eXPRESS Polymer Letters Vol.2, No.12 (2008) 890–895
Available online at www.expresspolymlett.com
DOI: 10.3144/expresspolymlett.2008.104

Study of the strength and erosive behavior of $CaCO_3$/glass fiber reinforced polyester composite

M. G. Yilmaz[1], *H. Unal*[1], *A. Mimaroglu*[2*]

[1]University of Sakarya, Faculty of Technical Education, Esentepe Kampusu, Adapazari, Turkey
[2]University of Sakarya, Faculty of Engineering, Esentepe Kampusu, Adapazari, Turkey

Received 3 September 2008; accepted in revised form 12 November 2008

Abstract. In this study, the strength and erosive characteristics of $CaCO_3$ filled unsaturated polyester/glass fiber (UPR/GFR) composite are evaluated. Samples of UPR with 40, 50 and 60 wt% content of $CaCO_3$ and different $CaCO_3$ particle sizes of 1, 2, 3, 5 and 10 micron were prepared and tested under tensile loading, indentation and erosion conditions. The tensile strength, hardness and erosion wear rate of unsaturated polyester/glass fiber (UPR composite)/$CaCO_3$ composite were obtained and evaluated. The results showed that the higher is the percentage of $CaCO_3$ in the composite and the smaller is the $CaCO_3$ particle size, the higher is the strength and the erosive resistance of the glass fiber reinforced/unsaturated polyester composite (UPR-GFR). Furthermore, the highest erosion wear rate is at 90° impingement angle. Finally the results show that the erosive wear of $CaCO_3$ content UPR/GFR composite in a brittle manner.

Keywords: *polymer composites, $CaCO_3$, strength, erosion*

1. Introduction

Unsaturated polyester (UPR) is one of the most important thermoset resins in use in applications due to its ease of handling, molding characteristics and cured properties [1, 2]. Having said that in composites technology, in which particulate fillers such as $CaCO_3$, glass fiber and carbon black are added into the polymers, may provide a good method to improve their stiffness, modulus and to reduce costs [3–5]. Fillers affect the tensile properties according to their packing characteristics, size and interfacial bonding [6]. The maximum volumetric packing fraction of filler reflects the size distribution and shapes of the particles. Srivastava and Shembekar [7] showed that the fracture toughness of epoxy resin could be improved by addition of fly ash particles as filler. Polymer composites are increasingly used in engineering applications such as gears, pump impellers where the components undergo erosive wear. Having said that the composite materials present a rather poor erosion resistance [8, 9]. Hence, it is essential to evaluate their strength as well as their erosive behavior. Generally, variables influencing the erosive wear of composite materials are, mechanical properties of the composites, fiber content, eroding particle size, impingement angle and velocity. In viewing past work on erosive wear of composites, most efforts were focused on the study of the influence of the material properties rather than the operating parameters [10–13]. Srivastava and Pawar [14] studied the effect of additives and impingement angle and eroding particle velocity on erosive wear of neat E-glass fiber reinforced epoxy resin composite materials and composites with 2 and 4 g fly ash additive particles. They concluded that the erosive wear rate of GFRP composite with 4 g fly ash is the lowest and that the maximum erosion occurs at 60°

*Corresponding author, e-mail: mimarog@sakarya.edu.tr

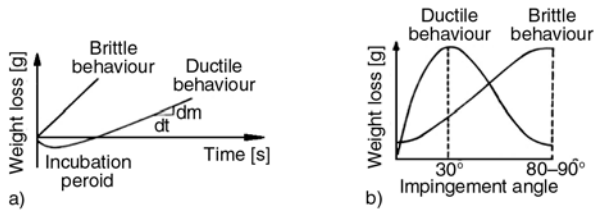

Figure 1. Schematic representation of brittle and ductile type of erosive wear [4]

impingement angle. Finnie [15] and Barkoula and Karger-Kocsis [16] studied the influences of operating condition such as impingement angle and speed on the erosion of polymer composites under small particle erodes. Barkoula and Karger-Kocsis [16] summarized the behavior of polymer composite materials under erosion conditions in schematic diagram see Figure 1. This figure shows and state the typical erosion diagram as a function of impingement angle and time. The erosion mechanisms can be grouped into ductile and brittle. In ductile type initially due to entrapment there is a gain in weight then a linear weight loss. In case of brittle type a linear weight loss is observed with higher loss at 90° degree angle. The ductile materials are characterized by maximum erosion at low impingement angles (15–30°). Having said that this grouping is not definitive [17]. Hutchings [18] observed that material behavior can vary with the variation of erosion conditions. Häger *et al.* [19] carried out erosion test for several thermoset and thermoplastics composites and observed a semi-ductile behavior. Maximum erosion is observed at 60° impingement angle for most of the tested composites. A different observation was made by Tsiang [20] as using Al_2O_3 particles erosion sand. He concluded that in GF/EP and some other thermoset matrices, the erosion occurred in a brittle manner, while in thermoplastic matrices a semi-ductile erosion was dominant. Rajesh *et al.* [21] studied erosive wear of five different polyamides and observed that all polyamides showed maximum erosion wear at 30° impingement angle indicating a ductile failure behavior. Tilly and Sage [22] have investigated the influence of velocity, impingement angle, eroding particle size and weight on the erosion wear of nylon, carbon fiber reinforced nylon, and epoxy resin, polypropylene and glass fiber reinforced plastics. Their results show that these particulate filled materials behave in an ideal brittle fashion and E-glass fiber reinforced epoxy composite exhibits erosion rates less than those of the other composites by a factor of 5. The E-glass epoxy composite exhibits semi-ductile erosion at 45 and 60° impingement angle while others eroded in brittle manner with a maximum weight loss occurring at 75–90° impinging angles. Zahavi and Schmitt [23] and Miyazaki and Takeda [24] also studied the erosive behavior of fiber reinforced polymer composites and concluded that the maximum erosion rate is at 90° impingement angle. Bitter [25, 26] in his study on erosion phenomenon, stated that ductile behavior shows a peak erosion rate around 30° impingement angle because the cutting mechanism is the dominant in erosion. Past work shows some uncertainty in this respect, because most of studies concentrated on erosive and strength behaviors of polymer composites separately. To reach more clear conclusions there is a need to investigate both strength and erosive behavior of polymer composites in parallel.

In composite technology additives have been used in composite materials to minimize the overall material cost. This is also the case for the addition of $CaCO_3$ to GFR unsaturated polyester (UPR). It is believed that the additive is influencing the strength and the erosive wear behavior of GFR-UPR composites. In this study, the tensile strength, the hardness and the erosive wear behaviors of $CaCO_3$/GFR filled unsaturated polyester (UPR) composites were examined. The variation of the strength, the hardness and the erosion resistance with $CaCO_3$ weight fraction, $CaCO_3$ particle size and impingement angle were studied and evaluated. Samples of UPR with 40, 50 and 60 wt% content of $CaCO_3$ and different $CaCO_3$ particle sizes of 1, 2, 3, 5 and 10 micron were prepared and tested under tensile loading and erosion conditions. The results indicated the effect of filler content, filler size and test conditions on the strength and erosive behavior of UPR/GFR/$CaCO_3$ composite.

2. Experimental procedures

2.1. Materials and preparation of composite material

In this work the compound under investigation is UPR/GFR/$CaCO_3$ composite consisting of unsaturated polyester resin (UPR), fiber glass (GF) and $CaCO_3$ powder. For materials details see Table 1. In the sample preparation process the unsaturated

Table 1. Materials

Materials	Supplier	Size
Unsaturated polyester (UPR)	From Poliya Polyester Inc.	13 micron in diameter, 12mm in length
Fiber glass(GF)	From locally available Turkish Glass Fiber Inc.	
The BC500 inhibitor	Akzo Nobel, Turkey	
$CaCO_3$ powder	Omya Mining, Turkey	1, 2, 3, 5 and 10 micron

polyester and the styrene were mixed in a ratio 100:25 parts by weight respectively. Additionally methyl ethyl ketone peroxide was used as a catalyst, BC500 as an inhibitor; zinc stearate as stabilizer; magnesium oxide as a thickening paste; viscosity reducer and pigment were added and all were mixed for 10 min. Then the paste was transferred to a Z-mixer and surface modifier and $CaCO_3$ were added and were mixed for 0.5 hr. Afterwards 25 wt% glass fibers were added to the paste and mixed for another 15 min. Afterwards the mixture was conditioned for one week before samples preparation. Finally, samples (tensile, hardness and erosion) were prepared from the mix by molding using a hydraulic press at 1500 MPa pressure. The samples were then cured at a temperature of 150°C for about 60 second within the mold.

2.2. Tensile strength, hardness and erosive tests

Tensile tests were carried out at a cross head speed of 5 mm/min and temperature of 23°C. The tensile strength and elongation at break were recorded. Indentation test was carried out using Barcol hardness measurement. On each sample several tests were carried out and average values were recorded. The erosion tests were carried out using in-house made erosion rig, see Figure 2. This rig consists of a compressed air-supply system, a sand-supply system and a sample holder unit. During the test the holder was held at selected angles of 30, 60 and 90° with respect to the flow of the impingement sand particles. Al_2O_3 impingement sand particles of 400–500 micron size were used as eroding elements. Before and after each test, composite samples were cleaned with acetone and a brush was used to remove Al_2O_3 particles attached to the surface and their weights were recorded. All tests were carried out at a 40 m/sec impingement speed. Erosion wear was measured by the weight loss. The normalized erosion rate (W_s) was expressed in terms of Equation (1):

$$W_s = W_c/W_{Er} \tag{1}$$

Where W_c is the loss in weight of the composite material and W_{Er} is the total weight of erodent (Al_2O_3) used (W_{Er} = 2360 g). Wc is determined by weighing the sample before and after the erosive wear test using a balance with an accuracy of $1 \cdot 10^{-4}$ g. Each erosive wear tests was performed twice and average wear values were calculated.

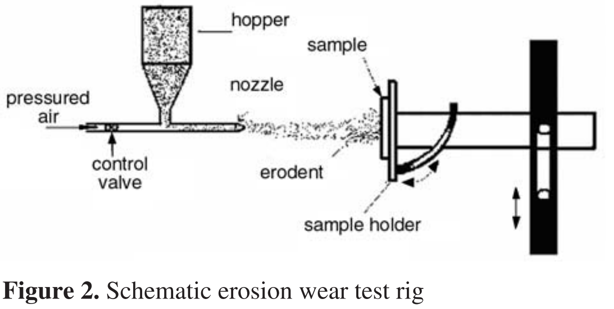

Figure 2. Schematic erosion wear test rig

3. Results and discussions

Figures 3–5 illustrate the influences of $CaCO_3$ content (by weight) and $CaCO_3$ particle size on the mechanical properties of UPR/GFR/$CaCO_3$ composites. Figure 3 presents the influence of $CaCO_3$ content on the tensile strength of 10 micron $CaCO_3$ particle size UPR/GFR/$CaCO_3$ composite. It is clear from this figure that the tensile strength is increasing with the increase in $CaCO_3$ content. As the investigation is mainly focused on filler content rather than neat composite, taking the 40% $CaCO_3$

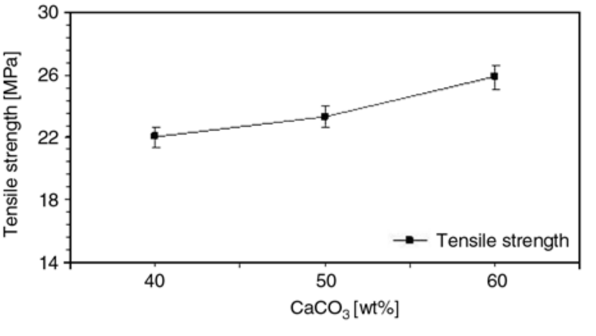

Figure 3. Influence of $CaCO_3$ content on the tensile strength of composite material (particle size 10 μm)

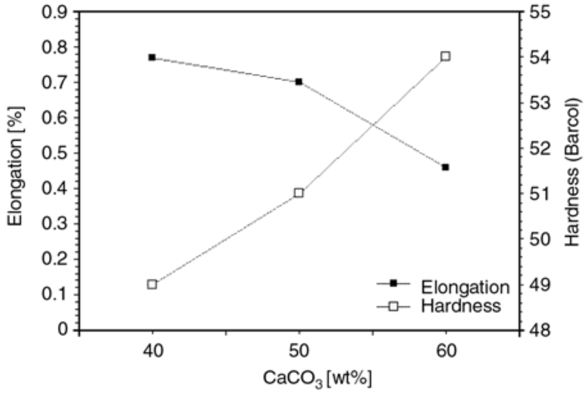

Figure 4. Influence of $CaCO_3$ content on the elongation at break and hardness of composite material

content composite the baseline there is about 18% increase in tensile strength for a 50% increase in $CaCO_3$ content. Because all added component materials are brittle in nature in comparison to UPR therefore this is reflected by the mechanical properties of the composite as a whole compound. Thus there is an increase in tensile strength of UPR/GFR/$CaCO_3$ composite with the increase in $CaCO_3$ content. Figure 4 presents the influence of $CaCO_3$ content on the elongation at break and on the Barcol hardness. In this particular case $CaCO_3$ of 10 micron particle size UPR/GFR/ $CaCO_3$ composite were tested. It is clear from this figure that the elongation at break is decreasing while the hardness is increasing with the increase in $CaCO_3$ content. This figure shows that for a 50% increase in $CaCO_3$ content there is a 40% decrease in percentage of elongation at break and 10% increase in hardness. The increase in $CaCO_3$ content result to increase in brittleness of the composite. Hence this results in a decrease of the percentage of elongation at break and in an increase in hardness value of the composite. On the other hand more brittle the material, the larger is the fraction of volume that is removed and hence the erosion rate is higher. The results from Figures 3 and 4 suggested that 50% content $CaCO_3$ composite has a balanced properties (tensile strength, hardness and elongation at break). Therefore further studies were carried out on 50% $CaCO_3$ content compound only. Figure 5 presents the influence of the $CaCO_3$ particle size on the tensile strength of UPR/GFR/$CaCO_3$ composite. It is clear from this figure that the tensile strength decreases with the increase in $CaCO_3$ particle size. This is related to the fact that for a particular $CaCO_3$ content the contact surface between the matrix and $CaCO_3$ particles decreases with increasing particle size resulting in a weaker bonding with the matrix, hence in a drop of the strength of the composite.

Figure 6 presents the influence of the impingement angle and $CaCO_3$ particle size on the erosion wear rate of UPR composite. It is clear from this figure that the larger is the impingement angle and the larger is the $CaCO_3$ particle size, the higher is the erosive wear rate of UPR/GFR/$CaCO_3$ composite. This could be explained so that in case of impingement of hard particles on a brittle material, plastic indentation takes place along with generation of long cracks extending from plastic zone. As these cracks do not stop and reach the surface leading to material removal. Impingement at 90° leads to greater depth in plastic zone hence to larger removal of material and maximum erosion rate.

Figure 7 present scanning microscopy of o 50 wt% and 1 µm particle size $CaCO_3$ content UPR/GFR/$CaCO_3$ composite surface eroded at different impingement angles: (a) 30°, (b) 60° and (c) 90°.

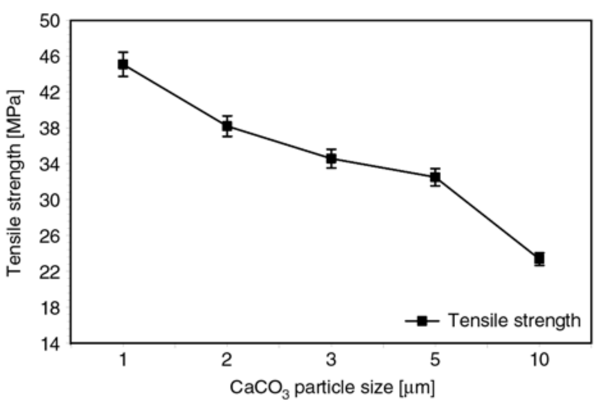

Figure 5. Influence of $CaCO_3$ particle size on the tensile strength of composite material (50wt% content $CaCO_3$)

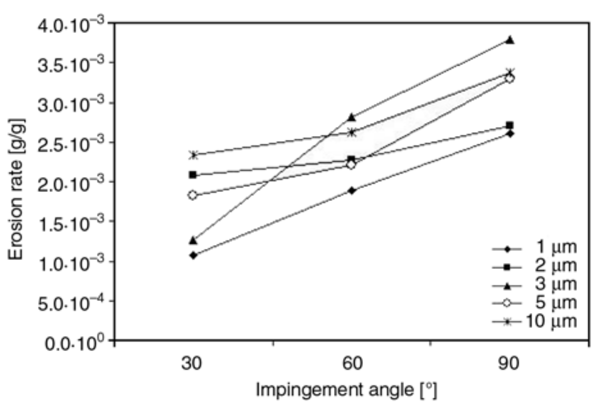

Figure 6. The influence of impingement angle on erosion rate of 50wt% $CaCO_3$ filled unsaturated polyester composites, erodent: Al_2O_3, velocity: 40 ms^{-1}

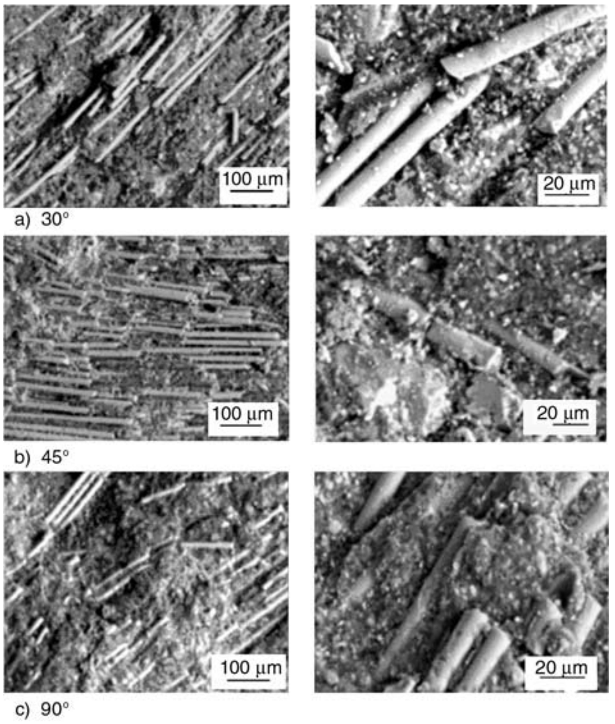

Figure 7. Scanning electron micrographs showing erosion features of unsaturated polyester 50 wt% $CaCO_3$ (particle size 1 µm) /UPR composites at different angles of impingement: a – 30°, b – 60° and c – 90°

The figure illustrates that the higher is the impingement angle, the more glass fibers are exposed. This means higher erosion in the matrix and filler materials and embedding of the GPR fiber. This shows the brittle behavior of UPR/GFR/$CaCO_3$ composite. Therefore the erosion is mainly caused by damage mechanisms as cracking due to the impact of Al_2O_3 particles.

4. Conclusions

It could be concluded that:

– The higher percentage of $CaCO_3$ content in UPR/GFR/$CaCO_3$ composite results to higher tensile strength, hardness and a less percentage of elongation at break.

– The larger the size of $CaCO_3$ particles, the higher is the decrease in tensile strength of UPR/GFR/$CaCO_3$ composite. A composite with 50% content with 1 micron $CaCO_3$ particle size has balanced erosive resistance with reliable tensile strength, elongation at break and hardness values.

– The maximum erosive wear rate is observed at 90° impingement angle.

– The SEM microscopy for UPR/GFR/$CaCO_3$ composite showed the brittle behavior and the cracking mechanism under erosive conditions.

– Although the addition of $CaCO_3$ to the composite has the advantage of minimizing the material cost there is a limitation in its percentage in the compound from point of view of strength and erosive resistance.

References

[1] Katz H. S., Milewskin J. V.: Handbook of fillers and reinforcements for plastics. van Nostrand Reinhold, New York (1978).

[2] Nalwa H. S.: Handbook of advanced functional molecules and polymers. Gordon and Breach, London (2000).

[3] Sare I. R., Mardel J. I., Hill A. J.: Wear-resistant metallic and elastomeric materials in the mining and mineral processing industries – an overview, Wear, **250**, 1–10 (2001).

[4] Zhou S. S., Wu L. M., Sun J., Shen W.: The change of the properties of acrylic-based polyurethane via addition of nano-silica. Progress in Organic Coatings, **45**, 33–42 (2002).

[5] Baral D., De P. P., Nando G. B.: Thermal characterization of mica-filled thermoplastic polyurethane. Polymer Degradation and Stability, **65**, 47–51 (1999).

[6] Srivastava V. K., Prakash R., Shembekar P. S.: Fracture behavior of fly ash filled FRP composites. Composite Structures, **10**, 271–279 (1988).

[7] Srivastava V. K., Shembekar P. S.: Tensile and fracture properties of epoxy resin filled with fly ash particles. Journal of Materials Science, **25**, 3513–3516 (1990).

[8] Tilly G. P.: Sand erosion of metals and plastics: A brief review. Wear, **14**, 241–248 (1969).

[9] Pool K. V., Dharan C. K. H., Finnie I.: Erosive wear of composite materials. Wear, **107**, 1–12 (1986).

[10] Kulkarni S. M., Kishore: Influence of matrix modification on the solid particle erosion of glass/epoxy composites. Polymer and Polymer Composites, **9**, 25–30 (2001).

[11] Miyazaki N., Hamao T.: Solid particle erosion of thermoplastic resins reinforced by short fibers, Journal of Composite Materials, **28**, 871–883 (1994).

[12] Bijwe J., Rattan R., Fahim M., Tiwari S.: Erosive wear of carbon fabric reinforced polyetherimide composites: Role of amount of fabric and processing technique. Polymer composites, **29**, 337–344 (2008).

[13] Rattan R., Bijwe J.: Carbon fabric reinforced polyetherimide composites: Influence of weave of fabric and processing parameters on performance properties and erosive wear. Materials Science and Engineering: A, **420**, 342–350 (2006).

[14] Srivastava V. K., Pawar A. G.: Solid particle erosion of glass fiber reinforced flyash filled epoxy resin composites. Composites Science and Technology, **66**, 3021–3028 (2006).

[15] Finnie I.: Some reflections on the past and future of erosion. Wear, 1**86–187**, 1–10 (1995).

[16] Barkoula N. M., Karger-Kocsis J.: Solid particle erosion of unidirectional GF reinforced EP composites with different fiber/matrix adhesion. Journal of Reinforced Plastics and Composites, **21**, 1377–1388 (2002).

[17] Barkoula N-M., Karger-Kocsis J.: Effects of fiber content and relative fiber-orientation on solid particle erosion of GF/PP composites. Wear, **252**, 80–87 (2002).

[18] Hutchings I. M.: Tribology: Friction and wear of engineering materials. Edward Arnold, London (1992).

[19] Häger A., Friedrich K., Dzenis Y. D., Paipetis S. A.: Study of ersion wear of advanced polymer composites. in: 'ICCM-10 Conference Proceedings, British Columbia, Canada' 155–162 (1995).

[20] Tsiang T-H.: Sand erosion of fiber composies: Tesing and evaluation. in 'Test Methods and Design Allowables for Fibrous Composites, vol 2.' (ed.: Chamis C. C.) ASTM, Philadelphia, 55–74 (1989).

[21] Rajesh J. J., Bijwe J., Tewari U. S., Venkataraman B.: Erosive wear behavior of various polyamides. Wear, **249**, 702–714 (2001).

[22] Tilly G. P., Sage W.: The interaction of particle and material behavior in erosion process. Wear, **16**, 447–465 (1970).

[23] Zahavi J., Schmitt G. F.: Solid particle erosion of reinforced composite materials. Wear, **71**, 179–190 (1981).

[24] Miyazaki N., Takeda T.: Solid particle erosion of fiber reinforced plastics. Journal of Composite Materials, **27**, 21–31 (1993).

[25] Bitter J. G. A.: A study of erosion phenomena part I. Wear, **13**, 5–21 (1963).

[26] Bitter J. G. A.: A study of erosion phenomena part II. Wear, **13**, 169–190 (1963).