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Effect of friction and wear parameters on acrylonitrile butadiene styrene/aluminum-boron carbide-glass spheres polymer composites

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1. Introduction

Wear behavior is one of the most important properties of polymer and its composites. Therefore, many studies on wear properties of polymer and its composites have been carried out [1]. A scientific understanding of the mechanism of friction and wear is still lacking, because wear is complex phenomenon and its mechanism depends on many parameters like the chemical and physical properties of polymer, composition, load, velocity etc. [2]. In recent years polymers have been extensively used in tribological components such as gears, cams, wheels, brakes, seals, and bushing because of their self-lubricating properties, low coefficient of friction, and better wear resistance. However, unfilled polymers could not satisfy the requirement wherein a combination of properties such as good mechanical and tribological properties is required. The wear resistance of polymer composites is significantly decreased and increased depending upon the type of particles, particles size and size distribution, interfacial actions between polymer matrix and fillers, as well as wear test conditions, i.e., wear mode, sliding distance, applied load, test temperature, and humidity [3]. Some polymer composites are a widely used for gear and bearing applications and its tribological properties have been studied by many researchers. Investigations report that the coefficient of friction can, generally, be reduced and the wear resistance with polymer sliding against steel improved when the polymers are reinforced with glass, carbon or aramid fibers. The behavior is, however, affected by factors such as the type, amount, size, shape, and orientation of the fiber, the matrix composition and the best conditions such as load, speed and temperature [4-7]. Hutchings [8] and Tewari et al. [9] reported that the friction between polymers could be attributed to two main mechanisms, deformation and adhesion. The deformation mechanism involves complete dissipation of energy in the contact area. The adhesion component is responsible for the friction of polymer and is a result of breaking of weak bonding forces between polymer chains in the bulk of the materials. Zhang et al. [10] studied the effect of particle surface treatment on the tribological performance of epoxy-based nanocomposites with silica fillers. It has been found that, unlike micrometer silica, the low volume percent of silica, i.e., 2% showed better wear resistance.

The objective of this work is to investigate the tribological behavior of acrylonitrile butadiene styrene based composites filled with aluminum, boron carbide and glass spheres particles. Tribological tests were at room temperature under 5, 10, 15 and 20 N load values for wear (at 40 rpm cylinder rotational speed) and 2,3,4,5 and 7 N load values for friction (at 100 mm/min sliding speed).

2. Experimental

2.1. Compositions and materials

Thirteen different polymer composites were prepared. Compositions of ABS polymer composites that were formed are given in Table 1. Acrylonitrile butadiene styrene (AN 450) was supplied by Proplus Sourcing Co., Ltd. (Bangkok, Thailand). Inert gas atomised aluminium powders (99.5% purity, 0.45%O, 0.040%Si and 0.010%Fe) provided by Ecka Granulate GmbH & Co. (Furth, Germany) were used. It has particle size distributions of D10 = 3.88 μm, D50 = 7.35 μm and D90 = 13.62 μm. Boron carbide (1000 BC) was supplied Electro Abrasives Co. (NY, USA). Its molecular weight is 55.3 gm/mol. Glass spheres (filled with alumina silicate) (MinTron 7) was supplied by RockTron International (Bristol- United Kingdom). Its moisture content and particle specific gravity are < 0.5% and 2.2-2.4 g/cm3 respectively. Particle size distribution (D50) is 20-35 μm.

Table 1

Composition of the different ABS polymer composites formulations

Groups	ABS (wt%)	Aluminum (Al) (wt%)	Boron carbide (B_4C) (wt%)	Glass Spheres (wt%)
1	100	-	-	-
2	95	5	-	-
3	90	10	-	-
4	85	15	-	-
5	80	20	-	-
6	95	-	5	-
7	90	-	10	-
8	85	-	15	-
9	80	-	20	-
10	95	-	-	5
11	90	-	-	10
12	85	-	-	15
13	80	-	-	20

2.2. Sample preparation

Mechanical premixing of solid compositions was done using a LB-5601 liquid-solids blender (The Patterson-Kelley Co., Inc. east Stroudsburg, PA-USA) brand batch blender for 15 min. Samples with various proportions of ABS polymer composites were produced between 200-240°C at 25-35 bar pressure, and a rotation rate of 25 rpm, with a Microsan extruder (Microsan Instrument Inc. Kocaeli - Turkey). *L*/*D* ratio is 30, Ǿ25 mm, Polymer composites were also dried in vacuum oven at 80°C for 24 hours after extrusion. Subsequently, test samples were molded in injection molding machine. Injection temperature was between 200-240°C and pressure was 120-160 bar.

2.3. Mechanical characterization

The tensile strength and modulus of the compressed plates were measured by using a tensile testing machine (Zwick Z010, Ulm-Germany) according to ASTM D638 at room temperature and crosshead speed of 50 mm/min. For every composition, five samples were tested, and the averages of the five measurements were reported. To investigate fracture behavior, Izod impact test (notched) was done at room temperature according to the ASTM D256 method with Zwick B5113 impact test device (Zwick, Ulm-Germany). Flow behavior testing of all the mixtures was done according to ISO 1133 standard with Zwick 4100 MFI equipment.

2.4. Tribological tests

Static and dynamic coefficient of friction test was done according to the ISO 8295 method with Devotrans friction coefficient measurement equipment. The dimensions of the tested specimens were 80x200x4 mm and the dimensions of the sled specimens were 63x63x4 mm. Speed was selected as 100 mm/min.

2.4.1 Static coefficient of friction (μs)

The force increases linearly to a maximum which represents the static frictional force F_S. Measurements made at a high friction drag permit the dynamic coefficient of friction to be calculated, but not the static coefficient of friction. The static coefficient of friction μs is given by the equation,

$$\mu s = F_S/F_P, \tag{1}$$

where F_S is the static frictional force, N; F_P is the normal force exerted by the mass of the sled, N (=1.96 N).

2.4.2. Dynamic coefficient of friction (μ_D)

The friction force acting during the sliding motion often differs from the constant value which would exist in an ideal situation due to secondary effects related to increasing path length. The dynamic frictional force F_D is the average force over the first 6 cm of movement after the start of relative movement between the surfaces in contact, neglecting the static force peak Fs. The dynamic frictional force using the equation,

$$\mu_D = F_D/F_P\,, \tag{2}$$

where F_D is the dynamic frictional force, N; F_P is the normal force exerted by the mass of the sled, N (=1.96 N) [11].

Scheme of friction coefficient test is presented in Fig. 1.

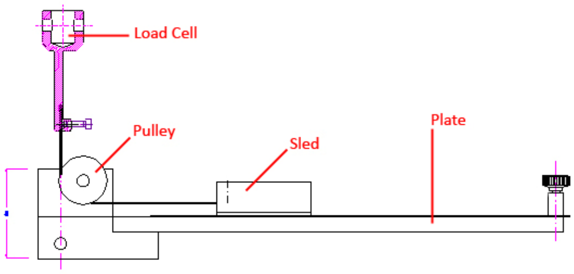


Fig. 1 Scheme of friction coefficient test [12]

2.4.3. Wear rate

The wear tests were done according to the DIN 53 516 method with Devotrans DA5 (Devotrans quality control test equipment Istanbul-Turkey) abrasion test equipment. The thickness of the test specimens was 7.0 mm and diameter was 15.5 mm. Cylinder rotational speed was selected as 40 rpm and normal load F_N of 10 N was used. Total sliding distance L was 40 m. The mass loss of the samples Δm was measured after the wear process, and the specific wear rates Ws were calculated using the following equation:

$$Ws = \Delta m / \rho\, F_N\, L, \text{ mm}^3/\text{Nm}, \tag{3}$$

where Δm is the specimen's mass loss, ρ is the density of specimen, F_N is the normal load applied, and L is the total sliding distance.

The friction coefficients and wear rates reported in the present study were the averages of at three measurements. Scheme of wear test is presented in Fig. 2.

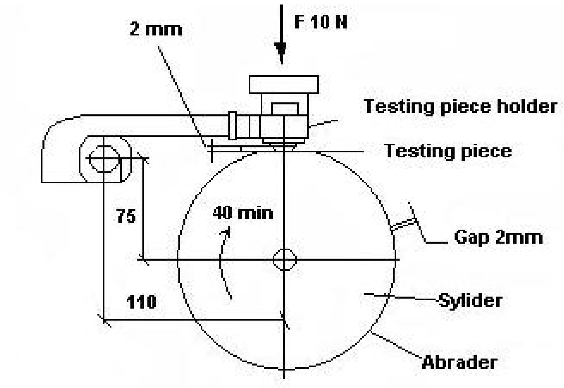


Fig. 2 Scheme of wear test [13]

2.5. Microscopy

The fractured surfaces of the ABS polymer composites were coated to an approximate thickness of 10 nm of a gold (Au) (80%)/palladium (Pd) (20%) alloys to prevent electrical charging by Polaron SC 7620 (Gala Instrumente GmbH, Bad Schwalbach-Germany). The surfaces of the prepared samples were observed by the JEOL-JSM 5910 LV (JEOL Ltd., Tokyo, Japan) scanning electron microscopy (SEM) at an acceleration voltage of 20 kV.

3. Result and discussion

3.1. Mechanical properties of ABS polymer composites

The tribological behavior of materials has close relations with its mechanical properties. The effects of powders content on the mechanical properties of the ABS polymer composites are given in Table 2. The elasticity modulus of ABS composites increases as the all filler concentration increases from 5 to 20 wt %. This was due to the uniform distribution of all filler in the ABS matrix. On the other hand, tensile strength, % elongation and Izod impact strength values are decreased as the filler concentration increased from 0 to 20 wt %. The embrittlement of the composites resulted from the weak interfacial adhesion between fillers and ABS matrix.

Table 2

Mechanical properties of the ABS composites

Groups	Tensile strength, MPa	Elasticity modulus, MPa	Izod impact test (notched), kJ/m^2	MFI g/10min
1	48	578	24	5
2	37	432	13	4.5
3	38	510	11	3
4	36	577	9	2.9
5	36	612	8	2.8
6	41	549	12	3
7	40	698	10	2.9
8	41	711	8	2.8
9	40	726	7	2.5
10	40	555	16	3.2
11	39	609	13	2.7
12	39	653	11	2.7
13	38	715	10	2.9

3.2. Wear properties of the ABS polymer composites

The effects of applied load, sliding distance and fillers content on the tribological behaviors of ABS composites were examined. The values of sliding distance-wear loss relationship are shown in Table 3. Table 3 shows the wear loss for various specimens sliding distance against the sand paper (#60) under 10 N load and 0.32 m/s abrasion speed. It can be seen that the wear loss of composites increase with increasing sliding distance. On the other hand wear loss of composites increase with increasing filler content (except boron carbide groups). The same trend is taken on for the applied load-wear loss relationship (Table 4). When the distance was more than 20 m, the wear loss began to increase rapidly. When the load was more than 5 N, the wear loss began to increase rapidly as well (Tables 3-4).

But in 6-9 groups wear loss decreased because of hard boron carbide particles. It suggests that this is a critical load and distance value for transition from mild wear to severe wear of the materials. If the load and distance exceeds the value, the pressure on the wear surface is so big that the surface of ABS composite is serious destroyed and severe wear occurs. Note that wear loss of specimen with high fillers content increased greatly, reflecting the effectiveness of the addition of aluminum and glass sphere particles on increasing wear loss of specimen. For example, ABS/Al (80/20) or ABS/glass sphere (80/20) is a low mechanical resistance material which easily occur deformation. The contact area and wear loss of the counterpart is proportional to applied load. The less deformation of the composite, the smaller friction force and wear loss of the friction counterpart is, due to the decreased contact area between the friction counterparts.

Table 3

Sliding distance-wear loss relationship of ABS polymer composites

Sliding distance, m (applied load:10N)				
	20	40	60	80
Groups	Wear loss, mg			
1	112.0	246.1	313.2	413.5
2	138.1	275.0	395.0	502.0
3	152.2	311.3	432.1	554.0
4	159.5	329.5	467.4	594.5
5	169.0	341.3	489.0	627.2
6	140.0	271.8	381.2	466.0
7	133.8	272.7	352.1	424.4
8	127.5	266.4	327.2	374.8
9	116.4	255.8	281.8	326.5
10	71.1	199.9	204.3	221.6
11	73.7	195.5	211.1	251.2
12	81.8	202.8	216.9	255.2
13	83.9	241.7	244.4	255.6

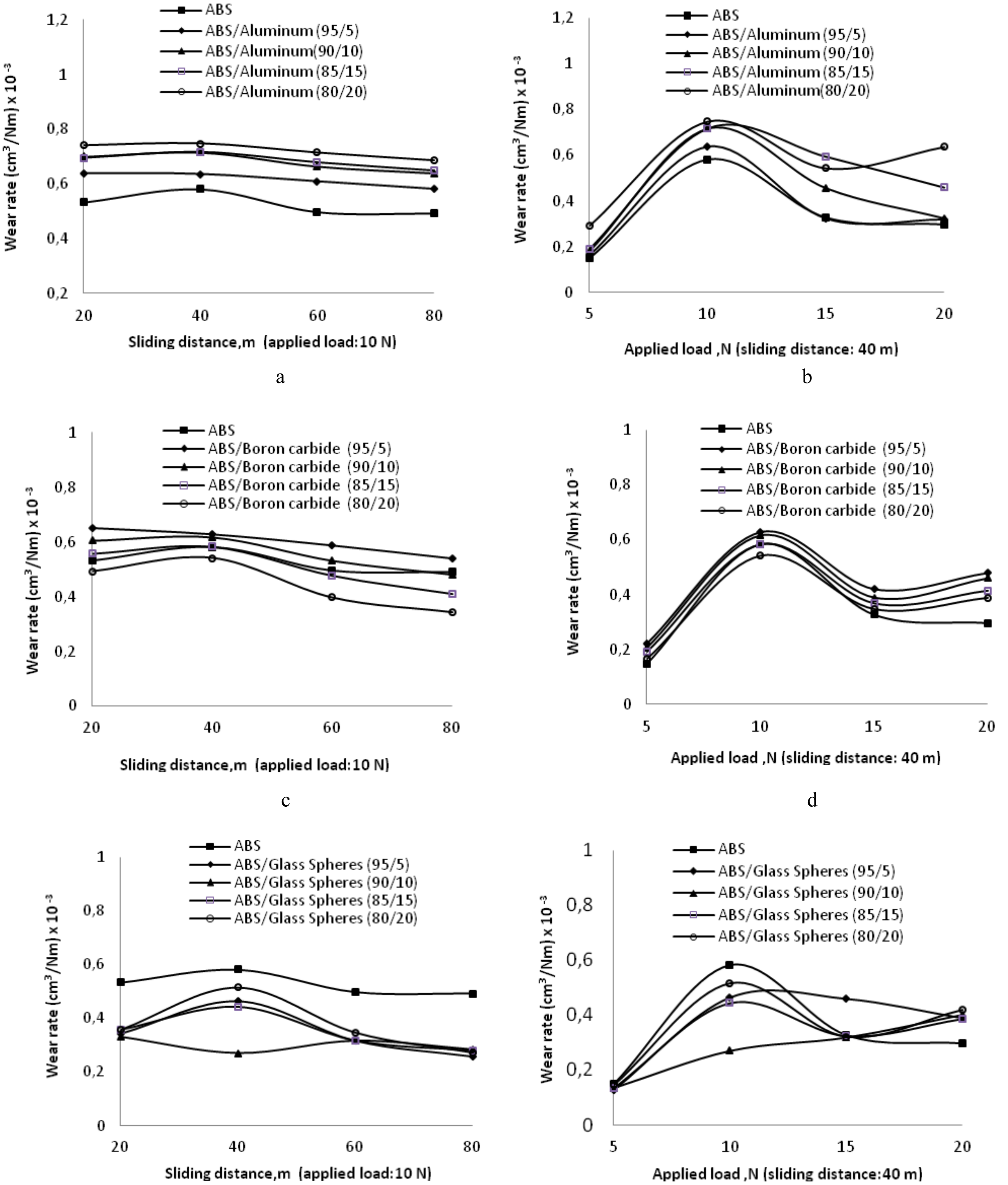
Table 4

Applied load-wear loss relationship of ABS polymer composites

Applied load, N (sliding distance:40 m)				
	5	10	15	20
Groups	Wear loss, mg			
1	31.4	246.1	206.1	249.0
2	35.0	275.0	208.9	275.2
3	39.3	311.3	296.9	281.3
4	44.2	329.5	409.5	421.7
5	67.2	341.3	372.6	581.5
6	48.1	271.8	272.8	414.4
7	45.5	272.7	258.2	406.7
8	44.1	266.4	253.1	379.2
9	39.2	255.8	245.8	366.4
10	27.5	199.9	296.5	335.3
11	30.1	195.5	210.9	353.6
12	30.5	202.8	221.0	352.0
13	33.8	241.7	226.2	393.3

The results of the wear rate of ABS/Al, ABS/boron carbide and ABS/glass sphere polymer composites at different loads and sliding distances are presented in Fig. 3. Aluminum particulates much larger wear rate (Fig. 3) than that of the pure ABS, which could be attributed to the weakened adhesion between the fillers and polymer matrix in the presence of an excessive amount of aluminum particulates. Boron carbide and glass sphere particles much smaller wear rate than that of the pure ABS, which could be attributed to the hard particles. Boron carbide is one of the hardest materials known, behind cubic boron nitride and diamond.

Fig. 3 shows the variations of the wear behavior of the composites with the sliding distance and applied load. It is seen that the sliding distance and applied load had a great effect on the wear rate of composites. Wear rate increased with the increase of the sliding distance up to 40 m but it decreased within the sliding distance from 40 to 80 m. On the other hand, wear rate increased gradually with the increase of the load up to 10 N but it decreased



a

b

c

d

e

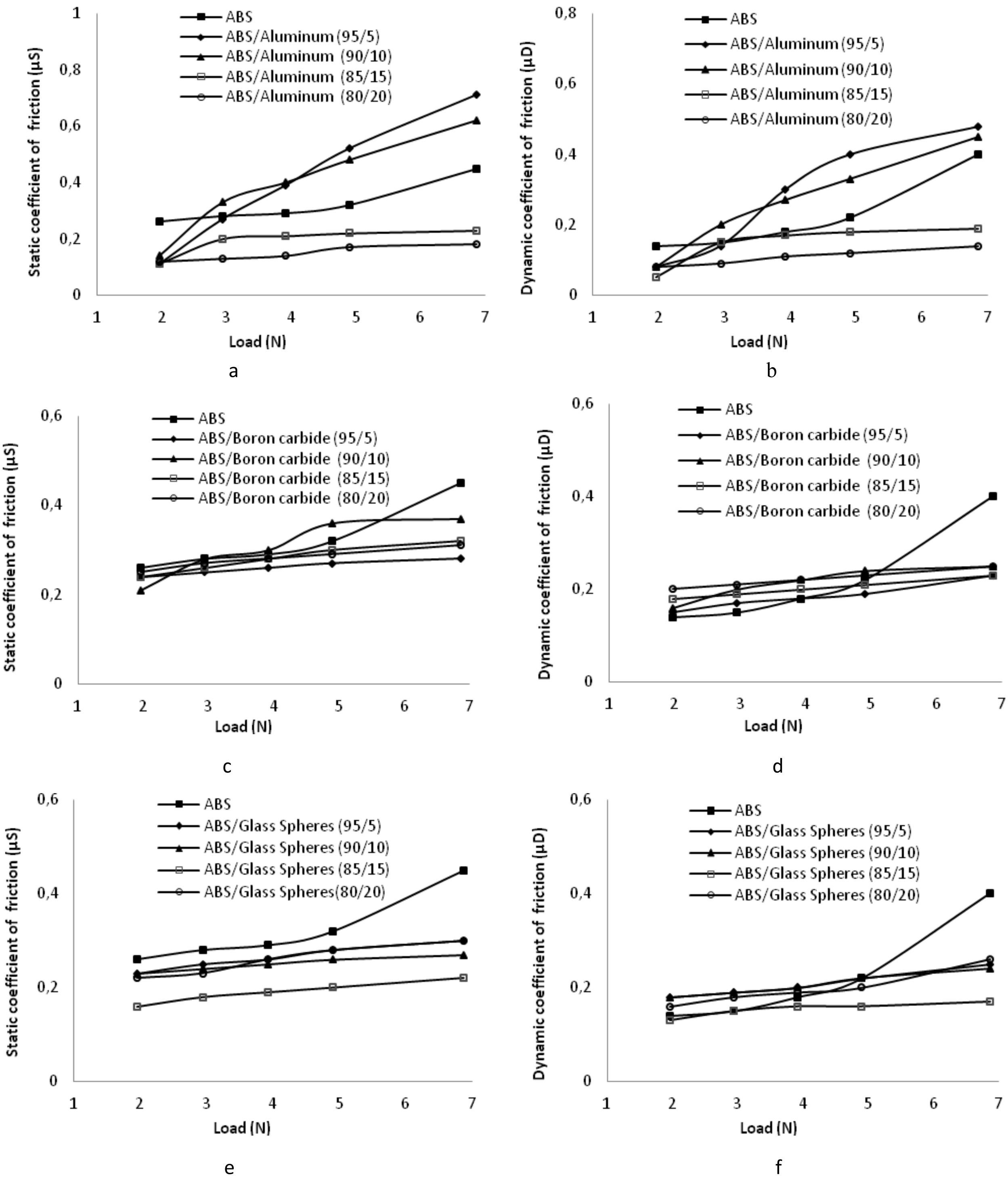
f

Fig. 3 Wear rates of the ABS polymer composites against distance and load: a - wear rate-sliding distance relationship of aluminum; b - wear rate-applied load relationship of aluminum; c - wear rate-sliding distance relationship of boron carbide; d - wear rate-applied load relationship of boron carbide; e - wear rate-sliding distance relationship of glass spheres; f - wear rate-applied load relationship of glass spheres

within the applied load from 10 to 20 N. It was inconsistent that the sliding distance and applied load affected on the wear rate of ABS polymer composites. Based on these results, it could be postulated that the level of the filler can affect the matrix hardness and bonding strength between the filler and polymer matrix [14]. The weak bond led to the filler particles detaching from the matrix and the matrix pulling out more easily, which could increase the wear rate of the composites.

3.3. Friction coefficients of the ABS polymer composites

Friction performance is shown in Fig. 4 when speed was 100 mm/min; load separately was 2, 3, 4, 5 and 7 N respectively. It is seen that the load had a great effect on the static and dynamic friction coefficient of the ABS composite. As the load increases, the friction coefficient of all kinds of composites increases. The effect of load on the friction and wear properties is mainly due to the tempera-



a

b

c

d

e

f

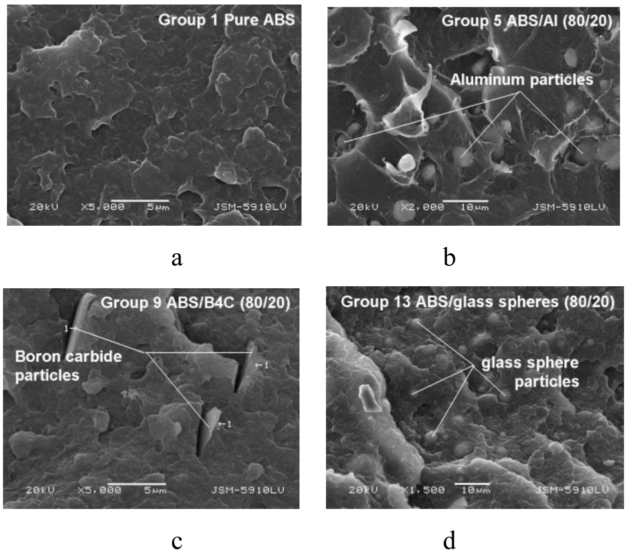
Fig. 4 Static and dynamic coefficients of friction of the ABS polymer composites against load: a - static coefficient of friction-load relationship of aluminum; b - dynamic coefficient of friction-load relationship of aluminum; c - static coefficient of friction-load relationship of boron carbide; d - dynamic coefficient of friction-load relationship of boron carbide; e - static coefficient of friction-load relationship of glass spheres; f - dynamic coefficient of friction-load relationship of glass spheres

ture change of the frictional surface. With the increases load, the accumulated velocity of frictional heat on the surface increased, which resulted in increased temperature and the viscoelastic of material to enhance the performance of tribology. At the same time shear resistance of molecular decreases and matrix of composites be adhered to counterface, forming a dual friction of filler in composite with counterface, so the friction coefficient increases [4, 15]. The specimens with Aluminum particles of lower concentration (up to 10%) increased the static and dynamic friction coefficient and higher concentration (15% and higher) decrease it. It might be a reason that the exposed aluminum particles most of the load between the contact surfaces and reduced the real contact area.

When the temperature was high, the polymer might be softened, which could cause the polymer to be detached easily and result in severe wear. During the sliding, some big debris on the wear surface would be crushed or sheared into small particles and acted as lubricants, the newly formed debris would come into being a more integrated layer on the worn surface and reduced the direct contact between the composites and the counterpart, which could decrease the friction coefficient and wear rate [16].

3.4. Morphological properties of the ABS polymer composites

The SEM study was carried out to study the dispersion of fillers in the polymer matrix. The boundaries and the contrast can be obviously seen between the filler and ABS matrix on the fractured surfaces of polymer matrix (Fig. 5).



a b

c d

Fig. 5 SEM micrographs of the ABS polymer composites: a - Pure ABS; b - ABS/Al(80/20), c - ABS/B_4C (80/20); d - ABS/glass sphere (80/20)

4. Conclusions

The tribological properties of ABS composites filled with aluminium, boron carbide and glass sphere were studied at different loads and distance under dry sliding. The effects of aluminum, boron carbide and glass sphere content on the wear and friction behavior were discussed. So, Ultimate tensile strength, Izod impact strength and MFI values were reduced by adding alumina, boron carbide and glass spheres. The wear loss of ABS and its composites increases with increasing load and distance. With the addition of fillers to the composite, the wear rate and friction coefficient significantly changed. The sliding distance and applied load had a great effect on the wear rate of ABS composites. The applied load is a more significant parameter than the sliding distance. Wear rate increased with the increase of the sliding distance up to 40 m but it decreased within the sliding distance from 40 to 80 m. On the other hand, wear rate increased gradually with the increase of the load up to 10N but it decreased within the applied load from 10 to 20 N. It was inconsistent that the sliding distance and applied load affected on the wear rate of ABS polymer composites. The results showed that the coefficients of friction increases linearly with the load increase for ABS and its composites.

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TRINTIES IR DILIMO PARAMETRŲ ĮTAKA AKRONITRILO BUTADIENO STYRENO/ALIUMINIO BORO KARBIDO-SFERINIO STIKLO POLIMERŲ KOMPOZITAMS

Reziumė

Šiame darbe ištirta trinties ir dilimo įtaka akronitrilo butadieno styreno pagrindu kompozitams užpildytiems aliuminio, boro karbido ir sferinėmis stiklo dalelėmis. Užpildų turinys ABS buvo 5, 10, 15 ir 20%. Rezultatai parodė, kad kompozitų užpildo rezultate pasikeitė trinties koeficientas ir dilimo intensyvumas. Visų bandinių dilimo mažėjimas didėjo didinant apkrovą ir slydimo kelią tuo tarpu trinties koeficientas (statinis ir dinaminis) didėjo iki slydimo keliui pasiekus 40 m, bet mažėjo toliau slystant nuo 40 iki 80 m. Iš kitos pusės, dėvėjimosi intensyvumas didėjo palaipsniui didinant apkrovą iki 10 N, bet nuo 10 iki 20 N pridėtoms apkrovoms mažėjo. Buvo nesuderinama, kad slydimo atstumas ir apkrova įtakojo ABS polimero kompozitų dilimo intensyvumą. Rezultatai parodė, kad trinties koeficientas didėjo ABS ir jo kompozitams tiesiškai didinant apkrovą.

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EFFECT OF FRICTION AND WEAR PARAMETERS ON ACRYLONITRILE BUTADIENE STYRENE/ALUMINUM-BORON CARBIDE-GLASS SPHERES POLYMER COMPOSITES

Summary

In the present work, the friction and wear properties of acrylonitrile butadiene styrene based composites filled with aluminum, boron carbide and glass spheres particles were studied. Fillers contents in the ABS were 5, 10, 15, and 20 wt%. The result showed that the addition of fillers to the composite changed the friction coefficient and wear rate. All specimen wear loss increases with increasing load and sliding distance; meanwhile the friction (static and dynamic) coefficient increases.

Keywords: friction, wear parameters; acrylonitrile butadiene styrene/aluminum-boron carbide-glass spheres polymer composites.

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