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SHORT COMMUNICATION

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THE INTERLAMINAR STRENGTH OF THE GLASS FIBER POLYESTER COMPOSITE

The paper outlines the method and the results of the experimental investigation of interlaminar strength of glass fibre reinforced polyester composites, with the aim of determining the influence that the structure, a reinforcement type and a sort of resin exert upon the interlaminar strength. The tested specimens were fabricated under different formation conditions, namely in eight composition patterns and with three sorts of resin used for polymerization.

Key words: composite materials; interlaminar shear test.

This paper outlines the experimental investigation of interlaminar shear strength as the critical mechanical property of composite constructions of structure elements placed between two thin glass mat layers where a layer is placed on the glass fabric of the same structure but of different density, with different polyester resin matrices. The significance of the shear strength lies in the fact that for all types of composites it is strongly influenced by factors weakening the interface binds. Boundary interfaces between the fibers and the matrix, as well as the thin matrix layer between the fibers represent the potential sources of composite weakening. Shear forces in these regions can easily cause shear damages. It is recognized that shear strength of a composite is low compared to its tensile strength in a fiber direction. Fibers bound with binders exhibit higher shear strength, while the exposure to moisture lowers it drastically. The pores in the composite material, *i.e.* the voids, lower the shear strength too [1-5].

EXPERIMENT

Specimens were made by manual pressing as three-layer composites [6]. Eight combinations of the composition patterns (M1, M2, M3, P2, P3, P4, P5 and P6) were produced with different specific weight and the structure shown in Table 1. As the matrix, three types of polyester resins were used with properties given in Table 2.

Table 1. The structure of composite materials

Layer	M1	M2	M3	P2	P3	P4	P5	P6
I	Glass mat (240 g/m^2)							
II	Glass mat (g/m^2)		Glass woven 0°/90° (g/m^2)					
	240	360	400	180	240	360	600	800
III	Glass mat (240 g/m^2)							

Table 2. The properties of resins used for polymerization

Property	Bisphenolic resin (BR)	Water resistant (WR)	Acid resistant (AR)
Viscosity	85	60	60
Polymerization time(20 °C)	12-15 min.	12-15 min.	12-15 min.
Accelerant (6 % cobaltnaphtenate)	0.35 %	0.25 %	0.25 %
Accelerant (100 % dimethylanilyne)	0.2 %	-	-
Catalyst (50 % methylethylketh-oneperoxyde)	2 %	2%	2 %
Styrene	-	12%	12 %
Formation pressure	1.97×105 Pa	1.97×105 Pa	1.97×105 Pa

The samples were made as three-layered by the same procedure of performance and under the same conditions. Outer layers of the samples represent the layers reinforced by short dispersal spread fibers (glass mat), while inner layers are glass fiber woven oriented 0°/90°, of different specific weight (Table 1). Thick-

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ness of outer layers would be 1 mm, while middle layer of thickness 0.5-0.8 mm, depending on the specific weight, according to the data from the catalogue of the producer. The samples were set between two metal plates for the extraction of undesirable bubbles which would lead to flaws in the structure. The time of polymerization for all the samples was 12-15 min, on $t = 20$ °C. After samples were formed, test specimens were cut out which were tested on dimensions 200 mm×20 mm×2.5 mm.

Bisphenolic resin (BR) is fabricated on the basis of propoxylated bisphenole, with an outstanding chemical resistance to acids, bases and oxidants. It is mostly used in chemical industry for manufacturing reaction vessels, storage tanks, pipelines and for insulating.

Water resistant resin (WR) of viscosity suited for direct use. This resin is suitable for manufacturing boats, automobile parts and containers for sanitary concrete and marble.

Acid resistant resin (AR) is excellent for its chemical resistance to various organic or inorganic acids. It is used mostly for anti-corrosion protection in chemical industry. Also, this resin satisfies the standards in the sense of health suitability and applicability for manufacturing storage and transport containers in food industry.

The experimental investigation of the interlaminar shear strength, *i.e.* a short rod three-point bending test was conducted in a SCHENCK TREBEL RM 100 universal servo-hydraulic testing machine. The testing procedure is defined by the ASTM D 2344 standard [7]. The original SCHENCK bending tool was used with the load wedge radius $r_1 = 3$ mm, and radii of the supports $r_2 = 3$ mm, Figure 1. The standard defines the ratio of the span between the supports (L_0) and the specimen thickness (d), *i.e.* L_0/d where $L_0 = 5d \pm 0.2$. For monitoring the applied load an extension-compression load cell of the capacity 100 kN was used.

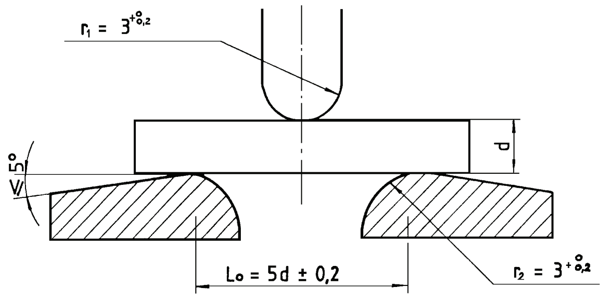

Figure 1. Specimen bending tool.

During the tests, a crack was being formed at the "outer layer" surface (in the 1-2 plane) caused by the applied load. The crack propagated at a sharp angle towards the "inner layer". In the vicinity of the upper surface of the specimen, the crack changed its direction sharply and broke the upper surface at a right angle. In the central plane of the specimen, delamination occurred because of the interlaminar shear. This delamination is caused by the maximal load and herewith determined strength represents the interlaminar shear strength, *i.e.* the measure of the fibre-matrix (resin) binding strength.

When examining all groups of specimens with the P6 pattern, delamination was observed in the specimen center before the crack appeared at the "outer layer". For this pattern, a relatively high value of the interlaminar shear strength was obtained (approx. 30 MPa), which is characteristic for the shear in the 1-3 plane of uniaxial composites of the fiber orientation 0°. In these specimens, the destruction by shear in the 1-2 plane occurred at the very end of the test at the surface of the "outer layer" exposed to extension.

For pattern P4, two macroscopically visible destructions, followed by bang, were observed to appear simultaneously or in an arbitrary order.

RESULTS

For the sake of accuracy in determination of the interlaminar shear strength, for each combination of pattern and sort of the resin used for polymerization, five specimens were tested experimentally, conforming to the appropriate standards. For each specimen, the initial dimensions were measured, and then the maximal shear force F_{max} (N), *i.e.* the force causing the delamination of the specimen, was determined by means of the testing machine. Based upon this value, the geometry of the tested specimen (width and thickness) and using the equation (1), the interlaminar shear strength was calculated as:

$$\tau_{13} = 0.75\frac{F_{max}}{bd} \tag{1}$$

where τ_{13} is interlaminar shear strength (MPa), F_{max} is maximal force at which specimen delamination occurs (N), b is specimen width (mm) and d is specimen thickness (mm).

Representative values of the interlaminar shear strength, for each combination of pattern and sort of the resin used for polymerization, were calculated as the arithmetic means of five recordings and are summarized in Table 3. For the sake of clarity and easier comparison of the results, along with the tabulated values, they are presented in a graphical form. For each resin, the calculated values of the interlaminar shear strength are presented graphically (Figures 2-4) as a function of the composition pattern. On the other hand, a comparative graphical presentation of calculated values of the interlaminar strength is given in Figure 5 as a function of the sort of resin used for polymerization, for all kinds of composition patterns.

Table 3. Average values of intelaminar shear strength τ_{1-3} (MPa)

Resin	Structure							
	M1	M2	M3	P2	P3	P4	P5	P6
Bisphenolic (BR)	5.6	15.6	21.6	22.2	21.0	21.8	23.8	32.4
Water resistant (WR)	24.4	20.8	20.4	25.2	22.4	28.2	26.4	27.6
Acid resistant (AR)	28.2	20.6	22.0	20.2	22.6	20.6	25.4	30.0

For bisphenolic resin (BR) (Figure 2), the interlaminar shear strength rises from pattern M1 to M3 and from P4 to P6. For patterns M3, P2, P3 and P4, uniformity of the obtained results is observed. The best composition pattern for this sort of resin is P6 for which the calculated value of the interlaminar strength is 32.4 MPa, which is simultaneously the highest value for all tested resins and for all composition patterns. On the other hand, for this resin, the lowest value of the interlaminar strength is calculated too, namely for pattern M1 (5.6 MPa). It is observed that only for this resin, the interlaminar strength grows steadily from the first (M1) up to the last (P6) composition pattern, so it is evident that P patterns give better strength results than the M ones.

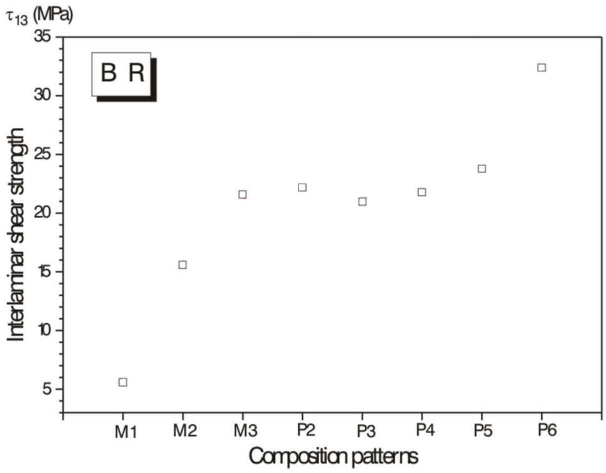

Figure 2. Interlaminar shear strength for composite with bisphenolic resin (BR).

For water resistant resin (WR) (Figure 3) all the calculated values are very close but vary depending upon the composition pattern. So, the values of the interlaminar strength decay from pattern M1 to M3 (lowest calculated value being 20.4 MPa) and from P2 to P3, whereas for patterns P4, P5 and P6 they remain relatively high. The highest calculated value corresponds here to pattern P4 (28.2 MPa), and it is observed that P type exhibit higher interlaminar strength than the M ones.

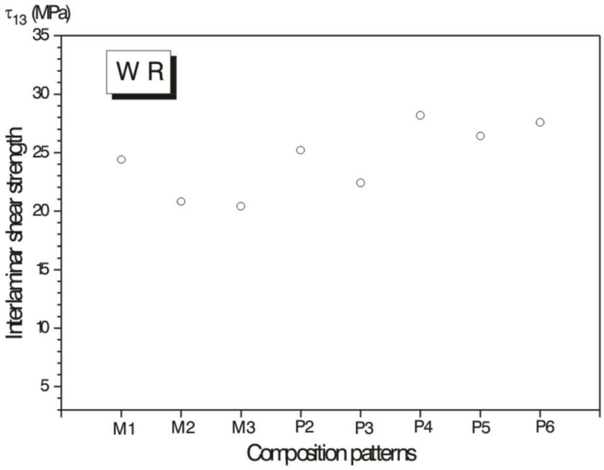

Figure 3. Interlaminar shear strength for composite with water resistant resin (WR).

For acid resistant resin (AR) (Figure 4) the variation of results is evident as well. The calculated value of the interlaminar strength is fairly high for pattern M1, becoming much lower for pattern M2 and retaining the approximately same value for patterns M3, P2, P3 and P4 (about 22 MPa). For patterns P5 and P6 the interlaminar strength grows up reaching its highest value for pattern P6. With two exceptions, for patterns M1 and P6, where the calculated values of the strength are extremely high (28.2 and 30 MPa), for all other combinations the results are fairly close, so that from the aspect of the interlaminar shear strength patterns M and P are relatively similar.

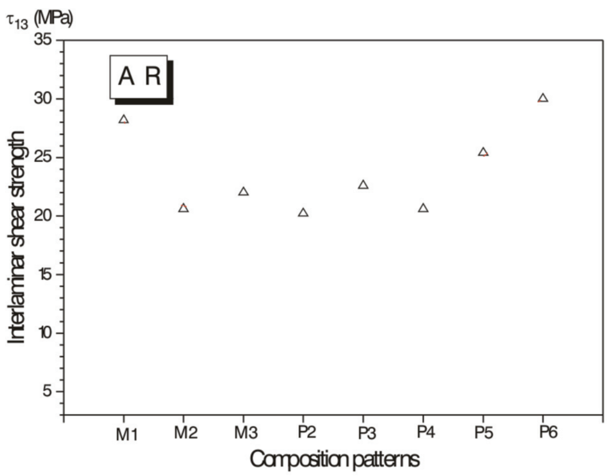

Figure 4. Interlaminar shear strength for composite with acid resistant resin (AR).

The values of interlaminar strength exhibit a relatively small variation for different sorts of resin used for polymerization (Figure 5). The exceptions are patterns M1 and P4. For pattern M1 the worst results are obtained with the bisphenolic resin (BR), while for pattern P4 the water resistant resin (WR) exhibits the best performance. An interesting result was obtained for the composition pattern P6.

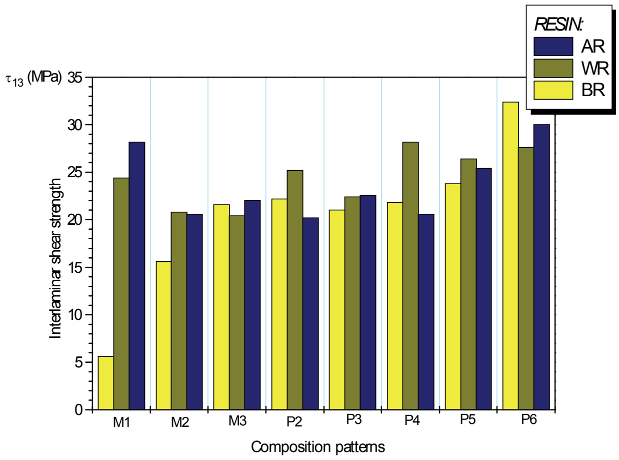

Figure 5. Interlaminar shear strength.

CONCLUSION

Based upon the calculated values of the interlaminar shear strength and the performed analysis of the results, the following questions can be answered: 1. Which of the two composition pattern types is better, M or P? 2. Which is the most favorable composition pattern? 3. Which sort of resin yields the best interlaminar shear strength results?

1. P type patterns yield better results than M type ones for all three sorts of resin. This is especially pronounced for the composites polymerized with the bisphenolic resin (BR) (where the lowest strength values were recorded for M patterns), but for other two resins too with an exception for pattern M1 with the acid resistant resin.

2. For all three sorts of resin used for polymerization it is observed that patterns P5 and P6 yield the highest values of the interlaminar shear strength, so they are concluded to be the most favorable. This experimentally confirms the theoretically known fact that glass fabrics of greater surface weight exhibit better interlaminar shear strength.

From the stated two conclusions it follows that composite materials with the middle layer of glass fabric with weaving 0°/90° yield better results in the sense of the interlaminar shear strength, as opposed to the composites with all layers of glass mat. Based upon the obtained results and previously stated conclusions, they are not recommended for use in constructions exposed to the interlaminar shear stress.

3. Regarding the small variation of the calculated results, and the way they differ from pattern to pattern, it is hard to decide which sort of resin is the most favorable. Water resistant resin (WR) yields satisfactory results for all composition patterns, even the best results, for patterns M2, P2, P4 and P5. Similar conclusion can be drawn for the acid resistant resin (AR) where the best results are obtained for patterns M1, M3 and P3. It is evident that with the bisphenolic resin (BR) somewhat worse results are obtained, except for pattern P6.

Determination of the interlaminar shear strength was performed with the aim of determining the shear stress in the central plane of the specimen inducing delamination for different composition patterns and for three sorts of resin used for polymerization of the glass fiber reinforced polyester composites. The generation of the crack at the "outer layer", a direction of its propagation within the composite to the "inner layer" and an occurrence of delamination in the central plane of the specimen at the maximal load, fully correspond to the theoretical considerations dealing with the mechanical investigations of the interlaminar strength found in literature [6].

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