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Modeling the elastic properties of paper honeycomb panels using the finite element method

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Abstract: Light-weight wood-based panel products have recently appeared as raw-material for furniture industry. Some information on their overall mechanical performance is either given by the manufacturers or can be obtained by simple test methods. However, for an engineered utilization of these complex sandwich-type products, in-depth understanding of their behavior is needed. In this study, the authors demonstrate the use of finite element modeling of honeycomb-core panel products to assess deformations, and stresses in the component materials under bending and compression load. Material properties used in the model were determined by expedient testing; orthotropic material models were used where appropriate. Models were verified by comparing simulation results with test results on identical physical models; a good agreement with respect to maximum stresses and deformation could be achieved.

Keywords: honeycomb, sandwich panel, finite element analysis, bending, stress and strain

1 Introduction

In recent years, product development trends are characterized by high degree of variability, individuality, the use of newly developed materials (composites, plastics, structured surfaces, functional materials, etc.), and combination of different material types. Due to this high variability during the structure design and dimensioning a careful attention should be paid for these heterogeneous products comprising two or more materials with different properties in order to fulfill the esthetical, strength, durability, stability and other requirements. As the market and economic expectations point to continued reduction of product development time quick determination of mechanical properties, durability and reliability is of utmost importance. These expectations can be fulfilled by using certain simulation and modeling techniques. If the estimation accuracy of the simulation models verified empirically is adequate, the models can be integrated in the design process, thereby shortening the design activities and the overall development time. These adequate models and can replace the costly destructive tests.

The lightweight construction is becoming more common around the world and is gaining more interest in Hungary also. Sandwich structures were used in aerospace applications for the first time in World War II. The wings and the fuselage were constructed of plywood with balsa core. A sandwich structure is usually a 3-ply construction comprising simplex or complex alternating layers which are bonded to form a structural unit. The main advantage of sandwich structures over traditional ones is the high strength-to-weight ratio, good heat and acoustic insulation properties. The skin layers are made of high strength materials and are relatively thin, although they respond for the structure's overall load bearing capacity. The core layer is generally made of low strength and lightweight material. The core task is to separate and space the skins and to bear the shear forces according to Kovács

(1975). Nowadays sandwich panels have many application fields like in constructions, metal, plastic and wood industry.

Because of the high complexity of sandwich structures many research works have been done to determine and model their physical and mechanical properties. A study by Aktay (2007) showed that the compression strength of aluminum with Nomex honeycomb core structure depends on the cell size and wall thickness regardless of the material properties.

Fiber-reinforced polymer honeycomb sandwich beams' behavior against torsional loads were studied by Davalos (2008) performing mechanical measurements and finite element modeling. Chen (2012) in his paper demonstrated the relationship between surface and core thickness ratio on sandwich panels with MDF surface layers and paper honeycomb core. According to results the lower the ratio the higher the modulus of elasticity and modulus of rigidity. The increase is significant when the thickness ratio is less than six.

The bending creep as a function of time was studied by Chen (2011). The results show the influence of core geometry and wall thickness as well as the thickness of surface layers and the material properties of the surface on creep.

In an article by Wang (2009) sandwich panels with paper honeycomb and cardboard surface were used to study the energy absorption. Petras (1999) examined the failure mode of Nomex honeycomb beams at three point bending tests.

2 Materials and Methods

In the present paper, sandwich panels with particleboard surface layers and paper honeycomb core were analyzed with the finite element method and the results compared with the destructive test results. The thickness of the surface layers were 8 mm and the paper honeycomb middle layer's height were 22, 34, and 44 mm resulting in a total panel thickness of 38, 50 and 60 mm respectively. In order to perform the finite element analysis the modulus of elasticity and the Poisson's constants were determined. For the modulus of elasticity (E) and bending strength (σ_b) determination the MSZ EN 310 standard was used, which is based on the three point bending test. After separating the paper honeycomb from particleboard layers the inner side of the panels showed glue spots, therefore the bending tests were performed on both sides, i.e. placing the glued side on top and bottom. The number of specimens was 10 + 10 and the total length was 210 mm with 160 mm span. For the tests an Instron 5566 type material test machine was used. The bending test results are shown in Table 1. The modulus of elasticity (1) and bending strength (2) were determined by the following formulae:

$$E = \frac{l_1^3 \cdot (F_2 - F_1)}{4 \cdot b \cdot v^3 (a_2 - a_1)} 0 \ [MPa], \tag{1}$$

$$\sigma_b = \frac{3 \cdot F_{max} \cdot l_1}{2 \cdot b \cdot v^2} \ [MPa], \tag{2}$$

where:
- l_1 span [mm],
- b specimen width [mm],
- v specimen thickness [mm],
- F_{max} maximum load [N],
- $(F_2 - F_1)$ the increment of load on the load-deflection curve, where F_1 was approximately 10% and F_2 40% of the maximum load F_m
- $(a_2 – a_1)$ the increment of deflection corresponding to (F_2-F_1) in load-deflection curve

The standard paper modulus of elasticity was determined just on the 44 mm width paper because of the size constrains. The tests were performed according to MSZ ISO 5628 standard using a two point paper bending instrument in the Institute of Paper Research. The measuring principle is shown in Figure 1.:

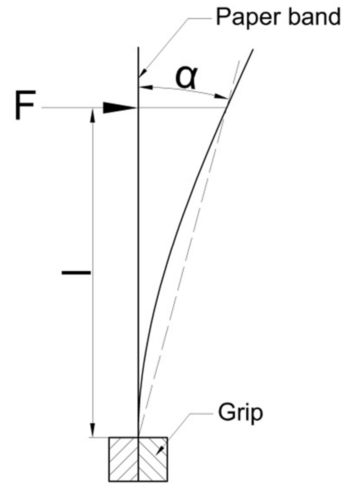

Figure 1. The two point bending test of paper

The paper's modulus of elasticity determination was based on:

$$E = \frac{60 \cdot F \cdot l^2}{\pi \cdot \alpha \cdot I} \quad [MPa], \qquad (3)$$

where: F load [N],
l specimens length [mm],
α deflection angle [°],
I second moment of inertia [mm^4]:

$$I = \frac{b \cdot v^3}{12} \quad [mm^4], \qquad (4)$$

b specimen width [mm],
v specimen thickness [mm].

The E values were calculated at α = 15 ° deflection angle and specimen length was set at l = 10 mm. The paper was of v = 0.2 mm thick. For the 38 mm thick panel the modulus of elasticity was determined by compression because of the size constrains. Specimens size were set to 140x140 mm, 10 samples were used for both panel types. After the test the surface layers were removed to measure the paper honeycomb thickness and to determine the paper surface. The compression strength was determined using the formula:

$$\sigma_{comp} = \frac{F_{max}}{A} \quad [MPa], \qquad (5)$$

where: F_{max} maximum load [N],
A surface area [mm^2].

The bending tests for the whole panel slabs were also carried out in accordance with MSZ EN 310 standard (Fig.2). The specimen were of 50 ± 1 mm wide, and of 1000 mm length with a span of 900 mm. Test set up is represented in Figure 2. with a typical deformation pattern.

For the Finite Element Analysis (FEA) the Poisson's ratios of μ = 0.3 were taken from literature according to Bodig and Jayne (1982). As a modeling tool the ANSYS software was used, but because of honeycomb orientation the calculations were performed along and across the paper strips orientation.

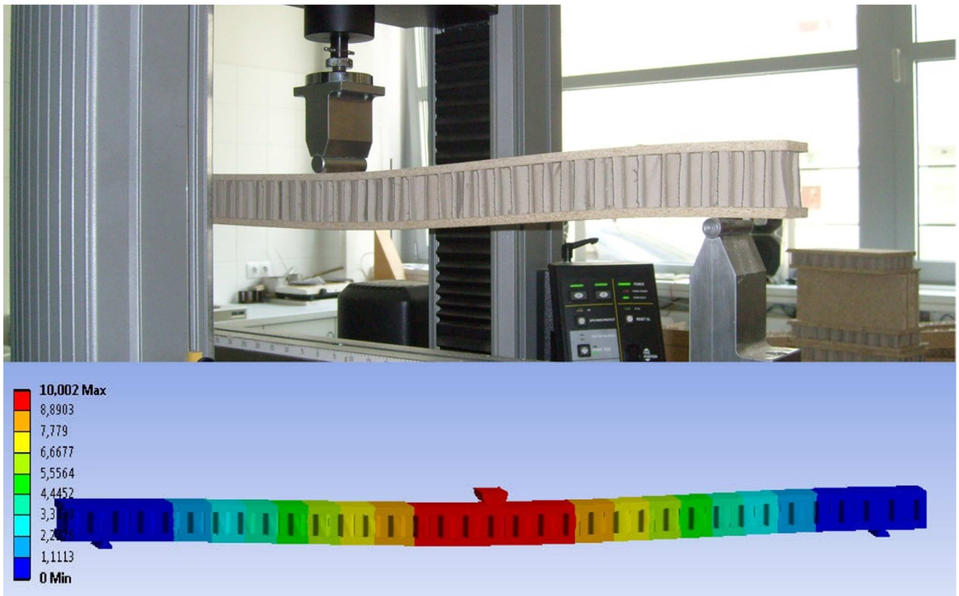

Figure 2. The bending test set up and the finite element model

3 Results and discussion

The bending test results for the 8 mm thick particleboards are shown in Table 1. The number of samples was 10 for each side.

Table 1. The influence of side of the surface layers

	MOE (Mpa)			s (Mpa)		
	Mean (MPa)	SD (MPa)	CV (%)	Mean (MPa)	SD (MPa)	CV (%)
Glued side up	6898	469,5	6,8	19,12	1,991	10,41
Glued side down	7179	530,7	7,4	18,90	1,543	8,16

According to the results no significant difference were observed between the two loading direction, therefore the average values were taken for further analysis. The modulus of elasticity values of the paper honeycomb determined by both methods, i.e. by compression and by using the MSZ ISO 5628 standard are listed in Table 2.

Table 2. The modulus of elasticity of the honeycomb paper

Sandwich panel thickness, mm	Samples	E , MPa		
		Mean (MPa)	SD (MPa)	CV (%)
38 mm	10	215,6	43,26	20,07
60 mm MSZ EN 789	10	752,1	117,29	15,60
60 mm, MSZ ISO 5628	32	661,4	91,29	13,80

The results for the 60 mm thick panels demonstrate no statistically significant alteration, in the case of compression tests the load bearing capacity is driven by the paper

honeycomb too. Therefore both methods can be used to determine the paper's modulus of elasticity, the one of the most important mechanical property essential for finite element simulations. The lower values for paper flexibility tests could be explained by the sample preparation method i.e. smooth steaming and ironing the samples in order to flatten them. The paper honeycomb elasticity of the 38 mm panels were significantly lower than of 60 mm, with approximately 35%. The alteration is due to the quality difference of papers.
The bending and compression strength of the whole sandwich panels are summarized in Table3.

Table 3. Bending and compression strength of the sandwich panels

		σ_b (MPa)			σ_{comp} (MPa)		
		Mean	SD	CV	Mean	SD	CV
Panel thickness	Samples	(MPa)	(MPa)	(%)	(MPa)	(MPa)	(%)
38mm	6	3,510	0,1324	3,8	0,1686	0,0095	5,6
60mm	6	1,425	0,3106	21,8	0,2055	0,0112	5,5

The comparison of measured and simulated values for bending load and displacement are shown in Figure 3.

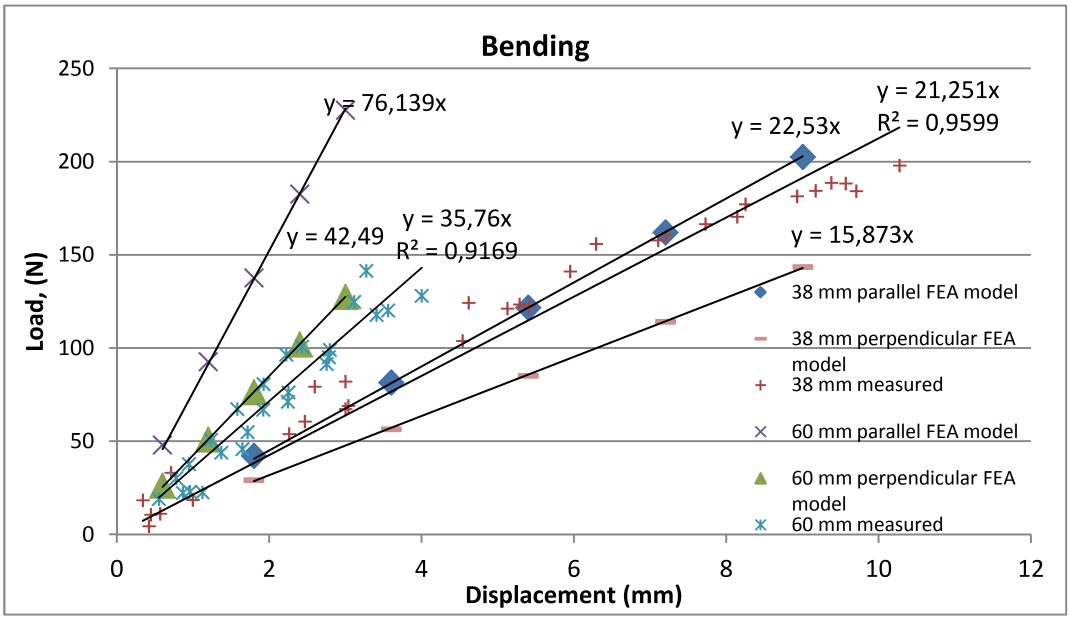

Figure 3. Measured and simulated load – displacement values for bending

The diagrams show the measuring points of the samples and the finite element simulation curves as well (blue rectangles and green triangles with trend line). It can be concluded that the load-displacement simulations with the input properties determined for constituting materials in previous tests is adequate and assess well the elasticity of the examined sandwich panels. The influence of paper honeycomb orientation is revealed also: honeycomb papers oriented perpendicular to the main axis provides lower elasticity while the paper oriented parallel are stiffer.

The load-displacement values for compression are represented in Figure 4. In this case the influence of the paper honeycomb orientation disappears. According to the results the compression strength and stiffness is higher in the case of 60 mm thick panels than those of 38 mm which emphasis the quality difference of the paper used for the two panels. The finite element simulation results are comparable with the measured values, the coefficients of determination are acceptable, however they are lower than those of bending values.

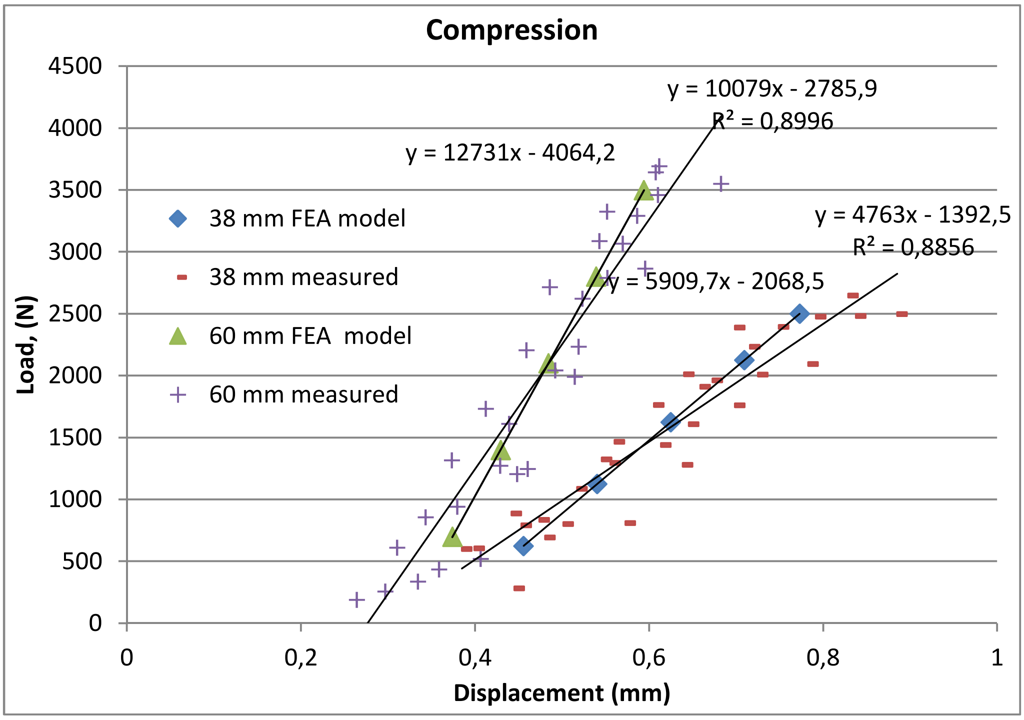

Figure 4. Measured and simulated load – displacement values for compression

4 Summary

In conclusion, we can say that modeling certain mechanical properties of paper honeycomb sandwich panels imply the determination of elastic properties of the constituent materials. The measured load-displacement values are comparable with simulated values using the finite element analysis. During testing we found that the orientation of the paper honeycomb influences significantly the tested mechanical properties. Both simulated and measured values for samples with the paper honeycomb core oriented parallel were significantly higher than those oriented perpendicularly. The explanation is given by the paper honeycomb geometry, i.e. the parallel orientation assures a higher stiffness. Therefore, a special attention should be given during the design in order to avoid the excessive deformations of parts made of paper honeycomb sandwich panels.

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