueberlandstrasse 129, CH-8600 Dübendorf, Switzerland
[b] Division of Structural Mechanics, Faculty of Engineering LTH, Lund University, P.O. Box 118, SE-221 00 Lund, Sweden
[c] Department of Structures, Faculty of Civil Engineering, University of Zagreb, Kaciceva 26, 10 000 Zagreb, Croatia
[d] Civil Engineering Research Centre, Queen's University, Belfast University Road, Belfast BT9 5AG, Northern Ireland, United Kingdom

HIGHLIGHTS

- Glued-in rods (GiR) connections/reinforcement to be regarded as systems.
- System parts: timber, rod, adhesive, geometry, setting procedure, quality control.
- Ductile failure modes in GiR to be preferred.
- Few technical approvals for specific products available.
- Limited number of design rules in actual and former design codes available.

ARTICLE INFO

Article history:
Received 28 January 2015
Received in revised form 17 March 2015
Accepted 23 March 2015
Available online 20 April 2015

Keywords:
Reinforcement
Steel rod
FRP rod
Design
Application
Adhesive
Eurocode 5
Quality control
Linear elastic fracture mechanics
Non-linear elastic fracture mechanics

ABSTRACT

The research and development of connecting and strengthening timber structural elements with glued-in rods (GiR) has been ongoing since the 1980s. Despite many successful applications in practice, agreement regarding design criteria has not been reached. This state-of-the-art review summarises results from both research and practical applications regarding connections and reinforcement with GiR. The review considers manufacturing methods, mechanisms and parameters governing the performance and strength of GiR, theoretical approaches to estimate their load-bearing capacity and existing design recommendations.

1. Introduction

Glued-in rods (GiR) are an effective way of producing stiff, high-capacity connections in timber structures. In addition GiR have been successfully used for almost 30 years for in-situ repair and strengthening of structures, as well as for new construction works. GiR are used for column foundations, moment-resisting connections in beams and frame corners, as shear connectors and for strengthening structural elements when extensively loaded perpendicular to grain and in shear. Early examples of their use also include the connection of windmill blades made from glued laminated timber (glulam) [1,2]. Most applications have used the GiR connections/reinforcement with metal bars glued into

* Corresponding author. Tel.: +41 58 765 42 15.
E-mail addresses: rene.steiger@empa.ch (R. Steiger), erik.serrano@construction.lth.se (E. Serrano), mstepinac@grad.hr (M. Stepinac), vrajcic@grad.hr (V. Rajčić), coneill86@qub.ac.uk (C. O'Neill), d.mcpolin@qub.ac.uk (D. McPolin), robert.widmann@empa.ch (R. Widmann).
URLs: http://www.empa.ch (R. Steiger), http://www.byggmek.lth.se (E. Serrano), http://www.grad.unizg.hr (M. Stepinac), http://www.grad.unizg.hr (V. Rajčić), http://www.qub.ac.uk/research-centres (C. O'Neill), http://www.qub.ac.uk/research-centres/cerc/ (D. McPolin), http://www.empa.ch (R. Widmann).
1 Tel.: +46 46 222 03 19.
2 Tel.: +385 1 4639 281.
3 Tel.: +385 1 4639 283.
4 Tel.: +44 28 9097 4027.
5 Tel.: +44 28 9097 3091.
6 Tel.: +41 58 765 40 01.

http://dx.doi.org/10.1016/j.conbuildmat.2015.03.097
0950-0618/

softwood. In practice, glulam made from softwood in combination with rods with metric threads is the most commonly used combination. Immense experience exists in the repair and strengthening of timber beams both softwood and hardwood, and in connecting concrete slabs to floor beams. For applications where corrosion or weight of the structure could be of concern, the use of pultruded FRP rods is quite common. Some investigations have also aimed at the use of reinforcing bars (rebar), e.g. [3,4].

All known types of adhesives applicable for wood bonding have been trialled for GiR, but one and two-component epoxies, polyurethane and resorcinol types are those most frequently used in practice. Specific adhesive products have been formulated to fulfil the needs of GiR connections/reinforcement with timber, which offer much better performance with respect to strength. A large number of parameters impact the strength of GiR [5]. Hence, the challenge is to adequately account for these in design and to provide quality control measures to guarantee a reliable load bearing behaviour of GiR, which are usually assigned high loads by the designer.

2. Reinforcement of structural elements with GiR

Key deficiencies of timber in terms of comparably low tensile and compressive strength perpendicular to the grain as well as moderate shear strength can be overcome by strengthening the timber with GiR in zones subjected to excessive stress. Examples are notched beams or beams with holes, curved or tapered beams and contact zones or supports with high compression stresses perpendicular to the grain (Fig. 1). Due to their availability in different lengths and their high stiffness, GiR are an efficient tool in strengthening of timber structures. Since, however, their application in practice is quite demanding (see chapter 3), self-tapping screws are often preferred by designers, particularly for existing structures.

Reinforcing of timber structures is considered an important topic. Hence, as part of the active development of EN 1995, one working group is exclusively dealing with this topic. Their work is based on document CEN/TC 250/SC 5 N 300 [6] which describes the state-of the art related to reinforcement of timber structures.

It is important to note that incorporating GiR strengthens elements when overloaded, but will not prevent them from developing cracks due to effects like moisture cycling or non-critical loading!

2.1. Strengthening in tension perpendicular to the grain

Amongst the earliest applications of GiR to strengthen timber structures were members with excessive tension stresses perpendicular to the grain (curved and tapered beams, notched beams, beams with holes) [7–9]. The GiR reinforcement in these cases prevent the members from early cracking (design of new structures) or stop crack propagation and restore initial load bearing capacity in/of members in existing structures suffering from damage caused by severe cracks [10]. The GiR reinforcement acts like rebar in concrete. Design rules for GiR applied to strengthen members perpendicular to the grain can be found in chapter 6.8 of the German National Annex to EN 1995-1-1 [11]. According to these rules, glued-in rods with metric thread as well as glued-in profiled rebar can be utilised. When designing the reinforcement of notches or holes, tensile strength perpendicular to the grain is not taken into account, i.e. cracking of the structural member is assumed to have taken place already [12].

2.2. Strengthening in shear

The significant impact of crack formation on shear resistance and the desire to prevent the spread of already existing cracks encourages the strengthening of beams. From numerical and experimental studies on shear reinforcement by means of GiR or self-tapping screws [13–18] it can be concluded that GiR (and self-tapping screws) set under an angle of 45° with respect to the beam axis provide an efficient mean of increasing the shear strength of beams. Beams strengthened in shear can reach higher load bearing capacities in bending if early shear failures are prevented. The reinforcing elements also contribute to a considerable

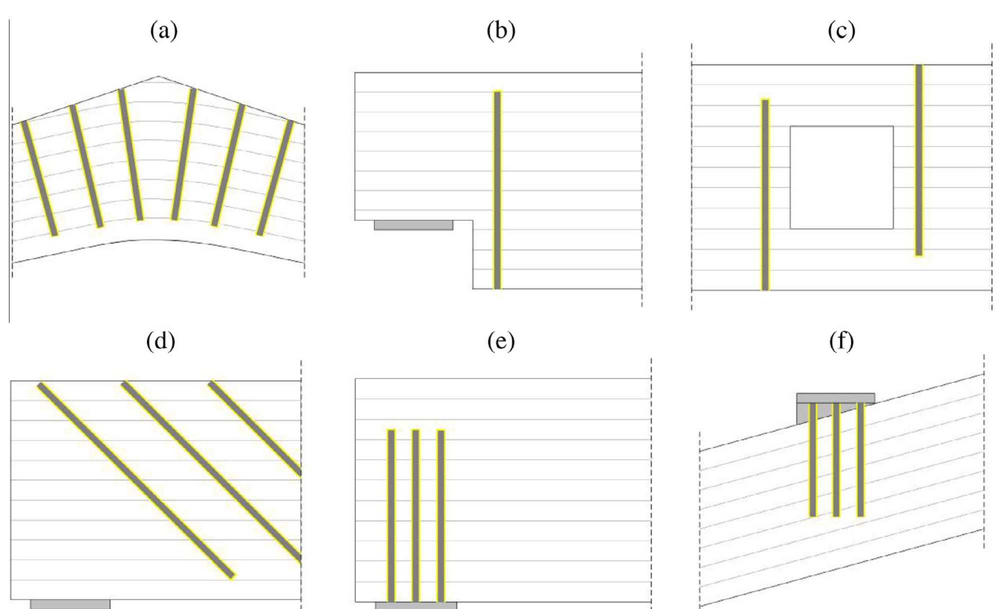

Fig. 1. Application of GiR to strengthen timber structural elements: zones of high tensile stresses perpendicular to the grain in: (a) curved and tapered beams, (b) notched beams, (c) beams with holes, (d) zones of excessive shear stresses, (e, f) compression stresses perpendicular to the grain at supports.