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Investigation of Mechanical and Dry Sliding Wear Behaviours of AlB_2/PE Polymer Matrix Composites

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In this study, mechanical and wear behaviour of polymer-boride composite (AlB_2/PE) materials produced through pressure moulding technique have been experimentally investigated. Three different composite materials that include 5 wt%, 10 wt%, and 20 wt% AlB_2 reinforcement phase were tested using pin-on-disk arrangement. Compared with the matrix, the 20 wt% AlB_2 composite shows a 71% increase in the ultimate tensile strength and the highest wear resistance.

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1. Introduction

Polyethylene (PE) is an engineering plastic which has a wide spectrum of applications, particularly as a material for orthopedic prostheses due to its high strength, excellent toughness, high resistance to chemicals and physical abrasion, and low friction coefficient [1, 2]. In engineering, PE was used for some components or parts of machines in chemical engineering, textile engineering, food processing, paper making industry, pharmacy, transportation engineering, agricultural engineering, coal and ceramic production, where PE was substituted for carbon steel, stainless steel and bronze, because of its better anti-chemical-corrosion, water-repellent function, anti-adhesion, self-lubrication and higher impact resistance [3].

Polymer and polymer based composites are preferred for many industrial sectors such as automotive, electrical/electronic, aircraft and household applications. This is because these materials provide high strength/weight ratio in comparison to classic material and self-lubricant conditions. However, application areas of polymeric materials are restricted due to their low mechanical, thermal and tribological properties. Therefore reinforcements are used to increase their mechanical properties [4].

The used reinforcement and additive materials are glass fibre [5, 6], $CaCO_3$, [7, 8] kaolin, [9, 10], talc [11], wollastonite [3], and mica [12, 13] fillers and MoS_2, graphite, carbon, wax, polytetrafluoroethylene (PTFE), and dry lubricants [14, 15]. Dry lubricants are materials which despite being in the solid phase, are able to reduce friction between two counterparts sliding against each other without the need for a liquid medium [16].

In this study, aluminum diboride (AlB_2) has been used as a reinforcement material. It is used commercially to scavenge transition-metal elements during the production of aluminum electrical wire [17] and is also used as an aluminum grain refiner [18]. It is known that the crystal structure of borides is hexagonal close packed (HCP) and the density of the AlB_2 borides are higher (3.190 kg/m^3) [19]. They are also a finer flake shape which can range ratio values of 30 up to 400 with a thickness of a few μm [19, 20]. AlB_2 flakes have been produced by liquid state reaction between aluminium and boron in an aluminium-boron (Al–B) alloys or systems [19–22].

In order to study the influence of AlB_2 boride flakes on tribological properties of PE, PE composites were produced by pressure moulding technique.

2. Experimental procedure

In this study, AlB_2 boride flakes wave been used as the reinforcement materials. AlB_2 borides flakes have been produced by liquid state reaction between aluminum and boron in the aluminum matrix with adding boron oxide into liquid aluminium as explained elsewhere by Savas et al. [20]. In order to separate AlB_2 boride structure, aluminum matrix has been dissolved in a solution of 20% HCl solution for 1 h at 25 °C. A scanning electron microscope (SEM) image of the AlB_2 boride flakes is shown in Fig. 1A. The flakes have a hexagonal flake shape. The average width of AlB_2 flake is 35 μm and thickness of AlB_2 is 0.6 μm.

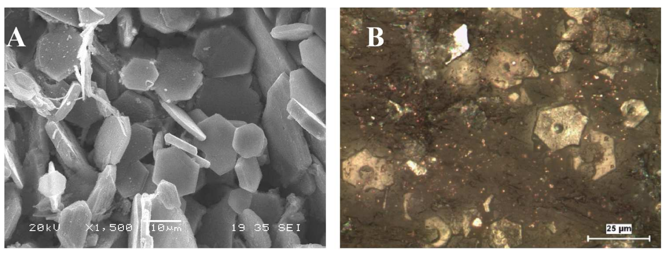

Fig. 1. (A) SEM image of the AlB_2 boride flakes and (B) a typical microstructure of the AlB_2/PE composite material.

Polymer matrix materials with no reinforcement, reinforced with 5 wt%, 10 wt% and 20 wt% AlB_2 flake have been produced by using pressure moulding technique.

A typical microstructure obtained from AlB_2/PE composites is given in Fig. 1B. The production of all matrix and composites was performed under the same process parameters as shown in Table I.

TABLE I

Production of process parameters.

Process parameters	
temperature	175 °C
holding time	5 min
pressure	160 bar
heat rate	10 °C/min
cooling rate	20 °C/min

An Olympus optical microscope equipped Image Analysis Software–Clemex Vision was used for microstructure analyses and measurements of AlB_2 flake of widths, thickness, SEM analyses were performed using a JEOL JSM 6060LV to determine the reinforcement shape. The tensile strength was analyzed using a 50 kN computerized universal testing machine as per the ASTM-E8M standards at room temperature.

Wear tests were carried out using by a pin-on-disc arrangement at room temperature under the dry sliding conditions. The cylindrical pin specimens of 6 mm diameter and 10 mm length were tested against stainless steel disc. The counter body is a disc made of ground stainless steel (AISI 440C, hardness 63hRC, surface roughness 0.24 μm). After each test the mass loss in the pin was measured. Wear volume in pin was calculated from recorded mass losses. Finally, the specific wear rate, K_s [mm^3/(N mm)] was calculated by

$$K_s = \Delta V / PS, \quad (1)$$

where ΔV is the wear volume, P — the applied load and S is the sliding distance. Sliding wear data reported here is the average of at least three runs. The test was carried out by applying normal loads of 30, 80, and 120 N and run for constant sliding distance of 2000 m at constant sliding velocity of 1.5 m/s.

3. Results and discussion

The matrix (PE) and the composites with reinforced 5 wt%, 10 wt%, and 20 wt% AlB_2 flake are listed in Table II. The results indicate that the ultimate tensile strength (UTS), yield strength and modulus of the composite are increased by increasing the $A1B_2$ flake. The 5 wt% composite shows a modulus increase over the matrix (PE) of 7%, the 10 wt% composite exhibits an 5% increase in modulus over the matrix (PE) (Table II). Compared with the matrix, the 20 wt% $A1B_2$ composite shows a 71% increase in the ultimate tensile strength (UTS), % increase in the yield strength and 91% increase in modulus, the strain of the composites is also 317%.

It was found that the coefficient of friction of the PE composites against the steel disk was a function of the AlB_2 flakes contents, the applied normal loads. The AlB_2 flakes played a role in decreasing the coefficient of friction of the composites and, as a result, the coefficient of friction increased with the content of the AlB_2 flakes. The modification of the AlB_2 flakes resulted in a reduction of the friction coefficient, as shown in Fig. 2A.

TABLE II

Mechanical properties of the AlB_2/PE composites and PE matrix.

Properties	Matrix (PE)	5 wt% AlB_2/PE	10 wt% AlB_2/PE	20 wt% AlB_2/PE
UTS [MPa]	25.10	26.87	26.37	28.74
yield strength [MPa]	7.56	10.19	11.14	12.89
strain [%]	506	273	522	317
module [MPa]	691.2	1081.8	1115.6	1318.4

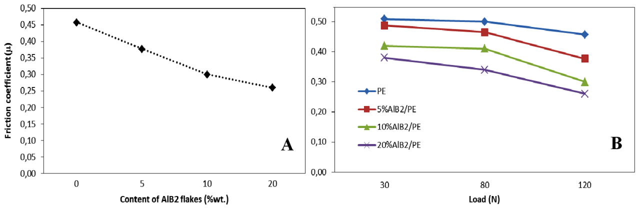

Fig. 2. (A) The variation of the coefficients of friction of PE–AlB_2 flakes composites with the AlB_2 flake contents at a velocity of 1.5 m/s and under a load of 120 N and (B) relationship between coefficient of friction and load for pure PE and PE polymer composites with AlB_2 flakes (sliding speeds 1.5 m/s).

The coefficient of friction of the PE composites with AlB_2 was decreased as the applied normal load was increased, as shown in Fig. 2B, which approximately followed the relation of $\mu = Kp^{n-1}$, where μ is the coefficient of friction, p — the applied normal load, K and n — the constants, and in the most cases, n is more than 2/3 and less than 1.

Figure 2 represents the variation of specific wear rate with load and at 1.5 m/s sliding speed. It has been observed that the specific wear rate decreases with the increase in the weight fraction of the reinforcement phase within the composite. Compared to the pure PE, hard AlB_2 flakes in composite material may cause reduction in the real area of contact between wear couples [3, 23]. The asperity interactions taking places over the AlB_2 flakes of composite are expected to form weak junctions [24, 25]. These two major factors may collectively decrease the wear rate of the composite material with respect to the matrix alloy. As expected, the highest wear rate was observed with the pure PE and then with the composite with 5% AlB_2 flakes.

For all the test conditions, the composite sample containing 20% AlB_2 reinforcement phase has displayed the best wear resistance of all other materials (Fig. 3A). The wear resistance of the pure PE was increased with the AlB_2 flakes content as shown in Fig. 3B. The wear resistance of the AlB_2/PE composites was increased as the AlB_2 flakes content was increased. That is, the AlB_2/PE

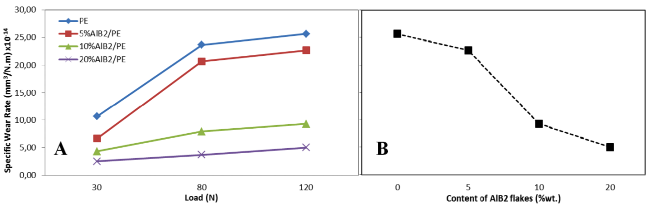

Fig. 3. (A) Effect of normal load on friction coefficient of PE and its composites under at constant 1.5 sliding speed and (B) the effects of the content the AlB_2 flakes on the sliding wear of the pure PE.

composites had the highest wear resistance when the AlB_2 flakes content was about 20 wt%.

4. Conclusions

1. Compared with the matrix, the 20 wt% $A1B_2$ composite shows a 71% increase in the UTS, % increase in the yield strength and 91% increase in modulus, the strain of the composites is also 317%.
2. The coefficient of friction of the PE composites was decreased with the contents of the AlB_2 flakes.
3. The wear resistance of the composites was the highest when the AlB_2 flakes content was about 20 wt%.

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