EXPERIMENTAL TESTING OF COMPOSITE MATERIALS AND SANDWICH PANELS WITH COMPOSITE FACE SHEETS WITH POLYESTER AND EPOXY MATRIX

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SUMMARY: This paper presents the experiment test for the tensile properties of two series of composite materials and two series sandwich panels with composite face sheets, which differed according to the type of matrix. The ultimate tensile strength and the initial module of the elasticity of the composite materials were experimentally determined. Sandwich panels in the experimental tests were subjected on three points bending by linear load in the middle of their span. The analysis was performed in order to evaluate the influence of the matrix type on the ultimate mechanical characteristics of the sandwich panels. Influence of the matrix type used in the composite face sheets was evaluated by analysis of F – δ behavior of series of sandwich panels, as well as by analysis of F – σ behavior of the composite face sheets.

EKSPERIMENTALNO ISPITIVANJE KOMPOZITNIH MATERIJALA I SENDVIČ PANELA S KOMPOZITNIM OBLOGAMA OD POLIESTERSKE I EPOKSIDNE MATRICE

SAŽETAK: U radu se prikazuje ekperimentalno ispitivanje vlačnih svojstava dvije serije kompozitnih materijala i dvije serije sendvič panela s kompozitnim oblogama koje se razlikuju po vrsti matrice. Vlačna čvrstoća i početni modul elastičnosti kompozitnih materijala određeni su eksperimentalno. Sendvič paneli u eksperimentalnim ispitivanjima slobodno su oslonjeni i opterećeni linijskim opterećenjem u sredini raspona. Provedenim proračunima ustanovljen je utjecaj vrste matrice na krajnje mehaničke značajke sendvič panela. Taj je utjecaj utvrđen analizom ponašanja F – δ za seriju sendvič panela i analizom ponašanja F – σ za kompozitne obloge lica.

1. INTRODUCTION

Sandwich structures are being often used as constructive elements in the civil engineering. The usage is mostly based on their high performance, such as high stiffness and high strength compare with their weight. Based on the concept of increasing the bending bearing capacity and stiffness sandwich panels are defined as structures that have low weight. They are multi layered composites formed of two thick, but strong and stiff face sheets, and lower core. Depending on the specific application of the final product different materials could be used for fabrication of sandwich panels.

Any constructive product available as a thin plate could be used for the face sheets [2]. Material are chosen so that face sheets will have high bending stiffness, high tensile and compressive strength and excellent resistance to external influences. Composite materials, as anisotropic materials, especially as materials with high strength to weight ratio, high stiffness to weight ratio and as non-corrosiveness easy handling material that offer many options in the design process, are very often used as materials for the face sheets.

Lingaiah and Suryanarayana [7] in their work present experimental research of sandwich panels with composite face sheets and aluminum honeycomb core subjected on bending, while the Alias [1] did experiments on sandwich panel with steel face sheets and polyvinylchloride core statically loaded with concentrated force. The fracture mechanism should be well-known in order to determine the mechanical characteristics of sandwich panels. Fracture types of sandwich panels in linear part are studied and discussed by Allen [2], Ashby and Gibson [3] and Plantema [10]. In order to simplify the mathematical operations numerous analyses of sandwich panels are being performed on beam model. Swanson and Kim [11] and Mines and Alias [9], focused on analyses of sandwich beam fracture. Fracture of the sandwich elements could occur as a result of reaching the ultimate compressive or tensile strength of the face sheets or as a result of reaching the ultimate shear strength of the core [8, 6]. According to the available literature the mechanical characteristics and the fracture type of the sandwich panels depend on the used materials. Mechanical characteristics of sandwich panels with composite face sheets depend also on the components used for the composite material.

Many papers that concern composite materials present the excellent mechanical characteristics of the composite materials. Many experimental research work show that the mechanical characteristics of the composite materials depends on the matrix and fiber reinforcement selection. The strength and stiffness of the composite materials according to Barbero [5] depend on the matrix choice, while the strength of the composite material to compression and tension, in a direction normal to the reinforcement fibers, depend on the matrix strength, on the strength of the contact surface between the matrix and the reinforcing fibers and from the defects in the matrix such as holes and micro fractures. Despite the fact, that the mechanical characteristics of the composite materials could be estimated from previous gained knowledge, the experimental testing should be performed if new composite product is developing, in order to obtain precise mechanical characteristics. Furthermore, the experimentally obtained results could give clear view on the behaviour of the mechanical characteristics due to changes of components or changes of environmental conditions, and help the designer to analytically predict behaviour of a complex structure.

This paper presents an experimental tests performed on two series of composite materials and two series of sandwich panels with composite face sheets differed by the type of the used matrix. Two types of matrix material-polyester and epoxy based resins are used for these experiments. In order to analyse the influence of the different components on the final mechanical characteristics of the composite materials the basic mechanical characteristics from experimentally obtained σ-ε diagrams, such as ultimate tensile strength and module of elasticity, were determined. Sandwich panels in the experimental tests were subjected on three points bending. The analysis was performed in order to evaluate the influence of the matrix type on the ultimate mechanical characteristics of the sandwich panels. Influence of the matrix type used in the composite face sheets was evaluated by analysis of F-δ behavior of series sandwich panels, as well as by analysis of F-σ behavior of the composite face sheets.

2. SPECIMENS PREPARATION AND EXPERIMENTAL PROCEDURE

2.1. COMPONENTS OF COMPOSITE MATERIALS AND SANDWICH PANELS

For the purpose of the experiment the testing was performed in two parts: testing of the composite materials and testing of the sandwich panels. For the experimental testing of the composite materials two different series of thin laminates were fabricated, using two types matrix and fiber glass reinforcement in two plies. The laminates were fabricated using rowing with density 0,535 kg/m^2 for fiber glass reinforcement and polyester resin and two-component epoxy resin for matrix. The examined sandwich panels were fabricated of polyurethane core and thin composite face sheets, same as the previously experimentally tested composite materials. The core of sandwich panels is 60 mm hard foam polyurethane with density of 30 kg/m^3. Actually, the sandwich panels' series differ by type of matrix used for the thin composite face sheets.

Marking of the laminates and sandwich panels was according to the components used for the production of composite materials: the symbol (S) refers to the sandwich panel, the symbols (P or E) refers to the type of the matrix, the symbol (2) refers to the number of reinforcement plies and the last symbol (R) denotes the type of used reinforcement. The materials types used for production of the laminates and sandwich panels are summarized in Table 1.ž

Table 1: Components of series tested sandwich panels

Laminate	Sandwich panels	Core	Composite face sheet		
			Matrix	Reinforcement plies	Reinforcement
P2R	SP2R	Polyurethane	Polyester resin	2	Rowing
E2R	SE2R	Polyurethane	Epoxy resin	2	Rowing

2.2. SPECIMEN GEOMETRY

Test specimens for the first part of the experiment were cut from fabricated laminates. Their geometry was defined according to American test standard ASTM D 3039 [4], Figure 1. All test specimens had a constant rectangular cross section and tabs on each side. These tabs were made form G11 laminate, epoxy material reinforced with E glass rowing under high temperature. In order to avoid different surface stresses, the bond between tabs and specimen was made by araldite, epoxy and polyurethane based adhesive with high extensive properties.

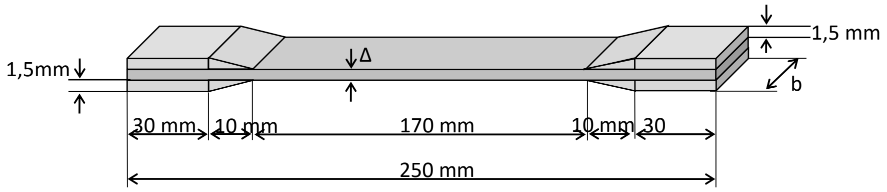


Figure 7: Geometry of composite test specimens

For the second part of the experiment test specimens were fabricated by hand lay-up of the composite face sheets on the hard foam polyurethane. Their geometry was defined by the properties of the test machine, Figure 2. All test specimens had a constant length of 1000 mm and rectangular cross section with width of 300 mm. The depth of each sandwich panel differs depending on the depth of the composite face sheets. For precise determination of the relative strain of each composite face sheet of the tested sandwich panel, strain gages in longitudinal direction were used.

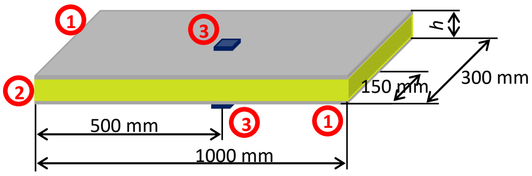


Figure 8: Geometry of sandwich panel specimens 1) composite face sheets; 2) core; 3) strain gages

2.3. EXPERIMENT TEST SETUP

Test procedure for the composite material was defined in accordance with American test standard ASTM D 3039 [4]. Prior to the tension tests the final surface preparation was carefully examined for each test specimen. The dimensions of the specimens were measured before tension testing and the specimens' area were determinate at three places in order to record the average area.

Experiments were performed by using testing machine SCHENCK HYDROPLUS-PSB, with capacity of 250 kN. Tests were made in range up to 25 kN. Pressure controllable hydraulic grips were used. Initial trails were made in order to determinate the most appropriate pressure on the hydraulic grips. The speed of the testing machine was set to 1 mm/min in order to obtain constant strain rate in the gage section, which was observed with trail tests. The specimens were inserted in the grips of the testing machine taking care of alignment of the ripped specimen with the test direction.

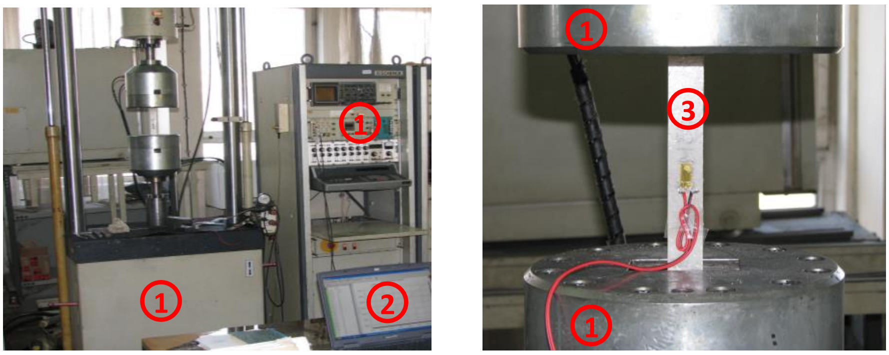


Figure 9: Testing machine and equipment for tensile test of FRP specimens: 1) testing machine; 2) computer; 3) test specimen

The final surface preparation of the sandwich panels was carefully examined for each test specimen prior to the flexural tests. The dimensions of the specimens were measured before flexural testing. In order to record the average area of the specimens' their area was measured at three places.

The tests specimens were subjected on three point bending. Additional device was set on the test machine in order to test the flat beams loaded on flexure. The specimens were carried by steel supports with 50 mm width set on 50 mm diameter steel cylinders which permit slip and deformation of the sandwich panels during the experiments. Slip on the contact surface was avoided by using of 2 mm neoprene layers between sandwich panels and a steel support. Line load was applied through 100 mm width steel beam mounted on steel cylinder with diameter of 50 mm. A 40 mm square hole was made in the middle of the steel beam in order to set a strain gage on the top face sheet of the sandwich panel in the middle of the span. By placing a 4 mm thick neoprene layer between steel beam and sandwich panel the local fracture of the top layers of the composite face sheet was avoided. The actual span of the sandwich beam was 800 mm and the load was applied with constant speed of 5 mm/min.

Tension force and flexural force was determined with force transducer integrated in the testing machine. The full bridge strain gage type force transducer was used. Head displacement of the testing machine was determined by displacement transducer of inductive type. Strain data were determinate using strain gage in longitudinal direction. The strain gage with resistant of 350 Ω, type HBM 10/350LY11 were selected in order to reduce the heating effects due to the low conductivity of the used composite materials. The surface preparation and the selection of bonding agent for the strain gage installation was done in consultation with the strain gage producer. The temperature compensation was done by a passive strain gage, connected in half-bridge. The force versus head displacement and the force versus strain were continuously recorded with sampling rate of 50 Hz. The HBM Spider 8 and software HBM CATMAN 4.0 were used for data acquisition.

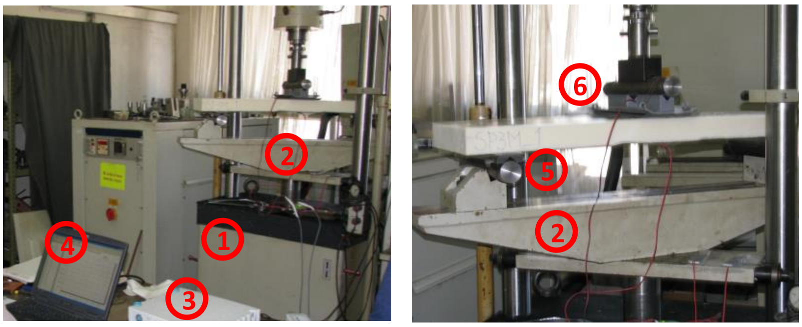


Figure 10: Testing machine and equipment for flexural test of sandwich specimens: 1) testing machine; 2) additional device for testing flat beams; 3) acquisition unit; 4) computer; 5) steel support lay on cylinder; 6) loading steel beam on cylinder

3. EXPERIMENTALLY OBTAINED RESULTS AND DISCUSSION

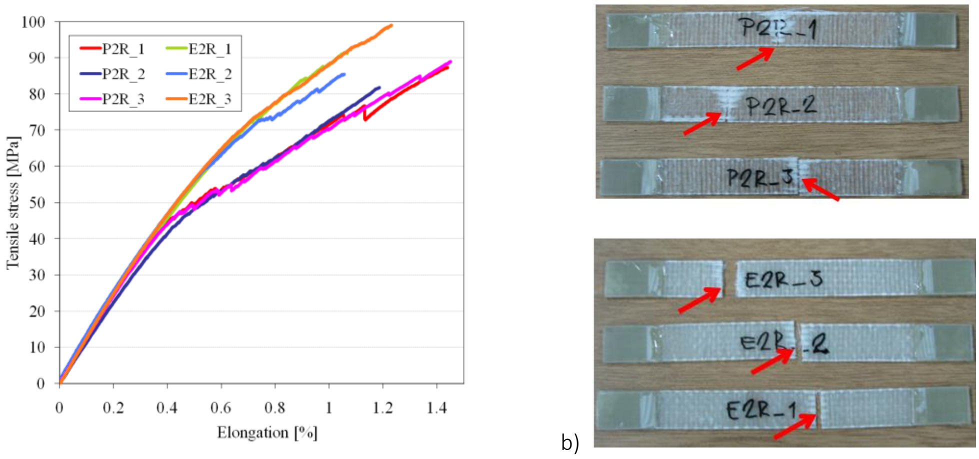
3.1. COMPOSITE MATERIALS

The tensile testing has been performed on two different series of specimens. For the purpose of the experiment three specimens of each serial were tested. Geometry and experimentally obtained results for tested FRP specimens are summarized in Table 2.

Table 2: Geometrical and mechanical properties of tested composite specimens

Specimen	*b* [mm]	Δ [mm]	Tensile strength [MPa]	Module of elasticity [MPa]	Average tensile strength [MPa]	Average module of elasticity [MPa]
P2R_1	25	1,5	87,33	12200	86,02	11445
P2R_2	25,1	1,6	81,77	10850		
P2R_3	25,2	1,6	88,96	11285		
E2R_1	25,1	1,4	91,66	12160	92,01	12170
E2R_2	25,2	1,3	85,41	12150		
E2R_3	25,2	1,3	98,96	12200		

In order to observe the influence of the components on the mechanical properties of the composite materials, comparative analyses of the experimentally obtained results were carried out. From the σ-ε diagrams shown on Figure 5 and results summarized in Table 2 could be concluded that tensile strength and module of elasticity are slightly higher for the composite materials with epoxy matrix. From Figure 5 could be seen that composite materials with polyester matrix have more distinct transitional boundary on the bilinear σ-ε diagram in comparison with the composite materials with epoxy matrix.



a) b)

Figure 11: Experimentally tested specimens of the series P2R and E2R: a) σ-ε diagrams; b) failure modes

The failures of all tested FRP specimens were sudden and brittle. Standard description of the failure modes was chosen using the three-part failure mode code, according to American standard ASTM D 3039 [4]. The failure mode for the test specimens was denoted as LGM (Lateral Gage Middle), Figure 5b). Actually, the type of the failure mode depends on the type of the used reinforcement and it doesn't depend on the type of the used matrix.

3.2. SANDWICH PANELS

The flexural testing has been performed on two different series of specimens. Two specimens of each serial were tested for the purpose of the experiment. The geometry and the experimentally obtained results for tested sandwich specimens are summarized in the Table 3.

Table 3: Geometrical and mechanical properties of tested sandwich specimens

Sandwich specimen	Face sheet thickness, *t* [mm]	Sandwich panel thickness, h [mm]	Load [N]	Deflection [mm]	Tensile strength [MPa]
SP2R_1	1,5	62	3340	30,67	34,65
SP2R_2	1,7	63	3367	29,08	29,18
SE2R_1	1,3	62	3538	32,27	41,48
SE2R_2	1,2	63	3511	32,58	45,07

From the performed tests can be concluded that the behavior of the tested sandwich panels subjected on three points bending can be divided in three characteristic parts. Behavior of the sandwich panels is linear up to the point where cracking of the polyurethane foam occurs reducing their stiffness. In the nonlinear part, by increasing the load, new micro cracks appear and spread through the depth of the core, while the composite face sheets are still in elastic part caring out the applied load. In the last stage crash of the top composite face sheet and core occur followed by a considerable drop in the stiffness of the sandwich panels.

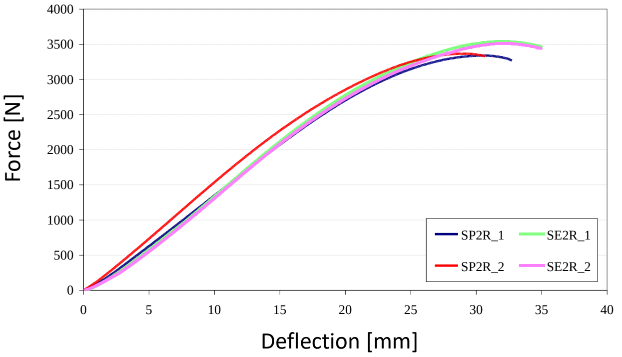


Figure 12: F-δ diagrams for specimens SP2R and SE2R subjected on three point bending

The F-δ behaviour of the tested sandwich panels SP2R and SE2R in the middle of the span is similar, as can be concluded from the Figure 6. The ultimate strength of the series sandwich panels SE2R is minimally higher in comparison to the series of sandwich panels SP2R. In particular, the behaviour of the both series of sandwich panels is in the linear part with the approximately equal stiffness and minor differences observed in the ultimate deformations.

In order to observe the influence of the used matrix on the mechanical properties of the sandwich panels, comparative analyses of the experimentally obtained results for the stress on the bottom face sheet were carried out, Figure 7. The analysis of the results summarized in Table 3 lead to conclusion that the deflections and ultimate tensile strength in the bottom face sheets in each series of sandwich panels are approximately equal under the ultimate load. Under the equal loading, the series of sandwich panels SE2R have minimal higher stress in the bottom face sheet in comparison to series sandwich panels SP2R, as can be seen in Figure 7. Nevertheless, it should be mentioned that the stresses in the composite face sheets are very small in comparison with the strength of the composite material, and the properties of the composite material are not completely used.

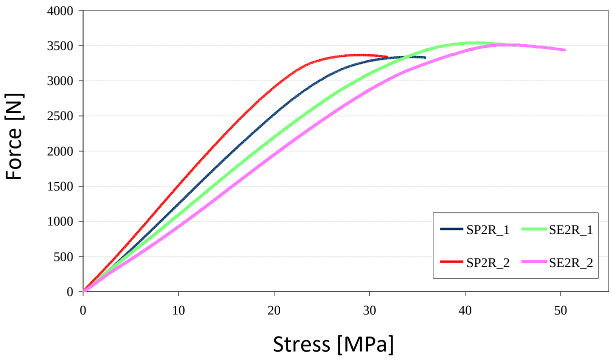


Figure 13: F- σ diagrams for specimens SP2R and SE2R subjected on three point bending

Figure 14: Fracture of the sandwich panels SP2R and SE2R subjected on three points bending

The results of the performed experiments state that the fracture of the sandwich panels was followed by fracture of the top composite face sheet and fracture of the polyurethane foam core in the top of the sandwich panel, while the bottom composite face sheet remained undamaged with no visible cracks, Figure 8.

4. CONCLUSIONS

This paper presents results from the experimental tests of two series of composite materials, subjected on axial tension and two series of sandwich panels subjected on three points bending.

The basic mechanical characteristics from σ-ε diagrams, ultimate tensile strength and module of elasticity, were determined in order to analyse the influence of the type of matrix on the final mechanical characteristics of the composite materials. Strains of the composite materials depend on the matrix characteristics, before the appearance of the first micro cracks. It could be concluded that the matrix selection has influence on the strain of the composite material, but it has no influence on composite material ultimate mechanical properties. The experiments show that the failure mode doesn’t depend on the choice of the matrix used for the material.

Analyzing the experimentally obtained results it can be concluded that the type of used matrix in the composite face sheets of the sandwich panels doesn't have a great influence on the initial strength of the sandwich panels and on their deformation. Similarly, the type of the used matrix in the composite face sheets doesn't have an influence on the stress in the bottom face sheet, on the stiffness of the sandwich panel and on their ultimate bearing capacity. Experiments show that the fracture of the sandwich panels is driven by the characteristics of the polyurethane foam core. Its low strength and deformation characteristics have great influence on the fracture of the sandwich panels. It does not permit an utilization of the characteristics of the composite materials used for the face sheets.

REFERENCES

[1] Alias, A.; Nor, N.A.A.; Said, M.R.: The Behaviour of Square Sandwich Panel. Part I: Under Static Loading, *Journal Teknologi*, Vol. 47 (2007), pp. 1-18, E-ISSN 2180-3722

[2] Allen, H. G.: *Analysis and Design of Structural Sandwich Panels*, Pergamon Press, ISBN 9780080128702, Oxford, 1969

[3] Ashby, M. F.; Gibson, L. J.: *Cellular Solids-Structure and Properties*, Cambridge University Press, ISBN 0521495601, Oxford, UK, 1997

[4] ASTM D3039/D 3039M-08: Standard Test Method for Tensile Properties of polymer Matrix Composite Materials, ASTM International, USA 2008

[5] Barbero, E. J.: *Introduction to Composite Materials Design*,Taylor & Francis, ISBN 1560327014, USA 1999

[6] Li, Q. M.; Mines, R. A. W.; Birch, R. S.: The Crush Behaviour of Rochacell-51 WF Structural Foam, *International Journal of Solids and Structures*, Vol. 37 (2000) No. 43, pp. 6321-6341, ISSN 0020-7683

[7] Lingaiah, K.; Suryanarayana, B. G.: Strength and Stiffness of Sandwich Beams in Bending, *Experimental Mechanics*, Vol. 31 (1991) No. 1, pp. 1-7, ISSN 0014-4851

[8] Mines, R. A. W. et al: On the Measurement of the Crush Behaviour of Structural Foams, 11th International Conference on Experimental Mechanics, pp. 287-292, ISBN 9058090140, Oxford, August 1998

[9] Mines, R. A. W.; Alias, A:, Numerical Simulation of The Progressive Collapse of Polymer Composite Sandwich Beam under Static Loading, *Composites Part A: Applied Science and Manufacturing*, Vol. 33 (2002) No. 1, pp. 11-26, ISSN 1359-835x

[10] Plantema, F.: Sandwich Construction, The bending and buckling of Sandwich Beams, Plates and Shells, John Wiley & Sons inc., ISBN 9780471691068, New York, USA 1966

[11] Swanson, S. R.; Kim, J.: Design of Sandwich Structure under Contact loading, *Composite Structures*, Vol. 59 (2003) No. 3, pp. 403-413, ISSN 0263-8223