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EROSIVE WEAR OF GLASS/EPOXY COMPOSITES COATING FILLED WITH HEXAGONAL BORON NITRIDE NANOPARTICLES

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Abstract: In this experimental study, organic and inorganic coatings are applied on glass/epoxy composite materials to acquire an advanced understanding of the erosive wear performance. After coating process, SiO_2 erodent particles having an average impact velocity of 53 m/s and an average diameter of 250 μm were used to evaluate the erosion rates based on the weight loss in the test specimens. The impingement angles used in the tests were 30°, 60° and 90° and the erosion rate – impingement angle graphs were produced for each different test specimen. It was observed that the organic coatings developed erosion resistance at the end of the experiments. Weight loss measurements were compared by using alternative measurement method (surface mapping method) and erosion wear difference are discussed.

Keywords: organic, inorganic, coating, wear performance, erosion rate.

1. INTRODUCTION

Today, polymers and their composites are widely used as structural material for different machine components and engineering systems due to their specific properties. Some examples of the application of polymer composites include sand transporting pipe lines, sludge transportation lines in oil refineries, rotor blades for helicopters, pump propulsion fins, high-speed vehicles and planes, plane motor fins and missile components.

An important property in these types of applications is resistance to particle erosion because these parts are often used in environments that interact with erodent [1–2]. One of the methods for improving the properties of polymers and their composites (mechanical, tribological etc.) is particle addition into the matrix. Additions conducted into the material in order to improve erosion wear performances of composite materials can be classified in literature under two headlines: micro additions [3–7], and nano additions [8–10]. In recent years, attention drawing improvements were observed in the properties of polymer composites obtained as a result of nanometer sized particle dispersion of some inorganic fillers into the polymer matrix. Due to the large surface area of these nanometer sized particles (1000 m^2/g), the load carrying from matrix to nanoparticles is facilitated and the mechanical properties of matrix are improved [11]. Optimal candidates for the realization of this load carrying are carbon nanofibres, nanotubes and nanoclays. To develop the properties of composites, studies on different reinforced materials are based on very old data. It is known from industrial examples that the coating applied in surface treatment has significant effects on the strength of the materials. Because of the necessity brought about by technological transformation, composite materials are being replaced by plastic and metal materials and how the properties of these materials change with surface treatment is being examined. In order to improve erosion resistance, different capabilities on coating should be questioned if the material is subjected to particle impact. It is aimed to evolve these properties with organic and inorganic coatings [12, 13]. It is important to interpret how they produce results as well as to obtain these coatings.

The experiments were carried out at impingement angle, impact velocity, abrasive particle size efficiency and the results were presented in units of erosion rate. The alternative measurement method

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also showed the parallel trend in the results obtained with the precision balance.

2. MATERIALS AND METHODS

The GF/EP composites were used as substrate materials in experiments were produced as stratified by "hand lay-up" technique (110 Bar pressure, 120°C temperature and a time of 3 top of the hour) with a thickness of 3 mm and dimensions of (1×1 m^2). After then, specimen cut to 30×30×3 mm^3 size. Fibres in composite materials with diameter of 17 μm, thickness of 0.20 mm and mass per unit area of 200 g/m^2 arranged in a multi/directional location provide homogeneous spreaded out fibres in the matrix form.

Pure GF/EP composite materials were selected as the main test specimen. $NaBH_4$ and NH_4Cl were reacted in the appropriate environment and pyrolysis-induced hexagonal boron nitride (h-BN) nanoparticles with a diameter of 70 nm were obtained in an inert environment at high temperature. The h-BN based polymer was interacted with Tetrachlorethylene monomer. As a result, a 20 μm thickness h-BN based polymer is coated on the GF/EP surface and homogeneously integrated into the GF/EP surface with high temperature annealing. On the other hand, h-BN nanoparticles were applied to the silica-doped polymer GF/EP surface prepared by Sol-Gel method with Tetraethylorthasilicate (TEOS) in an acidic medium with a thickness of 20 μm. Subsequently, the erosion wear resistance of pure GF/EP, h-BN based polymer obtained by interaction with Tetrachlorethylene and h-BN polymer interacted with TEOS with Sol-Gel technique was compared.

Pure GF/EP and organic and inorganic coated GF/EP are given in Figure 1. Moreover, the properties of the test specimens were determined using {ASTM D3039/D3039M–17 and ASTM D2583–13a} and are given in Table 1.

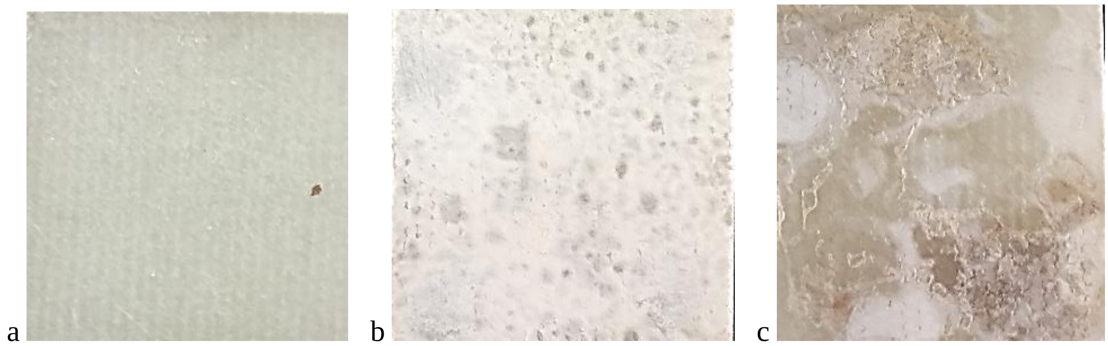


Figure 1. GF/EP test specimens: a) Pure; b) Organic coated; c) Inorganic coated.

The epoxy matrix used in the composite materials is a brittle thermosetting resin, while the fibres have thermoplastic properties with high plastic deformation. As a result of the combination of these different properties, the mechanical properties of erosion wear and rupture strength have been revised.

Table 1. Mechanical and physical properties of test specimens.

Material	ρ (g/cm^3)	σ_t (MPa)	H (HB)	E (MPa)
GF/EP (Pure)	1.683	533	87	144
GF/EP (Organic)	1.708	597	95	167
GF/EP (Inorganic)	1.695	515	79	139

In erosion tests, the abrasive particles affected the sample surfaces at different angles and velocity using dry and pressurized air. The pressure at the nozzle was controlled by means of a pressure regulating valve and a pressure gauge. An average of 250 μm diameter SiO_2 erodent with spherical geometry were used as abrasive particles (Figure 2 and Table 2). New particles were used in each experiment against problems that may occur due to fracture of particles.

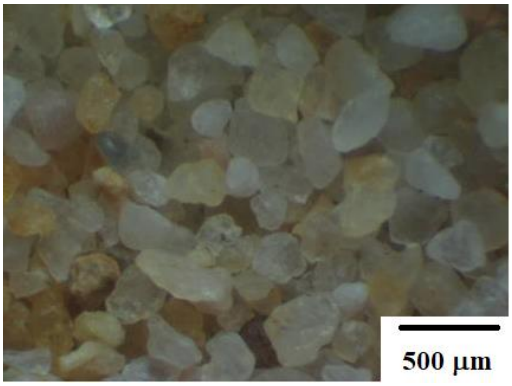


Figure 2. SiO_2 abrasive particles (~250 µm).

Table 2. Chemical compositions of SiO_2 abrasive particles.

Content	Min. (%)	Max. (%)
Humidity	3	8
Clay	0.1	0.5
SiO_2	98	99
Fe_2O_3	0.18	0.4
Al_2O_3	0.5	1.2

Tests were conducted in a specifically designed erosive wear test facility compatible with ASTM G76–95 standard test method in an environment with dry and pressurized air where abrasive particles were set to impact the test specimen surface. To determine the velocity of the erodent, the double disc method was used and the particle impact velocity was set to 53 m/s. With the impingement angle adjustment apparatus detailed in Figure 3, impingement angles 30°, 60° and 90° were applied.

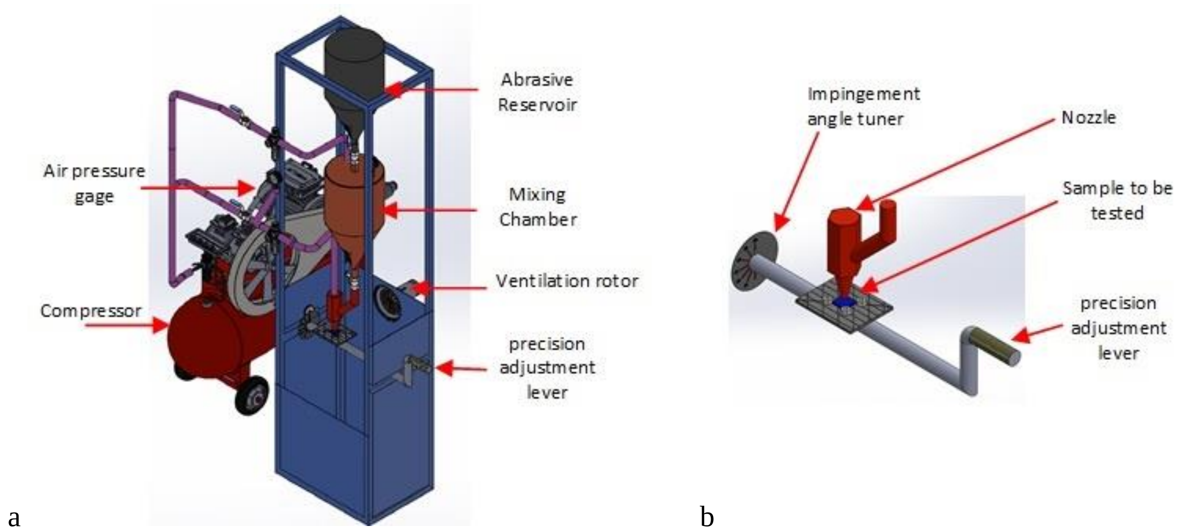


Figure 3. Schematic view of the test rig: a) 3D drawing; b) impingement angle adjustment lever.

In addition to the weight loss, the volumetric loss measurement was carried out. Volumetric losses occurred is calculated with the digital map method of the surfaces by using the point cloud and the mesh modelling. Firstly, point clouds were created and then, the mesh was placed on the specimen surface. After that by the help of 3D scanning using the digital map method of the surfaces, volumetric losses were calculated (Figure 4).

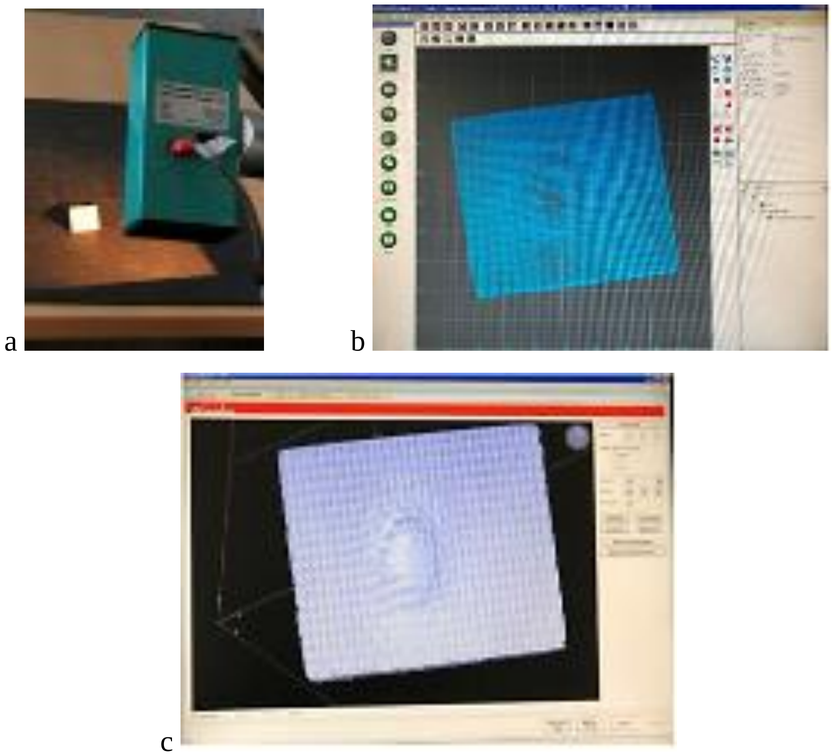


Figure 4. Surface mapping method: a) Point cloud; b) Mesh modelling; c) Volumetric loss.

3. RESULT AND DISCUSSION

To make specific comments on the tests results, the graph of impingement angle against erosion rate for all different materials is grouped together in Figure 5. When the graph is studied, it is seen that a decrease in impingement angle causes erosion rate to increase too. It was concluded that the decrease in angle deteriorate the ability of the specimen to resist erosion and this leads to higher wear rates. The presence of a scraper effect can be interpreted as the most basic result of the emergence of this cause.

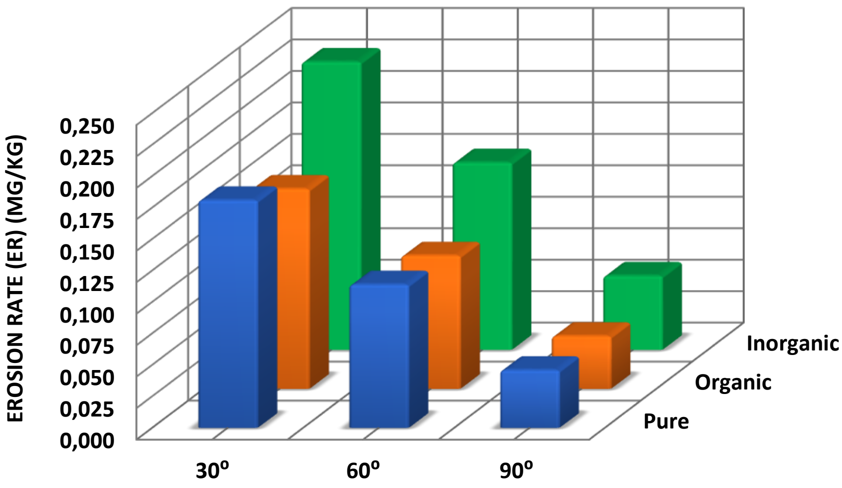
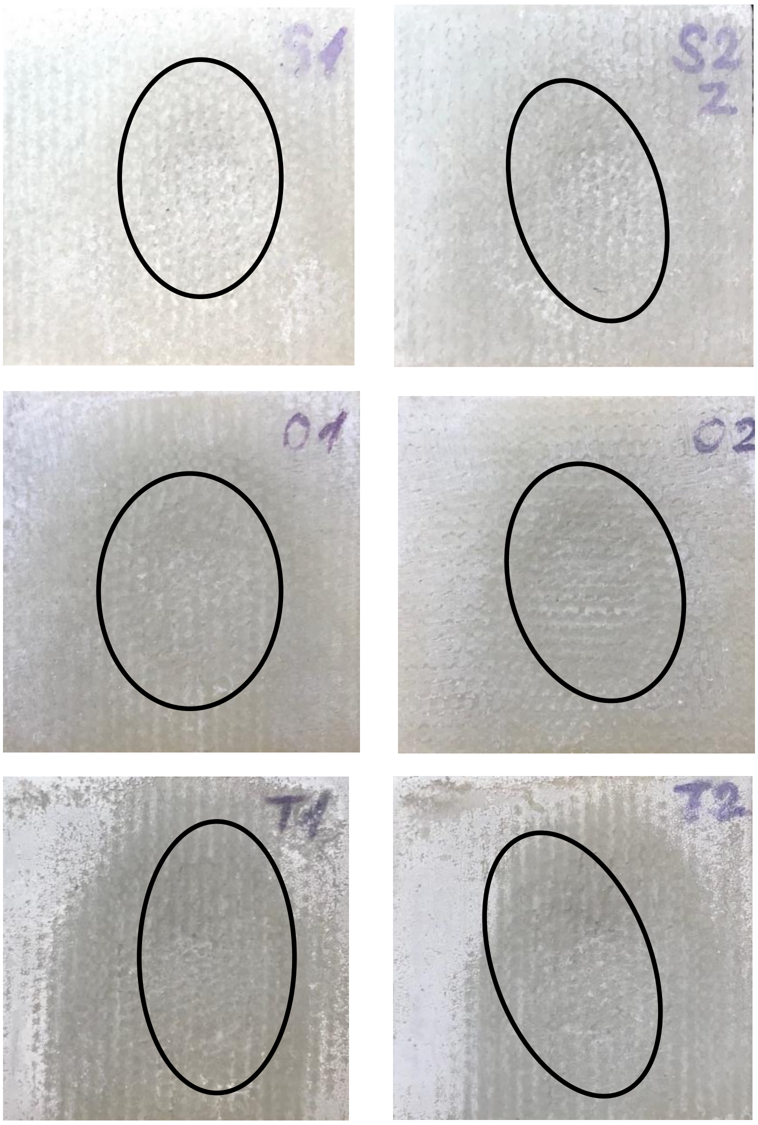


Figure 5. Graphs of erosion rate against impingement angle GF/EP materials: a) Pure; b) Organic; c) Inorganic.

In Figure 5, according to GF/EP (Pure) material, erosion rate of GF/EP (Organic) material decreased by 9.9%, while erosion rate of GF/EP (Inorganic) material decreased by 26.5%. At the same time, the change in impingement angle showed a similar tendency in all specimen and reduced wear. Consequently, ductile material ability of all test specimen was observed when literature data were examined. There is a need for protective coatings to reduce the solid particle erosion effect of the components that provide the definition of composite material. Coatings produced in two different types, organic and inorganic, were preferred in this experimental study. As a result of the tests, when the data obtained in Figure 5 were examined, it was determined that organic and inorganic coated composite materials had positive and negative effects on erosion wear, respectively. Figure 6 shows the superficial and in-depth cavities on all post-test surfaces of all test specimens. The erosion wear resistance of pure GF/EP, h-BN based polymer obtained by interaction with Tetrachlorethylene and h-BN polymer interacted with TEOS with Sol-Gel technique was compared. The organic coating process was added the h-BN based polymer was interacted with Tetrachlorethylene monomer. As a result, a 20 μm thickness h-BN based polymer is coated on the GF/EP surface and homogeneously integrated into the GF/EP surface with high temperature annealing. It was determined that the erosion rate of organic coated composite materials was lower because of restrict surface delamination. The inorganic coating process was added the h-BN nanoparticles were applied to the silica-doped polymer GF/EP surface prepared by Sol-Gel method with Tetraethylorthasilicate (TEOS) in an acidic medium with a thickness of 20 μm. Inorganic coated composite test samples showed higher erosion rate due to weak bond strength. It was determined that tribological systems could be optimized by choosing the right coating application based on the results data and literature information.



a

b

c

Figure 6. Surface views of GF/EP test specimens (×5): a) Pure; b) Organic coated; c) Inorganic coated.

4. CONCLUSIONS

In this study, solid particle erosion test was experimentally used to analyse wear behaviour of coating process GF/EP composites and the following conclusions can be drawn:

- Whether a coating process is added, all test samples exhibit a maximum erosion rate at 30° impingement angle pretended ductile materials. So the higher the angle of impingement, the less the erosion rate.
- The impact velocity and the abrasive particle size remained constant and the coating efficiency was examined.
- The mechanical properties of organic coating composites were improved. However, mechanical properties decreased when inorganic coating process.
- The lowest erosion rate was exhibited by GF/EP (organic) composites due to its strong adhesive strength. Erosion rate decreased by 12% in samples without any treatment.
- The mechanical properties of composites can be enhanced by surface coating process. This study shows the addition of inorganic coating (TEOS) can cause negative effects on GF/EP composites tribological properties such as erosion wear.
- This condition though can be perfectly recognized from the results, the microscope views also indicate extensive surface resistivity for the specimens with GF/EP. h-BN based organic coatings adhered to the substrate surface and reacted to the attack of abrasive particles. But GF/EP composites could not match with TEOS materials and the surface resistance is weakened.

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