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FEA OF STRESSES OF AN UPHOLSTERED FURNITURE SKELETON WITH SIDE PLATES FROM OSB

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Abstract

A linear static analysis of one-seat skeleton 3D model for upholstered furniture was carried out with CAD/CAE system Autodesk Simulation Mechanical® by the method of finite elements (FEM) simulating light-service loading of the skeleton. The orthotropic material characteristics of pine solid wood (Pinus sylvestris L.) for the rails and OSB for the side plates are considered in the analysis. Two variants of corner joints in the skeleton (model A – staples and PVA; model B - staples, PVA and strengthening elements) were considered. FEA was performed with regard to laboratory determined and calculated coefficients of rotational stiffness of used staple corner joints. As results the distribution of principal stresses in the 3D model of upholstered furniture skeleton with staple corner joints are presented and analysed. It has been confirmed that the strengthening of the upper rail of the seat leads to reduction of the stresses in the skeleton and in the side plates of OSB.

Key words: *upholstered furniture skeleton, staple joints, OSB, stresses, CAE, FEM*

INTRODUCTION

The skeleton of upholstered furniture is usually wood and/or wood-based products. Although the wood composites are commonly used in box type furniture, their utilization in the frame type furniture is not widespread. There is limited number of references concerning the strength behaviour of upholstered frames constructed with structure elements of OSB although OSB panels are increasingly used in the construction of upholstered furniture frames latterly.

Wang, X. (2007a) has investigated a three-seat sofa frame made entirely of 18 mm thick OSB plates. She has created 3D linear models by beam finite elements with software SAP 2000 of 3 different constructions of a sofa frame with two types of connections – rigid and semi-rigid and two types of connectors: 1) screws and metal plates; 2) staples and metal plates. Nonlinear static analysis has been performed simulating 3 loads: light-, medium- and heavy-service. Wang has established the most appropriate configuration of the sofa frame of OSB under investigated loads and has concluded that the type of connectors does not change the joint displacements and strength remarkably.

Kasal, A. (2006) has investigated the strength properties of glued-dowel joined sofa frames constructed of solid wood and wood based composite materials by using the finite beam elements by CAE. Considering wood materials as isotropic, he has established that the OSB (18 mm thick) has lowest load bearing capacity. The failure of OSB sofa frame

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has been the pull-out of dowels from the member with some core wood particles attached to the dowel and some splits have occurred at the edge of the butt members in the sofa frames.

Erdil Y. et al. (2008) have investigated the behaviour of 3-seat upholstered furniture frames constructed with ¾ inch thick OSB and joining elements - yellow birch dowels and aliphatic resin glue (PVA) using the simplified methods of structural analysis in the engineering of such frames. They have concluded that OSB may be used in construction of upholstered furniture frames to meet specific design loads.

More information concerning the strength characteristics of upholstered furniture joints made of OSB is available: Jivkov et al. (2003) have established the ultimate bending strength under compression of end corner joints of 18 mm thick OSB with different connectors – screws, dowels, “Confirmat”; Wang, X. et al. (2007b) and Wang, X. et al. (2007c) have investigated T-shape corner gusset-plate joints with staples and with/without PVA glue of details of 18 mm thick OSB panels under static bending, torsion and fatigue load. They have concluded that the static bending strength increases with 27% when the reinforcing elements are glued. They have established that both stapled and glued stapled joints had similar static-to-fatigue moment capacity ratios.

Data about strength characteristics of other joints of OSB for upholstered furniture in tension, shear, bending and cyclic loads are given by Erdil Y. et al. (2008) in the result of previous researches for dowel joints of different construction elements (front rail to stump, top rail to back post and back post to top rail joints of 4-inch thick OSB), Zhang, J. et al. (2001a), Zhang, J. et al. (2002) for dowel joints; Wang, X. et al. (2007d), Wang, X. et al. (2008) for metal-plate connected joints; Zang, J. et al. (2001b) for gusset-plate joints; Dai at al. (2008) for glued face-to face and end-to-face joints.

The literature study revealed a limited number of publications on skeleton strength studies of upholstered furniture with staple joints and side plates made of OSB.

The aim of this study was to define and analyze the stresses of one-seat skeleton of upholstered furniture with staple joints and side plates of OSB by CAD/CAE using the method of finite elements (FEM).

MATERIALS AND METHODS

3D model of one-seat upholstered furniture skeleton with length 600 mm, width 680 mm and height 625 mm was created with Autodesk Inventor Pro® – Fig.1. The used rails are with cross section 25x50 mm. A linear static analysis of 3D modeled skeleton was carried out with CAD/CAE system Autodesk Simulation Mechanical® by the Finite Elements Method (FEM). Two discrete models were created - *model A* without and *model B* with strengthening details under the upper rails of the seat with a shape of triangle prism and two design scenarios were performed. The generated Midplane mesh has 5130 orthotropic plate finite elements and 33616 DOF's for *model A* and 5230 orthotropic plate finite elements and 34096 DOF's for *model B*.

Orthotropic materials type was used for construction elements of the skeleton:

Scots pine (*Pinus sylvestris L.*) for rails and strengthening details with measured density 435.50 kg/m³ according to BDS EN 323:2001 and elastic characteristics: $E_z=E_L=9000.10^6$ N/m², $E_x=E_T=593.10^6$ N/m², $G_{LT}=554.5.106$ N/m², $\nu_{LT}=0.027$, $\nu_{TL}=0.41$, $\nu_{LR}=0.03$, $\nu_{RL}=0.049$;

Oriented strandboard (OSB), type EGGER OSB2 EN 300 E1 CE, designed for load-bearing structures for use in a dry environment with thickness 16 mm and technical requirements according to BDS EN 13986:2004+A1:2015 were used for side plates. The physical and mechanical characteristics of the OSB panels are: density 595.67 kg/m³, measured according to BDS EN 323:2001; modulus of elasticity in bending (major axis) – E_x=3800.10^6 N/m^2; modulus of elasticity in bending (minor axis) – E_y=3000.10^6 N/m^2; bending strength (major axis) – 16.4.10^6 N/m^2; bending strength (major axis) – 8.2.10^6 N/m^2; Poisson ratios ν_{12}=0.030 according to Thomas, W. (2003) and ν_{21}=0.24, calculated according to Bodig et al. (1982) by the equation: $\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2}$.

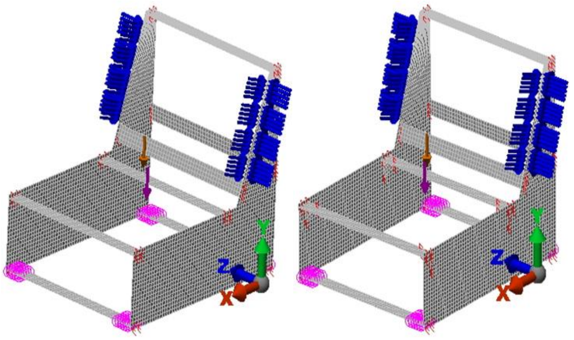

Fig. 1. 3D skeleton models *A* and *B* and loading

Support boundary conditions were set: bottom front rail – no translation on *y* direction and bottom rear rail no translation on *x*-, *y*- and *z* direction.

In order to simulate semi-rigid connections between rails and side plates of the skeleton two actions were performed: First – narrow zones were created in the place of joints in the discrete model with established via tests by FEM lower modules of elasticity of the used materials perpendicular to the common edge of the corner joint; Second - the laboratory determined by Hristodorova, 2018 coefficients of rotational stiffness of the corner joints with 2 staples and PVA glue, loading under compression were introduced in the nodes of the respective corner joints - case butt joints (c=766.84 N.m/rad) and end to face butt joints (c=509.99 N.m/rad).

The both discrete skeleton models were loaded with a total load of 800 N, distributed as follows (Fig.1): *Seat*: 80% were set as a remote force, distributed between upper rails of the seat with application point of 100 mm in front of the upper rear rail, simulating upholstery base made of zig-zag springs; *Backrest*: 16% were set as equal nodal forces, distributed on the edges of the two sides of the backrest simulating elastic belts.

RESULTS AND DISCUSSION

The results for maximum principal stresses (σ_1) – tension stresses and minimum principal stresses (σ_3) – compression stresses for both *models A* and *B* are shown in Fig.2 to Fig. 5 for the skeleton and for the side plates of the skeleton respectively. The visualizations of the deformed model are shown with a scale factor 3% of model size for the skeleton and with a scale factor 5% of model size for the side plates.

For *model A* the maximum principal stresses (tension; (+)) and the minimum principal stresses (compression (-)) have maximal values located in the upper rear rail of the seat at the bottom and on the top respectively – Fig. 2 and Fig. 3. For *model B* maximal values of the tension and compression stresses are located in the strengthening details of the upper rear rail of the seat.

The tension and compression stresses in the upper rear rail of the seat decrease in the *model B* 1.3 times and 1.2 times respectively, comparing to the same in *model A.*

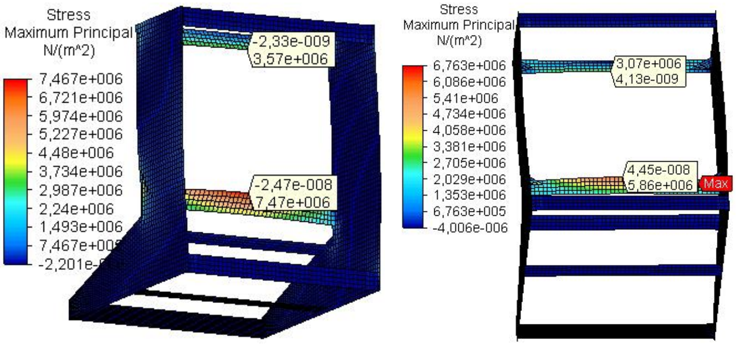

Figure 2. Distribution of maximum principal stresses for model A and model B

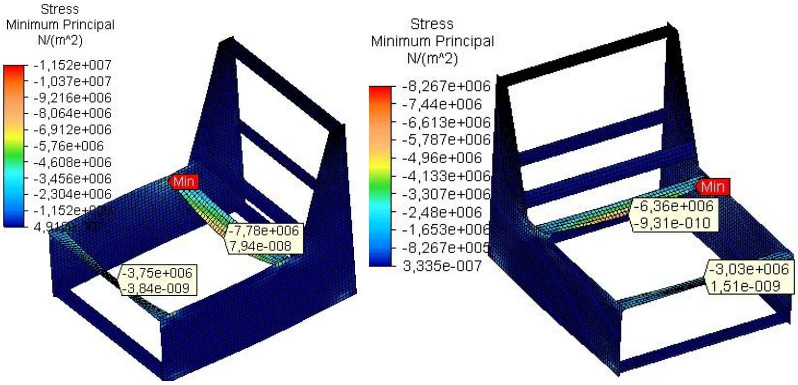

Figure 3. Distribution of minimum principal stresses for model A and model B

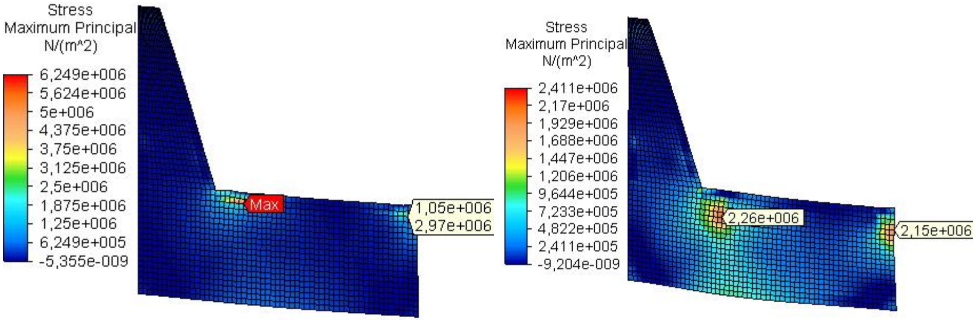

Figure 4. Distribution of maximum principal stresses in the side plates for model A and model B

In the side plates of OSB the maximal values of tension and compression stresses are located in the field of upper rear rail for both models – Fig.4 and Fig.5. It is evident that the compression stress in the field of upper rear rail in the side plates of OSB for *model A* is greater than the maximum bending stress of OSB plates (8.2.10^6 N/m^2).

It was established a reduction of the tension stresses almost 2,6 times and reduction of the compression stresses approximately 4 times in the side plates of the skeleton for *model B* comparing to the same in *model A.*

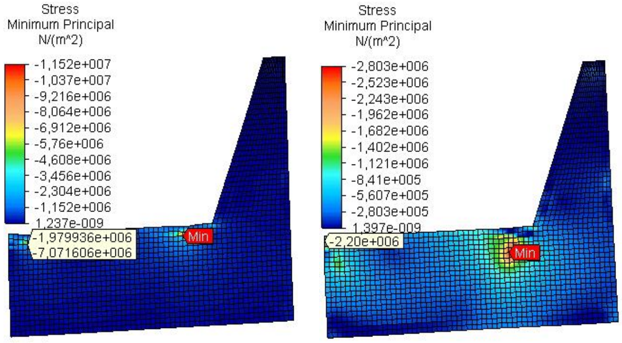

Figure 5. Distribution of minimum principal stresses in the side plates for model A and model B

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CONCLUSIONS

From the results of this study by FEM with CAE program Autodesk Simulation Mechanical® on the deformations and stresses of one-seat upholstered furniture skeleton with staples and glue joints made of Scots pine and OSB several conclusions can be derived:

Under light-service load the most loading construction part of the skeleton with side plates of OSB is the rear upper rail of the seat where the maximum values of stresses are received due to the nature of the applied force.

The reinforcement of the upper rails to side plate joints with solid wood components improves the strength behaviour of the skeleton with side plates of OSB – the tension stresses are reduced with 22%, compression stresses with 18%.

The strength behaviour of the side plates is also impruved after reinforcement – tension stresses are reduced with 22%, compression stresses - more significantly with 75%.

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