CHIP AND CHIPLESS WOODWORKING PROCESSES, 11(1): 165–170, 2018
Zvolen, Technical University in Zvolen, ISSN 1339-8350 (online), ISSN 2453-904X (print)

3D MODELLING AND FEM ANALYSIS OF DEFORMATIONS OF A FURNITURE SKELETON WITH OSB SIDE PLATES

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Abstract

3D geometric model of one-seat skeleton for upholstered furniture was created by CAD system. A linear static analysis was carried out with 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 displacements and equivalent strains in the 3D discrete model of upholstered furniture skeleton with staple corner joints are presented and analysed.

Key words: *upholstered furniture skeleton, staple joints, deformations, 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. It is recommended that wood composites could be used in the production of the frame type furniture, especially in the upholstered furniture frames, but, in this case, it is important according to material type used that the additional reinforcing details and giving a decision about its place (Kasal, A., 2006).

There is limited number of references concerning the deformation 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. With software SAP 2000 she has created 3D linear models by beam finite elements 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 remarkably.

Erdil Y. et al. (2008) have investigated the behaviour of 3-seat upholstered furniture frames constructed with ¾ inch thick OSB (EN 300, 1997) and joining elements - yellow

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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.

The aim of this study was to define and analyze the displacements and strains 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® (Educational product) – 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 (Fig.1) 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*.

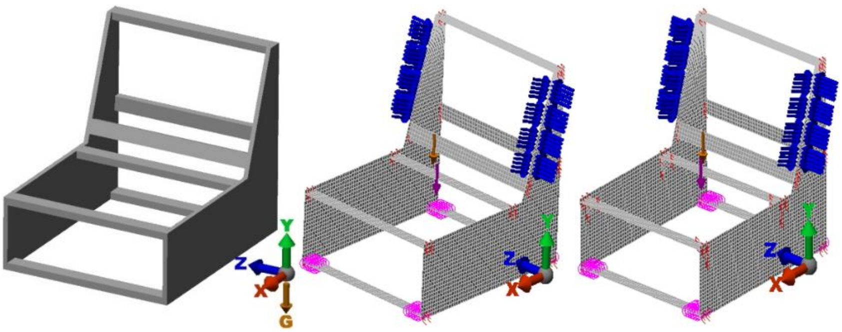

Fig. 1. 3D skeleton models *A* and *B* and loading

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/m^2, $E_x=E_T=593.10^6$ N/m^2, $G_{LT}=554{,}5.106$ N/m^2, $\nu_{LT}=0{,}027$, $\nu_{TL}=0{,}41$, $\nu_{LR}=0{,}03$, $\nu_{RL}=0{,}049$.

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; Poisson ratios $\nu_{12}=0{,}030$ according to Thomas, W. (2003) and $\nu_{21}=0{,}24$, calculated according to Bodig J. and B. Jayne (1982) by the equation: $\frac{\nu_{12}}{E_1}=\frac{\nu_{21}}{E_2}$.

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 Hrisodorova (2018) coefficients of rotational stiffness of the corner joints with 2 staples (type M1) 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 (Genchev, 2018) - 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.

The changed angle γ between the joint shouders at upper front rails of the seat was mesuared with the program Autodesk Simulation Mechanical®.

RESULTS AND DISCUSSION

The results for linear displacemets u, nodal rotations θ, and equivalent strains $\boldsymbol{\varepsilon}_{von\ Mises}$, as well as the changed angle γ between the joint shouders at upper front rails of the seat for both *models A* and *B* are shown in Table 1, Table 2 and 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.

In Fig.2 the distribution of resultant displacement is presented. The maximal resultant displacements of 2.5 mm for *model A* and 1.79 mm for *model B* are received in the

Table 1. Maximal displacements and strains of the skeleton

Parameters and location		*model A*	*model B*
u_x, [mm]	side plates	0.03	0.04
u_y, [mm]	front upper rail	-1.28	-0.92
	rear upper rail	-2.50	-1.79
u_z, [mm]	side plates	0.30	0.50
θ_x, [°]	rear upper rail	0.75	0.51
θ_y, [°]	side plates	1.55	0.16
θ_z, [°]	front upper rail	1.62	1.3
	rear upper rail	-1.74	-1.38
$\varepsilon_{von\ Mises}$, [m/m]	side plates	0.0072	0.0049
γ, [°]	front upper rail	89.81	89.95
	rear upper rail	89.69	89.94

Table 2. Maximal displacements in the side plates

Parameters and location		*model A*	*model B*
u_x, [mm]	front upper rail	-0.039	-0.036
	rear upper rail	0.028	0.029
	Backrest	0.026	0.043
u_y, [mm]	front upper rail	0.093	0.055
	rear upper rail	-0.107	-0.062
u_z, [mm]	Base	0.30	0.488
	rear upper rail	-0.108	-0.061
	Backrest	-0.091	-0.086
θ_x, [°]	front upper rail	-0.28	-0.07
	rear upper rail	-0.55	-0.39
θ_y, [°]	rear upper rail	-0.15	-0.15
θ_z, [°]	front upper rail	0.23	0.15
	rear upper rail	-0.15	-0.08
$\varepsilon_{von\ Mises}$, [m/m]	front upper rail	0.0074	0.0047

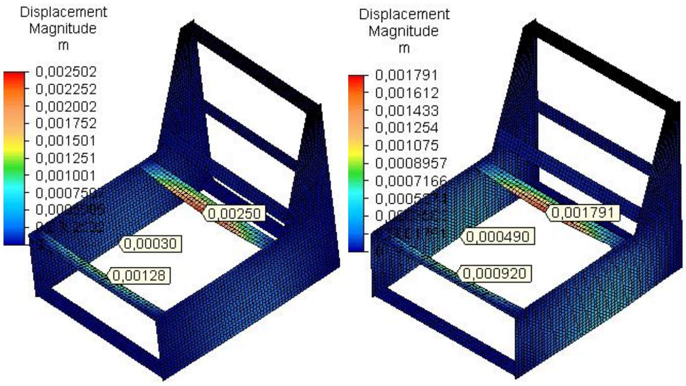

Figure 2. Distribution of resultant displacements for model A and model B

middle of the upper rail of the seat, on the inside of the rails and are determined mainly by the *y*-displacements (u_y) – Table 1. The resultant displacement is 1.4 times greater in *model A* than the same in *model B.*

In the side plates the maximum values of the resultant displacement for both models are received in the places of the base of the seat where dissolution of the side plates is observed - Fig.3. This is due to the fact that the resultant displacements are determined mainly by *z*-displacements (u_z) – Table 2. The resultant displacements in the base of the seat of *model B* are 1.6 times greater that this of *model A* because of rearrangement of displacements due to the strengthening details, but in the upper rails of the seat they are reduced approximately 1.6 times for *model B.*

The maximal resultant nodal rotations θ_{res}=1.74° for *model A* and θ_{res}=1.38° for *model B* are located in the rear upper rail for both models (Fig.4) and they are determined mainly by rotations about *z*-axis –Table1. The resultant nodal rotations of *model A* are 1.3 times greater than the same in *model B.*

Maximal values of resultant nodal rotation in the side plates are received in the contact field with the rear upper rail for both models (Fig.5). The resultant nodal rotations in the side plates of *model A* are 1.4 times greater than the same in *model B.*

Expectedly, the change in the angle γ between the joint shouders at upper front and upper rear rails of the seat is minor in the presence of the strengthening elements (*model B*) – Table 1.

The maximal values of equivalent starin are located in the side plates in the field of front upper rail of the seat for both models, as for *model A* they are 1.5 times greater than the same of *model B* – Table 1 and Table 2.

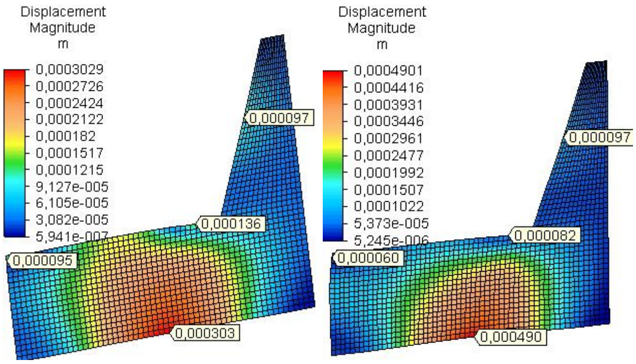

Figure 3. Resultant displacements in the side plates for model A and model B

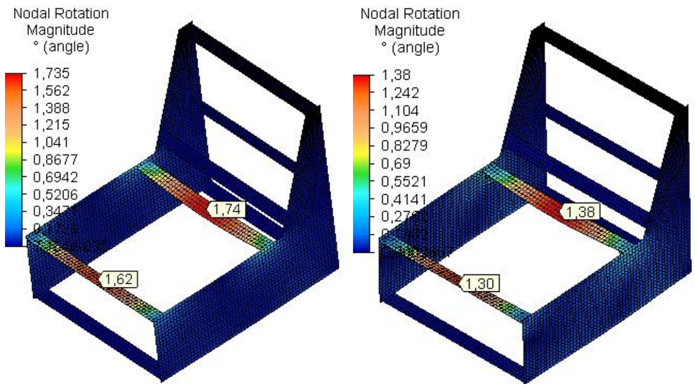

Figure 4. Distribution of resultant rotational displacements for model A and model B

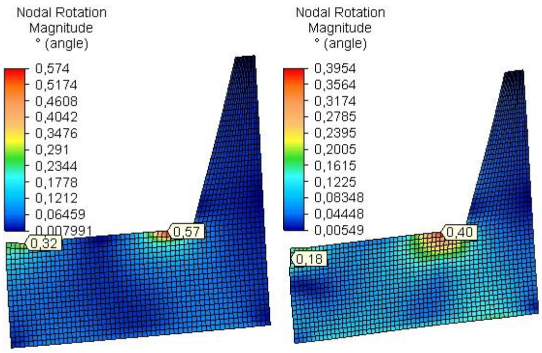

Figure 5. Resultant rotational displacements in the side plates /model A and model B/

Acknowledgments

This document was supported by the grant No BG05M2OP001-2.009-0034-C01, financed by the Science and Education for Smart Growth Operational Program (2014-2020) and co-financed by the EU through the ESIF.

CONCLUSIONS

From the results of this study by FEM with CAE program Autodesk Simulation Mechanical® on the deformations 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 due to the nature of the applied force the maximum values for linear displacements and nodal rotations are received in the rear upper rail of the seat.

The strengthening with solid wood components of the upper rails to side plates joints infuences the deformability of the skeleton with side plates of OSB – the linear displacements reduce with 28.00% and nodal rotations reduce eith 21%. The strengthened skeleton with side plates of OSB has greater stiffness. The change in the angle γ between the shoulders of the upper rails to side plate of the seat is also minor in the presence of strengthening elements.

The deformation behavior in side plates of OSB is considerably improved after strengthening of the upper rails to side plate joints of the seat - the linear displacements are reduced approximately with 28%, the nodal rotations - 21%.

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