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Influence of the stacking sequence on the mechanical proprieties of glass fiber reinforced polymer

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Abstract. The reinforced composite materials are in a very impressive development in the last decades. In this paper the influence of the ply-stacking sequence of glass fiber reinforced polymer on mechanical properties is investigated. Composite material structures consist of layers from glass mat and fabrics with different disposal sequence. The mechanical properties of the manufactured composite materials have been determined by tensile and bending tests. The obtained results are used to design the optimal materials architecture.

1 Introduction

Composite materials, especially those with a polymeric matrix, are of considerable interest to researchers and engineers due to the use of them in a broad spectrum of applications, particularly for high-performance aerospace and automotive components and a wide range of possible combinations to get specific material properties. In almost all engineering applications requiring strength, high stiffness and fatigue resistance, composites are reinforced with continuous fibers rather than small particles or whiskers. Fiber reinforced plastic (FRP) composites can be simply described as multi-constituent materials that consist of reinforcing fibers embedded in a rigid polymer matrix. Most composites used in engineering applications contain fibers made of glass, carbon or aramid. A wide range of polymers can be used as the matrix to FRP composites, and these are generally classified as thermoset (eg. epoxy, polyester) or thermoplastic (eg. polyether-ether-ketone, polyamide) resins.

Glass fiber reinforced polymeric composite (GFRP) is a composite material made of a plastic (resin) matrix reinforced by fine fibers made of glass. GFRP is a lightweight, strong material with very many uses, including boats, automobiles, water tanks, roofing and pipes. The mechanical behavior of a GFRP composite basically depends on the fiber strength and modulus, their amount, orientation and type, the chemical stability, matrix strength and the interface bonding between the fiber/matrix to enable stress transfer [1, 2]. Various GF reinforcements like long longitudinal, woven mat, chopped fiber (distinct) and chopped mat

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in the composites have been produced to enhance the mechanical and tribological properties of the composites.

Influence of the stacking sequence on the mechanical properties of composites is investigated the literature. Amico S C et al. [3] are focused on the mechanical properties of pure sisal, pure glass, and hybrid sisal/glass compression-molded composites, in which various stacking sequences of fiber mat layers were used, the importance of controlling the stacking sequence to enhance properties was evident. Similar study of the tensile and flexural properties of glass fiber epoxy composites hybridized with basalt, flax or jute fibers is presented in [4] and for cotton/glass fiber reinforced polyester composites in [5]. Mechanical properties of hybrid composites made from glass fiber (plain-woven and stitched bi-axial ±45˚) and plain-woven carbon fiber was analyzed by Irina M [6]. Effect of fiber orientation and stacking sequence on mechanical and thermal characteristics is investigated also for hybrid natural composites based on banana-kenaf fibers [7]. Davallo M [8] studied the effects of laminate thickness and ply-stacking sequence on the mechanical properties and failure mechanism of unidirectional glass-polyester composites.

The primary goal of this study is to evaluate the effect of the stacking sequence on the mechanical properties of GFRP laminates, and to assess the best combination that can be applied to design the optimal materials architecture. The first part of the paper presents manufacturing process of the material. The mechanical proprieties of the material, presented in the second part of the paper, were determined by standard tensile tests and three point bending test according to ASTM standards. The main results and conclusion are included at the end of the paper.

2 Materials and manufacturing method

2.1 Materials

To investigate the stacking sequence on mechanical properties of composite materials two types of plates were manufactured. The same reinforcement material and the same matrix were used, the difference between them being the architecture of the reinforcement material. In the both cases of glass/epoxy composite plate the reinforced ratio obtained was 40% and was calculated as ratio between weight of reinforcement material and weight of composite material.

Reinforcement material was a roving fabrics type Combimat RT 300/S300 (Keltecs, Croatia) with a density of 600 g/m^2. The base materials are E glass and ECR glass. This type of material is made by a layer of 300 g/m^2 glass mat and balanced biaxial glass woven fabrics with 300 g/m^2. These two types of materials are assembled together like a single layer. The glass woven fabrics has the role to increase the mechanical properties of composite materials. In the same time, it also reduces the workmanship for the laminating of another layer of reinforcing material. The matrix impregnation in case of Combimat materials is simultaneous for both materials that composed the roving fabrics.

The epoxy matrix was Epiphen RE 4020/De 4020, with the ratio between resin and hardener of 100:30 in weight fraction. The matrix properties are: transparent aspect; pot life at 20 ºC - 45 min; Brookfield viscosity at 25 ºC – 300 mPa.s; gelling time (thin layer in hours at 20°C) - 8 to 9 hours; density at 25 ºC - 1150 kg/m^3; curing at 20 ºC - 24 hours.

2.2 Manufacturing method

The Hand Lay-up and pressured processes were used to obtain the composite materials plates [9, 10]. Two 10 mm thick steel plates were used as a mold. The surface of the mold was

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milled and polished to prevent the bonding of composite material on the mold surface. Additionally, five layers of wax were applied.

Both plates (denoted A and B) were manufacturing by two layers of Combimat materials and epoxy matrix. The difference between them is the stacking sequence, respectively the position of reinforcement materials. For the material "A" the balanced biaxial glass woven fabrics was applied on outer position. The glass mat layers are positioning in the interior of the plates like presented in Figure 1.

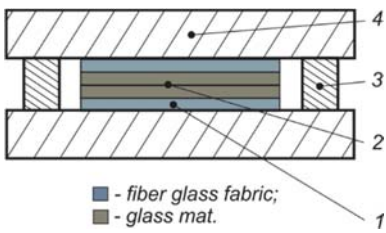

Fig. 1. Manufacturing set-up (1- glass woven fabrics, 2- mat layers, 3- path spacers, 4- mold).

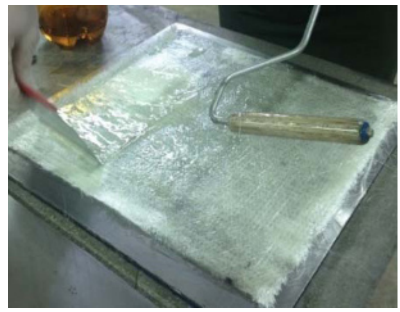

Fig. 2. Composite plate laminating process.

The fiber glass mat layers are outer positioned and the biaxial glass woven fabrics layers in inner position for the composite material "B". After reinforcement materials impregnation, the composite materials were covered by metallic steel mold and pressed at 9 kPa using a screw press. This operation was performed to eliminate the matrix excess from composite material. On the border of the mold path spacers by 1.8 mm were placed to obtain the composite materials limitation of this dimensions. Polymerizations of composite plates were made 24 hours at 24 °C. Post-polymerization heat treatment temperature at 80^{o} C for 24 hours it was carried out in an oven. After this time the composite plates were kept to full cooling in the oven for more 6 hours.

3 Mechanical characterization

To determinate the mechanical properties of the manufactured materials standard samples were cut out from the plates by a water jet machine. To prevent the samples delamination during the water jet penetration time of the composite plates, the penetration water jet area was positioned at 30 mm distance from the samples border. For tensile test five specimens from each material were manufactured according to ASTM standard. At the ends of the specimens the TABs were glued by a structural two-compound epoxy adhesive 3M Scotch-Welt 9323 B/A.

Mechanical proprieties of the above described materials were determined by standard tensile tests and three point bending test according to ASTM standards D638-10 and D790-02 respectively. All measurements were carried out at room temperature (23°C) and humidity in the range of 45-50%. The specimens for tensile test 1.8 mm thick and 25 mm wide (Figure 3a), were loaded to failure with constant crosshead speed (5 mm/min) using an Instron 8801 (100 KN) servo hydraulic testing system. The gauge length was 180 mm and the engineering strain was calculated based on the crosshead displacement. For the bending test the specimens have 1.8 mm thickness and 15 mm width (Figure 3b), the calculated test speed being 0.948 mm/min.

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a) b)

Fig. 3. Composite samples subjected to tensile test (a) and bending test (b).

Comparatively in Figure 4 is presented the strain-stress diagrams obtained from the tensile test for the two types of composites. Similarly, Figure 5 shows the flexural behavior of the GFR composite material.

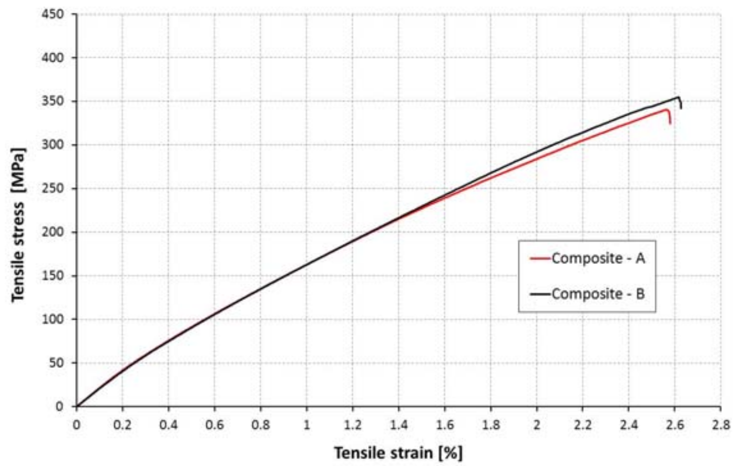

Fig. 4. Tensile strain-stress diagrams of GFR composites.

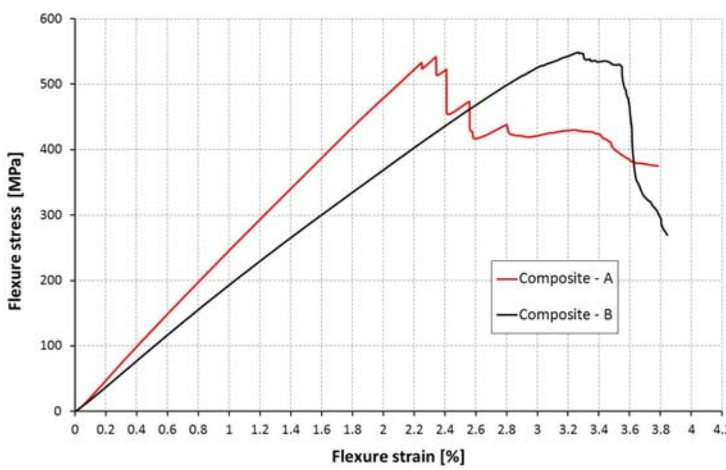

Fig. 5. Flexure strain – stress diagrams of GFR composites.

The measured mechanical data for the tensile test are presented in Table 1 and for the three-point bending test in the Table 2. For each stacking sequence five specimens were

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tested, the reported data are the measured mean values, the standard deviation appearing in the brackets.

Table 1. The mean values of maximum tensile stress and strain of the GFR composite.

Composite type	Load at Brake [N]	Tensile strain at tensile strength (mm/mm)	Tensile strength (MPa)	Young's modulus (MPa)
A	15004 (575)	0.0253 (0.0016)	334 (13)	18655 (598)
B	16135 (1923)	0.0260 (0.0030)	359 (43)	18294 (216)

Table 2. The mean values of maximum flexure stress and strain of the GFR composite.

Composite type	Flexure Load [N]	Flexure strain at flexure strength (mm/mm)	Flexure strength (MPa)	Flexural modulus (MPa)
A	549 (28)	0.026 (0.0024)	542 (28)	26124 (321)
B	673 (45)	0.032 (0.0011)	539 (36)	19683 (1075)

Flexure stress is more than 500 MPa for both composite materials and tensile stress is around 350 MPa, the obtained values being comparable with the metals but in condition of 6 times reduced density.

To highlight the compatibility between fiber and matrix the microstructure of damaged samples area was investigated. The morphological analyses were carried out by electronic microscope type Quanta 200 3D DUAL BEAM. Microstructures of damaged samples area presented in Figure 6 indicate a good impregnation of glass monofilaments and good adhesion between matrix and glass monofilaments surfaces.

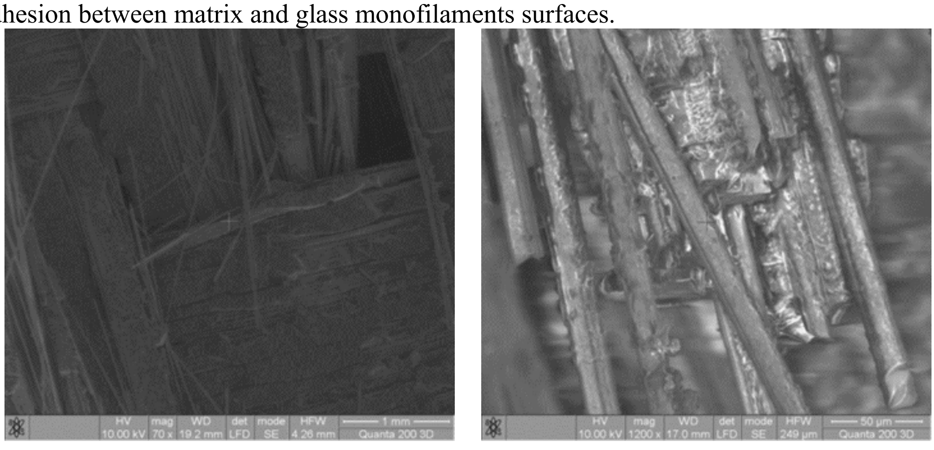

Fig. 6. Microstructure of damaged samples (material type A).

4 Conclusions

The hand lay-up and pressure is a simple and very used technology of composite materials that allows to obtain short manufacturing time and a minimal investment. In our case the manufactured GFR composite plates had a constant thickness and good surface quality. For "A" type composite plate, where the glass woven fabrics are applied on outer surfaces, a resin insufficiency was observed on the surface of the plates, the warp and weft glass wires being visible. For "B" type material where we have the glass mat on exterior the surface is smoother.

Analyzing the obtained mechanical characteristics, it can be noticed that the tensile proprieties of the composite material is not influenced by the stacking sequence. Positioning of the reinforcements closer to the neutral axis or the outer fibers will strongly affect the flexural proprieties, composite A being much stiffer than B. The importance of controlling the stacking sequence to enhance properties was evident. For instance, to optimize flexural behavior, there must be glass fibers mainly on the top and bottom surfaces.

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