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LONGITUDINAL GLUED JOINTS OF TIMBER BEAMS AND THE INFLUENCE OF QUALITY MANUFACTURING ONTO THEIR CARRYING CAPACITY

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ABSTRACT

The content of this article is to analyse destructive testing results of longitudinal solid wood joints of structural size beams with internal and external glued wood-based panels (plywood) stressed in bending, which was mostly focused on simulating the effect of the glued line thickness (1 and 3 mm) and the influence of contact surfaces of longitudinally connected elements when bending loads.

The aim of this article is to compare the carrying capacity and the joint real behaviour under load with values obtained using numerical modelling and calculation according to valid standards.

KEYWORDS: Timber, joint, carrying capacity, plywood, adhesive.

INTRODUCTION

The growth of timber use in the building industry brings new trends, not only to the field of innovative wood-based materials, but also to the joining of the timber structure elements. Besides already well normatively described and laboratory tested joints with steel glued-in elements, most commonly rods or plates, glued timber-timber joints, used in furniture or the building industry are created as well. In the building industry it is possible to use glued joints especially for the reconstruction of timber structure elements – for its strengthening or for the replacement of damaged sections of wood. The stiffness and load bearing capacity of glued joints is influenced by several aspects (type of wood species, moisture, thickness of glued line, quality of gluing process, etc.).

Glued wood-steel joints, mainly in the form of threaded rods, are already an established practice in the construction industry with normative described values of bearing capacity

(Eurocode 5, 2006; CSN 73 1702, 2007) along with and perpendicular to grains supported by many laboratory experiments and scientific works. Some specialists from all around the world (Gustafsson et al. 2001; Aicher et al. 1999; Gaun 1998) and also from the Czech Republic (Vašek and Mikeš 1998; Lokaj and Klajmonová 2014) are dedicated to the issue of carrying capacity and the performance of joints of timber structures with glued-in steel rods and plates. These joints are used both for new buildings and for restoration and redevelopment in locally damaged elements of timber structures, where there is no need of total replacement, but only the local repair of damaged parts.

The load bearing capacity and deformation of glued wood-wood joints is influenced by considerably more factors than in the case of steel-wood joints. They are mainly: The type of wood species, adhesive properties, glued line thickness, moisture and geometry. A number of influences affecting the behaviour therefore offer a wide range of questions that need to be answered in this issue. Worldwide, research inquiries and the testing of these joints, focusing on various influences and their combinations affecting their bearing capacity, are already in progress.

For example (Serrano 2002) is devoted to the mechanical behaviour of these joints. Other works are mainly devoted to the carrying capacity of adhesives in combination with various aspects (Noguchi and Komatsu 2006), (Cameron and Pizzi 1985) and (Stoeckel et al. 2013) and the thickness of the glued lines (Pizzio et al. 2003).

For this work, glued joints were selected and tested, where the following aspects that may affect the bearing capacity were observed and simulated:

1) parameters of the joint - testing of outside and inside plywood;
2) thickness of the glued line, which mainly for timber elements with an uneven surface affects the quality of the joint – two thicknesses of 1 and 3 mm were chosen;
3) the quality of longitudinally connected elements faces the simulation of the possibility of no-contact of longitudinal elements and an existing gap between them - in the first series the longitudinal members are joined without gaps, in the second series a gap of 10 mm is left between the elements.

Due to the high sensitivity of these joints on the quality of their manufacture identical sets of specimens were compiled with an incorrect procedure not according to the rules of adhesive producers (the bond line was not created in the horizontal plane by spreading the adhesive over the entire surface, but the connections were created vertically with the leaking of adhesive to the glue gaps between elements, as often happens on site), which leads to the creation of an imperfect glued line and the reduction of the carrying capacity of these joints.

MATERIAL AND METHODS

Description of static test samples

For testing, sets comprised of 10 test samples were assembled. To determine the real behaviour and carrying capacity of joints, testing samples with structural dimensions of 140×200×1400 mm were assembled. The test samples were made of solid spruce wood with a strength class of C24.

For inside and outside the glued element plywood with dimensions of 27×140×280 mm of beech veneers D40 consisting of 7 layers was used. The grains of the inner layers of plywood went parallel with the grains of the timber elements. The thicknesses of the glued lines between the timber elements and plywood were selected with values of 1 and 3 mm.

The bio component epoxy adhesive with low viscosity and high wetting power (Figs. 1 and 2) was used for gluing. The test samples were conditioned prior to destructive testing in a standard ambient temperature of 20±2°C and relative humidity of 65±5 %. To determine the moisture of test samples, a moisture detector was used.

Fig. 1, 2: Preparation of test samples.

Three test sets with the following characteristics were prepared (Fig. 3):

- inside plywood;
- outside plywood, glued line thickness 1 mm, without gap between elements,
- outside plywood, glued line thickness 3 mm, without gap between elements,
- outside plywood, glued line thickness 1 mm, 10 mm gap between elements,
- outside plywood, glued line thickness 3 mm, 10 mm gap between elements.

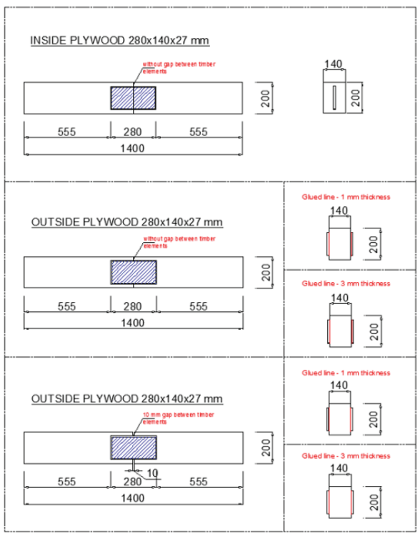

Fig. 3: Test samples geometry.

Course of the static tests

The testing was proceeded on a EU100 pressure machine at the laboratories of the Faculty of Civil Engineering, VSB-TU Ostrava, while the force was increased gradually (Fig. 4). The chosen rate of the press seems to be optimal, because the failure of all the tested samples appeared in a time-boundary of 300±120 sec, which corresponds to the interval of laboratory tests for short–time strength according to the current European standards for timber structures – Eurocode 5 (2006).

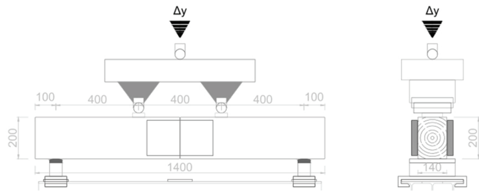

Fig. 4: Laboratory testing scheme.

The sample was loaded with an increase of deformation within the specified time so the resulting carrying capacity wasn´t significantly affected by the speed of loading.

Calculation according to standards

The calculation of the tested joints bearing capacity has been proceeded according to the rules provided in (Eurocode 5, 2006; CSN 73 1702, 2007), with input material data taken from (CSN EN 338, 2010).

The minimal value of bearing capacity is for tested samples in the glued line. The value shall be calculated according to the following expression (CSN 73 1702, 2007).

$$F_{t,c} = k_{\mathrm{mod}} \frac{f_{k,2,k} A_{tc}}{\gamma_M}$$

where: k_{mod} - modification factor for duration of load and moisture content,
$f_{k,2,k}$ - strength of glued surface,
A_{tc} - effective glued area,
γM - partial factor for material properties.

Numerical modelling

Numerical model in ANSYS was calculated as the volume using the finite element SOLID45 and auxiliary member elements BEAM189 and it was created for the glued line of 3 mm. Using volume elements modelled studied parts of the structure and joint (Fig. 5).

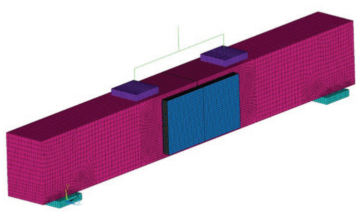

Fig. 5: Finite element network.

Using beam elements, the head of the press and its transfer to steel distribution plates were simulated. The numerical model was calculated taking into account the construction (contact task), geometrical and physical nonlinearity. Physical nonlinearity was considered in material models of the individual parts of construction joints. Geometric nonlinearity in this case had no effect but for the sake of completeness was included in the calculation of the numerical model. The timber of the main element and plywood was modelled as orthotropic. This allowed a more appropriate response of connected parts and thus a more realistic distribution of strain and stress in the volume of the numerical model. The numerical model had about 121 degrees of freedom on three unknown shifts in the node. Loading in the numerical model was selected as a strain with a specified movement of the press head of 14 mm. Calculation was made to the maximum step of 0.607, which corresponds to the deformation of the press head of about 8.5 mm. Further steps weren´t calculated. The calculation hasn´t converged. The equilibrium forces haven´t been reached.

These results were observed only to the step 0.335 because in this step a break in the diagram of the numerical test occurs, which indicates the non-linear behaviour of the joint.

RESULTS AND DISCUSSION

Laboratory testing

Inside plywood

In joints with plywood glued inside the breaking of plywood boards occurred in tension at the interface connected elements in all tested joints, not a breach of the glued lines or beam (Figs. 6 and 7). The average value of bearing capacity for this type of joint is 16.25 kN.

Fig. 6, 7: Breach of inside plywood.

Outside plywood

In joints with plywood glued outside without dependence on the thickness of the glued line, the shear damage in the timber element along the grain or in the plywood in the first or second veneer occurs (Figs. 8, 9).

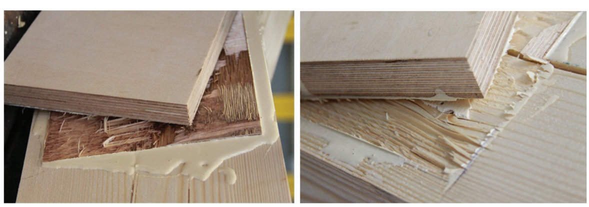

Fig. 8, 9: Damage in timber plywood veneer and timber element.

In test samples without a gap between the longitudinal elements for the glued line of 1 mm, the average value of the bearing capacity is 23.64 kN and for the glued line of 3 mm 61.79 kN. In test samples with a gap of 10 mm between longitudinal elements for the glued line of 1 mm, the average value of the bearing capacity is 23.06 kN and for the glued line of 3 mm 54.33 kN.

In the following picture (see Fig. 10) deformation curves of each set of measurements are represented, which show the highest value of the carrying capacity of joints with glued lines of 3 mm ranging above 50 kN at an average deformation of the joint of about 10 mm. Joints with glued lines of 1 mm show a bearing capacity ranging from 20 to 30 kN. The lowest value of the bearing capacity indicates inside plywood with an average value lower than 20 kN.

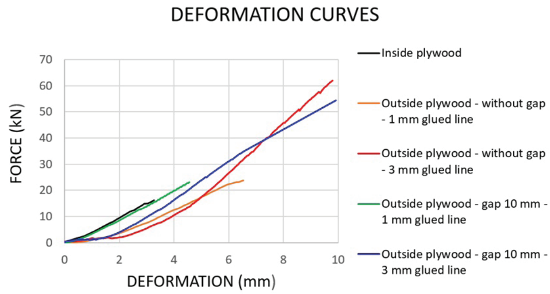

Fig. 10: Average deformation curves of tested joints.

Calculation according to standards

The minimal value of resistance in the glued line for the loading mechanism based on the results of standard calculations according to formula is 4.25 kN, when uniform shear stress distribution is not provided. In order to secure uniform shear stress distribution in the glued line the minimal value of the bearing capacity is given as a breach in the inner layer of the beech plywood with a value of 6.80 kN for the given loading mechanism according to formula.

Numerical modelling

In Fig. 11, shear stresses in the outer veneers of plywood for step 0.335 are shown, which corresponds to the deformation of the press head without a slip about 5.72 mm. The stress reaches the maximal value of approximately 6.01 MPa. These values are still within the limits of non-damaged beech and its grains. These deformations in the outer plywood veneers create rolling shear in the inner layer of plywood. The moment in the joint is redistributed to the entire thickness of the plywood in this way.

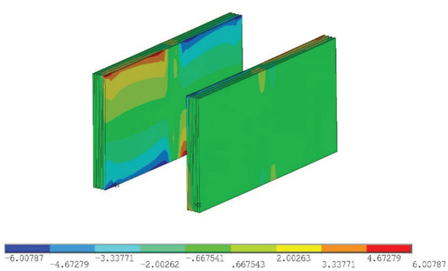

Fig. 11: Shear stress in plywood – outer veneers.

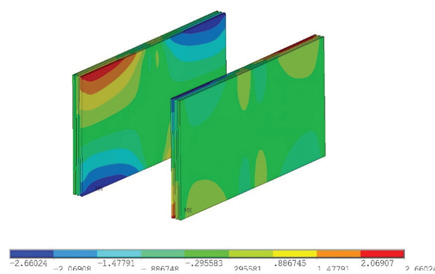

Fig. 12: Shear stress in plywood – rolling shear.

In Fig. 12 rolling shear stresses in the inner veneers of plywood for step 0.335 are shown, which corresponds to the deformation of the press head without a slip about 5.72 mm. The stress reaches the maximal value of approximately 2.70 MPa. These stresses in combination with other stress cases are decisive for the type of breach. This breach occurred as rolling shear in the inner layer of the beech plywood.

In Fig. 13 shear stresses in timber elements for step 0.335, which correspond to the deformation of the press head without a slip about 5.72 mm are shown. The stress reaches the maximal value of approximately 5.20 MPa. These values are still within the limits of the timber element of the C24 strength class.

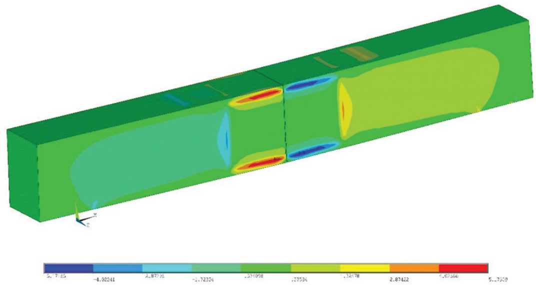

Fig. 13: Shear stress Sxy for timber elements in plane of loading.

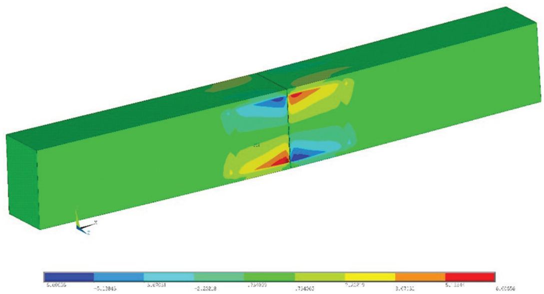

Fig. 14: Shear stress Sxy for timber elements cross the plane of loading.

In Fig. 14 shear stresses in timber elements for step 0.335 are shown, which correspond to the deformation of the press head without slip about 5.72 mm. The stress reaches the maximal value of approximately 6.70 MPa. These values are still within the limits of the timber element of the C24 strength class. In the glued line between the adhesive and wood the triple-axis tenseness occurs.

Comparison of results

The above values show that the lowest bearing capacity is demonstrated by the joint with the plywood glued inside, which is limited by its bearing capacity in tension. Implementing a joint with more plywood glued inside is not suitable with respect to the stiffness of the wood element.

A joint with the plywood glued outside which strength is strongly dependent on the thickness of the glued line shows significantly higher bearing capacity.

Especially with very thin adhesive lines (1 mm), due to the uneven surface of the wood and glue there is leaking into the cracks, creating discontinuously glued lines and thereby reducing the carrying capacity of the joint, which (Pizzio et al. 2003, Noguchi and Komatsu 2006, Cameron and Pizzi 1985) confirm in their research.

Numerical modelling is helpful for physical tests verification and the optimization of pre-tests and thereby the reduction of extensive laboratory measurements costs (Lokaj and Klajmonová 2014). Furthermore, numerical models provide insight into the redistribution of strain and stress in the structure and detail.

CONCLUSIONS

The carrying capacity of joints with glued lines 3 mm (with or without gap between timber elements) ranges above 50 kN.

From the numerical modeling, similar values in breaches as for the physical tests of a glued line of 3 mm were obtained. Similarity was achieved in the maximal bearing capacity of the joint. For the glued line of 3 mm, the gained value is 57 kN.

According to the values achieved in the physical tests and numerical models, the maximum bearing capacity is around 60 kN. This value exceeds the calculated normative carrying capacity in the order difference. The difference is mainly caused by a consistent concept of the security of the glued joint also by the fact that it is a brittle joint without ductility behavior.

The loading capacity is greatly influenced by the quality of gluing which cannot always guarantee a perfect contact of connected surfaces. Values obtained from calculation according to standard values are based on the characteristic values, which can be several times lower than the physical ones.

These glued joints are very sensitive to the quality of manufacturing. In case of the poor quality of the gluing line (discontinuities in gluing line) the bearing capacity decreased to 60 -70 %. These values have been approved by our laboratory tests.

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