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THE IMPACT OF THE TYPE AND MODE OF GLASS FIBERS STACKING ON THE MECHANICAL PROPERTIES OF COMPOSITE MATERIALS

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Abstract: *The paper presents the impact of the type and mode of stacking glass fibers on the mechanical properties of structural composite materials. The aim of this paper is to describe the dependence of the mechanical properties of composite materials from the standpoint of the use of glass reinforcement and the orientation of the fibers in the composite. Short and long glass fibers were used, as well as three types of stacking glass reinforcement. Detailed mechanical testing should point out that, with the appropriate type and orientation of the glass fibers, composite products for different loads can be successfully selected.*

Keywords: *composite materials, short fibers, long fibers, stacking glass fibers, mechanical properties.*

1. INTRODUCTION

Practical application of new construction materials should be preceded by a detailed study of their mechanical and exploitation properties, so that the safety of construction parts, and thus the structure as a whole, is fully ensured at the level of already achieved safety, or even improved [1].

Static mechanical characteristics serve as the initial data on the applicability of composite materials based on glass fibers as reinforcements and polymer resin as matrix. This primarily refers to the tensile properties and characteristics to the pressure.

2. MATERIAL

For construction of composite glass fibers – polyester resin, we used polyester resin as matrix and the long and short glass fibers as reinforcement [2]. The composite short glass fibers - polyester resin was prepared by dispersed short glass fiber (E-glass) in polyester resin, so-called mat fabric. Nominal weight of the composite - mat was 450 g/m^2. This mat presents a great reinforcement of unsaturated polyester resins for manual lamination. Tensile properties of used mat fabric are given in Table 1, whereas the layout of used mat is given in Figure 1.

To create mat with stacking 0/90° and ±45° we used long glass fibers-E glass (roving). Basic properties of used roving are given in Table 2.

Table 1 Tensile properties of mat with short fibers

Property	Method	Value
Tensile strength, MPa	ISO3268/ DIN 53455	108
Strain, %	ISO3268/ DIN 53455	1,8
Tensile modulus of elasticity, MPa	ISO3268/ DIN 53455	7800

Figure 1 Short glass fibers-mat

Table 2 Mechanical properties of direct roving [3]

Properties	Value	Resin
Tensile strength, MPa	2345	Polyester
Tensile modulus of elasticity, MPa	79794	Polyester
Shear strength	63	EP

The layout of used roving is given in Figure 2.

Figure 2 Direct roving

The fabric is made of direct roving type 1200 tex, with stacking 0/90° and ±45°, with nominal weight of 600 g/m^2. Technical data of the used fabric is given in Table 3, whereas the layout of used fabric is given in Figure 3.

Table 3 Technical data of roving fabric

Thread	1200 ±5% tex E- glass
Weft	1200 ±5% tex E- glass
Final material	600 g/m^2 ±5%

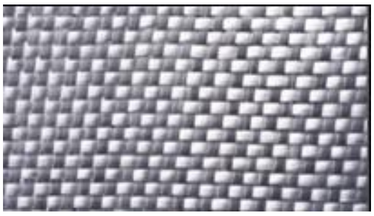

Figure 3 Direct roving knitted in roving fabric

For matrix we selected polyester orthophthalic resin CHROMOPLAST GP 2000/9W which presents [3]:

- Unsaturated polyester resin based on orthophthalic
- Medium reactive with good water resistance.

It is primarily intended for making vessels and general application with spraying or manual application procedure.

The basic characteristics of the resin in the delivery form are given in Table 4, whereas the mechanical properties are in Table 5.

Table 4 Properties of resin in delivery form [3]

Acid number	mg KOH/g	19-25
Brookfield RVT/25°C sp.2/5rpm sp.2/50rpm	mPas	 1300-1700 450-600
Appearance	-	Blue-greenish
Ind. thix	-	2-3
Styrene content	%	40-45
Stability /25^{0}C	months	3

Table 5 Mechanical properties of hardened resin [3]

Properties	Value
Bending strength, MPa	50
Tensile modulus of elasticity, MPa	3800
Strain, %	1,5
Hardness	42
Volume contraction, %	8,3

The influence of type and method of stacking glass fibers on the mechanical properties of structural composite material was conducted for three types of composite materials:

- short fibers mark ''A'' (mat - 450 g/m^2),
- directed fibers mark ''B'' (0 and 90° - 600 g/m^2), and
- directed fibers mark ''C'' (± 45° - 600 g/m^2).

3. TENSILE TESTING

Tensile testing of specimens was conducted according to standard ASTM D 3039-03 [4] on specimens whose geometry is given in Figures 4 to 6.

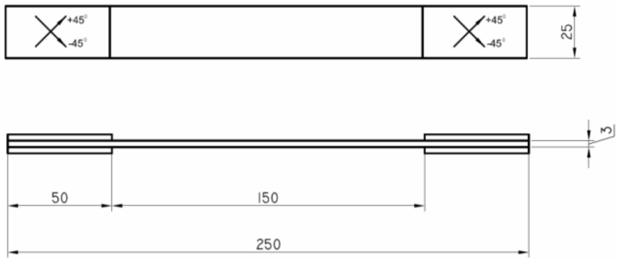

Figure 4 Specimen type ''A-1''

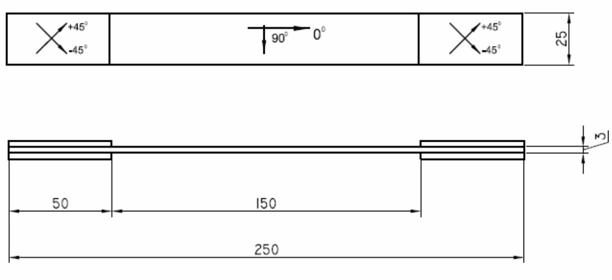

Figure 5 Specimen type ''B-1''

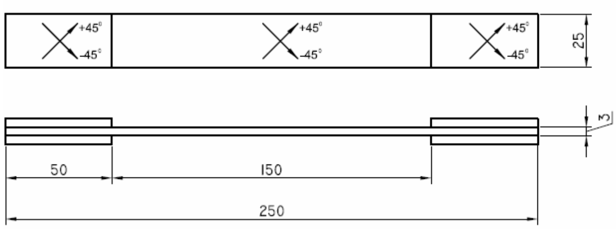

Figure 6 Specimen type ''C-1''

Tensile testing was conducted on servo-hydraulic testing machine, Fig. 7, using hydraulic jaws.

Figure 7 Testing equipment

Tensile strength R_{m1} of composite is calculated according to the equation [4]:

$$R_{m1} = \frac{P_{\max 1}}{b \cdot d} \tag{1}$$

wherein stands:

- R_{m1} - tensile strength, MPa;
- P_{max1} - maximum testing force, kN;
- b - specimen width, mm; and
- d - specimen thickness, mm.

Modulus of elasticity E_1 of composite specimens was calculated with the following expression [4]:

$$E_1 = \frac{\Delta R}{\Delta \varepsilon} = \frac{\Delta P_1}{\Delta \varepsilon_1} = \frac{1}{b \cdot d} \tag{2}$$

wherein the ratio $\Delta P1/\Delta \varepsilon 1$ was determined by linear regression method of the rectilinear parts of stress-strain curves.

Figures 8 to 10 show typical stress-strain diagrams obtained by testing specimens from groups A1, B1 and C1. Summary results are given in Tables 6 to 8. As can be noticed, best mechanical properties are of specimen type ‘’B-1’’ which was expected, since the structure of the reinforcement is directed (0 and 90°) so that the load is carried in the direction of the fibers, i.e. in the 0° direction.

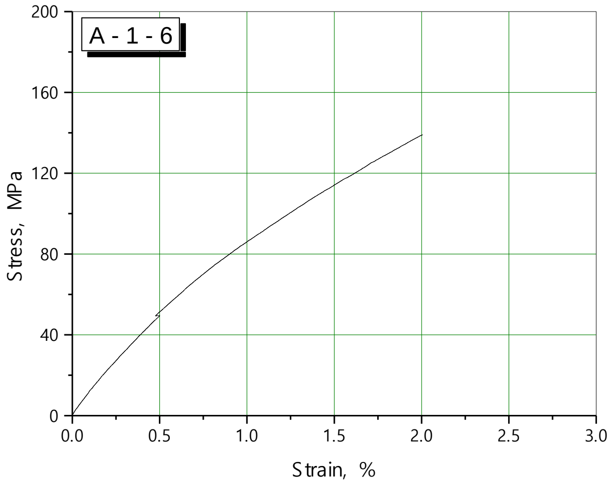

Figure 8 Stress-strain diagram of the specimen A-1-6

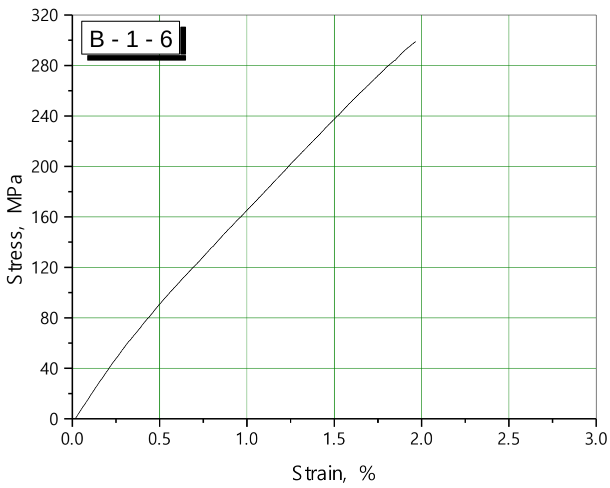

Figure 9 Stress-strain diagram of the specimen B-1-6

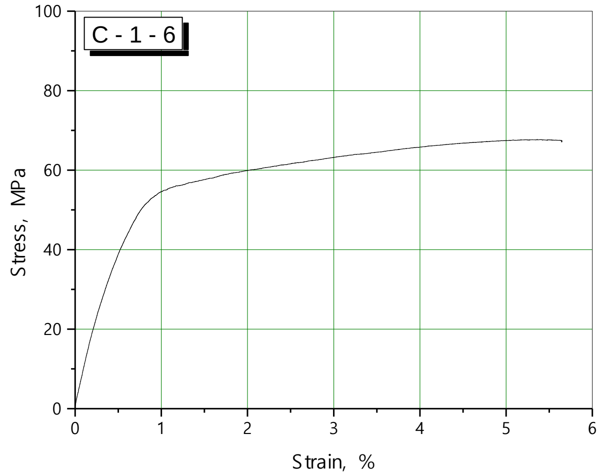

Figure 10 Stress-strain diagram of the specimen C-1-6

Table 6 Results of testing specimen group ‘’A-1’’

Specimen mark	Strain [%]	Tensile strength [MPa]	Modulus of elasticity [MPa]
A-1-6	2,0	139,5	6558,1
A-1-7	2,2	139,2	6210,9
A-1-8	2,0	150,9	6548,9
A-1-9	2,0	134,9	6167,2
A-1-10	1,8	133,9	5948,3
Mean value	2,0	139,6	6286,68

Table 7 Results of testing specimen group ‘’B-1’’

Specimen mark	Strain [%]	Tensile strength [MPa]	Modulus of elasticity [MPa]
B-1-6	1,9	299,0	16797
B-1-7	2,1	310,8	17236
B-1-8	1,9	333,2	17688
B-1-9	1,7	309,9	16645
B-1-10	1,7	296,1	16812
Mean value	1,8	309,8	17035,6

Table 8 Results of testing specimen group ‘’C-1’’

Specimen mark	Strain [%]	Tensile strength [MPa]	Modulus of elasticity [MPa]
C-1-6	5,3	67,7	7457,1
C-1-7	5,6	67,3	6682,5
C-1-8	3,5	68,1	8493,9
C-1-9	5,1	60,3	6616,7
C-1-10	3,9	66,8	7737,7
Mean value	4,6	66,0	7397,5

4. PRESSURE TESTING

Pressure testing was conducted according to Standard ASTM D3410 [5] on specimens whose geometry is given in Figures 11 to 13. The testing was also conducted on servo-hydraulic testing machine, Figure 7, using hydraulic jaws.

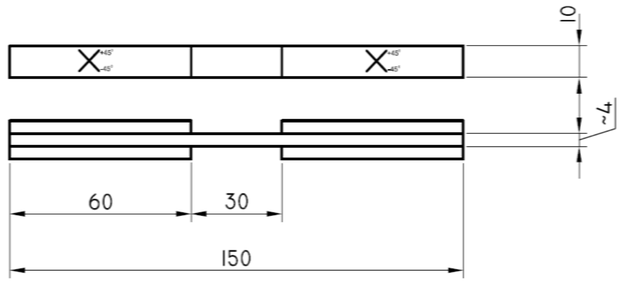

Figure 11 Specimen type ''A-2''

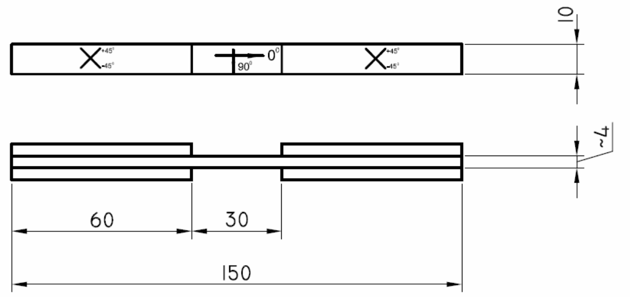

Figure 12. Specimen type ''B-2''

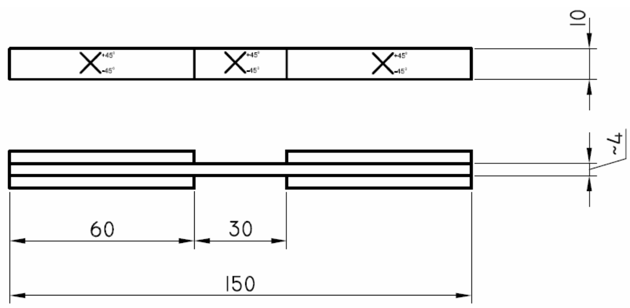

Figure 13 Specimen type ''C-2''

Pressure strength, R_{c1} of composites is calculated according to the equation [5]:

$$R_{c1} = \frac{P_{\max c1}}{b \cdot d} \qquad (3)$$

Wherein stands:

- R_{c1} - compression strength, MPa;
- P_{maxc1} - maximum force, kN;
- b - specimen width, mm; and
- d - specimen thickness, mm.

Strength modulus of elasticity, E_{1c} of composite specimens was calculated with the following expression [5]:

$$E_{1c} = \frac{\Delta R_c}{\Delta \varepsilon_c} = \frac{\Delta P_{c1}}{\Delta \varepsilon_c} = \frac{1}{b \cdot d} \qquad (4)$$

wherein the ratio $\Delta P/\Delta\varepsilon_c$ was determined by linear regression method of the rectilinear parts of stress-strain curves.

Figures 14 to 16 show typical stress-strain diagrams obtained by testing specimens from groups A2, B2 and C2. Summary results are given in Tables 9 to 11.

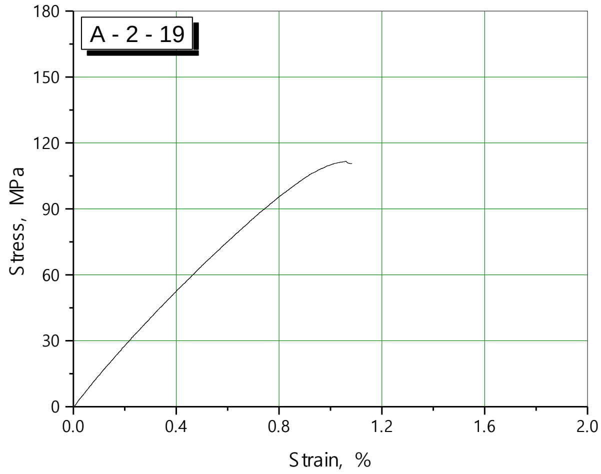

Figure 14 Stress-strain diagram of the specimen A-2-19

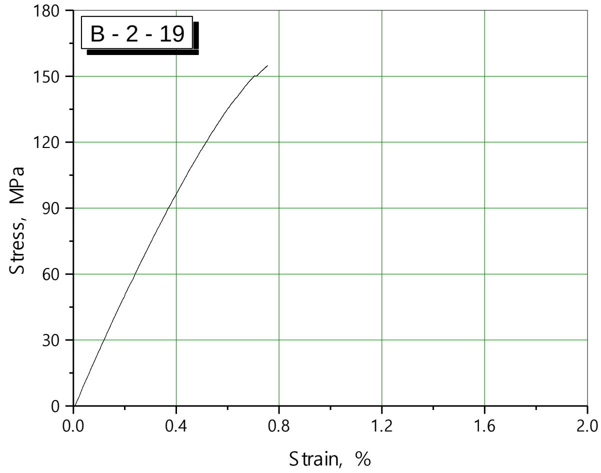

Figure 15 Stress- strain diagram of the specimen B-2-19

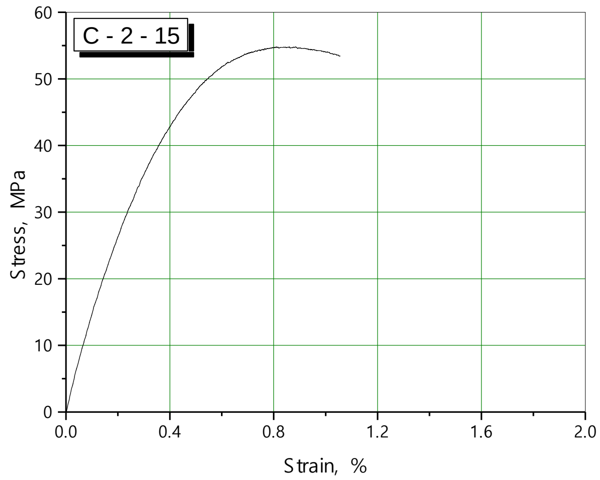

Figure 16 Stress- strain diagram of the specimen C-2-15

Table 9 Results of testing specimen group ''A-2''

Specimen mark	Strain [mm]	Compressive strength [MPa]	Strength modulus of elasticity [MPa]
A-2-15	1,07	80,95	7765,5
A-2-16	0,83	84,56	10141,3
A-2-17	1,25	81,15	10920,4
A-2-18	0,98	83,10	8401,2
A-2-19	1,06	117,55	11082,5
Mean value	1,038	89,462	9662,18

Table 10 Results of testing specimen group ''B-2''

Specimen mark	Strain [mm]	Compressive strength [MPa]	Strength modulus of elasticity [MPa]
B-2-15	0,61	132,24	21563,9
B-2-16	0,76	142,67	18691,8
B-2-17	0,67	139,10	21632,0
B-2-18	0,71	146,02	20289,7
B-2-19	0,75	157,78	20859,6
Mean value	0,7	143,562	20607,4

Table 11 Results of testing specimen group ''C-2''

Specimen mark	Strain [mm]	Compressive strength [MPa]	Strength modulus of elasticity [MPa]
C-2-13	0,80	61,32	7619,7
C-2-14	0,83	58,19	7000,7
C-2-15	0,81	55,60	6855,2
C-2-16	0,83	64,83	7742,2
C-2-17	0,91	59,39	6516,1
Mean value	0,836	59,866	7146,78

5. CONCLUSION

The results of determining the tensile and compression properties of the composites indicate that depending on the type of composite reinforcement and direction of stacking glass fiber designers could define different mechanical properties of the final composite, depending on the needs of the projected product.

Slight scattering of individual results can be explained with the selected technology of testing material development (manual procedure).

In addition, due to the interference of fibers and different stress distribution along the axis of the fibers, the fibers are not loaded equally. The result is a different time of fiber cracking, i.e. some fibers are cracking at lower loads and some at higher loads. Fibers which crack early cause a disruption in the fracture area, i.e. local shear stress occurs along the cracked fibers. These are usually fibers that are directly connected to the fibers with opposite direction (orientation 90°).

6. REFERENCES

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[5] ASTM D 3410/D 3410-03, Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading, 2003.