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Simulation of Mechanical and Thermal Properties for Sandwich Panels with Cellular Wood Cores

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Abstract

This paper deals with the numerical simulation of mechanical and thermal behaviour of cellular wood material, DendroLight®. The commercial computer code ANSYS is used. DendroLight® is a cellular wood material made of profiled wood boards stacked in layers perpendicular to each other and then sliced once more in plates perpendicularly to the board layers. Gained weight saving of such a solution is approximately 60 % compared to the solid wood, allow to present this type of solution as core structure for sandwich panels in the furniture industry. Complex structure and orthotropic wood mechanical behaviour makes it inconvenient task to model in sufficient detail the core structure by any numerical simulations. Therefore special attention has been devoted to experimental validation of elaborated mechanical and thermal resistance models. Series of coupon scale sandwich panels with DendroLight® core has been tested in bending mode and pure compression. In addition to traditional deformation measuring methods, non-contact optical measuring system ARAMIS has also been employed. In general a good agreement between the finite element simulation and physical experiments has been confirmed. Scatter among acquired experimental and numerical results is within the 20 % margins. Another challenge was to develop a numerical model to be as simple as possible in order to reduce the computer calculation time. Therefore shell elements have been used for wood frame simulation instead of solid elements in ANSYS.

Keywords: cellular wood material, DendroLight®, ANSYS numerical simulation, ARAMIS, equivalent stiffness.

1 Introduction

DendroLight® is relatively new wood core material. Manufacturing of this product has been started in year 2010 at Ventspils (Latvia). However despite innovative

structure and low weight this material is currently used exclusively in furniture applications only. In order to introduce the sandwich panels made out of the DendroLight® core material as structural primary elements (walls, floors) in building industry, a dedicated design and certification procedures should be further developed. In particularly numerical simulation best practice for engineers should be introduced and verified with extensive experimental test programme.
First prototypes of large scale 3-layer sandwich panels with the cellular wood core have been produced and tested by Iejavs [1] demonstrating good perspective of these panels as load bearing building elements. The reported panels consist of wood or plywood face materials and DendroLight® core. However this was exceptionally experimental work, without any analytical or numerical obtained results.
Complex topology of the DendroLight® makes it difficult task for analytical methods to match the actual behaviour of the structure under the physical tests. In contrary, numerical finite element (FE) analyses allows simulating sandwich panels, studying the cellular wood core behaviour, without restriction of load introduction patterns and boundary conditions. The aim of current research was to create the parametrical FE model of cellular wood material, and to verify it's mechanical and thermal behaviour compared with the physical tests. Such an approach allows predicting the changes in core mechanical behaviour by varying individual core web parameters, like board total height or wall thickness. Model verification is essentially important during development process. Therefore specimen's experimental displacement values have been compared with numerical results. For this task the non-contact displacement measuring system ARAMIS, has been used. It is recognised by many authors as ultimate tool for recording of the strain and displacement patterns on composites [2] or wood specimens [3]. In particulary ARAMIS have been employed in order to evaluate the Poisson`s ratio. Multifunctionality has become more significant for the industry and private sector when preselecting the structural elements in civil engineering. In particularly the outer walls of any building must have efficient thermal isolations thus requiring the essential knowledge on thermal isolations/resistance of all of it`s components [4,5]. The further application of developed numerical model could be derivation of equivalent continuum layer formulation in design of the large scale sandwich panels. Similar approach has been taken by several researchers mainly for aluminium honeycomb core [6] or honeycomb core with foam filler [7].

2 Materials and methods

2.1 Numerical simulations

3D structure of cellular wood core has been modelled employing SHELL 181 elements available in commercial finite element computer code ANSYS. Transversal isotropic wood material mechanical properties have been assigned to wood frame structure. Main wood mechanical parameters like modulus of elasticity in longitudinal direction E_L=11 GPa is taken as characteristic values for C24 timber strength class accordingly to the European standard [8]. Other properties like shear modulus and Poisson's ratios taken from Wood handbook [9] using given ratios for specific wood species. Wood properties used for simulation of cellular wood frame are the following: modulus of elasticity in transverse and radial direction E_R= E_T=0.6 GPa, shear modulus: G_{LR}=G_{LT}=0.34 GPa, G_{RT}=0.2 GPa. Poisson`s ratios μ_{LR}= μ_{LT}=0.34, μ_{RT}=0.03. To reduce calculation effort only linear analysis has been performed, this corresponds to serviceability limits stated by panel allowed deflection before the critical stress state, according to the engineering design practice. Cellular wood structure was created to match the real production process- starting from profiled board, assembling them into perpendicular layers and cutting in required dimensions using boolean operations (Figure 1). Separate shell elements are connected together at the coincident points.

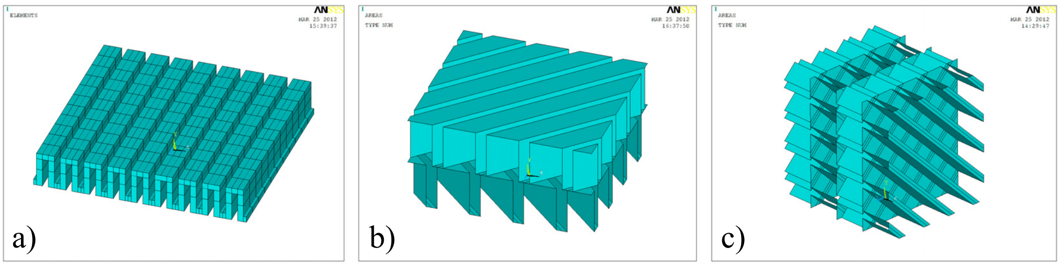

Figure 1: Cellular wood material structure: a) profiled boards b) boards stacked in layers c) DendroLight® material

Simplified thermal resistance model has been evaluated by PLANE55 element. It`s is suitable for simulation of convection or heat flux and radiation. Model represents one cross-section of the sandwich panel with DendroLight® core with overall height of 60 mm (Figure 2). Thermal conductivity ratio for wood is set to 0.12 W/(mK) and for air 0.025 W/(mK). The aim of current model is to predict sandwich panel`s heat flux and compare acquired results with experimental test results for the same structure acquired employing the hot box method [10].

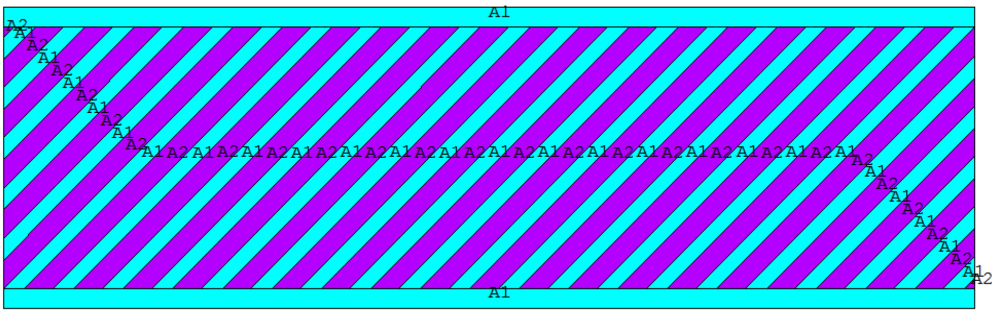

Figure 2: Thermal model of sandwich panel section with DendroLight® core.

2.2 Experimental investigation

In order to assure that numerical model captures the actual DendroLight® behaviour, a special attention was given for initial verification between the numerical model and the physical test results. The small scale test specimen configurations used to verify the analysis model are summarised in Table 1. As one may foreseen a mechanical properties of DendroLight® may vary significantly accordingly to the cells orientation. For these reason responses of the various specimen configurations have been studied. A "Structure direction" column indicates the specimen orientation, where label DL means that DendroLight® has been tested in traditionally utilised direction like shown in Figure 1.c. Likewise DL_P stands for perpendicular orientation around the vertical axis, therefore it change sandwich structure stiffness in bending mode. Label B stands for cellular material in board's direction as shown in Figure 1.b.

Nomen-clature	Dimensions			Board thickness, mm	Spec. count	Test set-up	Structure direction
	Length, mm	Width, mm	Height, mm				
C1	72	72	72	18	10	Compression	DL
C2	72	72	72	18	10	Compression	B
C3	100	40	100	25	4	Compression	DL
C4	100	40	100	25	3	Compression	B
B1	300	50	40	25	3	3-point bending	DL
B2	300	50	30	25	3	3-point bending	DL
B3	300	50	30	25	3	4-point bending	DL_P
B4	300	50	60	25	3	4-point bending	DL_P

Table 1: Cellular wood material specimens used for numerical model validation

One may notice that C1 , C2 are cubic samples in un C3 un C4 are rectangular specimens tested in compression . Differences between them are in board thickness and cells direction. Specimens from B2, B3 and B4 series have a HDF (high density fibreboard) skins with 4 mm nominal thicknesses. Mechanical determination of cellular wood material properties has been performed on ZWICK Z100 testing equipment for both the bending and the compression test set up (see Figure 3).

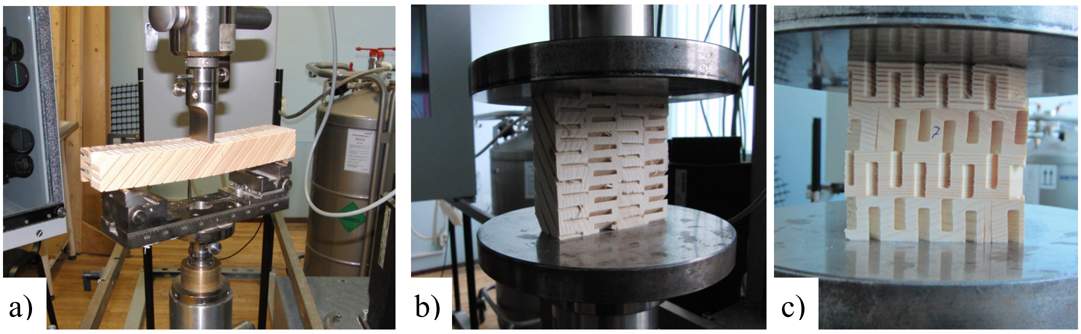

Figure 3: Cellular wood material mechanical investigation in bending (a) and compression mode (b and c).

3 Numerical model validation

3.1 Comparing numerical model with experimental results

For better analysis of obtained numerical results, the load versus shortening graphs have been elaborated and compared with the experimental results. One may notice that majority of the specimens have linear mechanical response before reaching the 80% of the critical load value. This fact confirms the application of simplified - linear solution is adequate for simulation purposes (Figure 4-7). Results obtained for compression specimens indicate the lower stiffness in physical tests compared to the numerically obtained values by ANSYS (Figure 4 and 5). Nevertheless mean critical pressure for C1 and C2 type specimens is 2.30 MPa and 1.54 MPa with standard deviations (SD) of 0.21 MPa and 0.23 MPa respectively. Mean critical pressure for C3 and C4 type specimens is 0.88 MPa and 1.38 MPa with SD of 0.05 and 0.11 MPa.

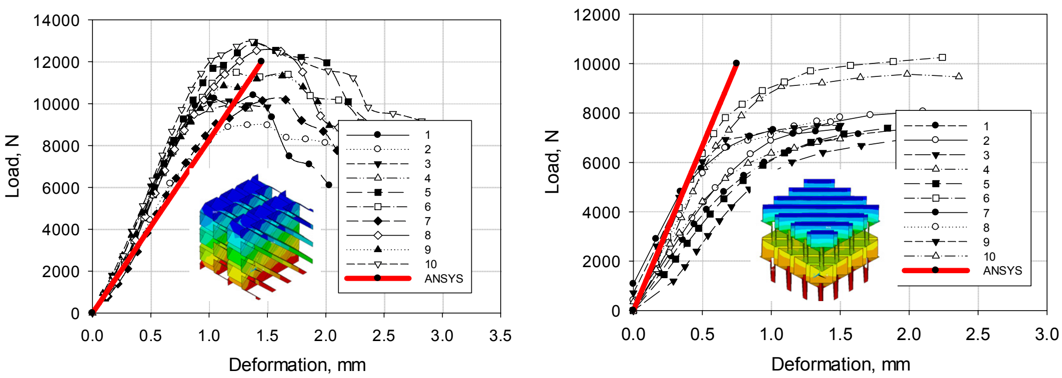

Figure 4: Experimentally obtained compression deformation values compared with numerical results; C1 specimens (on the right); C2 specimens (on the left)

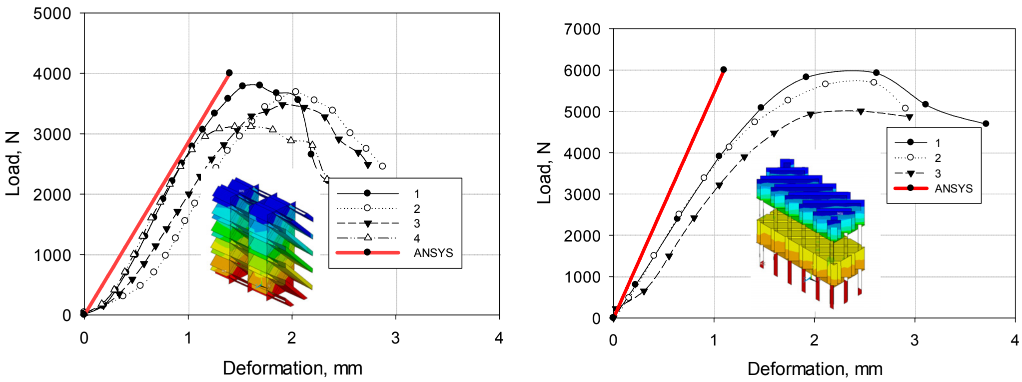

Figure 5: Experimentally obtained compression deformation values compared with numerical results; C3 specimens (on the right); C4 specimens (on the left)

Due to notches and imperfections in bonds between board layers, scatter of experimental results may be observed, especially for specimens without skins (Figure 4 and 5). Another reason of result scatter is non-uniform wood mechanical properties. During production, raw wood materials are not being sorted by species. Spruce and pine raw material is mixed during DendroLight® manufacturing. For this reason it is almost impossible to create model with identical behaviour as for real material.

Specimens tested in the bending has reasonably small scatter in both stiffness and ultimate load values, moreover shoving higher level of correlation among the numerical and the experimental results curves (Figure 6 and 7). The effect of botch presence may be observed for B2 series third specimen, which critical force is significantly lower than for other two specimens.

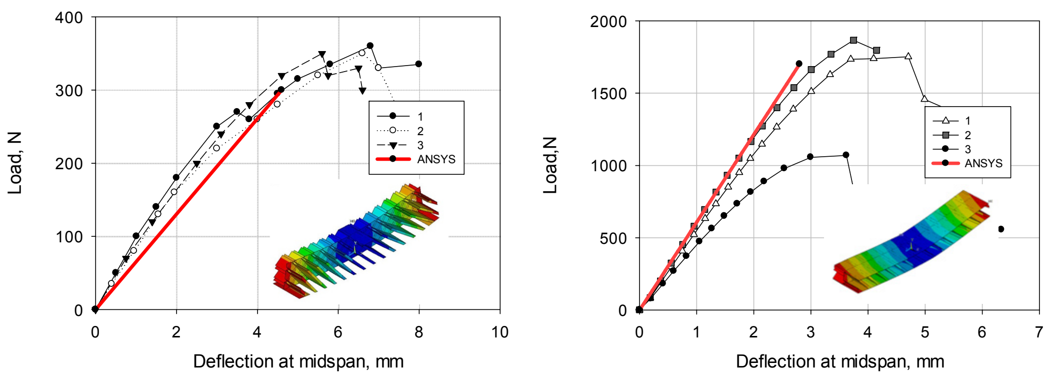

Figure 6: Experimentally obtained bending deformation values compared with numerical results; B1 specimens (on the right); B2 specimens (on the left)

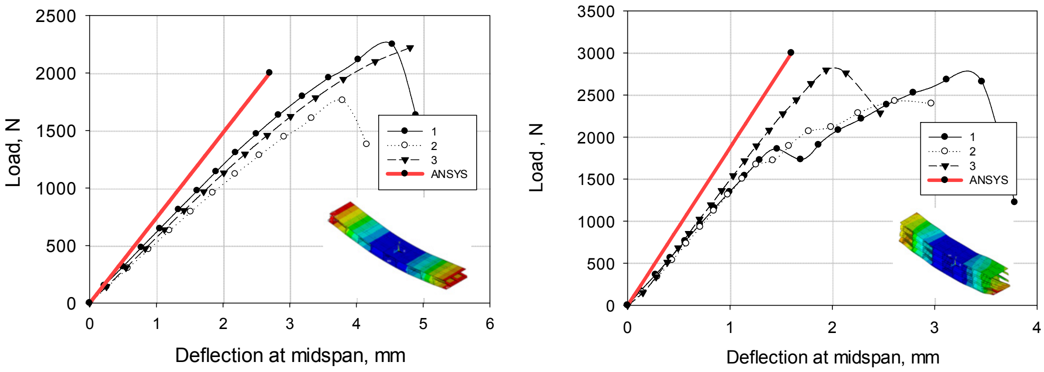

Figure 7: Experimentally obtained bending deformation values compared with numerical results; B3 specimens (on the right); B4 specimens (on the left)

3.2 Investigation with ARAMIS

Several specimens has been tested in bending and compression, parallel reading strains at surface with non-contact optical deformation measuring system ARAMIS (Figure 8.). Using such system is possible to precisely determine displacements for each point on the surface as well as displacement curves for surface section.

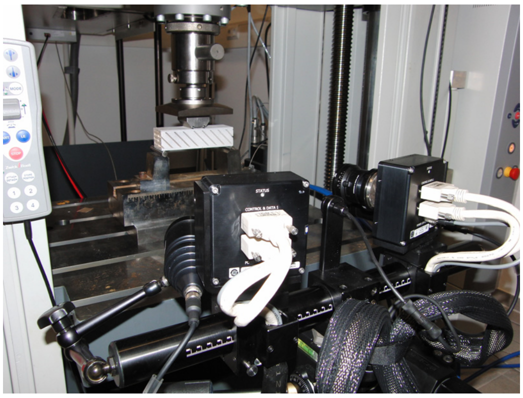

Figure 8: Experimental ARAMIS set-up

In current research main emphasis has been directed towards determining of Poisson's ratio for C1 type specimens. These values have been compared by results achieved employing numerical model for the same task. As one can see in Figure 9, experimental deformation plot have inhomogeneous horizontal deformations instead numerical model. Dividing maximal horizontal deformation with known vertical displacement, Poisson`s ratio values has been acquired. For C1 specimen investigated with ARAMIS $\mu_{xy,exp}$=0.39, and acquired with numerical model $\mu_{xy,num}$=0.44.

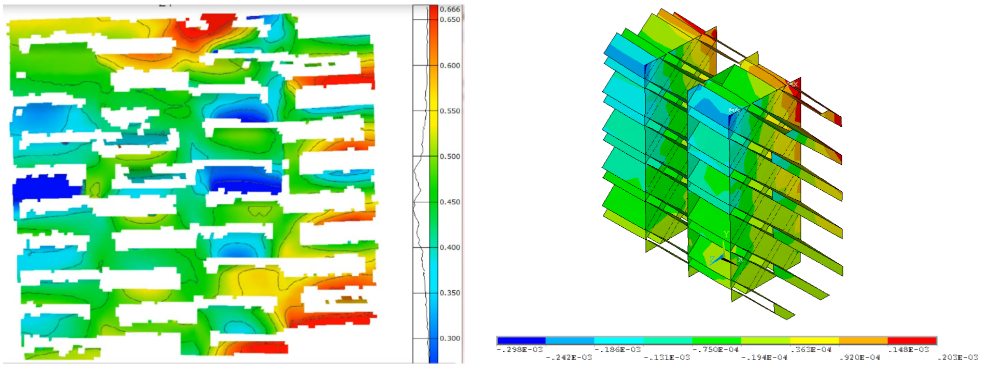

Figure 9: Horizontal displacements and strains on specimen surface and on the numerical model (on the left)

3.3 Thermal model validation

Validation of thermal model has been performed comparing numerically acquired heat flux values with the same values acquired from experimental tests according ISO 8990 [7] standard. For specimen with 60 mm thickness, average experimentally measured heat flux is 35.5 W/m^2. Numerical analyses provide quite close value of 32 W/m^2. So it can be considered that numerical model is suitable for performing thermal analyses of sandwich panels with DendroLight® core. Some drawbacks of current model are flux concentrators in the bottom part of structure not allowing using scale max. values. However it is not affecting values on panel outer parts (Figure 10).

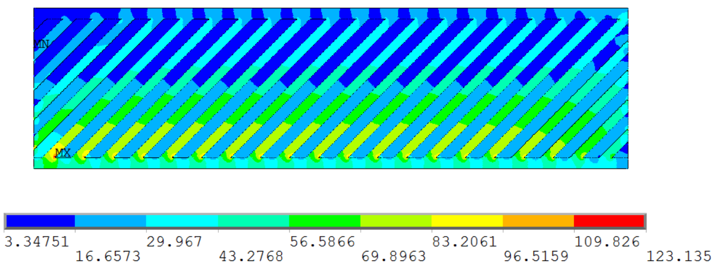

Figure 10: Thermal flux in sandwich panel`s section

4 Conclusions

It has been demonstrated that detailed finite element analysis employing the SHELL 181 elements are capable to simulate complex behaviour of DendroLight® cell structure with high level of confidence. The difference obtained between experimental and numerical results does not exceed 20 % margin, comparing numerical results with the mean deformation value for each test series. Specimen's imperfections and notches in DendroLight® structure, as well as non-uniform wood material properties, have significant influence on result scatter obtained experimentally both in compression and bending. Nevertheless it is not a reasonable task to implement random notches distribution in order to increase the correlation of the numerical model. More robust solution method would be to reduce the wood mechanical properties by 10% in numerical simulations. In addition it has been demonstrated that using numerical models is possible to predict both mechanical and thermal behaviour of complex wood core structure thus assessing the multifunctional core properties with simple simulation model. Further work will be focused in elaborating the equivalent stiffness methodology for design of large scale sandwich panels.

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