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BRIEF ORIGINAL

Glued-in rods in beech laminated veneer lumber

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Abstract Beech laminated veneer lumber is a new engineered wood product with superior mechanical properties and high density. In order to take advantage of this superior mechanical performance in the case of connections with glued-in rods a series of pull compression tests with different angles to the grain have been performed applying both polyurethane and epoxy resin as adhesives. No influence of the grain angle on the load carrying capacity could be found. In addition, a survey on design rules and their acceptance in practice has been carried out, showing a clear need for further standardization.

1 Introduction

Glued-in rods (GiR) have been used for several decades in timber structures to transfer forces from one member to another. Furthermore they have been applied as a reinforcement of timber members loaded in tension perpendicular to the grain. They are also used in heavy timber constructions where joints with a high load capacity are needed. They represent a versatile joint system with advantages of high load transition, appropriate behavior in case of fire, easy application combined with a high level of prefabrication for fast installation. Moreover, what cannot be neglected is the aesthetic appearance of the finished joint (Stepinac et al. 2013).

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The work described in this paper was conducted at Holzforschung München, Germany, in January 2013 as part of the Short Term Scientific Mission (STSM) of COST Action FP1004 "Enhance mechanical properties of timber, engineered wood products and timber structures". STSM was obtained in three phases. In the first phase state of the art in glued-in rods was examined and comparison between different design approaches of such systems was obtained. In addition to the comparison of design rules, in the second phase, an online survey on the usage, requirements for a design rule and scientific research was developed and sent to scientists, timber industrialists and structural designers all over Europe. In the final stage of STSM, pull-compression tests of GiR in laminated veneer lumber (LVL) were obtained. LVL made of European beech is a new product on the market and it would be interesting to analyse the performance of GiR in beech LVL timber frames.

The first part of this paper was used for the conference paper (Stepinac et al. 2013) and the second part formed the basis of a scientific article (Hunger et al. 2016).

2 State of the art and comparison of design rules for GiR

One outcome of the discussion within the COST Action FP 1004 was to gather relevant information from published articles and known design rules and try to find out what needs exist and what hinders the introduction of design rules for GiR in Eurocode 5 family of standards. The idea was to focus all research knowledge and experiences (GIROD, Licons, etc.) to point out key issues regarding glued-in rods that need to be resolved. Briefly, what was concluded from past researches is that pull-out strength

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depends primarily on interfacial layer and shear strength parameter which is influenced by mechanical and geometrical properties of three different materials (Tlustochowicz et al. 2010; Steiger et al. 2007; Widmann et al. 2007).

Different design methods are in use in a number of countries but contradictions between design models and the studied influence of parameters are conspicuous, so a common European design procedure would be helpful. Caused by disagreements, the design rules considering GiR in a pre-version of the Eurocode (prEN 1995-2, 2003) were not adopted in the current version of EN 1995 (Stepinac et al. 2013). Consequently, design rules are considered necessary in Eurocode 5. A calculation model should take into account several parameters that are linked to different modelling approaches, influence of materials and geometrical parameters, type of load, and duration of load effects and boundary conditions. Also, three materials (steel, adhesive, timber) with distinct different mechanical properties are combined in such joints, thus representing a very complex system with a specific stress distribution. Present standards and design rules differ significantly one from each other, however, the basic principle is always similar. The calculation of the pull-out strength of single glued-in rod depends on several parameters, albeit with slight variations. These are the anchorage length, diameter of rod and a parameter that characterizes the shear strength of the rod/adhesive/timber interface. But there are also numerous other questions about these parameters, such as which diameter (diameter of rod, diameter of hole, equivalent diameter) and anchorage length (length of bonded rod, equivalent anchorage length) to use and which parameters should be included in the shear strength parameter (timber density, moisture content of timber, modulus of elasticity of timber, rod and adhesive, rod surface, rod material, type of adhesive, slenderness ratio, geometrical factors, etc.). In order to get feedback on these issues from a wider public, a survey was conducted.

3 Online survey

The main objective of the online survey was to gather overall knowledge and interest in glued-in rods. The questionnaire was divided into three parts: use of glued-in rods in practice, regulations and standards, and the extent of scientific research on the subject. Questionnaire was sent to scientists, timber industrialists and structural designers all over Europe. The questionnaire was filled out by 56 respondents from 15 European countries. Only 9 % of respondents are using glued in rods frequently in practice, whilst 68 % had never used them or used them in practice only a few times. The main reason for this was reported to be because of the lack of standards and regulations and consequently lack of adequate information about the design, quality control and installation methods. Rules for design were characterized as unreliable and unsatisfying. As seen from Fig. 1, almost 60 % of respondents were not confident whilst 89 % were not satisfied with present standards and regulations. It can be concluded that there is a general dissatisfaction with the present design rules and procedures.

The key problems with design rules mentioned in the questionnaire were the following (Stepinac et al. 2013):

1. Unified European design rules do not exist,
2. definition of rod spacing and edge distances were not reliable for rods under tension and shear load,
3. design rules were underestimating the load bearing capacity of the connection,
4. the situation of combined bending and shear was not covered,
5. ductility should be treated as a key issue,
6. there was no reliable rule for multiple rods (e.g. brittleness could lead to progressive failure in multiple rod connections),
7. lack of understanding on duration of load, the interaction between axial load and transverse load, and the influence of grain angle,
8. non user-friendly formulae.

4 Pull-compression tests on GiR parallel to grain in laminated veneer lumber made of beech

Beech laminated veneer lumber (LVL) is a new product with a density of close to 700 kg/m^3 and a characteristic bending strength of more than 70 MPa. It would be very interesting to apply this kind of wood elements in multi-storey residential and commercial buildings and for special applications in structural timber constructions. Except for load capacity, great attention should be given also to the behavior of joints. In this research work, four types of LVL made of European beech have been used for research of glued-in rods. Differences between specimens were in veneers direction (0°, 30°, 45°, 90°), dimensions of the specimen (length from 260 to 360 mm, height 110–120 mm, thickness 95–100 mm) and applied adhesives (epoxy EPX and polyurethane PUR). The purpose of the tests was to estimate the load carrying capacity of single GiR. The rods used were threaded steel bars with metric threads M12, in strength grade 10.9. Nominal anchorage length was 90 mm. Pull-compression tests were performed as shown in Fig. 2a and test specimen in Fig. 2b. Test method was according to EN 1382: 1999 standard. The load was applied at a constant rate between 0.5 and 1.5 mm/min until failure. For the measurement of the displacement,

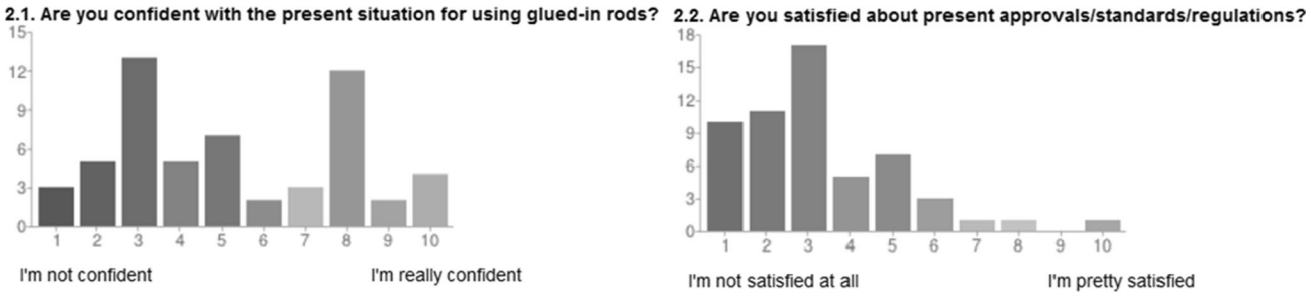

Fig. 1 Confidence and satisfaction about present norms and design rules from online survey obtained by Stepinac et al. (2013)

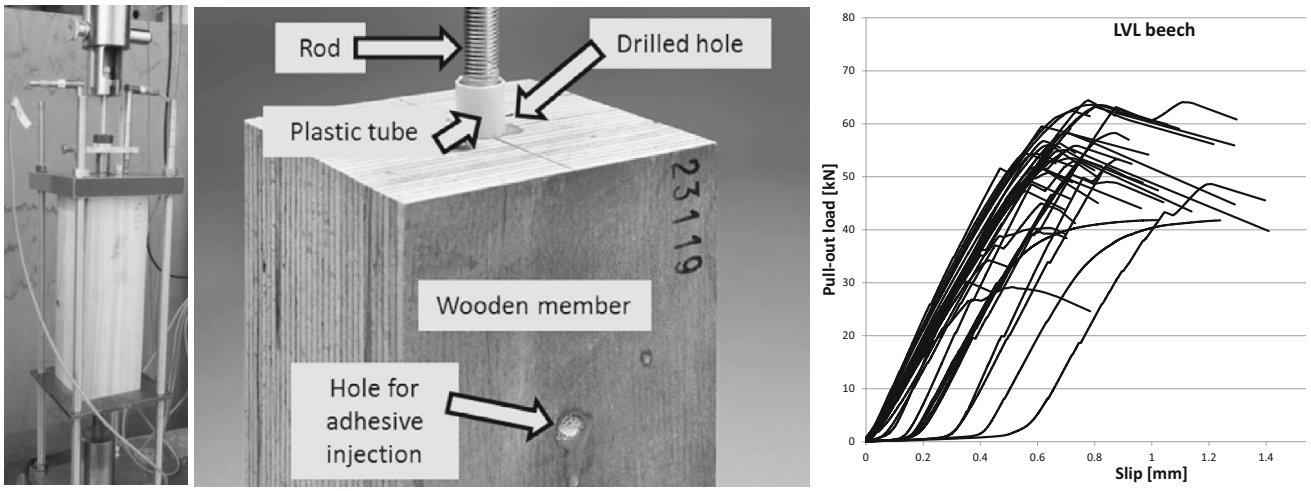

Fig. 2 **a** Test setup for pull-compression test of GiR in LVL; **b** test specimen; **c** load-slip-curves of all tested specimens (Hunger et al. 2016)

two LVDT displacement sensors were installed. Typical failure modes that occurred were shear failure along the rod in the adhesive layer, shear failure along the rod in the interface between the adhesive and the surrounding timber, shear failure along the rod in the surrounding timber and combined shear failure along the rod in the adhesive layer, in the surrounding timber and their interface. Conclusion is that there is no significant difference in pull-out strength of specimens with different veneers direction. Results of pull-out capacity of GiR in beech LVL were compared with results of pull-out capacity of GIR in solid beech (former scientific work conducted at Holzforschung München). In general, beech LVL show lower strength and stiffness values than the respective solid timber. The reason for the lower strength values of LVL made of European beech in comparison to solid beech might be explained by the production process. By producing rotary cut veneer, the inner side of the veneer is overstretched causing small longitudinal cracks. Cracks reduce the local shear strength in the timber around the glued-in rod more than other influences (Hunger et al. 2016).

5 Conclusion

The connections with glued-in rods have gained popularity as they provide solutions both for newly built structures and for strengthening existing ones. The performance of connections with glued-in rods is governed by very complex mechanisms and is dependent on a number of geometrical, material and configuration parameters and their combinations. During the past 20 years, despite of many national and international research projects and practical application of glued-in rods in timber structures is quite common there is still no universal standard for design thereof. Although there are many proposals for calculation and design of glued-in rods, there is no universal design rule and Eurocode 5 is desperately needed. It can be concluded that there is a general dissatisfaction with the present design rules and procedures. Laboratory tests on glued-in rods in LVL made from European beech were made and presented. Conclusion is that there is no significant difference in pull-out strength when using LVL's made with different fibre directions.

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