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# ABRASIVE WEAR RESISTANCE OF MATRIX COMPOSITES CARBON FIBER REINFORCED POLYMERS

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K e y w o r d s: Abrasive wear, fibrous composites, carbon fibers, polyester resin, ball-catering metod.

A b s t r a k t

The paper presents the results of the abrasive wear resistance test of composites based on polymers reinforced with carbon fibers. Two types of fiber composites obtained from a yacht manufacturer were used for the tests. The tests were carried out using the ball-cratering method without abrasive suspension. On the basis of the specific wear rate Kc, better tribological properties of the polyester matrix reinforced with glass fabric were observed compared to the polyester matrix reinforced with a glass emulsion mat. The composite material reinforced with glass cloth was characterized by smaller crater diameters, which may cause plastic deformation due to the low hardness of the material.

## Introduction

The dynamic development of technology requires the search and application of new construction materials that combine many features, such as: low cost, better mechanical properties, high durability at high temperature, less weight

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and other. One of the materials that meet the above criteria are, among others composite materials. The development of modern composite materials that will be environmentally friendly is related to the search and development of technologies for obtaining composites, as well as the use of natural plant fibers.

The most frequently used reinforcing fibers are glass fibers, which constitute approx. 87.7% of all fibers, natural fibers 11% and carbon fibers 1.2%. Composites based on carbon fiber reinforced polymers are commonly used for the hulls of yachts and boats. They are often subjected to abrasive wear processes against the bottom of a water reservoir. The tribological properties of composite materials result primarily from the properties of their reinforcements. One of the traditional methods of improving wear resistance is increasing their stiffness, hardness and compressive strength as well as reducing their adhesion to the material of the cooperating element (EL-SAYED et. al. 1995, CHANG 1982, LHYMN, LIGHT 1987). A great progress in the development of composites is the use of fibrous and molecular fillers as a reinforcement of the polymer matrix. The matrix material is also important, as in the case of thermosetting resin matrix composites, which can be designed for specific applications through the appropriate selection of the polymer. Commonly used polymers are: polyamide, vinyl ester, phenol, epoxy, polyethylene or unsaturated polyester (SURESHA et. al. 2006, WANG et. al. 2003).

In many cases, carbon fiber performs better than the more abrasive glass fiber. Carbon fiber improves the thermal conductivity and mechanical properties of polymer matrices, which also positively affects wear resistance.

The complexity of the wear process of fiber composites has been highlighted in many world studies. Among others, the authors of the work JESTHI, NAYAK (2020) designed hybrid composites such as [G3C2] S, [GCG2C] S and [G2C2G] S and compared, among others, abrasion resistance referring to glass fiber reinforced polymer composites. Hybrid composites were characterized by better strength properties. The paper ABD EL-BAKY, KAMEL (2019) presents water absorption and its influence on the abrasive wear of reinforced jute-training-carbon composites. The results showed that the hybridization of the glass fiber reinforced composite with jute and/or carbon fabrics improves the abrasion resistance of the resulting composite. XIONG et al. (2018) presented studies of abrasive wear of polyoxymethylene composites reinforced with linen fabric. The impact of the weave structure on the coefficient of friction and the wear rate of composites was varied depending on the level of the load value and the sliding velocity. The use of linen fabrics can reduce the wear rate by up to 4 times under conditions of high load and high sliding speed.

The aim of the study is to evaluate the tribological properties of fiber composites on a polyester matrix reinforced with glass fabric and glass emulsion mat.

# Material and metod

## Material

Two types of fibrous composites obtained from a yacht manufacturer, differing in the type of carcass and the type of reinforcement, were used for the tests (Tab. 1). The dimensions of the samples were 30 × 25 × 10 mm. The tests were performed on the side of the carbon fiber layers. A 2/2 weave carbon fiber is used. The samples were produced manually.

Table 1

Characteristics of the tested fiber composites

| Specification | Material | |
|---|---|---|
| | COM1 | COM2 |
| Structure | poliester resin | |
| Reinforcement | glass emulsion mat | glass fabric |
| | carbon fiber | |

Carbon fibers are obtained by pyrolysis of polyacrylonitrile (PAN). They can be made from other raw materials, such as asphalt, phenyl resins or cellulose (MAYER, KACZMAR 2000, FEJDYŚ, ŁANDWIJT 2010, BARTON et. al. 2014). They are characterized by thermal and chemical resistance, and their properties do not change in a non-oxidizing atmosphere up to the temperature of 200°C. The advantages of using carbon fibers include low density, low friction coefficient, high fatigue strength and creep strength, the ability to dampen vibrations and good thermal conductivity (OLEJNIK 2008).

Polyester resins belong to the group of synthetic resins, the main component of which is polyesters. One of the methods of their preparation is the polyesterification of hydroxy acids or acids with glycols. They are also formed by copolymerization of olefin oxides with acid anhydrides. A well-known, but less popular method is lactone polymerization (SZLEZYNGIER 1996). Hardened resins with high shrinkage of cross-linked compounds show low hardness and deformation at break. Various types of modifiers are used to improve the properties and impact strength, e.g. glass, carbon or rubbers. By increasing the cross-link density of the polymer or by stiffening the chain, the heat and chemical resistance of polyester resins is increased (DOBROSZ, MATYSIAK 1986).

Table 2 presents selected characteristics of the carbon fiber fabric and the polyester warp.

Tabele 2

Characteristics of tested materials

| Carbon fiber fabric | |
|---|---|
| Thickness | 0.33 mm |
| Grammage | 200 g/m$^2$ |
| The amount of warp needed for saturation | 180 g/m$^2$ |

## Tribological test

The tests were carried out using the ball-cratering method (Fig. 1) in accordance with the PN – EN 1071–6: 2007 standard without abrasive suspension. The method is based on the so-called the culotest method, used to determine the abrasive wear coefficient based on the measurement of the crater diameter, which resulted from abrasion with a ball.

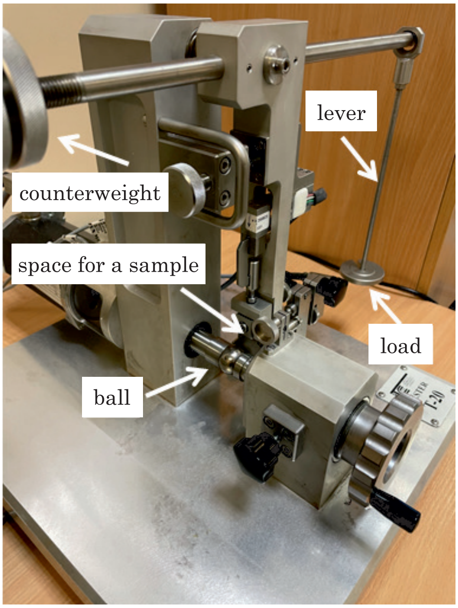


Fig. 1. Ball-cratering method view

On the surface of a stationary target (sample), the ball (counter-sample) rotates, resulting in the formation of a crater (spherical indentation). The counter-sample for the tests was a ball with a diameter of 25.4 mm, made of 100Cr6 steel, hardness 58.6 HRC and surface roughness Ra = 0.177 μm. The tests were carried out with the following parameters: contact load 0.2 N, ball rotational speed 752 rpm, sliding distance 1,000 m, 2,000 m, 3,000 m. test runs were performed in four repetitions.

The measurement of the crater diameter and the volume of the material used was carried out in the directions parallel and perpendicular to the direction of rotation of the ball (Fig. 2), using a microscope with an accuracy of 0.001 mm. The mean value of the crater diameter calculated on the basis of the measured values was used to calculate the wear intensity. To determine the wear intensity index, craters were used, the difference in bpar and bperp dimensions of which did not exceed 10%, in accordance with the PN-EN 1071-6: 2007 standard.

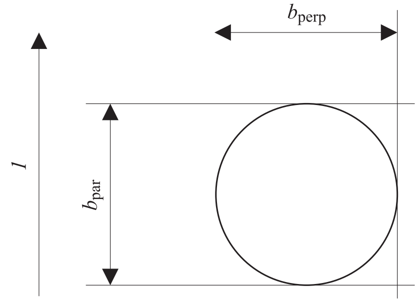


Fig. 2. Crater diameter measurement without shell perforation: *1* – direction of rotation of the ball

The tests were carried out without perforation of the coating. The volume of consumption was determined on the basis of the formula:

$$V = \pi \frac{b^4}{64R} \text{ [mm}^3\text{]} \tag{1}$$

where:

$R$ – ball radius [mm],

$B$ – crater diameter [mm].

The Archard wear equation is as follows:

$$V = K_c S N \text{ [mm}^3\text{]} \tag{2}$$

where:

$K_c$ – specific wear rate [mm$^3$/mN],

$S$ – distance [m],

$N$ – nominal load [N].

Hence:

$$K_c = \pi \frac{b^4}{64RSN} \quad \left[\frac{\text{mm}^3}{\text{m} \cdot \text{N}}\right] \tag{3}$$

The hardness of the tested materials was performed using the Vickers method for 15 s. and load 10 N in accordance with PN-EN ISO 6507-1: 1999.

The Hommel Tester T1000 was used to measure the arithmetic mean Ra roughness measurement in two axes. The measurement resolution is 0.01 µm. Accuracy class in accordance with DIN 4772.

## Research results and discussion

Table 3 shows the results of hardness and roughness of the materials accepted for testing.

Tabele 3

Summary of the average hardness and roughness of the tested materials

| Material | Medium hardness HV10 | Average roughness along the specimen $R_a$ [µm] | Average roughness across the sample $R_a$ [µm] |
|---|---|---|---|
| COM1 | 36 | 0.12 | 0.14 |
| COM2 | 31 | 0.11 | 0.15 |

The materials were characterized by a similar value of hardness and roughness. After analyzing the specific wear rate $K_c$ (Tab. 4), it can be concluded that the material made of glass fabric reinforced with polyester resin by 1,000 and 2,000 m friction turned out to be the most resistant to abrasive wear, while after 3,000 m the material of the glass emulsion mat reinforced with polyester resin was characterized by the best wear properties.

Tabele 4

List of wear results after friction tests.

| Material | Distance [m] | Ball recess [µm] | Intensity of abrasive wear of the coating $K_c$ [$mm^3/mN \cdot 10^{-6}$] |
|---|---|---|---|
| COM1 | 1,000 | 6.25 | 7.79 |
| COM2 | | 9.50 | 3.60 |
| COM1 | 2,000 | 16.50 | 27.15 |
| COM2 | | 8.75 | 7.64 |
| COM1 | 3,000 | 4.25 | 1.20 |
| COM2 | | 11.25 | 8.41 |

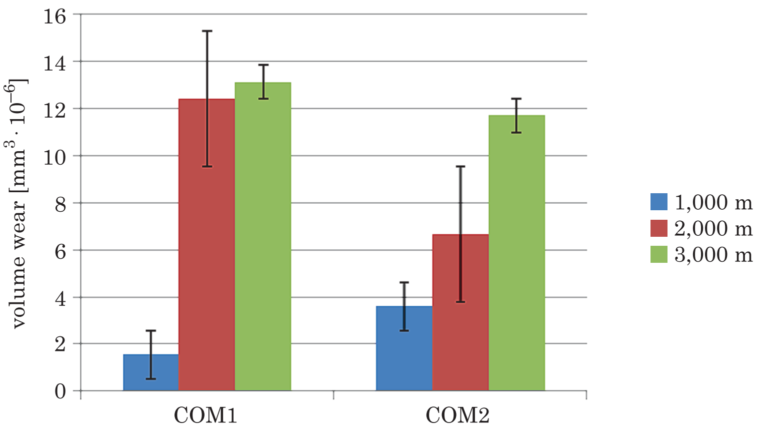


Fig. 3. The volume of wear depends on the material and the friction path travelled

From the test performed a significant difference in the recess is noticeable balls between 1,000 and 2,000 m (Fig. 3) for COM1 material. The material COM1 reinforcement is made of a glass mat combined with an emulsion binder. The glass mat is made of chopped general purpose glass fibers arranged randomly. On the other hand, an epoxy resin was used as an emulsion. The composite prepared in this way showed a low resistance to abrasion, especially after 2,000 m. It was caused by significant surfaces of the soft emulsion between the glass fibers. It should be emphasized that in this research method a better reflection of the wear process is the measurement of the used material with the help of volume. Each research cycle was started from scratch and lasted until the assumed friction path was achieved. In the case of heterogeneous materials, such as the tested composite, the test site is important for the results achieved due to the arrangement of the glass fibers. For COM1 material, the volumetric consumption between the distance of 2,000 m and 3,000 m was comparable. In the case of COM2 material, the wear between distances was proportional.

Figure 4 shows the craters formed during the abrasive wear test. In all tested cases, regular, smooth edges were observed. The COM2 material was characterized by smaller crater diameters, which may be caused by plastic deformation due to the low hardness of the material. The microscope image shows that carbon fibers are very durable fibers and no damage is visible in contact with a spinning ball. There was also no clear pattern of fiber rupture.

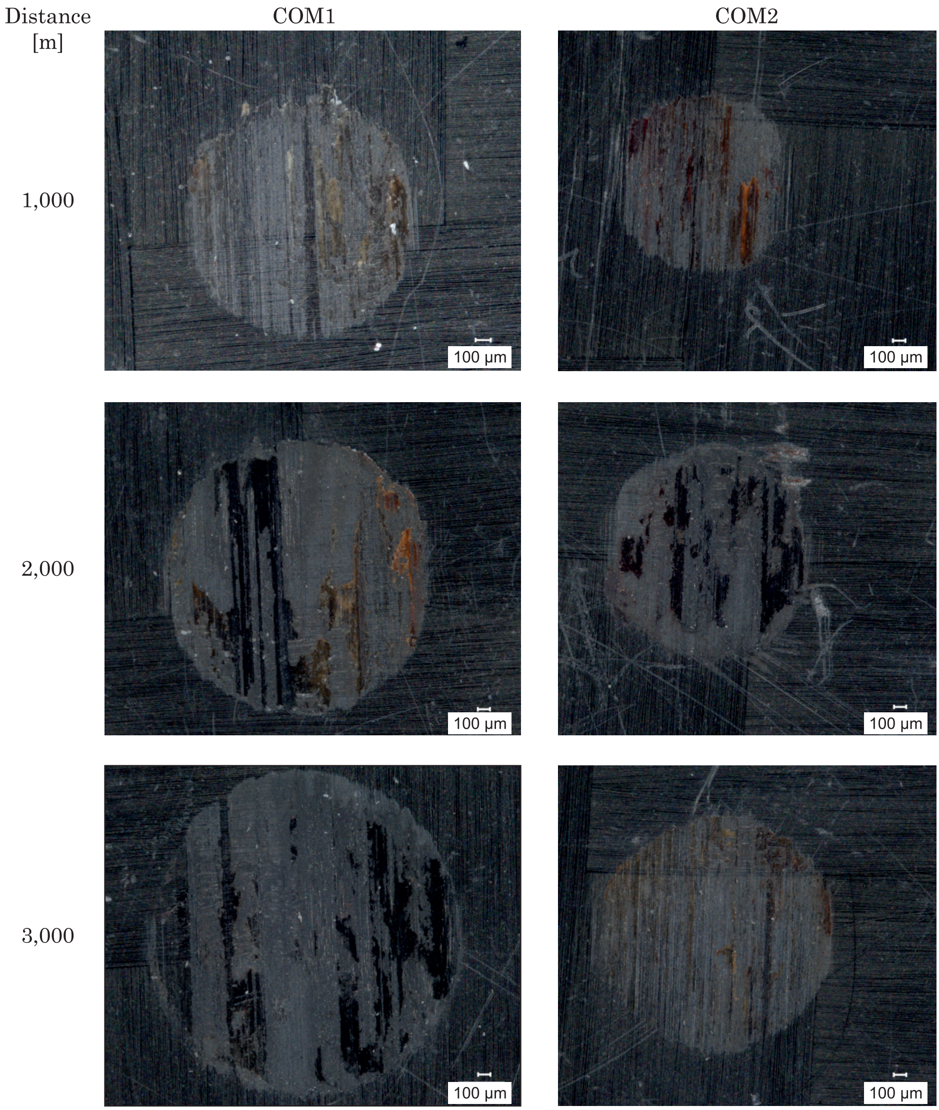


Fig. 4. View of the craters after the tribological test

## Conclusions

1. Due to the good abrasion resistance of carbon fibers, none of the samples could be wiped with fabric or glass mats. In such cases, the applied reinforcement below the carbon fiber fabric layer does not affect the quality of the fabric/glass

mat connection with carbon fiber, therefore the type of reinforcement does not affect the test result.

2. Based on the specific wear rate Kc, better tribological properties of the polyester matrix reinforced with glass fabric were observed compared to the polyester matrix reinforced with a glass emulsion mat.

3. The conducted research shows that attempts can be made to apply a layer of glass fabric reinforcement in composites exposed to the process of abrasive wear.

4. Established operating parameters of the friction junction allow the determination and comparison of the wear coefficients, which allows to systematize the tested coatings according to their abrasion resistance.

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