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EFFECT OF THE SPREAD ADHESIVE THICKNESS AND SURFACE ON STRENGTH AND STIFFNESS OF JOINT

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ABSTRACT
This paper presents the analysis of stiffness and strength of the glued joint that is carried out by experimental and numerical procedure. In numerical analysis, the equations for momentum balance are discretized by the finite element method. Effect of the spread adhesive thickness and surface on shearing stress of glue line, joint strength, expressed by moment M, and joint stiffness C are analyzed. Results showed that joint stiffness and strength increases with increasing bonding surface and decreases with increasing thickness of the adhesive. Analyses are carried out for joint made from beech wood elements glued with PVA glue.
Keywords: glued joint, wood, numerical analysis

1. INTRODUCTION
Product quality and durability of a wooden structure primarily depend on joint quality. Development of new products in wood-processing industry and particularly of design of structural joints are still mostly bases on empirics. Impact wich modification of dimensions and/or of manner in which glue line is formed have on quality of joint is higly important and therefore with tests we try to find the best dimensions and geometric shape of the joint elements [2].
In this paper was analyzed impact of thickess and surface of glue spread on strength and stiffness glue line exposed to the static stress. Here are presented the results of experimental and numerical analysis of stress in the element of surface of glue spread singled out from the joint found in chair structure.

2. PHYSICAL AND MATHEMATICAL MODEL
Physical model of joint was presented in the figure 1a. Dimensions of cross section of the joint element were 55x12mm. Beech-wood elements were joined together with PVA glue. Position of the formed rectangular glue line in relation to vertical element is shown in the figure 1b. For experimental testing are taken four nominal glued surface (A_1=8 cm^2, A_2=10,4 cm^2, A_3=13,5 cm^2 and A_4=16,5 cm^2) with sides ratio h/b=1,5 and three thicknesses of glue line (0,1 mm and 0,18 mm encountered in practice and extreme value 0,28 mm). The joint clamped at the lower vertical element was exposed to mechanical load on free ending of horizontal element, figure 1a.
In calculation of maximum shearing stress on the surface of glue line, based on experimental results, we started from the fact that glue line is exposed to a complex intensity of stress situation [4]. The

shearing stresses, given to torsion, are calculated using the Saint-Venant coefficients for prismatic rods with full cross section.
In numerical calculation of stress and deformations, the wood was taken as orthotropic and the glue line as isotropic material. A solid connection was considered to be achieved between glue layer and wooden elements.

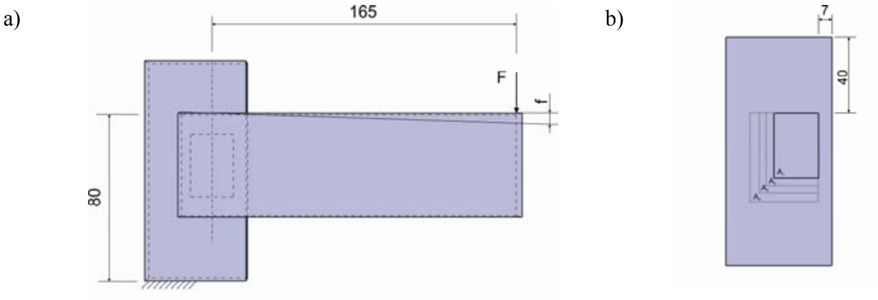

Figure 1. Physical model of joint: a) geometry and load scheme, b) position of glue line

Distribution of stress and strain in solid-body exposed to mechanical stress is described by momentum balance equation for the steady state

$$\frac{\partial \sigma_{ij}}{\partial x_j} + f_i = 0 \quad , \qquad \text{... (1)}$$

where are σ_{ij} - stress tensor, x_j - Cartesian spatial coordinates and f_i - volume forces.
Constitutive relation is

$$\sigma_{ij} = C_{ijkl}\varepsilon_{kl} = \frac{1}{2}C_{ijkl}\left(\frac{\partial u_k}{\partial x_l} + \frac{\partial u_l}{\partial x_k}\right) \quad , \qquad \text{... (2)}$$

where are C_{ijkl} - the elstic constant tensor components, ε_{kl} - the strain tensor components.
Boundary conditions must be specified in order to complete the mathematical model. That can be either displacements or stresses, i.e.:

$$u_i(x_g) = u_0 \,, \; \sigma_{ij} n_j = (\sigma_i)_{gr} \quad , \qquad \text{... (3)}$$

where are n_j - a component of normal vector on the surface edge, and displacement u_0 is zero at the fixed support.
Governing equations (1) combined with the constitutive relations (2) are solved by the numerical method based on the finite elements. For calculations is used software package CATIA.

3. EXPERIMENTAL RESULTS

For each of 14 joint variances 5 samples were examined. In assembling the samples, the glued pressure was 0,05 MPa. Quantity of glue for creation of a 0,1 mm glue line was 350 g/m^2, for a 0,18 mm tick 450 g/m^2 and for a 0,28 mm tick glue line it was 650 g/m^2. After assembling the samples were stored in controlled climate condition for 30-35 days.
Mean values of experimental test results are presented in the Table 1. Static strength of joint is expressed as the highest shearing stress in glue line and also trough bending moment M caused by fracture force F_{max}. Static stiffness of joint C is expressed through ratio between bending moment M caused by the fracture force F_{max} and free ending deflection angle at F_{max}.
Results showed that there is no significant impact of glue line thickness and glued surface to shearing stress, although there exists a slight dropping trend as those increase. There was no noted impact of glue line thickness to the moment M at the smallest glued surface, while for other examples this dependence becomes significant as glued surface increases. Impact to stiffness of joint C is considerable, either by increased glued surface or by increased glue line thickness. Strength of wood

in the area of joining the elements has important role in regard of joint destruction. In the Figure 2 are presented some of the most frequent forms of joint destruction.

Table1. Strength and stiffness of joint depending on surface glued and thickness of glue line

A cm^2	0,1 mm			0,18 mm			0,28 mm		
	τ MPa	M Nm	C Nm/rad	τ MPa	M Nm	C Nm/rad	τ MPa	M Nm	C Nm/rad
7,7	16,53	92,40	2206,66	16,91	79,86	1632,98	16,70	93,99	1311,22
10,4	14,97	123,42	2582,90	15,86	130,68	2807,80	16,78	138,23	2397,35
13,2	13,28	142,56	3052,81	15,61	190,41	3876,57	16,55	201,96	3912,98
15,1	13,47	186,78	4280,11	14,01	197,01	3648,25	14,69	229,02	2928,99

a) b)

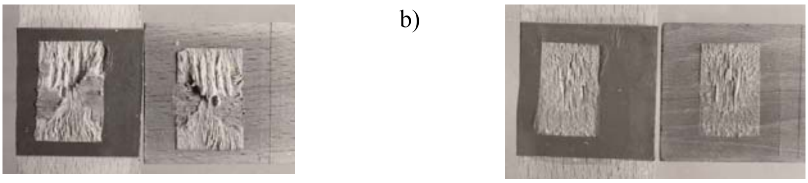

Figure 2. Forms of joint destruction: a) combined fracture, b) cohesion fracture on glue

4. NUMERICAL RESULTS

Numerical analysis of stress and strain was made for two glued surface (7,7 cm^2 and 15,1 cm^2) and three thicknesses of glue line(0,1mm, 0,18 mm and 0,28 mm). All examples were loaded at free ending with force $F = 225$ N, i.e. $\tau = 0{,}341$ MPa, what is ~40% of fracture force on the weakest joint. Mechanical properties of beech-wood for main directions (Figure 3a) are presented in the Table 2, and for PVA glue were taken $E = 465{,}74$ MPa i $\nu = 0{,}29$ [1, 3].

Table 2. Mechanical properties of beech (Fagus sylvatica L) ; $\rho = 0{,}75$ g/cm^3

Modulus of elasticity, GPa			Rigidity modulus, GPa			Poisson's ratio					
E_L	E_R	E_T	G_{LR}	G_{LT}	G_{RT}	ν_{LR}	ν_{LT}	ν_{RT}	ν_{TR}	ν_{RL}	ν_{TL}
13,97	2,28	1,16	1,65	1,08	0,47	0,450	0,510	0,750	0,360	0,075	0,044

a) b)

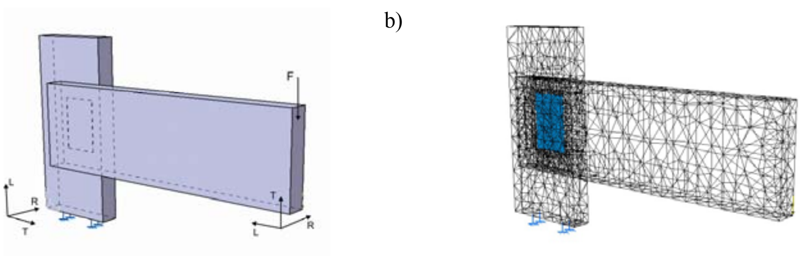

Figure 3. a) main wood directions, b) numerical grid

In the Figure 4a are presented results of joint stiffness depending on surface glued and thickness of glue line. Stiffness was calculated on the basis of horizontal displacement of glue line ending points, Figure 4b. Joint stiffness drops with decrease of surface and increase of thickness of glue line. Numerically obtained joint stiffness is higher than the one obtained in experimental testing.

In the Figure 5 is presented distribution of maximum shearing stress in the glue line for all 6 analyzed examples. The shearing stress reaches maximum value in the glue line corners and this maximum is higher for the joints with smaller glued surface. As thickness of glue line increase, the stress gradient in glue line decreases.

a) b)

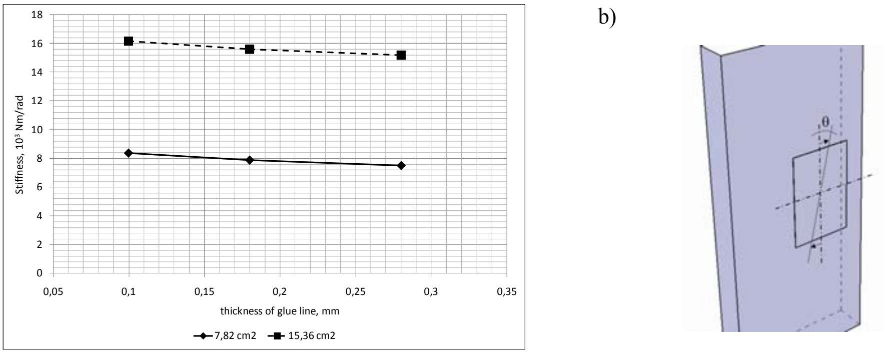

Figure 4. a) joint stiffness, b) displacements of glue line ending points

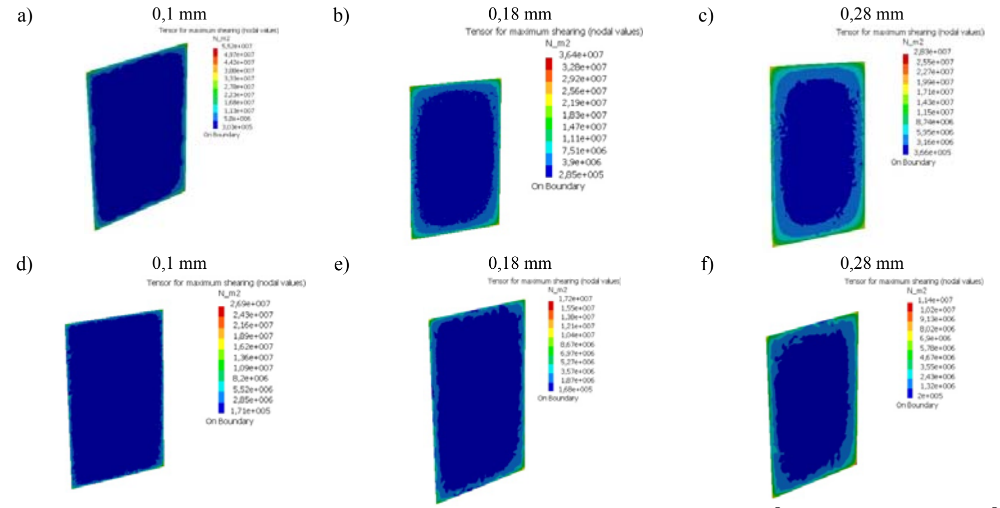

Figure 5. Distribution of max. shearing stress in glue line: a), b) , c) A=7,7 cm^2; d), e), f) A=15,1 cm^2

5. CONCLUSION

Results are presented for experimental testing of joint as well as numerical results obtained by application of finite elements method. The analysis conducted showed that strength and stiffness of joint depend on thickness of the glue line as well as on the glued surface. Based on the presented examples following may be concluded:

- strength and stiffness of joint increase as the glued surface increases and thickness of glue line decreases,
- distribution of maximum shearing stress in the glue line is not uniform and its maximum value significantly determines strength of the joint,
- the used numerical analysis may serve for relatively simple and swift evaluation of properties of the adhesive joints.

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