Investigation of the suitability of fiber reinforced polymer matrix composites for facilities operating in marine environment

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Abstract. This paper is related to the production and investigation of the structure, the mechanical and physicochemical properties of two kinds of fibre reinforced polymer matrix composites in order to assess their suitability as materials used in equipment operating in marine environment. The one of the investigated composites has a polyester resin matrix and a reinforcement phase of six-layer fibreglass, and the other one has a vinylester resin matrix and a reinforcement phase which is a combination of three-layer fibreglass and three-layer biaxial fibreglass. A comparative analysis has been made of the relative weight, tensile strength and bending strength of the two types of composite materials.

1. Introduction
The rapid growth in the manufacturing industries necessitates the need for materials that have better properties than many of the conventional materials like metals in various applications [1]. The most commonly used composites, as modern engineering materials with the largest application in marine industry, are the composite with resins matrices. Most of these composites included glass-reinforced polyesters, vinylesters, phenolics, and an epoxy (epoxy-polyamide) [2,3]. The glass-fiber-reinforced resin matrices have excellent ratios between performance and price and they better properties in terms of strength, stiffness, density, weathering properties, with improved sustainability and can be easily molded into complex shapes, than metals [1, 4]. These composites are commonly fabricated to near-net shapes of the reinforcement phase which increases their mechanical properties. [5]. But the exposure to seawater caused the greatest deterioration of the bending and tensile strengths of the composites [3].

The objective of the present work is to determine the strength of the composite materials studied in order to assess their suitability for manufacturing facilities and equipment operating in marine environment.

The investigated materials are net shaped glass-fiber reinforced Polymer Matrix Composites. One of the studied composites features a polyester resin matrix and a reinforcement phase of six layers of fibreglass, and the second has a vinylester resin matrix and a reinforcement phase of a combination of three layers of fibreglass and three layers of biaxial fibreglass 450 g / sm2. Biaxial fibreglass fabric consists of glass fibers intertwined on top of each other at an angle of +/- 45°. The + 45° and - 45° layers are of equal weight. Fabric is Silane coated for easier wetting out, and is compatible with both Polyester and Epoxy Resin systems. Glass biaxial fabric is generally used on components where the force is applied constantly in the direction of the grain.
2. Experimental procedure
The composites studied are produced in the form of 6 mm thickness panels, through layer-by-layer application of resin and reinforcement phase. Upon applying each layer of resin, mechanical impact, i.e. rolling, is employed in order to remove air bubbles. The panels thus produced are used for cutting samples for conducting tensile and bending tests and calculating the density of the composite materials. Upon test completion, a macro-fractographic analysis of the fracture surface of the tensile test samples was carried out by means of a EUROMEX stereomicroscope [6].

2.1. Tensile testing
The tensile test was carried out in compliance with ISO 527-4 Tensile Test of Plastic Composites & Thin Film Sheet standard at T = 20 °C [7, 8]. For the purposes of tensile testing, three identical-size samples were cut for each of the two types of composite, as shown in figure 1.

\[
R_m = \frac{F_m}{S_0} \text{ [MPa]}
\]  

(1)

Where: \(F_m\) - maximum applied load (force), N; \(S_0\) – the initial cross-sectional area of the sample, mm²

2.2. Flexural testing
The bending test was conducted according to ASTM D790 Testing for Flexural Properties of Plastics and Insulating Materials standard at T = 20 °C (figure 2). The determination of the bending strength was carried out using three identical samples with dimensions 180 mm / 30 mm cut for each type of composites.

\[
R_{mb} = \frac{3FL}{2bd^2} \text{ [MPa]}
\]

(2)

Figure 1. The samples sizes for tensile testing

Figure 2. Scheme of the bending test
Where: \( F \) - the load (force) at the fracture point, N; \( L \) - the length of the support span, mm \((L = 107 \text{ mm})\); 
\( b \) - the width of the sample, mm \((b = 30 \text{ mm})\); \( d \) - thickness of the sample, mm \((d = 6 \text{ mm})\);

Furthermore, the test results were used for determination of the vertical displacement \((h, \text{ mm})\) at maximum bending load, which is an indication of flexural deformation

2.3. Determination of the density of the composites

The calculations of the density of the composites studied were performed using the conventional hydrostatic weighing method based on Archimedes' law. The conventional hydrostatic weighing method uses water as a primary standard for measuring the density. The size of the test samples used (three for each type of composite) is 30 mm / 30 mm \[8, 9\]. The density \((\rho, \text{ g/cm}^3)\) of the materials tested is determined by the following formula:

\[
\rho = \frac{m}{V} \left[ \text{g/cm}^3 \right]
\]

Where: \( m \) – the sample mass, g; and \( V \) – the sample volume, cm\(^3\);

3. Results and analysing

Table 1 shows the tensile test results obtained. The tensile strength obtained for biaxial reinforced vinylester matrix composites (BRVMCs) is slightly higher than that of fiberglass reinforced polyester matrix composites (FRPMCs), which can be seen in the diagram in figure 3. The greater values of BRVMCs are most probably due to the fact that the fibers of the biaxial texture are intertwined on top of each other at an angle +/- 45 °. This is also confirmed by the macro-fractographic analysis (figure 4), where indicates that in BRVMCs the crack propagation is tangential, unlike FRPMCs, where the crack propagation is linear, perpendicular to the tensile load. Tangential crack propagation requires more work of fracture than linear crack propagation.

| Sample  | \( F_m \) (N) | \( S_0 \) (mm\(^2\)) | \( R_m \) (MPa) |
|---------|---------------|----------------------|-----------------|
| BRVMC\(_1\) | 16440         | 120                  | 137             |
| BRVMC\(_2\) | 16420         | 120                  | 136.8           |
| BRVMC\(_3\) | 16500         | 120                  | 137.5           |
| FRPMC\(_1\) | 13850         | 120                  | 115.4           |
| FRPMC\(_2\) | 13690         | 120                  | 114.1           |
| FRPMC\(_3\) | 13820         | 120                  | 115.2           |

Figure 3. The tensile test diagram of the investigated composites
The results of the bending test are given in table 2. The bending strength values obtained for BRVMCs are higher than those for FRPMCs, but in this case, the difference is significant - twofold (figure 5).

In addition, the vertical displacement of the BRVMCs samples at maximum load is twice as great as that of FRPMCs samples, which indicate that they have a higher degree of deformation. This is due to both the reinforcement phase of biaxial texture and the vinylester
resin matrix material. From the fractographic analysis (figure 6) of the fracture surface of the FRPMCs samples, complete fracture of the layers of the reinforcement phase was observed upon removing the load, while in the BRVMCs samples the integrity of the inner layer under compression was preserved.

Table 3 indicates the average values of the mechanical and physical characteristics of the composites tested, which can be used for a complete comparative analysis. It can be seen that the density of the two materials is almost the same, but BRVMCs have better mechanical properties than FRPMCs, especially in terms of flexural strength. This fact is particularly important taking into account that the facilities operating in marine environment are subjected mainly to bending stresses.

Table 3. the average values of the mechanical and physical characteristics of the investigated composites

| Sample | Density (g/sm³) | Tensile strength $R_m$ (MPa) | Bending strength $R_{mb}$ (MPa) |
|--------|----------------|----------------------------|-------------------------------|
| BRVMC  | 1.46           | 137                        | 290                           |
| FRPMC  | 1.49           | 115                        | 150                           |

4. Conclusion

The investigation of the suitability of Fiber Reinforced Polymer Matrix Composites for the manufacture of facilities operating in marine environment has shown that:

1. The density of both materials is approximately the same, lower than that of the traditional metallic materials used for manufacturing equipment operating in marine environment.
2. BRVMCs have higher tensile strength and significantly higher bending strength compared to FRPMCs, which is mainly due to the fact that its reinforcement phase is composed not only of fiberglass but also of biaxial fabric.
3. Both composite materials are suitable for the construction of equipment and facilities operating in marine environment, but taking into consideration that the equipment

Figure 6. Macro-fractographic analyse of the fracture surface: a) of the FRPMCs; b) of the BRVMCs
operating in the marine environment is subjected mainly to bending stresses, BRVMCs would be the more suitable material as compared to FRPMCs.

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