

Effects of Silicon Oxide Filler Material and Fibre Orientation on Erosive Wear of GF/EP Composites

M. Bagci, H. Imrek, and Omari M. Khalfan

Abstract—Materials added to the matrix help improving operating properties of a composite. This experimental study has targeted to investigate this aim where Silicon Oxide particles were added to glass fibre and epoxy resin at an amount of 15% to the main material to obtain a sort of new composite material. Erosive wear behavior of epoxy-resin dipped composite materials reinforced with glass fibre and Silicon Oxide under three different impingement angles (30°, 60° and 90°), three different impact velocities (23, 34 and 53 m/s), two different angular Aluminum abrasive particle sizes (approximately 200 and 400 μm) and the fibre orientation of 45° (45/-45) were investigated. In the test results, erosion rates were obtained as functions of impingement angles, impact velocities, particle sizes and fibre orientation. Moreover, materials with addition of Silicon Oxide filler material exhibited lower wear as compared to neat materials with no added filler material. In addition, SEM views showing worn out surfaces of the test specimens were scrutinized.

Keywords—Erosive wear, fibre orientation, GF/EP, silicon oxide

I. INTRODUCTION

EROSIVE wear is formed when solid particles moving at a certain velocity impact a surface and remove some materials off the top surface. Impingement angle, impact velocity, size and shape of the erodent particles, as well as the properties of target material are important variables that affect erosion wear. Because it is possible to encounter erosive type of wear in space craft industry, energy conversion systems, jet engines, helicopter rotor blades and in coal mine plants, the importance of this type of wear is progressively increasing [1], [2]. Composite can be defined as a material formed as a result of combining two or more materials on a macro scale bases in order to render the material superior features. In addition, these are the tendency of the composites to be natural, being made of at least two materials with different chemical properties that are separated at certain interfaces and that are brought together in three dimensional basis where the final

M. Bagci is with the Faculty of Engineering and Architecture, Department of Mechanical Engineering, Selcuk University, Alaeddin Campus, 42075 Selcuklu, Konya, Turkey (phone: +90.535.6880886; fax: +90.332.2410651; e-mail: meh_bagci@yahoo.com).

H. Imrek is with the Faculty of Engineering and Architecture, Department of Mechanical Engineering, Selcuk University, Alaeddin Campus, 42075 Selcuklu, Konya, Turkey (phone: +90.536.2535533; fax: +90.332.2410651; e-mail: himrek@selcuk.edu.tr).

O. M. Khalfan is with the Faculty of Engineering and Architecture, Department of Mechanical Engineering, Selcuk University, Alaeddin Keykubat Campus, 42075 Selcuklu, Konya, Turkey (phone: +90.536.6706256; fax: +90.332.2410651; e-mail: omashi@hotmail.com).

product bears specifications quite different from the individual components making the composite [3], [4]. These features make the composites to have adverse applications especially in erosive wear situations, nowadays [5], [6].

Srivastava and Pawar [7] investigated the effects of fly-ash filler, impingement angle and particle velocity on the solid particle erosion behavior of E-glass fibre reinforced epoxy composites. Fly-ash filler restricts fibre-matrix de-bonding. They also concluded that neat glass epoxy without any filler exhibits the highest erosion rate due to weak bonding strength. Patnaik et al. [8] reviewed research on solid particle erosion behaviour of fiber and particulate filled polymer composites. The new aspects in the experimental studies of erosion of fiber and particulate filled polymer composites were emphasised in this paper. Implementation of design of experiments and statistical techniques in analyzing the erosion behavior of composites were discussed. Recommendations were given on how to solve some open questions related to the structure-erosion resistance relationships for polymers and polymer based hybrid composites. In the study by Harsha and Jha [9] experiments were carried out erosion resistances of pure epoxy, unidirectional glass fiber reinforced epoxy, and unidirectional carbon fiber reinforced epoxy and bidirectional E-glass woven reinforced epoxy composites. Bidirectional glass fiber reinforced epoxy composites exhibited more erosion resistance than their unidirectional fiber reinforced composites. Pool et al. [10] investigated the behavior of polymer matrices composites. They concluded that the behavior of continuous graphite fiber-epoxy composites typically resemble that of brittle materials whereas the behavior of aramid fiber-epoxy and flake graphite fiber-polyphenylene sulfide materials is like those of ductile materials. Tilly and Sage [11] found that mechanical properties like stress and hardness of materials like metal, plastics and ceramics play important roles to their erosion resistances. In addition, they came to conclude that in reinforced plastics, depending on the type of fiber used, materials tend to improve their erosion resistance. Kim and Kim [12], investigated solid particle erosion behavior of epoxy base unidirectional and multidirectional carbon fiber reinforced plastic composites was investigated. Irregular SiC particles were used. The dependence of impingement angle on the erosive wear resembled the conventional ductile behavior with maximum erosion rate at 15°–30° impingement angle.

Matrix and additional material have an important role in

formation of composite. Material added to the matrix help improving operating properties of a composite. In this experimental study, solid particle erosive behavior of GF/EP composite material on which Silicon Oxide (15%) was added was investigated, where three different impingement angles (30°, 60° and 90°), three different impact velocities (≈ 23 , 34 and 53 m/s), two different angular Aluminum erodent sizes (≈ 200 and 400 μm) and the fibre orientation of 45° (45/-45) were used.

II. EXPERIMENTAL SETUP AND PROCEDURE

A. Test Device

In this wear tests, the method used is the one involving dry and compressed air accelerating the solid particles to strike the surface of specimens. The test device (Fig. 1) which was specifically designed for the tests consists of main reservoir, pressured particle tank, universal valves, manometers, flow control and pressure regulators, nozzle, specimen holder, recycling box and a compressor. The particles impact velocities used in the tests (23, 34 and ≈ 53 m/s) were adjusted by using the double disc method in which two discs were connected to a common shaft from a driving prime mover [13]. The impingement angle, one of the most important parameters affecting solid particle erosive wear, was varied by turning the test specimen holder around its own axis. In addition, moving the specimen holder up and down served as a distance adjusting mechanism between the nozzle and the test specimen.

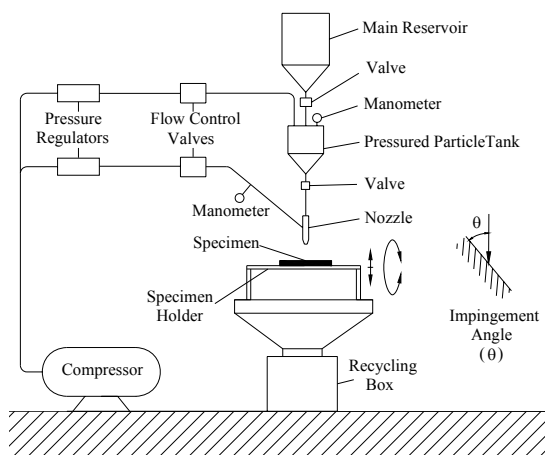


Fig. 1 Schematic view of erosion wear test device

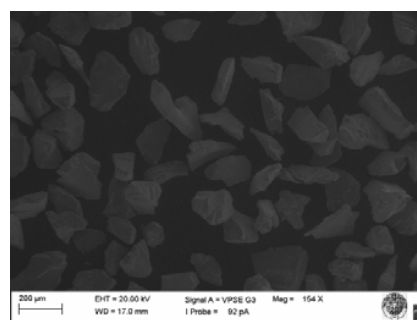
B. Materials

Epoxy was used as resin (flexural strength 145 MPa, compressive strength 130 MPa elasticity modulus 2.9 GPa, fracture strain 3.5%, glass transition temperature 95 °C). 15% of the resin was added with Silicon Oxide (≈ 150 μm) as a filler material and a composite material with a different structure was obtained. E-glass fibres with 17 μm diameter, thickness of 0.15 mm and mass per unit area of 200 g/m^2

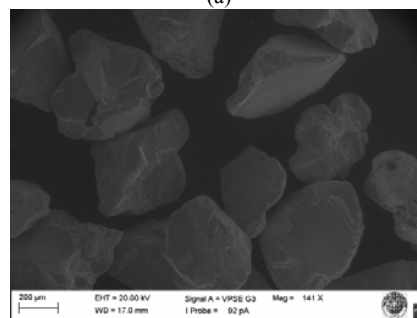
arranged in a bidirectional location provide equal strengths in either direction and homogeneously distributed fibres in the matrix form an isotropic structure. All new test specimens were made with a hand lay-up technique at operating conditions of 110 Bar pressure, 120 °C temperature and 3 hour pressing interval where the plates having thicknesses of 3 mm and sizes of 1x1 m^2 were made. Then, in order to enable the specimens to be attached to the specimen holder, the specimens were cut to a 30x30 mm^2 size with a diamond saw. In Table I, mechanical and physical properties of the test specimens are given, whereas in Fig. 2, SEM views of angular Aluminum erodent (density 3.94 g/cm^3 , hardness 9 Mohs and melting point 1950 °C) are shown.

TABLE I
MECHANICAL AND PHYSICAL PROPERTIES OF THE TEST SPECIMENS

Properties	GF/EP (Neat)	GF/EP (Silicon Oxide)
Tensile strength	533 MPa	431 MPa
Compressive strength	607 MPa	474 MPa
Modulus of elasticity	144.3 MPa	138.19 MPa
Hardness value	87 HB	55 HB
Fibre volume ratio	0.50	0.50



(a)



(b)

Fig. 2 SEM views of angular erodent: (a) ≈ 200 μm ; (b) ≈ 400 μm

III. EXPERIMENTAL RESULTS AND DISCUSSION

Erosive wear behavior of glass fibre reinforced epoxy composite material on which Silicon Oxide was added was investigated, where three different impingement angles (30°, 60°, 90°), three different impact velocities (23, 34, 53 m/s), two different abrasive particle sizes (200, 400 μm) and the fibre orientation of 45° (45/-45) were used. The graphs in Fig. 3 (a) and (b) show variations of erosion rates with

impingement angles at impact velocities of 23, 34 and 53 m/s where the abrasive particles used had average diameters of 200 μm . Whereas the graphs in Fig. 4 (a) and (b) show variations of erosion rates with impingement angles at impact velocities of 23, 34 and 53 m/s where the abrasive particles used had average diameters of 400 μm .

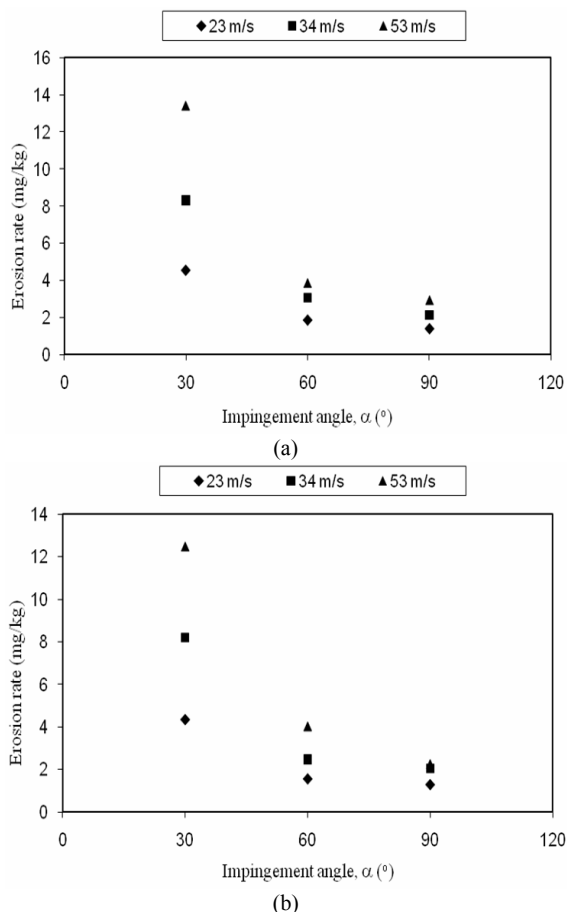


Fig. 3 Variation of impingement angle – erosion rate at impact velocities of 23, 34 and 53 m/s and at fibre orientation of 45° for 200 μm : (a) GF/EP (Neat); (b) GF/EP (Silicon Oxide)

A. Effects of Silicon Oxide Materials

As fibre reinforced polymers take place in most of the studies conducted on erosive wear of composites, studies involving erosion on composites with filler materials can hardly be encountered. This is due to the fact that it is not easy to clearly understand erosion mechanisms of these types of composites, properties of their components and their interface interactions.

In this study, Silicon Oxide filler materials were used in order to lower expenses and increase material strength. By observing Figs. 3 and 4, it is seen that the reinforced materials added into the matrix, impact velocity, impingement angle and the size of abrasive particles change the erosion rate. It was also found that by adding Silicon Oxide into the main matrix, the resulting new composite shows a decrease in erosion rate

at about 10–15% lower than the neat material and thereby being the best effect to the erosive wear.

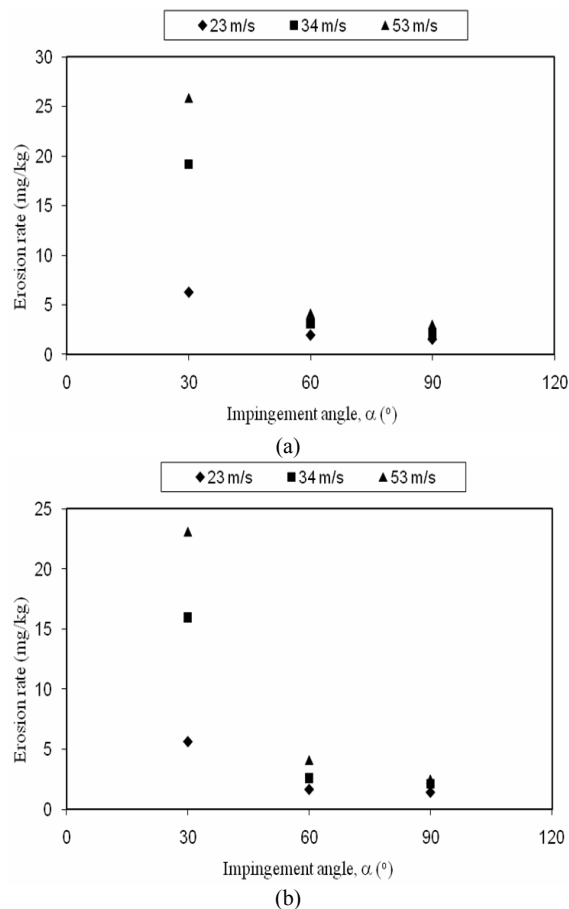


Fig. 4 Variation of impingement angle – erosion rate at impact velocities of 23, 34 and 53 m/s and at fibre orientation of 45° for 400 μm : (a) GF/EP (Neat), (b) GF/EP (Silicon Oxide)

B. Effects of Fibre Orientation

In this experimental study all the fibre orientations of the test specimens whose erosive wear behaviors were studied were taken as $45^{\circ}/45^{\circ}$ and the results obtained based on this fibre orientation. In the study conducted by Bagci and Imrek [14] erosive wear behavior of GF/EP (Silicon Oxide) were investigated where the fibre orientation was $0^{\circ}/90^{\circ}$. Comparison of these two experimental studies reveals that the specimens with fibre orientation of $45^{\circ}/45^{\circ}$ exhibit more resistance against erosive wear. This leads to conclusion that the orientation of the fibres which exerts resistance against abrasive bombarding particles is effective. That means, the normal force exerted by the abrasive particles is divided into two components when the specimens are subjected to $45^{\circ}/45^{\circ}$ orientation; and this causes a decrease in the bending moment. And consequently, this results into increasing the specimens' erosive wear resistance.

C. Effects of Impingement Angle, Impact Velocity and Erodent Size

When the graphs are studied it is seen that regardless of the fact the two graphs are at different values, the specimens in both sets of graphs seem to undergo much erosion rates at impingement angle of 30° . Together with this, it has also been observed that, parallel to the increase of the impingement angles (60° – 90°), the erosion rates tend to suddenly decrease. This condition shows that, a similar wear trend is observed as that seen in literature for ductile materials [15]–[17]. It was determined that beside the remarkable effects of impingement angle, striking speed and the size of abrasive particles also have substantial effects on erosive wear. By studying the graphs plotted from the experimental result data, it is seen that the effects of striking speed on erosive wear are more pronounced than those of the size of the abrasive particles.

D. SEM Views of Test Specimens

First of all, the SEM specimen views of pure composite and a glass fiber reinforced composite that was added with silicone oxide that are not subjected to erosive wear are shown in Fig. 5. The Silicone Oxide filler material added into the structure has caused remarkable visual appearance on the specimens. Due to this surface appearance change, it was found that depending on the contact of the abrasive particles, the added filler material brings about changes on erosive wear.

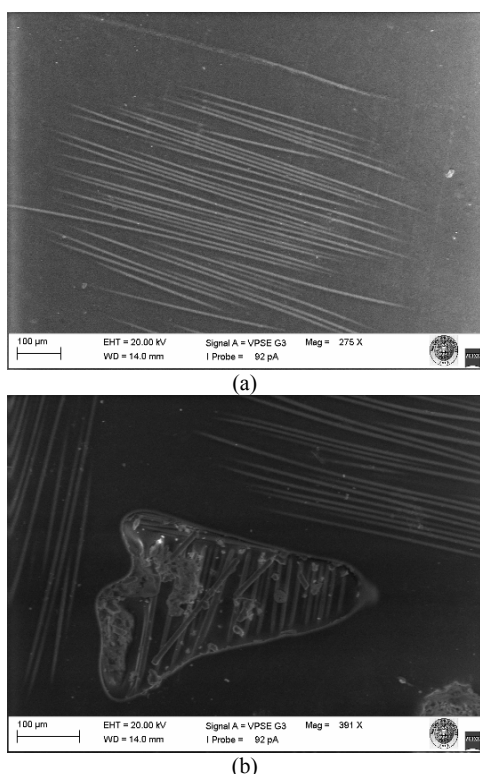


Fig. 5 SEM views of test specimens before erosion: (a) GF/EP (Neat); (b) GF/EP (Silicon Oxide)

Whereas the SEM views after the erosive wear tests are given in Fig. 6. The specimens, both pure and those with silicon oxide added, were subjected to $400\ \mu\text{m}$ diameter particle bombardments at 90° impingement angle and a striking speed of $34\ \text{m/s}$; and then these SEM views were obtained.

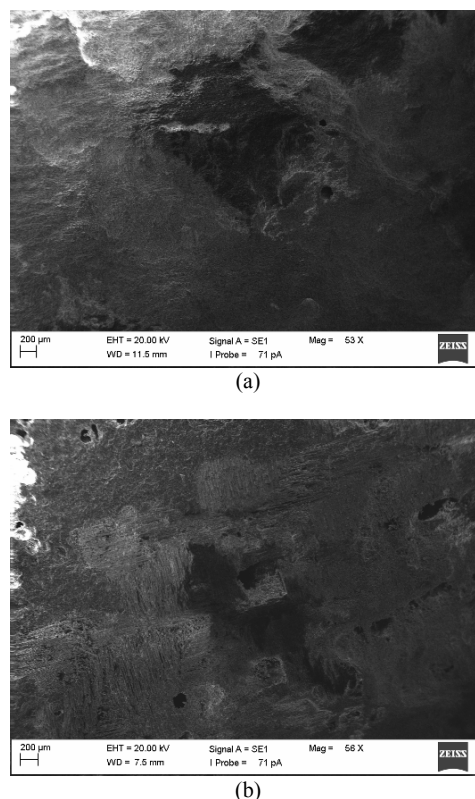


Fig. 6 SEM views of test specimens at angle, velocity and sizes of 90° , $34\ \text{m/s}$ and $400\ \mu\text{m}$ respectively after erosion: (a) GF/EP (Neat); (b) GF/EP (Silicon Oxide)

When the views are studied, it is found that the specimens with silicon oxide added have exhibited resistance against the abrasive particles and hence only slight deformation was encountered on the specimen surfaces. That is the filler material (Silicon Oxide) which forms a strong bond with epoxy prevents the fibers from delamination and this leads to low erosive wear rates. Apart from investigating the effects of silicon oxide as a filler material on erosive wear of composites, another aspect that makes this study special, is the fact that the fiber directions used throughout the study are 45° – 45° .

For this reason, by investigating the experimental results where the fiber directions are 45° – 45° , it is found that the erosive wear resistance has increased. Beside this, these positive effects can also be seen on Fig. 7 through the SEM views. By taking into account the angle biased SEM views, the effects of bending moment as a result of the normal forces on the fibers are also shown.

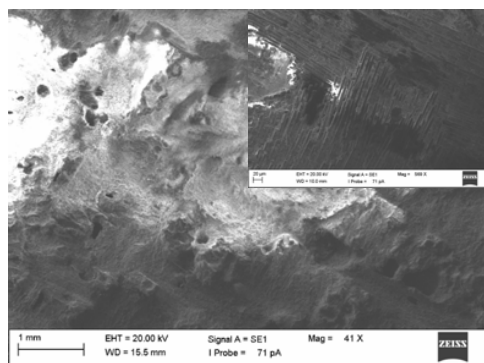


Fig. 7 SEM views of GF/EP (Silicon Oxide) test specimen under the effect of 45° (45/-45) fibre orientation

Abrasive particles striking at certain velocity and angle impose direct attacks on the fibres after removing the “skin” of the matrix material; thereby forming large bending moments on the fibres of the specimens with 0°/90° fibre orientation. As for the specimens with 45/-45 fibre orientation, the force acting on the fibres is divided into two components, a normal and tangential component. This means that there is a decrease in the normal force acting on the fibre. Therefore; the bending moment is low and hence some sort of wear resistance exists.

IV. CONCLUSIONS

The following results have been obtained from this experimental study [18];

- 1) The wear of GF/EP (Neat) test specimens is higher than that of GF/EP (Silicon Oxide) test specimens. That is; the added Silicon Oxide particles impose positive effects on erosive wear and thus decreasing the erosion rates.
- 2) All composites regardless of their different features exhibit maximum erosion rates at 30° impingement angle and thus exhibiting similar behavior as that observed for ductile materials. However; parallel to the increase of an impinging angle, the values of erosion rates tend to drop.
- 3) The remarkable increase in the erosion rate is correlated to the impact velocities used in the tests. Moreover, variation of impact velocity has more effects on erosion wear rate than variation of the abrasive particle sizes.
- 4) Large abrasive particles lead to an increase in wear. A marked increase in erosion rate was observed as the abrasive particle size increased from 200 μm to 400 μm .
- 5) Test specimens with 45/-45 fibre orientation are more wear resistant than their counter parts with 0/90 fibre orientation.
- 6) Even in the SEM views; after the tests cracks, fractures and grooves associated with micro ploughing are observed.

ACKNOWLEDGMENT

This paper was supported by “Selcuk University Scientific Research Projects Coordinatories” in 2011.

REFERENCES

- [1] I. Finnie, “Erosion of surfaces by solid particles,” *Wear*, vol. 3, pp. 87–103, 1960.
- [2] I. M. Hutchings, “The erosion of ductile metals by solid particles,” *Ph.D. Dissertation*, University of Cambridge, 1974.
- [3] J. Zahavi and G. F. Schmitt, “Solid particle erosion of reinforced composite materials,” *Wear*, vol. 71, pp. 179–190, 1981.
- [4] V. K. Srivastava, R. Prakash, and P. S. Shembekar, “Fracture behaviour of fly ash filled FRP composites,” *Composite Structure*, vol. 10, pp. 271–279, 1988.
- [5] U. S. Tewari, A. P. Harsha, A. M. Hager and K. Friedrich, “Solid particle erosion of carbon fibre– and glass fibre–epoxy composites,” *Composites Science and Technology*, vol. 63, no. 3–4, pp. 549–557, 2003.
- [6] M. Bagci and H. Imrek, “Solid particle erosion wear of GF/EP composites with added Al_2O_3 , *AIP Conference Proceedings*, vol. 1315, pp. 1389–1394, 2010.
- [7] V. K. Srivastava and A. G. Pawar, “Solid particle erosion of glass fibre reinforced flyash filled epoxy resin composites,” *Composites Science and Technology*, vol. 66, no. 15, pp. 3021–3028, 2006.
- [8] A. Patnaik, A. Satapathy, N. Chand, N. M. Barkoula and S. Biswas, “Solid particle erosion wear characteristics of fiber and particulate filled polymercomposites: a review,” *Wear*, vol. 268, pp. 249–263, 2010.
- [9] A. P. Harsha and S. K. Jha, “Erosive wear studies of epoxy-based composites at normal incidence,” *Wear*, vol. 265, pp. 1129–1135, 2008.
- [10] K. V. Pool, C. K. H. Dharan and I. Finnie, “Erosive wear of composite materials,” *Wear*, vol. 107, no. 1, pp. 1–12, 1986.
- [11] G. P. Tilly and W. Sage, “The interaction of particle and material behavior in erosion process,” *Wear*, vol. 16, pp. 447–465, 1970.
- [12] A. Kim and I. Kim, “Solid particle erosion of CFRP composite with different laminate orientations,” *Wear*, vol. 267, pp. 1922–1926, 2009.
- [13] A. W. Ruff and L. K. Ives, “Measurement of solid particle velocity in erosive wear,” *Wear*, vol. 35, pp. 195–199, 1975.
- [14] H. Imrek, M. Bagci and O. M. Khalfan, “Solid particle erosion of SiO_2 reinforced epoxy composites,” *13th International Materials Symposium*, Pamukkale, October 13–15., 2010.
- [15] J. J. Rajesh, J. Bijwe, B. Venkataraman and U. S. Tewari, “Effect of impinging velocity on the erosive wear behaviour of polyamides,” *Tribology International*, vol. 37, pp. 219–226, 2004.
- [16] R. Rattan and J. Bijwe, “Influence of impingement angle on solid particle erosion of carbon fabric reinforced polyetherimide composite,” *Wear*, vol. 262, pp. 568–574, 2007.
- [17] N.-M. Barkoula and J. Karger-Kocsis, “Solid particle erosion of unidirectional GF reinforced EP composites with different fiber/matrix adhesion,” *Journal of Reinforced Plastics and Composites*, vol. 21, no. 15, pp. 1377–1388, 2002.
- [18] M. Bagci, “Investigation of erosion wear behaviour of glass fibre reinforced composite materials,” *Ph.D. Thesis*, The Graduate School of Natural and Applied Science of Selcuk University, 2010.

Mehmet Bagci was born in Konya, Turkey, in 1981. He received the B.S. and M.S. degrees in Mechanical Engineering from the Selcuk University, Konya, Turkey in 2003 and 2005, respectively. Mr. Bagci finished his PhD in Mechanical Engineering at the same university in 2010. He has been working as a Research Assistant Dr. in Department of Mechanical Engineering, Selcuk University since January 2005. He is married. His interests are friction, wear, lubrication, composite material, machine elements and machine design. He is member of Chamber of Mechanical Engineering of Turkey.

Huseyin Imrek was born in Kahramanmaraş, Turkey, in 1964. He received the B.S. and M.S. degrees in Mechanical Engineering from the Selcuk University, Konya, Turkey in 1987 and 1989, respectively. Mr. Imrek finished his PhD in Mechanical Engineering at the same university in 1995. He has been working in Department of Mechanical Engineering, Selcuk University since 1988. He is married. His interests are hydraulic and pneumatic, tribology, machine design and manufacture.

Omari Mashi Khalfan was born in Tanzania, in 1976. He received the B.S. and M.S. degrees in Mechanical Engineering from the Selcuk University, Konya, Turkey in 2004 and 2008, respectively. Mr. Khalfan continues his PhD. His interests are machine elements, hydraulic and pneumatic systems.