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°
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 Al2O3 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 CaCO3 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 CaCO3/GFR filled unsaturated polyester (UPR) composites were examined. The variation of the strength, the hardness and the erosion resistance with CaCO3 weight fraction, CaCO3 particle size and impingement angle were studied and evaluated. Samples of UPR with 40, 50 and 60 wt% content of CaCO3 and different CaCO3 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/CaCO3 composite.

2. Experimental procedures
2.1. Materials and preparation of composite material

In this work the compound under investigation is UPR/GFR/CaCO3 composite consisting of unsaturated polyester resin (UPR), fiber glass (GF) and CaCO3 powder. For materials details see Table 1. In the sample preparation process the unsaturated

![Figure 1. Schematic representation of brittle and ductile type of erosive wear [4]](image-url)
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 CaCO₃ 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. Al₂O₃ 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 Al₂O₃ 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 \( W_i \) was expressed in terms of Equation (1):

\[
W_i = W_c/W_{Er}
\]

Where \( W_c \) is the loss in weight of the composite material and \( W_{Er} \) is the total weight of erodent (Al₂O₃) used (\( W_{Er} = 2360 \) g). \( W_c \) is determined by weighing the sample before and after the erosive wear test using a balance with an accuracy of 1·10⁻⁴ g. Each erosive wear tests was performed twice and average wear values were calculated.

### 3. Results and discussions

Figures 3–5 illustrate the influences of CaCO₃ content (by weight) and CaCO₃ particle size on the mechanical properties of UPR/GFR/CaCO₃ composites. Figure 3 presents the influence of CaCO₃ content on the tensile strength of 10 micron CaCO₃ particle size UPR/GFR/CaCO₃ composite. It is clear from this figure that the tensile strength is increasing with the increase in CaCO₃ content. As the investigation is mainly focused on filler content rather than neat composite, taking the 40% CaCO₃

![Figure 2. Schematic erosion wear test rig](image)

![Figure 3. Influence of CaCO₃ content on the tensile strength of composite material (particle size 10 μm)](image)
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 0.50 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°.
The figure illustrates that the higher is the impinge-
ment angle, the more glass fibers are exposed. This
means higher erosion in the matrix and filler mate-
rials and embedding of the GPR fiber. This shows
the brittle behavior of UPR/GFR/CaCO₃ compos-
ite. Therefore the erosion is mainly caused by dam-
age mechanisms as cracking due to the impact of
Al₂O₃ particles.

4. Conclusions

It could be concluded that:
– The higher percentage of CaCO₃ content in
UPR/GFR/CaCO₃ composite results to higher
tensile strength, hardness and a less percentage
of elongation at break.
– The larger the size of CaCO₃ particles, the higher
is the decrease in tensile strength of UPR/GFR/
CaCO₃ composite. A composite with 50% con-
tent with 1 micron CaCO₃ particle size has bal-
anced erosive resistance with reliable tensile
strength, elongation at break and hardness val-
ues.
– The maximum erosive wear rate is observed at
90° impingement angle.

– The SEM microscopy for UPR/GFR/CaCO₃
composite showed the brittle behavior and the
cracking mechanism under erosive conditions.
– Although the addition of CaCO₃ to the com-
posite 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., Milewski J. V.: Handbook of fillers and
reinforcements for plastics. van Nostrand Reinhold,
[2] Nalwa H. S.: Handbook of advanced functional mole-
cules and polymers. Gordon and Breach, London
(2000).
metallic and elastomeric materials in the mining and
mineral processing industries – an overview, Wear,
the properties of acrylic-based polyurethane via addi-
tion of nano-silica. Progress in Organic Coatings, 45,
33–42 (2002).
zation of mica-filled thermoplastic polyurethane.
ture behavior of fly ash filled FRP composites. Com-
[7] Srivastava V. K., Shembekar P. S.: Tensile and frac-
ture properties of epoxy resin filled with fly ash par-
ticles. Journal of Materials Science, 25, 3513–3516
[10] Kulkarni S. M., Kishore: Influence of matrix modifi-
cation on the solid particle erosion of glass/epoxy
composites. Polymer and Polymer Composites, 9, 25–
30 (2001).
mosplastic resins reinforced by short fibers, Journal of
of carbon fabric reinforced polyetherimide composites:
Role of amount of fabric and processing tech-
etherimide composites: Influence of weave of fabric
and processing parameters on performance properties
and erosive wear. Materials Science and Engineering:


