COMPARATIVE ANALYSIS OF BENDING STRENGHT OF END TO FACE BUTT STAPLE JOINTS BY FEM

Yancho Genchev – Nelly Staneva – Desislava Hristodorova

Abstract
Two corner end to face butt joints with 3 staples of different type M1 and 92 for upholstered furniture were 3D modeled with CAD system Autodesk Inventor Pro®. The wood members of the corner joints are with rectangular cross section 25x50 mm. A linear static analysis is carried out with CAE system Autodesk Simulation Mechanical® by the method of finite elements (FEM) simulating the compression bending loading of the joints. The orthotropic material characteristics of pine solid wood (Pinus sylvestris L.) for the wood members of the joints and friction between wood members and staples are considered in the analysis. As a results the distribution of stresses (von Mises and principal), displacements and deformation behaviour of staple corner joints are presented and analyzed. Bending strength of the jonts was evaluated. Results will help the design of upholstered furniture.

Key words: *end to face butt joint, staple, upholstered furniture, bending strength, FEM*

INTRODUCTION

The end to face butt joint with staples is practiced in skeletons of solid wood with spatial character and in the combination of board materials (chipboard, OSB, plywood) with solid wood. Strength and deformation characteristics of these joints should be precisely determined in order to ensure optimal design of upholstered furniture frames.

In Bulgaria and all over the world there are considerably more data concerning the experimentally established deformation behaviour and strength of different type corner joints for furniture frames (Erdil at al., 2003; Jivkov et al., 2006; Simeonova at al., 2015; Zhang at al., 2002; etc.). Since 1990 when J. Smardzewski, Poznan University, Poland has made the first attempt to use the finite element method for numerical analysis of furniture construction and in the last decade the finite element analysis (FEA) is increasingly applied in the wood industry, especially in furniture design (Archanowicz, 2012, Dzincic at al. 2013, Imirzi at al. 2015, Smardzewski at al. 2016, etc.)

In the literature there is no data about corner end to face butt staple joints. Upholstered furniture design lacks of sufficient precise data related to dimensions, deformation behaviour and strength of individual joints with staples.

The aim of research presented in this paper was to compare the deformation behaviour of end to face butt joints with 3 staples and two different types of staples (M1 and 92) by the method of finite elements (FEM).

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MATERIALS AND METHODS

Two corner end to face butt joints with 3 staples for upholstered furniture were 3D modeled with CAD system Autodesk Inventor Pro® (Educational product). The dimensions of the end to face butt joints are shown on Fig.1. The differences between the 3D modeled corner joints are the type of the staples (OMER S.p.A.), respectively the sizes, penetration and the material of the staples. Two types of staples were used:

- type M1 (1,3x1,45mm and penetration in the upper wood element 25 mm), made from cold drawn ware – AISI 1010 steel with density 7870 kg/m³, tensile strength 1050.10^6 N/m^2, modul of elasticity 205.10^6 N/m2 and Poisson ratio 0,29;
- type 92 (0,9x1,2 mm and penetration in the upper wood element 15 mm), made from cold drawn ware – AISI 1006 steel with density 7870 kg/m³ and tensile strength 1000.10^6 N/m^2.

For brevity created 3D models of the corner staple joints will be marked as "***model M1***" and "***model 92***".

The wood elements of the joints were made of Scots pine (*Pinus sylvestris L.*) with density 432 kg/m³ and elastic characteristics according Pěnčík (2014): $E_L=14300.10^6$ N/m^2, $E_R=700.10^6$ N/m^2, $E_T=545.10^6$ N/m^2, $G_{LR}=1230.10^6$ N/m^2, $G_{RT}=800.10^6$ N/m^2, $G_{LT}=500.10^6$ N/m^2, $\nu_{LR}=0,030$, $\nu_{RT}=0,38$, $\nu_{LT}=0,040$.

A linear static analysis of the two 3D models of the corner joints was carried out with CAE system Autodesk Simulation Mechanical® (Educational product) by the method of finite elements (FEM) simulating the compression bending loading of staple corner joints. Orthotropic material type was used for wood elements.

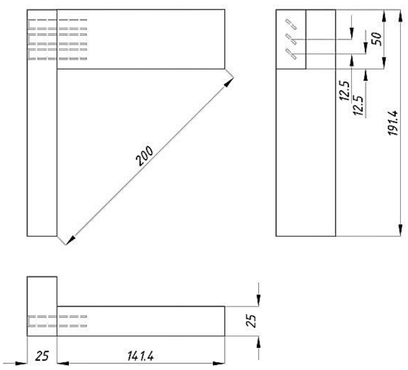

Figure 1. Dimensions of the joint sample

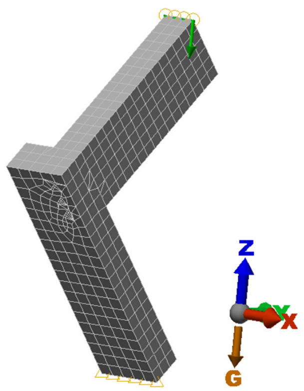

Figure 2. Mesh and loading: "model M1"

The contacts between the joint elements were defined to correspond to their respective counterparts in the phisical model. Surface contacts between upper wood element and staples were set for both models. Friction as an important factor was taken into account and friction coefficient of wood-steel μ=0,25 was set according to Staneva et al. (2016).

The static analysis was performed with cuboid 8-node finite elements of "brick" type – Fig. 2. The generated meshes of finite elements have 3989 nodes and 9841 DOF for „model M1" and 3946 nodes and 11812 DOF for „model 92".

Support conditions and loads were set - Fig.2. For determining of the deformation behaviour and ultimate strenght of the joints three design scenarios for both models were performed with three different loads, established by laboratory experiments (Hristodorova et al., 2015):

for „*model M1*“: F_{10} = 35,91 N, F_{40}=143,65 N and F_{max}=359,13 N;

for „*model 92*“: F_{10} = 21,90 N, F_{40}=87,60 N and F_{max}=219,0 N.

Loads F_{10} (10% from F_{max} and F_{40} (40% from F_{max}) correspond to the linear range of the curve expressed the relationship between the bending moment and semi-rigid rotation of the joints (Jivkov et al., 2006). The bending moments in the compression were calculated as the product of corresponding loading force F and the the length of deformed arm of bending l': $M=F.l'$, where the length of deformed arm of the bending moment l' was read from the program for every loading case.

RESULTS AND DISCUSSION

The results of static analysis of the two models of end to butt joints loading with F_{max} are presented in Fig.3 to Fig.7 and Table 1. The visualization of the deformed joint are shown with a scale factor 5% of model size for both models. The distribution of Z-displacement is presented on Fig.3. The maximal Z-displacements of 2,98 mm for „model M1“ and 1,68 mm for „model 92“ are received. The maximal Y-displacements (2,81 mm for model M1 and 1,61 mm for model 92) are almost equal with Z-displacements for both models, that is way both models are twisted in the XY- plane and ZY-plane, more clearly expressed for model M1 – Fig.3 – Fig.5.

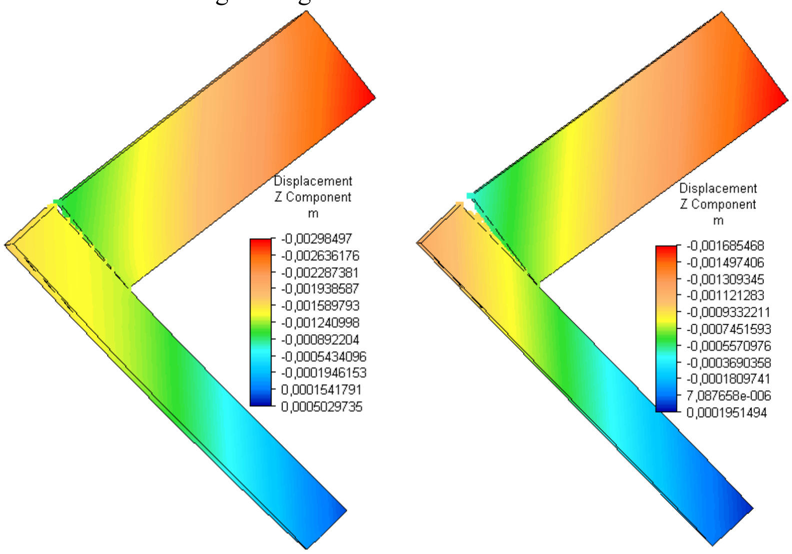

Figure 3. Distribution of Z-displacement: a) “model M1”; b) “model 92”

The distribution of von Mises stresses and minimum principal stresses in the joints are presented on Fig.4 to Fig.7. It is evident that the von Mises and principal stresses are higher for „model M1“. The maximal stresses are obtained in the zone of bending of the staples for both models - Fig.4 and Fig.5 . The maximal compression stresses in the wood elements are received in the inner corner of the joints – Fig.5.

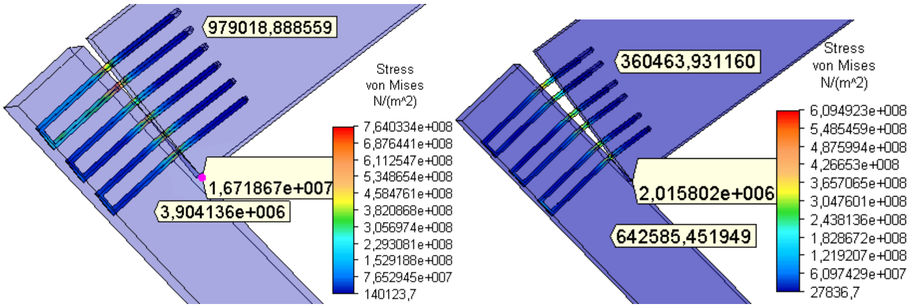

Figure 4. Distribution of von Mises stresses: a) “model M1”; b) “model 92”

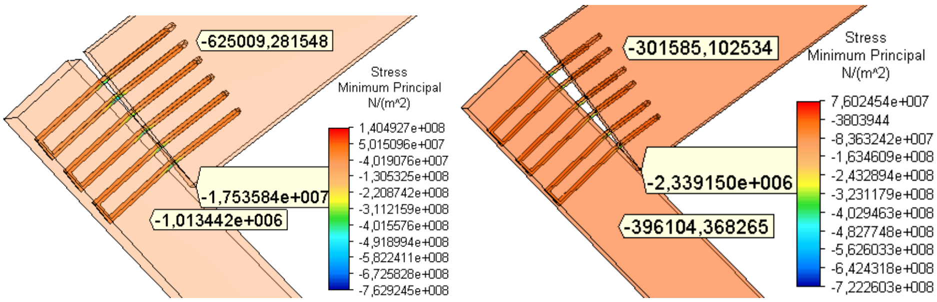

Figure 5. Distribution of minimum principal stresses: a)“model M1”;b)“model 92”

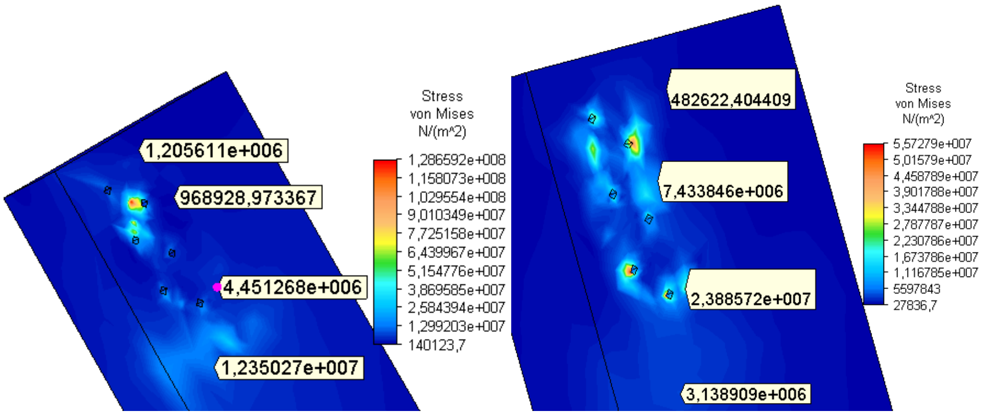

Figure 6. Distribution of von Mises stresses in the bottom element:
a) “model M1”; b) “model 92”

For the wood elements maximal stresses appear on the edges of the bored holes for staples - Fig.6. In the bottom wood element of „model M1“ maximal von Mises stresse was observed – $128,6.10^6$ N/m^2 only arround one hole, which may be is due to a singularity. For „model 92“ two zones with high stresses (up to $55,7.10^6$ N/m^2) are observed in the bottom wood elements. The zones of compression from the upper wood elements in the bottom wood elements for both models are clearly expressed - Fig 6. In the upper wood elements the stresses are concentrated in the zones correspondingly to the hole of staples in upper wood elements.

Distribution of factor of safety is shown on Fig.7. The factor of safety is calculated as the ratio of the maximum allowable stress to the maximum von Misses stress when using yield strength as a yield limit: Factor of Safety (FOS) = σ_{limit} /$\sigma_{von\ Mises}$. Logically a minimum factor of safety (less than 1) was received in the staples for both models: 0,658 for “model M1” and 0,797 for “model 92”, that means both joints are damaged at that loading.

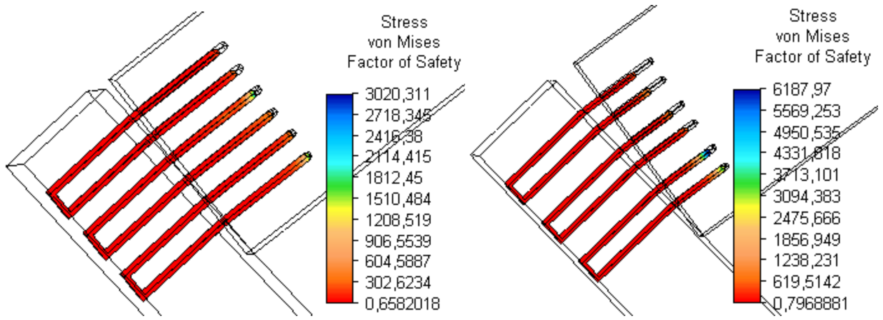

Figure 7. Distribution of factor of safety (von Mises): a) “model M1”; b) “model 92”

Numerical results for maximum Z-displacement and bending moment are compared with results of laboratory experiments for both models – Table 1. It is evident that the numerical values are very near to the laboratory ones, especially for bending moments. The bending strengths of the model M1 are greater than the bending strengths of model 92 due to greater penetration and friction area of staple type M1.

Table 1. Comparison of numerical (fem) and laboratory (test) results

Parameter	**DP_z^{max}**, mm model M1		**DP_z^{max}**, mm model 92		**Bending moment** N.m model M1		**Bending moment** N.m model 92	
	fem	test	fem	test	fem	test	fem	test
F_{10}	0,306	0,238	0,352	0,146	3,59	3,61	2,19	2,20
F_{40}	1,146	0,985	0,753	0,611	14,45	14,49	8,79	8,82
F_{max}	2,985	3,093	1,685	1,886	36,92	36,63	22,15	22,20

CONCLUSIONS

The type of staples as principal load-bearing fasteners in the corner end to face butt joints with staples influences on their deformation behaviour and bending strength. The joints with staples type M1 have higer bending strength then these with staples type 92.

The static numerical analysis by FEM of end to face corner joints with staples for upholstered furniture provides correct results about deformational and strength behaviour of the joints and can be used in the further investigations and design of such joints and furniture frames.

Acknowledgments

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