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# COMPRESSION STRENGTH OF VENEER REINFORCED SANDWICH PANELS

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***Abstract:***

*Sandwich structures, originally developed and used in aerospace industry have found applications in other industry branches such as marine, automotive and sports goods industries. Typical sandwich structures are made of a low-density core material bonded with thin, strong skins at top and bottom resulting in very efficient load bearing structures. This paper describes the evaluation processes of physical and mechanical properties of a recently developed veneer based sandwich composite. In the honeycomb-like construction of the sandwich panels, the veneer reinforcements provide strength and stiffness, sets the final dimensions in thickness while the polyurethane foam has lateral supporting effect. The effect of honeycomb geometry and number of constituent layers on the compressions strength was analyzed by 3-level, 2-factor robust parametric design ($3^{II}$ RPD). Standard test results confirmed the improved compression load resistance; while the cylindrical geometry over performed the sinusoidal shaped core reinforcements. The intended use of the developed composites include carrier substrates for counter tops, interior door leaves, indoor heat insulating and acoustic insulation panels, as well as structural insulated panels (SIP).*

***Key words:*** *sandwich structures; veneer honeycomb; compression strength; corrugated core.*

## 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. Sandwich structures, as a response to the above-enumerated requests, 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 which are relatively thin, although they respond for the structure's overall load bearing capacity because of the high tension and compression power. 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). In a sandwich structure generally the bending loads are carried by the force couple formed by the facesheets and the shear loads are carried by the lightweight core material (Nguyen, et al. 2005).

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. Multilayer sandwich panels using cork agglomerate as core material and Aleppo pine wood veneer as face sheets were developed by N. Lakreb et al. (Lakreb et al. 2015). The cork agglomerate provided a high performance under perpendicular compression, while the wood layers protected the core material and increased its mechanical strength. Modelling results on the mechanical behavior of the sandwich structures have been reported by Borsellino et al. (2004) using commercial ANSYS code in order to model the sandwich structures in compressive, shear and flexural loadings. The static-mechanical behavior of the composite structure was well approximated by numerical simulations in the elastic zone but in the plastic regime, there was not a compatibility with the experimental data. 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. Fatigue properties of sandwich beams with carbon woven/epoxy skins and Nomex hexagonal honeycomb core under 3-point bending cyclic loading were investigated by W. Boukharouba et al. (2014). The obtained data has shown the evolution of damage during the fatigue loading, and the formation of delamination between top skin and the core leading to the sandwich structure failure. The presented analytical model presented allows predicting the fatigue endurance of composite sandwich beams using only a limited number of loading levels.

Sandwich panels with rib stiffened and corrugated core have been numerically investigated by Kalnins et al. (2009). Stiffness-based optimization demonstrated significant weight savings over traditional plywood boards. L. He et al. have developed a semi-analytical method suitable for bending analysis of different kinds of sandwich panels. (He et al. 2012). They divided the real displacement of sandwich panels into the global displacement field and local displacement field, and determined accurately the real displacement solution and stress distribution of sandwich panels with the help of energy variation principle and the Galerkin approach. Compressive and bending behaviours of wood-based two-dimensional lattice truss core sandwich structures were studied by M. Jin et al. (2015). The theoretical model and experimental results of the compressive Young’s modulus are in good agreement based on the elastic deformation of the dowels. The results have indicated good energy absorption capability of the structure. The debonding of nodes were the primary failure mode of the sandwich structures under bending loads. Atas and Sevim (2010) investigated the impact response of sandwich panels with PVC foam core and balsa wood core. The primary damage modes were found to be the fiber fractures at top and bottom face-sheets, delaminations between adjacent glass–epoxy layers, transverse and in-plane shear fractures of core, and face/core debonding

## OBJECTIVE

The main objective of this research is to develop new wood-based sandwich panels with veneer based core reinforcements of different geometries, to optimize the manufacturing technologies, to determine the most important physical and mechanical properties of the newly developed products, to analyze the interrelationship between the materials, technology related parameters and panel characteristics. In this paper, the results of the compression strength tests are introduced.

## MATERIAL, METHOD, EQUIPMENT

For samples preparation commercially available beech 3 layered plywood with a thickness of 5mm and polyurethane foam were used. Beech (Fagus sylvatica) sliced veneer sheets were glued using conventional dispersed polyvinyl acetate resin and pressed in cold templates with sinusoidal wave geometry. The same glue was used for veneer tube production; the tubes were prepared by winding the side jointed veneer sheets on a metal tube with a diameter of 60 mm. After the resin setting both sine waved sheets and veneer tubes were cut to a width of 50 mm and glued to one of the plywood face sheets using a slightly foaming PU glue. The free space of these honeycomb–like cores was filled up with a one component polyurethane foam and covered with the second plywood sheet. Core reinforcements were made in three thicknesses in order to determine the effect of wall thickness on compression strength. The veneer core reinforcements comprised 3, 5 and 7 veneer layers respectively. Panels with the dimensions of 200 mm x 200 mm were prepared containing 9 full tubes and 1,5 long sine waves with the height of in the core. 10 specimens were produced per core type and number of layers. Specimens were tested in compression using a universal Instron testing machine. For the modulus of elasticity determination the cross head displacement was recorded. The measured data was further analyzed using standard statistical methods. Fig. 1 presents the test setup and the veneer reinforcement geometry of the core layer.

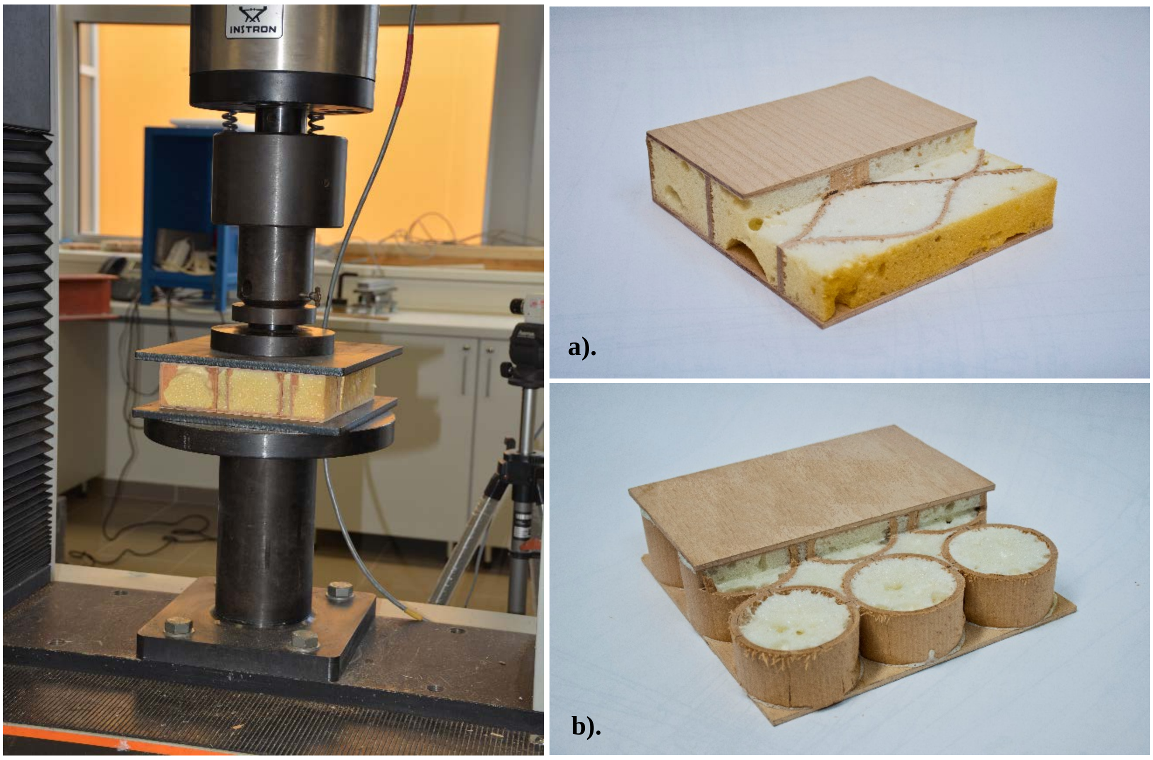

***Fig. 1.***
***The compression test setup and core geometry, a.) sinusoidal reinforcement; b.) tubular reinforcement***

## RESULTS AND DISCUSSION

The compression strength and elasticity results are given in Table 1. The positive influence of layer numbers can be observed for both tubular and sinusoidal core geometries and the higher the number of veneer layer the higher the standard deviation. The compression strength of the sandwich panels is significantly higher than similar values of the paper honeycomb core and 8mm thick particleboard skin panels (0,147Mpa) and the sinusoidal core panels are comparable with the cork core agglomerates (Lacreb et al. 2015). Compression load bearing capacity of the tubular core panels exceed multiple times the sinusoidal core panels' similar value (Fig. 2.).

*Table 1*

| | | Tubular core | | | Sinusaiddal core | | |
|---|---|---|---|---|---|---|---|
| | | **T1** | **T2** | **T3** | **S1** | **S2** | **S3** |
| **MOE, Mpa** | Mean | 121,59 | 147,67 | 152,37 | 20,38 | 30,28 | 38,52 |
| | SD | 9,83 | 13,21 | 19,27 | 3,83 | 4,95 | 4,37 |
| **MOR, Mpa** | Mean | 2,83 | 5,66 | 7,29 | 0,44 | 0,74 | 1,04 |
| | SD | 0,52 | 0,62 | 0,71 | 0,05 | 0,10 | 0,12 |

The Box plot diagrams of the compression strength and elasticity values are shown in Fig. 2. The seven veneer layer core geometries have the highest values, however the difference between the tubular and sinusoidal core geometries is 6,25MPa in case of MOR and 113,85MPa in case of MOE. The relatively high dispersion of the data underline the imperfections of the core manufacturing technology which should be improved in order to decrease the variability of the cores' mechanical properties. There is linear relationship between number of layers and compression strength and elasticity of the panels, except MOE of the tubular core panels, where the linearity is questionable.

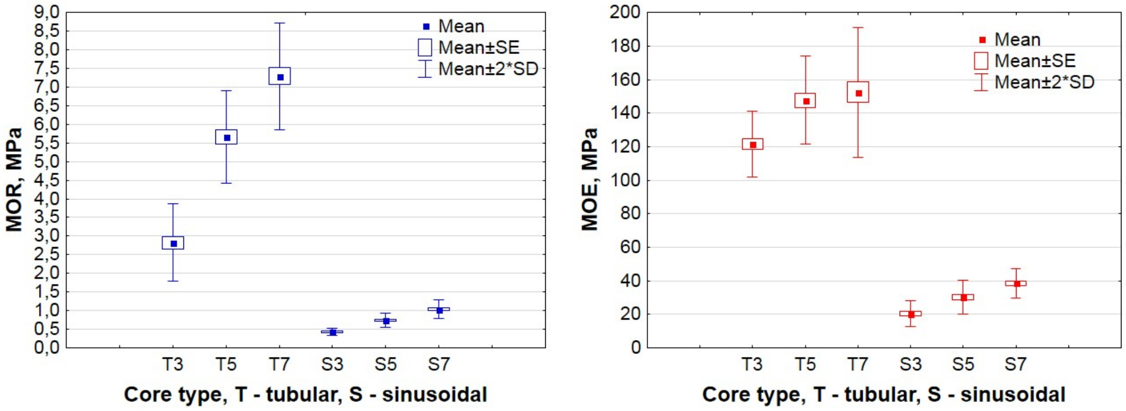

***Fig. 2.***
***The Box and Whisker Plot diagrams of the modulus of rupture and modulus of elasticity in function of core geometry and number of veneer layers.***

Fig. 3 shows the scatterplots of MOE and MOR against core types and layer numbers, the linear regression lines and regression equations. The dotted lines represent the 95% confidence regression bands of the mean values. The R square values indicate that the regression models fit well the measured data, except elasticity of the tubular core values, where the residual variability is 58% to the 42% of original variability. In the case of tubular cores the modulus of rupture increase very steeply with the increase of tube wall thickness, in rest the increase is more moderate.

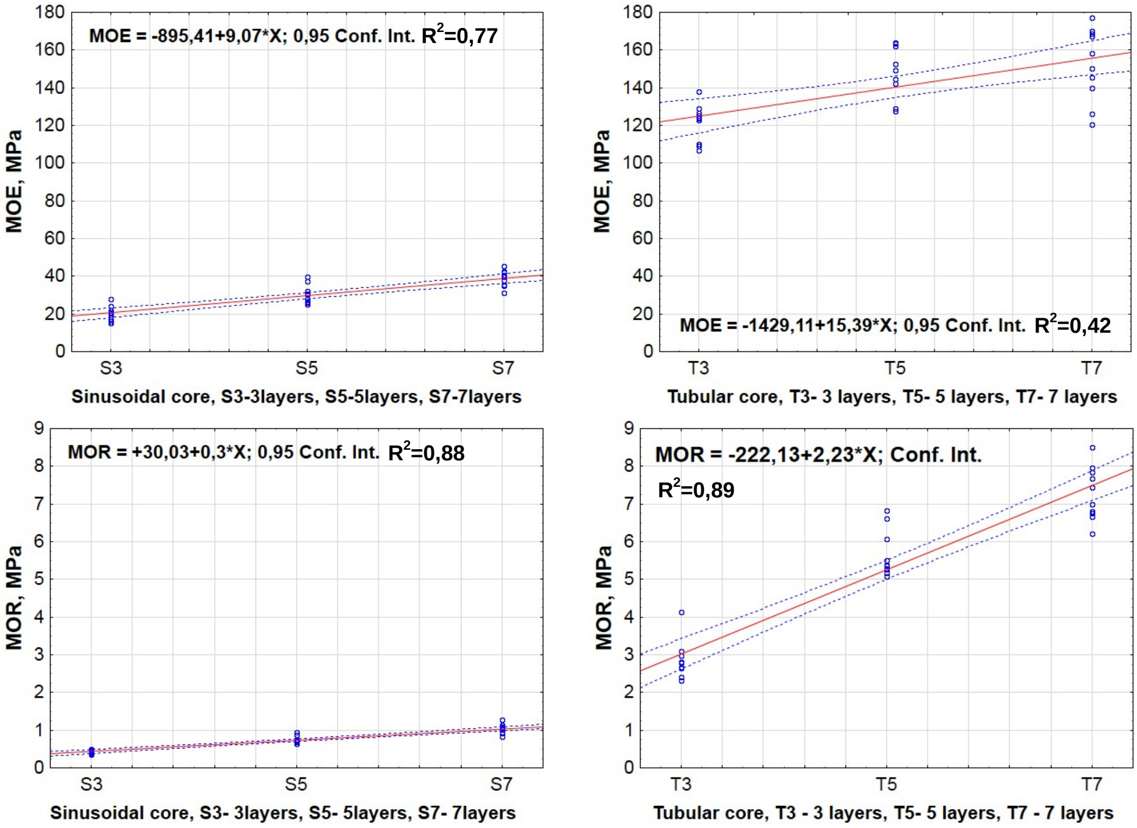

***Fig. 3.***
***Scatter plot diagrams with regression lines of the modulus of rupture and modulus of elasticity in function of core geometry and number of veneer layers.***

Typical failure modes are represented in Fig. 4. The buckling failure of the core wall is characteristic for sinusoidal reinforcements, the tubular cores fail in wall crushing and wrinkling.

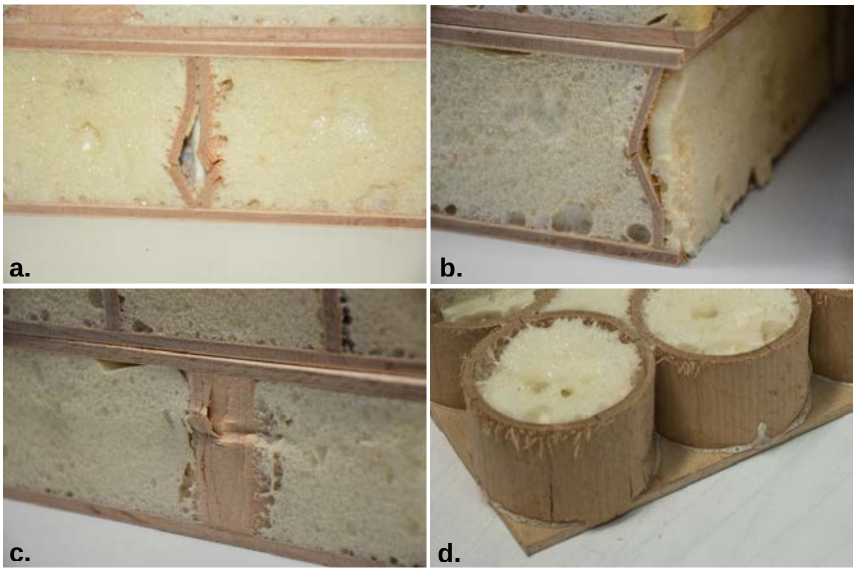

***Fig. 4.***
***Typical failure modes in compression: a, b - buckling failures, c,d – wrinkling failures.***

## CONCLUSIONS

- The developed veneer reinforcements used in the plywood face, polyurethane core sandwich structures remarkable increase the compression strength and elasticity of the panels
- The strength and stiffness of the tubular reinforcements are 4 to 6 times higher than of sinusoidal reinforcements
- The linear regression models describing the relationship between the number of veneer layers and strength and stiffness fits well on the measured data except modulus of elasticity of the tubular core sandwich panels
- The characteristic failure mode of the tested sandwich structures is the lateral buckling of the reinforcement walls of sinusoidal core and crushing and wrinkling of the tubular walls respectively.

## ACKNOWLEDGEMENT

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