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Selected mechanical properties of the reinforced layered composites

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Abstract: *Selected mechanical properties of the reinforced layered composites*. Publication concerns the production of fiber reinforced layered composites and its selected mechanical properties. The following reinforcement types of the layered composites were taken into consideration: linen fabric and fiberglass. Two types of core materials were tested: plywood and PUR foam. The assembled composites were tested for MOR, MOE and screw holding ability. Additionally density and density profile were determined. Fiberglass reinforced composites were used as a reference material for composites reinforced with natural fibres.

Keywords: layered laminate, plywood, PUR foam, reinforcement

INTRODUCTION

A layered composite (sandwich laminate), consists of at least two layers of an outer laminate, separated by a core material. The outer layers can be relatively thin - from around one millimeter, while the core layer can be a few to several centimeters. Such composites are characterized by high strength properties, low specific weight, relatively low production cost and high durability (Izbicka and Michalski, 2006; Bunsell, 2009).

The core material of layered composite is usually made of structural elements, characterized by a relatively low modulus of elasticity, such as wood and wood based boards, porous and cellular materials, profiled laminate boards, compositions with a filler in the form of hollow structures. Cores for sandwich products should meet the following conditions: 1. low density, 2. high compression and shear strenght, 3. dimensional stability, 4. low water absorption, 5. high gluability, 6. ease of machinability (Królikowski et al., 1986, Ramesh, 2019).

Reinforcement of the core layer of composites is used very often in order to improve its strength properties, increase resistance to abrasion, reduce thermal expansion and limit the spread of cracks. Fibers used to reinforce the core layer are characterized by a large length-to-diameter ratio. They should have high strength, stiffness and low specific weight. The propagation of fiber breakage starts with defects on its surface, reducing the fiber diameter helps to reduce surface defects. Long fibers are preferred because the fiber ends bear less stress, and by reducing the number of ends, the load-bearing capacity of the fibers is increased. As the fiber content increases in relation to the matrix, the strength and stiffness of the composite increases, but this ratio should not exceed 80%, because with higher proportions of fibers, it is difficult to fully embed them in the matrix. The matrix has multiple functions in the composite: 1. keeps the whole system in a compact form, 2. transfers external forces to the reinforcement, 3. protects the reinforcement against mechanical damage, 4. determines the chemical and thermal properties of the composite, 5. provides compressive strength and gives the products a specific shape, 6. separates the fibers and prevents the spread of cracks (Blicharski, 2017; Etcheverry and Barbosa, 2012, Miedzianowska et al. 2018).

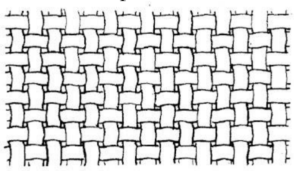
Natural fibers have more favorable prices in relation to synthetic fibers, what is the main advantage in the perspective of using them on an industrial scale. Due to the possibility of natural fibers recycling, natural fibers become an important alternative to glass fibers - EU guidelines specify that in the automotive industry the share of recyclable elements should be as high as 85% (Błędzki et al., 2014). Another advantage of natural fibers is their lower density than glass fibers - on average, natural fibers have a density of approx. 1.5 g cm^3, and glass fibers of approx. 2.5 g/cm^3 (Kozakiewicz and Nicewicz, 2003). Next important feature of natural fibers is their ability to absorb energy upon impact, the composite based on natural fibers does not produce sharp edges or fragments while cracking- as is the case with glass fibers. This unique feature of natural fibers - energy absorption - results from their ability to stretch (Błędzki et al., 2014, Maino et al., 2019).

The aim of the work was to verify the possibility of producing layered composites reinforced with natural fiber fabrics and to determine its selected physical and mechanical properties in relation to the reference material, reinforced with synthetic material.

MATERIALS AND METHODS

Research material consisted of 4 variants of produced composites (table 1).

Table 1 Variants of layered composites

Variant	Core material	Reinforcement	Weave of fabric	Grammage of fabric [g/m^2]
1.1	Plywood	Glass fabric, 2 layers	plain 	500 x 2 = 1000
1.2	Plywood	Linen fabric, 2 layers		525 x 2 = 1050
2.1	PUR foam	Glass fabric, 2 layers		500 x 2 = 1000
2.2	PUR foam	Linen fabric, 2 layers		525 x 2 = 1050

Two variants of the core material for the produced composites were used: plywood and PUR foam. The plywood used was dry-durable, general-purpose, 18 mm thick, consisted of 13 layers of birch wood veneers. In the second variant, the core material was made of the Ekoprodur CP4090 polyurethane system produced by PCC Prodex sp. z o. o. It was a mixture of polyalcohols and isocyanates. This system consisted of two components. Component A was a prescription polyol mixture in the form of an oily liquid with a brown color. Component B was a mixture of aromatic polyisocyanates, brown in color, which is extremely sensitive to moisture. It was used for the production of closed-chamber rigid foam. The full strength of the PUR foams is achieved after 24 hours.

Epidian 6011 resin with IDA hardener was used to make the matrix of the composite. Additionally, silica Areosil WL-180, in form of a volatile, amorphous powder with hydrophobic properties was used in a weight ratio to the 1:10 mixture of resin and hardener. The method of manual cold lamination was used in the production (Tobis, 1995).

Fabrics used to reinforce the core material are characterized in Table 1.

The samples were finished with natural pine veneer, 1.1 ± 0.1 mm thick. The sheets of veneers were 27 cm wide and 60 cm long. They were of high quality, without any knots and twisted fibers.

Figure 1 shows schematic layout of the five-layer composite, with a symmetrical arrangement. In a first stage of material preparation, one-sided reinforcement of the core material was made using a given fabric. Resin was applied with a roller, the application was 2500 g/m^2 in case of glass fiber and around 9000 g/m^2 in case of linen fiber. After that, between the reinforcement and natural veneer a layer of mixture of resin and colloidal silica was applied by a roller in amount of 1500 g/m^2. In the next stage, analogous operations of reinforcing the other side of the core material were performed. One board with a nominal dimensions of 400 x 500 mm was produced for each of four samples variants.

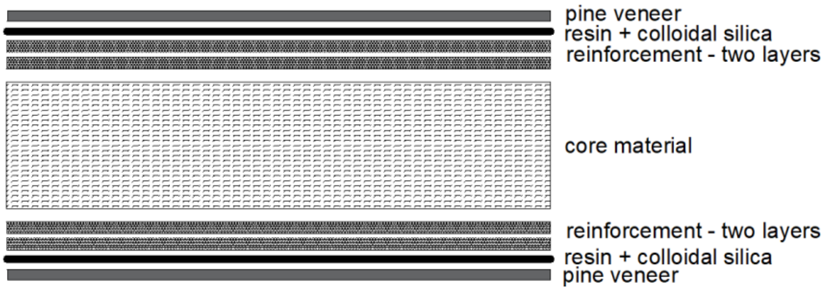


Figure 1. Schematic layout of produced samples

As a result of production process, four variants of composites were obtained, in the form of sandwich panels, each with dimensions of 400x500mm. The samples have been subjected to formatting in order to obtain samples of appropriate dimensions, dedicated to the determine:

- average density and its distribution determined with DAX density profiler by GreCon (50x50 mm),
- MOR and MOE according to EN 310:1994 with universal testing machine (50x450 mm),
- screw holding capacity according to EN 13446:2004 with Heckert FP-10 testing machine (50x50 mm).

RESULTS AND DISCUSSION

Table 2 presents a summary of the results obtained from testing the physical and mechanical properties of the produced composites.

Table 2. Physical and mechanical properties of tested composites

	Variant			
	1.1	1.2	2.1	2.2
Density ± st. dev. [kg/m^3]	762 ± 8.2	788 ± 6.4	299 ± 13.0	340 ± 34.1
MOR ± st. dev. [N/mm^2]	72.6 ± 15.5	65.8 ± 8.7	19.0 ± 2.2	18.1 ± 1.9
MOE ± st. dev. [N/mm^2]	8238 ± 1373	7745 ± 1167	2437 ± 314	2186 ± 140
Screw holding ability ± st.dev. [N/mm]	0.189 ± 0.008	0.214 ± 0.030	0.039 ± 0.006	0.040 ± 0.008

The average density values achieved by variants 1.1 and 1.2 significantly differ from the average density values of variants 2.1, 2.2. The main difference between variants 1. and 2. is the core material and its basic density. In case of variants 1.1 and 1.2 the core material is plywood, which has significantly higher (by around 230 %) density than PUR foam (core material of 2.1 and 2.2 variants). The t-student test (significance level 95%) showed statistically significant differences between average values of density obtained in case of 1.1 and 1.2 variants as well as 2.1 and 2.2 variants. Figure 2 shows representative density profiles.

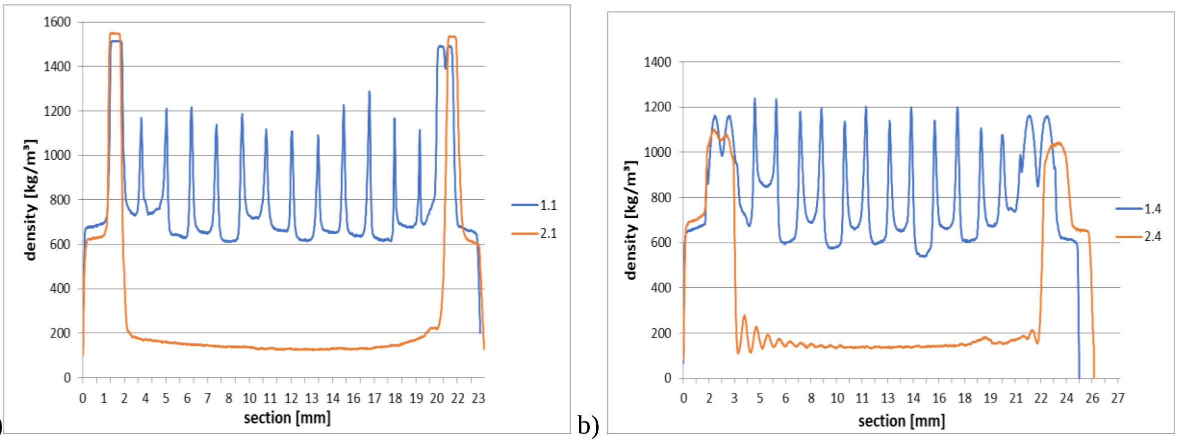


Figure 2.Density profiles for variants of the same reinforcement method, differ core materials a) 1.1 and 2.1 (reference variants) and b) 1.2 and 2.2

The obtained density profiles are similar for variants with the same core material. A symmetrical arrangement with a veneer as an outer layer with a density of 600-700 kg/m^3 is noticeable, followed by a large jump in density that reflects two layers of resin- soaked fabric as reinforcement. For composites in variants 1.2 and 2.2, the reinforcement density is approx. 1200 kg/m^3 and its thickness is approx. 2 mm. In the PUR foam, fluctuations in density can be seen on its outer parts.

Strength tests revealed that the higher average MOE have samples of variant 1.1 (8238 N/mm^2). Replacing the glass with linen fabric caused that MOE lowered by 6% compared to reference samples (statistically significant acc. to t-student test, sign. level 95%). In case of samples with PUR foam core material, maximum MOE was obtained for samples of variant 2.1 (2437 N/mm^2). Samples reinforced with linen fabric (variant 2.2) were characterized by about 10% lowered MOE compared to reference samples (variant 2.1). Samples of variants 1.1 and 1.2 achieved on average 345% higher mean values of MOE than samples of variants 2.1 and 2.2. MOE mean value of tested layered composited was smaller than reported in literature for plywood (Biadała et al., 2020). The final properties of plywood, such as modulus of elasticity, are affected by not only the wood species veneers are made from but also by wood density, type of adhesive, thickness and number of veneers and the effect of their growth conditions, steaming and drying temperatures (Peker and Tan 2014). An alteration in mechanical properties can also be achieved by changing the position of veneer in the plywood structure (Kljak et al. 2006, 2007, Popovska et al. 2017).

On the basis of table 2 it can be observed that the highest MOR (72.6 N/mm^2) has been achieved in case of 1.1 variant of sample. Samples of variant 1.2 reached around 10% lesser MOR. The lowest average MOR was obtained for PUR foam as the core material and linen reinforcement (18.1 N/mm^2), which is less by 5% compared to the reference material (2.1 variant). Samples of variants 1.1-1.2 achieved on average 186% higher MOR values than samples of variants 2.1-2.2. The MOR values obtained for layered composites with plywood core material were significantly higher than the values achieved for plywood material itself, pressed using different types of adhesive and pressing conditions (Bekhta and Sedliacik, 2019).

It is also noteworthy that the lowest values of strength parameters, i.e. MOR and MOE, were obtained while reinforcement with natural fiber was applied (variants 1.2 and 2.2). Similar results were obtained by Bal and Bektas (2014), who compared properties of plywood made from poplar, eucalyptus and beech. Therefore, it is reasonable to conclude that the change in the structure of plywood has enhanced its elasticity. All these findings correspond with results of earlier research works done by Biadała et al. (2015).

Among all tested variants, the highest average value of the screw holding ability was obtained by 1.2 variant of samples (0.214 N/mm - 8% higher than for the reference material 1.1). For variants of PUR foam core material, the highest average value was obtained by variant 2.2 (0.040 N/mm), comparable to the reference material.

Variants 1.1-1.2 achieved around 5.1 times higher values of screw holding ability than variants 2.1-2.4.

CONCLUSIONS

1. The method of manual laminating with the use of a press allows to obtain composites with a repetitive symmetrical layered structure,
2. Composites with natural reinforcement with plywood core material reached an average of 94% of the MOE value of the composite with glass fabric reinforcement. On the other hand, composites with natural reinforcement with a core material made of PUR foam reached an average of 90% of the MOE value of the reference material. The MOE values for the variants with a plywood core were on average 345% higher than the MOE values for the variants with a PUR foam core.
3. Composites with natural reinforcement with plywood core material reached an average of 90% of the MOR value of the reference material. On the other hand, composites with natural reinforcement with a core material made of PUR foam reached an average of 95% of the MOR value of the reference material. MOR values for variants with plywood core were on average 186% higher than MOE values for variants with PUR foam core
4. The average screw holding ability of composites with the reinforcement of natural fibers with a plywood core was 108% of the average screw holding ability of the reference material. Variants of composites with a PUR core and a natural fiber reinforcement reached an average of 101% of the value of the ability to hold the screw of the reference material. The variants with a plywood core achieved on average 510% higher values of the screw retention capacity than the variants with a PUR foam core.

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Streszczenie: *Wybrane właściwości mechaniczne wzmocnionego warstwowego kompozytu.* Publikacja dotyczy możliwości produkcji kompozytów warstwowych wzmocnionych materiałami różnego typu. Do celów badawczych wykorzystano tkaninę lnianą oraz tkaninę szklaną. Dwa rodzaje materiału rdzeniowego były przedmiotem badań – sklejka oraz pianka PUR. Przygotowane kompozyty były poddane badaniom MOR, MOE oraz zdolności do utrzymania wkrętu. Dodatkowo wyznaczono gęstość i profil gęstości. Kompozyt warstwowy wzmocniony tkaniną szklaną był wykorzystany jako materiał referencyjny w odniesieniu do kompozytu wzmocnionego włóknami naturalnymi.

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