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# Investigation of erosive wear behavior and physical properties of SGF and/or calcite reinforced ABS/PA6 composites

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ABSTRACT

The aim of this study was to investigate the erosive wear behavior of glass fiber, $CaCO_3$ particle and glass fiber/$CaCO_3$ hybrid reinforced ABS/PA6 blend based composites. The samples were prepared by using melt mixing and injection molding techniques. The mechanical, thermal, morphological properties and erosive wear behavior were investigated in terms of reinforcing agent type and composition. It was observed that the tensile strength and modulus values of hybrid composites gave a value between tensile strength and modulus values of only fiber reinforced composites and only particle reinforced composites. From DSC analysis it was revealed that $T_g$ and $T_m$ of composites were not significantly affected by reinforcement; however, degree of crystallinity was found to be sensitive to reinforcement type and composition. The impingement angle was found to have a significant effect on the erosive wear behavior. The results indicated that composite materials exhibited maximum erosion rate at impact angle of 30° conforming their ductile erosion behavior. In order to investigate wear mechanisms, eroded surface analysis was done by scanning electron microscopy. Surface analysis showed that repeated impact of hard silica sand particles caused a local removal of the matrix from the fiber surface and led to form craters on the surface of the composite material.



## 1. Introduction

Polyamide 6 (PA6) is a major class of engineering plastics with a well balance of chemical resistance, wear resistance, mechanical and thermal properties. On the other hand, it has some drawbacks associated with its processing instability, high mold shrinkage, dimensional instability and high water affinity [1]. In addition, acrylonitrile–butadiene-styrene (ABS) has high toughness, dimensional stability and good surface texture [2]. However, ABS shows poor solvent resistance, insufficient mechanical (tensile and flexural) strength, and low dimensional stability at high temperatures [3].

The blends of PA6 with ABS have commercial interest because of the relatively low cost of ABS and its contribution to the blend's dimensional stability, processability and high toughness [4].

PA6 and ABS blends or their composites are often used as automotive components where erosive wear occurs, such as mirror housing, front shield and axle cap [5]. In general the problems associated with erosion are the costs arising from the replacement of worn parts, increased labor, loss of productivity and indirect losses of energy. Therefore erosion of polymers and their composites have attracted both academic and industrial attention.

The erosive wear behavior of different polymeric materials is studied by various researchers in the literature. Arjula et al. investigated the erosive wear behavior of six types of high-performance thermoplastic polymers [polyetherimide (PEI), polyetheretherketone (PEEK), polyetherketone (PEK), polyphenylene sulfide (PPS), polyethersulfone (PES), and polysulfone (PSU)] [6]. They found that the polymers showed maximum erosion rate at 30° impact angle and minimum at 90° impact angle, indicating ductile behavior. Besides it was observed that mechanical properties of the selected polymers played an important role in controlling the erosive wear behavior. Rajesh et al. studied the erosive wear behavior of various polyamides with different methylene to amide ratio in the backbone [7]. They also used two different impact angles and impact velocities with silica sand as erodent. It was concluded that the same amount of particles at higher impact velocity caused significant damage at the sample surface and resulted in higher erosion rate.

Yilmaz et al. investigated tensile strength, hardness and erosive wear behaviors of $CaCO_3$ filled unsaturated polyester/glass fiber (UPR/GFR) composites [8]. They examined the effect of the $CaCO_3$ particle size and loading level. The results showed that the higher

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the percentage and the smaller the particle size of the $CaCO_3$, the higher the strength and the erosive resistance of the composites. The maximum erosive wear rate was seen at 90° impingement angle. Miyazeki et al. reported the erosive wear behavior of ABS and its glass-fiber-reinforced composites as a function of the angle of impact and the particle velocity [9]. It was found that the erosion rate was larger in a fiber reinforced polymer (FRP) than in a neat resin. In this study, fiber–matrix interfacial strength was emphasized. The erosion rate of fiber reinforced ABS decreased with the increase of the interfacial strength between matrix and fibers. Yilmaz studied the influence of annealing duration on the erosive wear behavior of $CaCO_3$ mineral particulate (25% w/w)/short glass fiber (SGF) (40% w/w) and SGF (40% w/w) reinforced polyphenylenesulphide (PPS) composites [10]. It was concluded that the erosion rate was maximum at 60° impingement angle and minimum at 90° for composite materials. Weight loss values of calcite/SGF composites were higher than SGF reinforced composite samples.

To the best of our knowledge, the combined effects of glass fibers and particulate filler on the erosion characteristics of ABS/PA6 blends have not been published. In this study, only glass fiber, only $CaCO_3$ particle and glass fiber/$CaCO_3$ hybrid reinforced ABS/PA6 blend based composites were prepared. The variation of mechanical, thermal, morphological properties and erosive wear behavior of each composite were examined in terms of reinforcing agent type, composition and impingement angle. In addition to that, correlation between the erosive wear behavior and physical properties of composites, were investigated.

## 2. Materials and methods

ABS/PA6 (Triax 1120) was used as matrix material and was provided in granule form from Lanxess. Glass fiber (PA1, Cam Elyaf A.Ş) and $CaCO_3$ (Omya A.Ş) were used as reinforcement materials.

$CaCO_3$, glass fibers and $CaCO_3$/glass fiber reinforced ABS/PA6 composites were prepared by using melt mixing method. The compounding of PA6/ABS and different ratio reinforced material were carried out in a laboratory scale co-rotating twin-screw mini extruder (DSM Xplore 15 ml Micro-compounder) at 235 °C, 100 rpm. Compounding ratios of prepared composites were given in Table 1. The compounds were subsequently injection molded with a laboratory type injection molding machine (DSM Xplore 12 ml Micro-injection Molder). The barrel temperature and mold temperature were 235 °C and 80 °C, respectively; and injection pressure was 10 bars.

Tensile tests of the composites were conducted by using an Instron 4411 universal testing machine. Tensile strength, modulus and strain at break values were measured according to ISO 527. Average results obtained from five dumbbell-shaped samples were reported for each composite. Rockwell hardness test of composites were performed using BROOKS Model MAT 10/250 Hardness Testing Machine, according to the ASTM D 785-08. Rockwell R scale was used with 12.7 mm diameter ball indenter, 10 kg minor load, and 60 kg major load.

**Table 1**
Compounding ratios of composites.

| Matrix/SGF/calcite | Composite type | Matrix (wt.%) | SGF (wt.%) | Calcite (wt.%) |
|---|---|---|---|---|
| 100/0/0 | Neat-matrix | 100 | 0 | 0 |
| 95/0/5 | Calcite reinforced composites | 95 | 0 | 5 |
| 90/0/10 | | 90 | 0 | 10 |
| 80/0/20 | | 80 | 0 | 20 |
| 70/0/30 | | 70 | 0 | 30 |
| 90/10/0 | SGF reinforced composites | 90 | 10 | 0 |
| 80/20/0 | | 80 | 20 | 0 |
| 70/30/0 | | 70 | 30 | 0 |
| 60/40/0 | | 60 | 40 | 0 |
| 80/10/10 | Hybrid composites | 80 | 10 | 10 |
| 70/15/15 | | 70 | 15 | 15 |
| 60/20/20 | | 60 | 20 | 20 |

The melting temperature and melting enthalpy of the composites were measured with a Mettler Toledo DSC 1 model differential scanning calorimeter (DSC) under nitrogen atmosphere. The DSC procedure was consisting of three segments. In the first segment, the samples were heated from 25 °C to 250 °C with a heating rate of 10 °C/min; then they were held at this temperature for 3 min in order to eliminate the thermal history; and then they were cooled to 25 °C at cooling rate of 10 °C/min. In the last segment, they were reheated to 250 °C at a heating rate of 10 °C/min. The degree of crystalinity of samples was calculated with the following expression:

$$X_c\ (\%) = \frac{\Delta H_f}{\omega \times \Delta H_{TRIAX}} \times 100 \quad (1)$$

where $\Delta H_f$ is the experimental heat of fusion, $\omega$ the weight fraction of the matrix, and $\Delta H_{TRIAX}$ is the heat of fusion of 100% crystalline matrix [11]. Triax is a trademark and a polymer blend consisting of ABS and PA6. Hence, there is no heat of fusion value for 100% crystalline Triax in literature. Because of this reason, heat of fusion value of unreinforced Triax, obtained from our DSC analyze was used as $\Delta H_{TRIAX}$ which is equal to 21.27 J/g.

Morphologies of composites were observed by means of scanning electron microscopy (SEM) with a JEOL JSM-6335F electron microscope. Tensile fracture surfaces of composites were sputter coated with gold and palladium prior to analysis.

Solid particle erosion tests were performed by using erosion wear test equipment as schematically shown in Fig. 1. Injection molded sample dimensions were $80 \times 40 \times 2$ mm. Erosion test conditions were given in Table 2. The eroding particles were driven by a static pressure of 4.5 bar and were accelerated along a 50 mm long tungsten carbide (WC) nozzle of a diameter of 5 mm. These accelerated particles impact the specimen, which can be held at various angles with respect to the impacting particles using an adjustable sample holder. The average velocity ($v$) of the silica sand at this pressure at the nozzle tip was 60 m/s. The velocity of the eroding particles is determined using a rotating disk method [12]. Erodent mass flow was measured as 9 g/s for 60 m/s impact velocity. A scanning electron micrograph of silica sand particles is shown in Fig. 2. A standard test procedure was employed for each test. The samples were cleaned, dried, and weighed to an accuracy of $1 \times 10^{-4}$ g using an electronic balance, eroded in the test rig for 15 s and then weighed again to determine weight loss.

## 3. Results and discussion

### 3.1. Mechanical properties of composites

The representative stress–strain curves for neat-matrix, 10% and 20% calcite reinforced composites are shown in Fig. 3; and representative stress–strain curves for 20% SGF reinforced and 20% SGF-20% calcite reinforced composites are shown in Fig. 4. In addition, Figs. 5, 7 and 8 exhibit the dependence of tensile strength, elongation at break and modulus of composites, respectively, with respect to filler type and loading level.

It is seen that the characteristics for neat matrix in tensile test are yielding and cold drawing which indicates a typical ductile behavior. The addition of calcite did not alter the yielding behavior of matrix independently from loading level (Fig. 3). This behavior can be attributed to the unrestricted chain slippage of the matrix during tensile test (especially in the plastic deformation region)