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Large diameter fastener in locally reinforced and non-reinforced timber loaded perpendicular to grain

Krunoslav Pavković [a,*], Vlatka Rajčić [b], Miljenko Haiman [c]

[a] Department for Civil Engineering, Polytechnic of Zagreb, Zagreb, Croatia
[b] Faculty of Civil Engineering, University of Zagreb, Zagreb, Croatia
[c] Faculty of Architecture, University of Zagreb, Zagreb, Croatia

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ABSTRACT

The research deals with a 49.0 mm in diameter mechanical fastener to which load perpendicular to grain is applied. The experimental research was divided in two series: the first series was carried out with locally reinforced, and the second with non-reinforced timber specimens. The local reinforcement of timber elements with textile sheets between lamellas in a layer of adhesive was made in the production process. Furthermore, research on finite element models using Abaqus/CEA software package was carried out. UMAT subroutine and cohesive contact between surfaces were used for modelling complex timber mechanical properties and cracks opening. The research results have shown that glass fiber textile placed between lamellas in adhesive layer effectively increases the resistance and splitting capacity of timber joint. Analytical approach has been proposed for predicting the splitting capacity of the reinforced joint.

1. Introduction

Joints with mechanical fasteners such as dowels, screws and nails are the most numerous among timber structures. Proper application of specified fasteners provides timber structure joints with sufficient strength and ductility. This is achieved by keeping minimum recommended distance between a mechanical fastener and a member edge, and between two adjacent mechanical fasteners, as recommended by European timber design code (EC5) [1].

The fasteners minimum edge and end distance recommended by EC5 often requires increasing of the member dimensions at the connection zone. Increasing the element dimensions causes increase in quantities of timber volume per square meter of the structure floor area. For instance, a particular problem arises when timber joint is made using fasteners $d = 30.0$ mm in diameter, which is also a maximum fastener diameter for which Eurocode recommends a design equations. In this case, EC5 recommends minimum distance between a mechanical fastener and a member edge of $7d = 210.0$ mm for loading perpendicular to grain. This recommended distance usually leads to an unacceptable size of timber.

In order to reduce dimension of the timber at joints, while maintaining sufficient ductility and strength, there is a need for local reinforcement of timber with glass or carbon fiber textile, steel plates or self-drilling screws mounted on the front side of the fastener.

The research presented in this paper is a part of researches conducted on joints for large span truss girders. The joint was produced with one mechanical fastener 49.0 mm in diameter through which load was applied. For these fasteners EC5 does not recommend a design equation for timber embedding strength, therefore excessive research is necessary.

This research was carried out in order to get a better insight into behavior of timber joint with reduced edge distance.

1.1. State of the art

The first researches, which dealt with the reinforcement of timber structural members, were carried out on timber beams with the reinforced tensile zone using steel and aluminum rods and strips [2–4]. Later studies carried out by Rowland on reinforced beams using several types of textiles and glues gave significant

* Corresponding author. Address: Av. Većeslava Holjevca 16, 10 000 Zagreb, Croatia. Tel.: +385 915753440.
E-mail address: krunoslav.pavkovic@tvz.hr (K. Pavković).

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results such as the increased stiffness and strength of the beams. The results also highlighted the economic viability of such reinforced timber and the possibility of using textile as a reinforcement at the connection zone [5].

Conducted researches were mainly aimed at increasing ductility and reducing the distance between the mechanical fastener, edge and end distance, using textile as a reinforcement [6–8]. Screws, dowels and nails were used as mechanical fasteners in these researches.

The researches carried out on a locally reinforced joint using a large diameter fastener, were presented in papers [9,10]. These researches were conducted using a mechanical fastener 50.0 mm in diameter while the applied load in both researches was parallel to grain. For the above mentioned researches, the textile was specially designed and timber lamellas had grooves in which the textile was placed.

Recent researches, using a fastener 90.0 mm in diameter mounted in reinforced timber by screws, were conducted and presented by Peter Kobel [11]. The applied load during these researches was parallel to grain.

1.2. Background and theory

1.2.1. Joint splitting capacity for fastener

For timber joint loaded perpendicular to grain, mode failure is caused by splitting of timber member parallel to grain. This mode of failure makes it natural to apply fracture mechanics. For a linear elastic body or in this case joint, loaded by a load F, the crack propagation energy release rate G is given by [12]:

$$G = \frac{F^2}{2b}\frac{dC}{da}, \tag{1}$$

where a is crack length, b is the width of the body, and C is the compliance given by the deflection of the loading point for a unit load. A crack starts propagating when the energy release rate reaches the critical value G^c. Assuming static condition and no energy dissipation outside the crack region, the critical value G^c becomes equal to the timber fracture energy for Mode I G_I^c.

The failure load F_c is given by:

$$F_c = \sqrt{\frac{2bG_I^c}{\frac{dC}{da}}}, \tag{2}$$

Assuming that load is applied perpendicular to grain in mid-span of simply supported beam, compliance method can be used. It is noted that orthotropic materials such as wood have three planes of material symmetry, and they are in L longitudinal, R radial, and T transversal direction. Procedure for finding failure load is to define the deflection of the loading point for a unit load as a function of the crack length, differentiate the function with respect to the crack length and use Eq. (2).

If the load is applied in T direction according to [13], failure load can be expressed as follows:

$$F_c = 2b\sqrt{\frac{2G_{LT}G_I^c h_e}{3\frac{G_{LT}}{E_L}\left(\frac{a}{h_e}\right)^2(1-\alpha^3)+\frac{6}{5}(1-\alpha)}}, \tag{3}$$

where h is beam height, h_e fastener distance from loaded edge, α is defined as $\alpha = h_e/h$. E_L modulus of elasticity (MOE) in longitudinal direction, G_{LT} is shear modulus for planes L–T.

If only deformation caused by shear force ($G_{LT}/E_L \to \infty$) or zero crack length is taken into account Eq. (3) leads to Eq. (4), which was first presented by Van der Put and Leijten in [14]:

$$F_c = 2bC_1\sqrt{\frac{h_e}{(1-\frac{h_e}{h})}}, \quad C_1 = \sqrt{\frac{5}{3}G_{LT}G_I^c}. \tag{4}$$

Model first presented in [13] and Eq. (4) has been implemented in EC5, with few changes, i.e. it was decided to use constant value of 14.0 N/mm$^{1.5}$ for C_1 and half of total splitting failure load in order to allow equation usage for location of loads other than mid-span. The characteristic splitting capacity according to EC5 can be expressed as follows [1]:

$$F_c = F_{90,Rk} = b \cdot 14.0\sqrt{\frac{h_e}{(1-\frac{h_e}{h})}}. \tag{5}$$

1.2.2. Stress concentration around a hole

Defining crack opening and propagation with applied fracture mechanics, as was described in the previous section for timber, cannot be used for the textile. The above mentioned theory is not an option, because shear modulus for glass fiber textile is zero, which leads to an incorrect value of textile sheet splitting capacity F_{ct} = 0.0.

For defining glass fiber textile failure load, the theory of stress concentration around a hole needs to be applied. Stress distribution away from the hole is uniformed but in the vicinity of the hole has a sharp rise, and peak stress of that rise can be written:

$$\sigma_{\max} = K_t\sigma_F, \tag{6}$$

where K_t is stress concentration factor and σ_F is uniform stress. Stress concentration factor depends of material mechanical characteristics, for homogeneous material such as steel it is K_t = 3.0 and for orthotropic materials such as textile reinforced timber it is not precisely defined. The most closer research which defines stress concentration factor in the carbon fiber reinforced plastic was given in [15] and it was based on research given in [16]. Stress concentration factor in mentioned literature was defined in a very large range from K_t = 0.81 to K_t = 4.47, depending of fiber orientation and fastener edge distance. Because of mentioned state of the art, most conservative approach was used. Stress concentration factor of K_t = 3.0 was used for textile placed in glue. Uniform stress in textile can be distributed on effective textile length which can be defined with angle of load-dispersion. Load-dispersion angle is dependent upon the deformation level, for small deformation is β = 45° and for large deformation is β = 34° [17]. Equation for uniform stress in textile now can be now be formulated as follows:

$$\sigma_F = \frac{F/2}{m \cdot h_e/tg\beta}, \tag{7}$$

where m is textile thickness. If peak stress is now changed to ultimate textile strength P_u [kN/mm] obtained by tests, and if Eqs. (6) and (7) are used, failure load in textile can be written

$$F_{ct} = \frac{2P_u h_e n}{3tg\beta}, \tag{8}$$

where n is a number of textile sheets.

2. Materials and methods

2.1. Specimens geometry and materials in experimental research

Experimental specimens were divided in two groups: reinforced (E-H) and non-reinforced (A-D). In each group, four specimens were prepared and tested.

Four lamellas 210.0 mm wide and 32.0 mm thick were glued together with Casco adhesives MUF system 1247/2526. Then they were milled in order to obtain specimens that were geometrically of the same size, 120.0 mm wide 200.0 mm high, and 1000.0 mm long. Specimens for this research were used in rotated position for 90°, i.e. with vertically oriented lamellas, which is quite different from traditional laminated timber usage. The produced laminated timber was classified as GL 24 h according to EN 1194.