STUDIUL COMPORTĂRII LA FRECARE ŞI UZURĂ A COMPOZITELOR DE TIP HDPE/ SFERE DE STICLĂ

STUDY ON THE FRICITON AND WEAR BEHAVIORS OF MODIFIED HDPE/GLASS SPHERES COMPOSITES

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In the present work, high density polyethylene based composites filled with glass spheres (hollow) and HDPE/glass spheres (filled with alumina silicate) particles were prepared. Fillers contents in the HDPE were 5, 10, 15, and 20 wt%. The mechanical, morphological and tribological properties of the polymer composites were investigated. Substantial improvements in the some mechanical properties were obtained by the addition of filler. For example, the results showed that the elasticity modulus of composites improved with increasing the glass spheres content. The addition of fillers to the HDPE changed significantly the friction coefficient and wear rate of the composites. HDPE filled with a high level content of fillers showed higher wear rate than pure HDPE under dry sliding. The structure and properties of the composites are characterized using a scanning electron microscopy (SEM).

Keywords: *Tribological behavior, Wear, Mechanical properties, Friction, Polystyrene, High density polyethylene, Glass sphere*

1. Introduction

Polymers and their composites are being increasingly employed because of their good strength and low densities. Besides, a wider choice of materials and the ease of manufacturing make them ideal for engineering applications [1-3]. There are two types of PE, which are high-density polyethylene (HDPE) and low-density polyethylene (LDPE). LDPE is flexible and tough; HDPE is much stronger and stiffer than LDPE. It is used for sheeting, bags “squeeze” bottles, ballpoint pen tubing, and wires and cable insulation [4]. High density polyethylene (HDPE) has been widely used in the industry on account of good process ability, desired properties and relatively low cost [5]. Fillers, in the form of particulates and fibers, are often added to polymeric materials to improve their stiffness and strength. The second phase filler material will influence the friction and wear properties of the composite materials [6]. 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 [7]. Much research on the wear performance of UHMWPE has been reported elsewhere [8-10]. However, very little has been reported on the wear performance of the HDPE/glass spheres polymer composites. Further, research into the wear of polymers has usually investigated the effects of a single factor-such as sliding distance, sliding speed, or contact pressure-on the wear performance. In recent years, thermoplastic resin/mineral filler composites have been widely used in molded products due to effective cost reduction. Much effort has been devoted to improving the properties of polymers by the addition of inorganic fillers, such as Talc, SiO_2, ZnO, $CaCO_3$, and carbon fibers [11-15]. The application of light weight fillers, in the form of hollow glass spheres, in plastics has become more and more important in the last few years. Nijenhuis et al. investigated of mechanical properties of PA-6/hollow glass spheres polymer composites [16].

Kubat et al. investigated that characterization of interfacial interactions in high density polyethylene filled with glass spheres using dynamic-mechanical analysis. In this study, The dynamic-mechanical properties of high density polyethylene filled with 20% by volume of untreated glass spheres or glass spheres treated with a silane-based coupling agent were studied as a function of temperature and imposed tensile deformation [17].

In the present study, the effects of the glass spheres (hollow) and glass spheres (filled with alumina silicate) concentration on the mechanical, tribological and morphological properties of HDPE composites were investigated. To this end, HDPE polymer composites containing 5, 10, 15 and

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Table 1

Composition of the different polymer composites formulations

Groups	HDPE (wt %)	Glass sphere (hollow) (wt %)	Glass sphere (filled with alumina silicate) (wt %)
1	100	-	-
2	95	5	-
3	80	10	-
4	85	15	-
5	80	20	-
6	95	-	5
7	90	-	10
8	85	-	15
9	80	-	20

20wt % glass spheres was produced, and the properties of the composites were investigated.

2. Experimental

2.1. Compositions and Materials

Nine different polymer composites were prepared. Compositions of HDPE/glass spheres polymer composites that were formed are given in Table 1.

High-density polyethylene (HDPE) (I 668 UV) was supplied by Petkim (Izmir-Turkey). Specific gravity is 0,970 g/cm^3. Melt flow rate is 5.2 g/10 min (190^{o}C–2.16 kg). Yield strength is 28 MPa and notched Izod impact (23^{o}C) is 12 kJ/m^2. Hollow glass spheres and glass spheres (filled with alumina silicate) were supplied by RockTron International. Talc was supplied Ankerpoort NV.

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 HDPE polymer composites were produced between 180-220 ^{o}C at 20-30 bar pressure, and a rotation rate of 25 rpm, with a Microsan extruder (Microsan Instrument Inc. Kocaeli - Turkey). L/D ratio is 30, Ø:25 mm, Polymer composites were also dried in vacuum oven at 80 ^{o}C for 24 hours after extrusion. Subsequently, test samples were molded in injection molding machine.

2.3. Mechanical Characterization

The modulus and elongation 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. The hardness test was done according to the ASTM D2240 method with Zwick hardness measurement equipment. 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).

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,

$$\mu s = F_S/F_P \quad (1)$$

Where F_S is the static frictional force, expressed in Newton, F_P is the normal force exerted by the mass of the sled, expressed in Newton (=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,

$$\mu_D = F_D/F_P \quad (2)$$

Where F_D is the dynamic frictional force, expressed in Newton, F_P is the normal force exerted by the mass of the sled, expressed in Newton (=1.96 N) [18].

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 10N 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:

$$W_s=(\Delta m)/\rho . F_N . L \ (mm^3/Nm) \quad (3)$$

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.

2.5. Microscopy

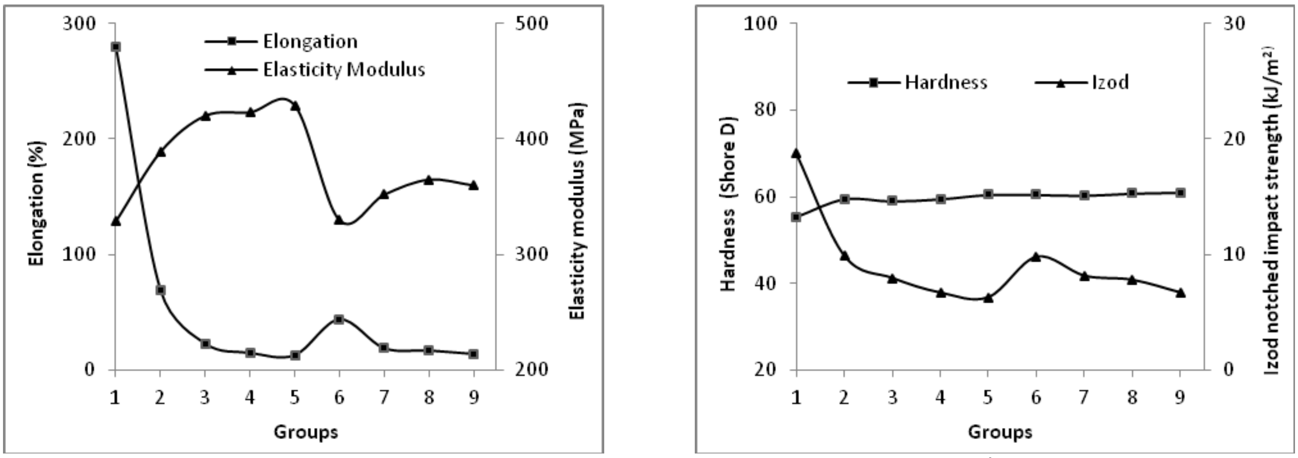
The fractured surfaces of the composites were coated to an approximate thickness of 10 nm of a gold (Au) (80%)/palladium (Pd) (20%) alloys to prevent electrical charging by Polaron SC 7620 (Gala Instrumente GmbH, Bad Schwalbach-Germany). The surfaces of the prepared samples were observed by the JEOL-JSM 5910 LV (JEOL Ltd., Tokyo, Japan) scanning electron microscopy (SEM) at an acceleration voltage of 20 kV. Elemental analysis was done using Energy dispersive X-ray spectroscopy (EDS) (Incax-sight-model: 7274-Oxford Instruments, England).

3. Result and discussion

3.1. Mechanical properties of glass spheres filled HDPE

The tribological behavior of materials has close relations with its mechanical properties. The effect of filler content on the mechanical properties of the HDPE polymer composites are given in Figure 1.

The elasticity modulus of HDPE/Glass spheres (hollow) composites increases as the filler concentration increases from 0 to 20 wt % (Figure 1a). The maximum elasticity modulus is observed at the 20 wt % glass spheres (hollow) concentration for HDPE. On the other hand, the elasticity modulus of HDPE/glass spheres (filled with alumina silicate) composites show an increment as the filler concentration increases from 0 to 20 wt % as well. The elongation of HDPE/glass spheres (hollow) and HDPE/glass spheres (filled with alumina silicate) composites decreased as the filler concentration increases from 0 to 20 wt % (Figure 1a). The impact strength decreased as the all particles concentration increased from 0 to 20 wt % (Figure 1b). This decrease was attributed to a possible cracking of the glass spheres. The hardness of the composites increased (from 0 to 5wt %) linearly with an increase weight percentage of glass spheres. This was due to the uniform distribution of filler in the HDPE matrix. At a larger filler concentration, the value of the hardness was not much changed. The maximum hardness is observed at the 20 wt % glass spheres (filled with alumina silicate) concentration for HDPE. In comparison with the hardness of virgin HDPE, the hardness increased by 11% for the composites at a 20 wt % filler concentration.



a b

Fig. 1 - Mechanical properties of the HDPE polymer composites.

3.2. Wear properties of glass spheres filled HDPE

Obviously, the tribological processes involved in this investigation are complex. The effects of applied load, sliding distance and fillers content on the tribological behaviors of HDPE composites were examined. The values of sliding distance-wear loss relationship were obtained and are shown in Table 2. Table 2 shows the wear loss for various specimens sliding distance against the sand paper (#60) under 10N load and 0,32 m/s abrasion speed. I can be seen that the wear loss of composites increase with increasing sliding distance and filler content. The same trend is taken on for the applied load-wear loss relationship (Table 3).

When the distance was more than 20 m, the wear loss began to increase rapidly (Table 2-3). When the load was more than 5 N, the wear loss began to increase rapidly as well. It suggests that this is a critical distance and load 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 HDPE composite is serious destroyed and severe wear occurs. The results of the wear rate of HDPE/glass spheres (hollow) and HDPE/glass spheres (filled with alumina silicate) polymer composites at different loads and sliding distances are presented in Figure 2. Figure 2 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.

By comparing with the HDPE without filler, it can be observed that the addition of filler increased the wear rate of the composites. In particular, the wear rate of HDPE/glass spheres (filled with alumina silicate) composites dramatic increases as the filler concentration increases from 0 to 20 wt %, which could be attributed to the weakened adhesion between the fillers and polymer matrix in the presence of an excessive

Table 2

Sliding distance-wear loss relationship of HDPE polymer composites

	Sliding distance (m) (applied load:10 N)			
	20	40	60	80
Groups	Wear loss (mg)			
1	29	69	73	85
2	37	97	100	115
3	51	109	122	140
4	57	139	156	189
5	75	158	191	224
6	42	63	72	138
7	50	107	127	152
8	63	120	159	191
9	70	130	177	231

Table 3

Applied load-wear loss relationship of HDPE polymer composites

	Applied load (N) (sliding distance:40 m)			
	5	10	15	20
Groups	Wear loss (mg)			
1	16	69	84	140
2	21	97	106	168
3	30	108	160	215
4	38	139	194	276
5	50	158	234	339
6	36	63	141	234
7	36	107	182	263
8	43	120	210	301
9	49	130	228	321

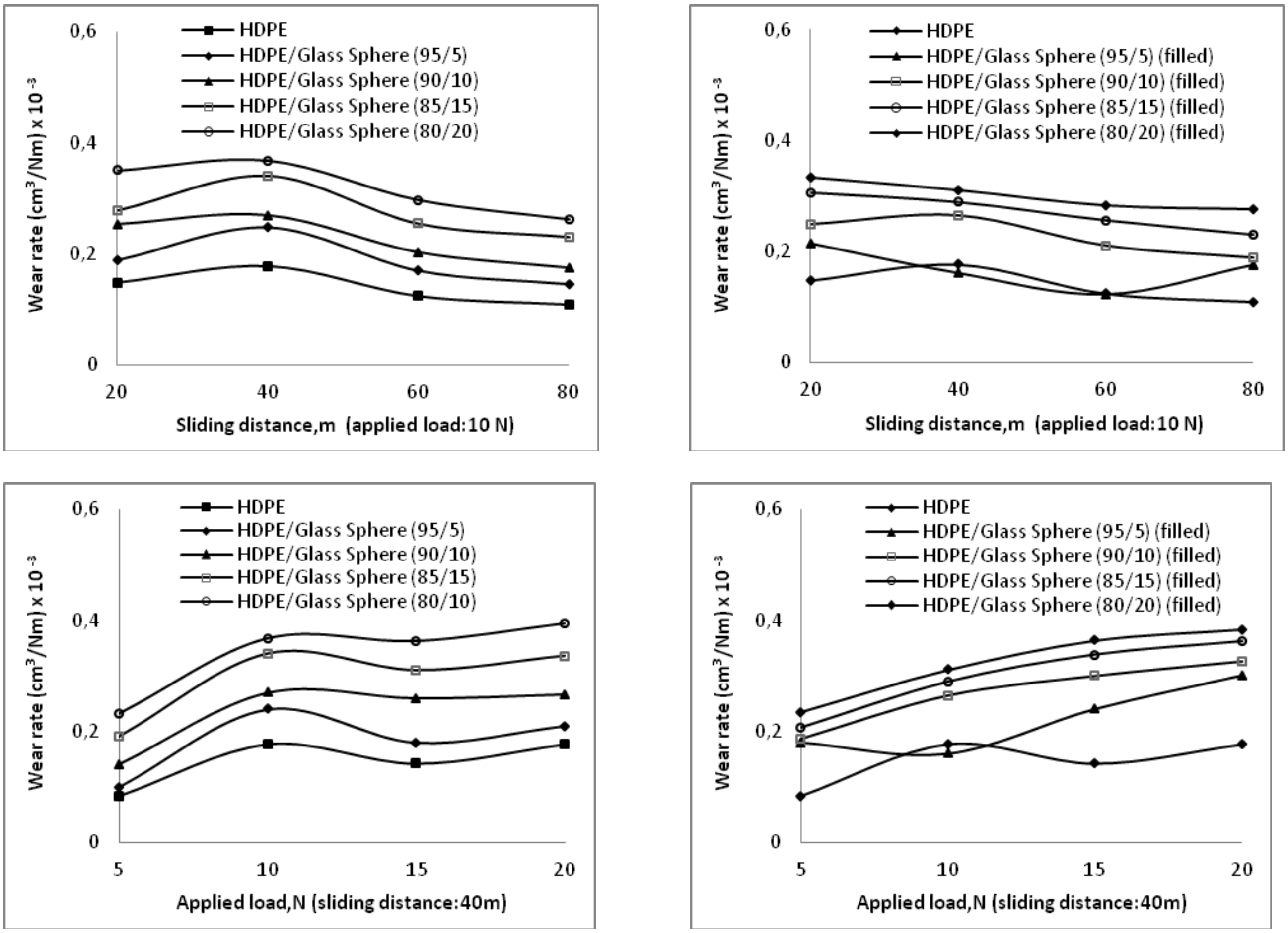


Fig. 2 - Wear rates of the HDPE polymer composites against load and distance.

amount of glass sphere particulates. 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. 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 composite. So, a high level of the filler led to the high wear rate of the composite.

3.3. Friction coefficients of the glass spheres filled HDPE

Friction performance is shown in Figure 3 when speed was 100mm/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 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 temperature 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 [19, 20]. At the same time shear resistance of molecular decreases and matrix of composites be adhered to counter face, forming a dual friction of filler in composite with counter face, so the friction coefficient increases.

According to the friction transfer theory materials' transfer of the adhesion tend to enhance along with the increased temperature on the frictional interface. However in the friction process, adhered materials constantly be abraded and transfer to the surface of counter face, result in the wear of material increase [19].

3.4. Morphological properties of the glass spheres filled HDPE

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 HDPE matrix on the fractured surfaces of polymer matrix (Figure 4). The micrographs (Figure 4) indicate that the all particulates are homogeneously dispersed on the fractured surfaces of polymer matrix. Figure 5 shows the EDS survey spectra of the polymer composites.

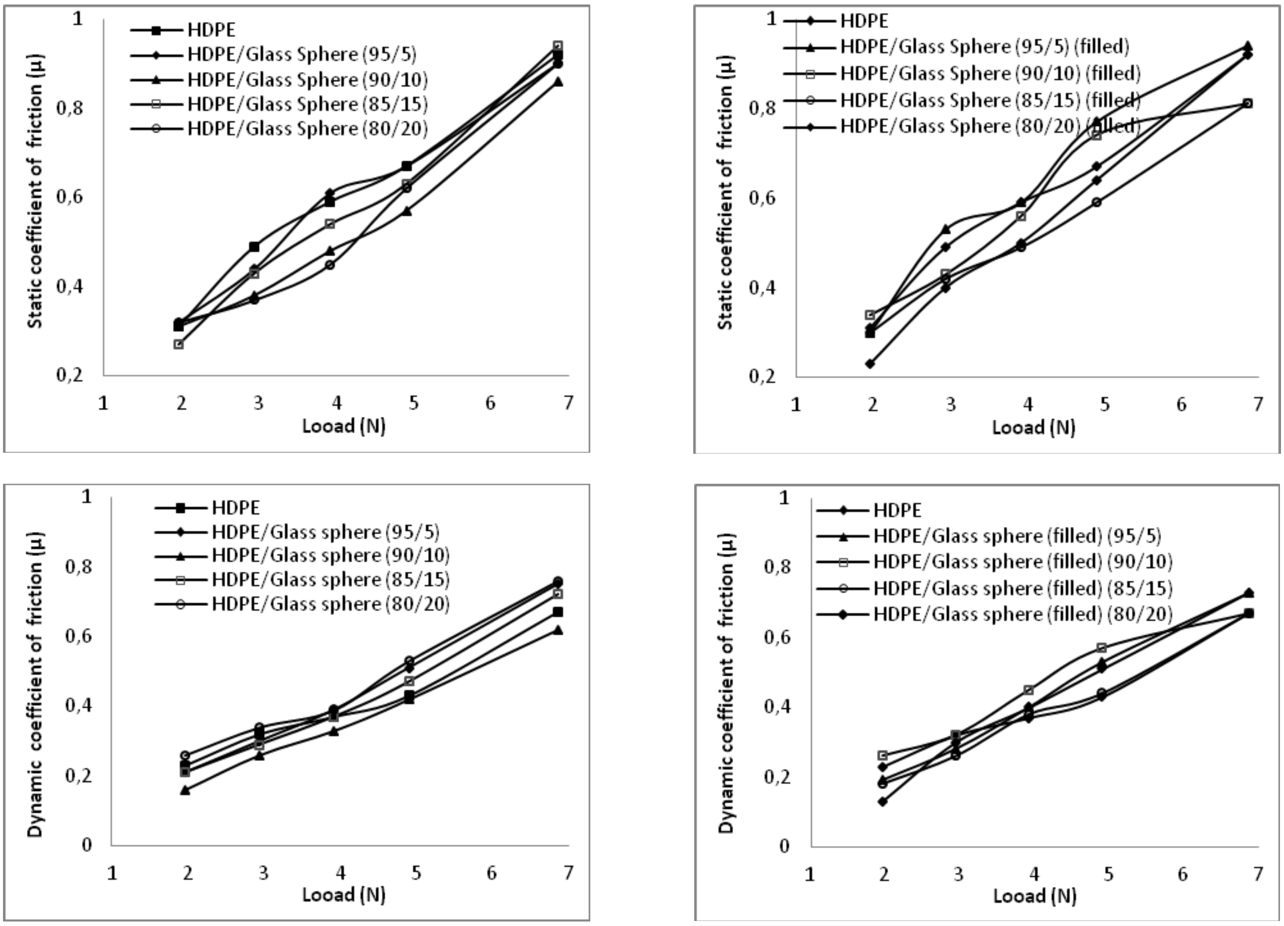


Fig. 3 - Friction coefficients of the HDPE polymer composites against load.

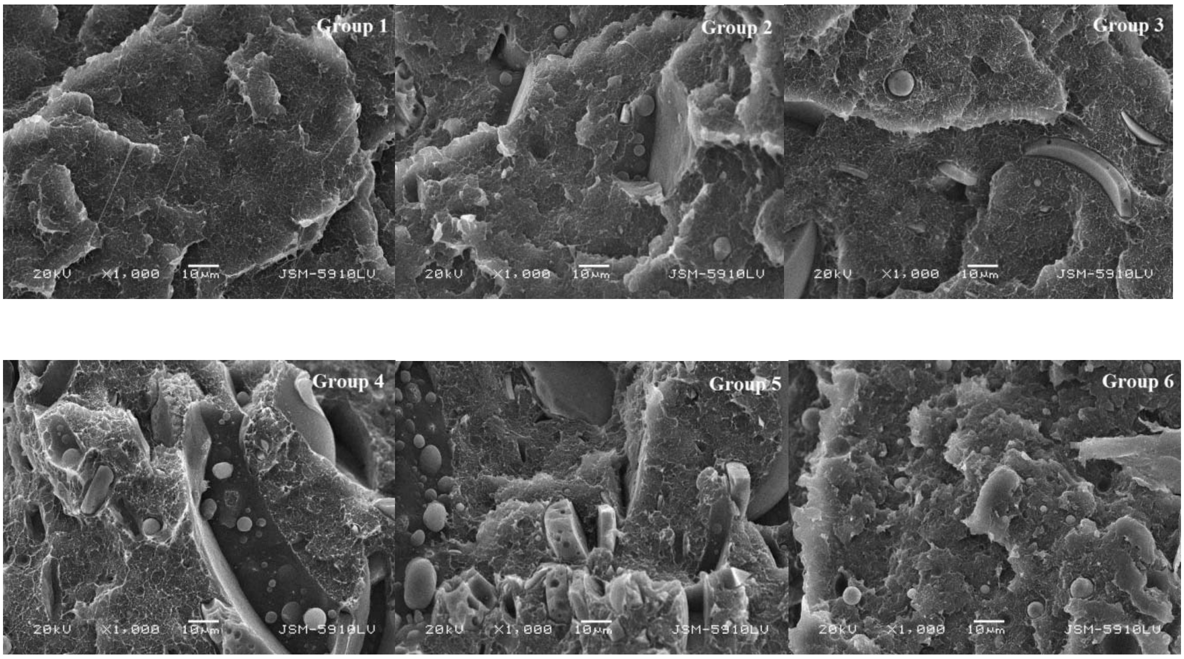


Fig. 4 - SEM micrographs of the HDPE polymer composites.

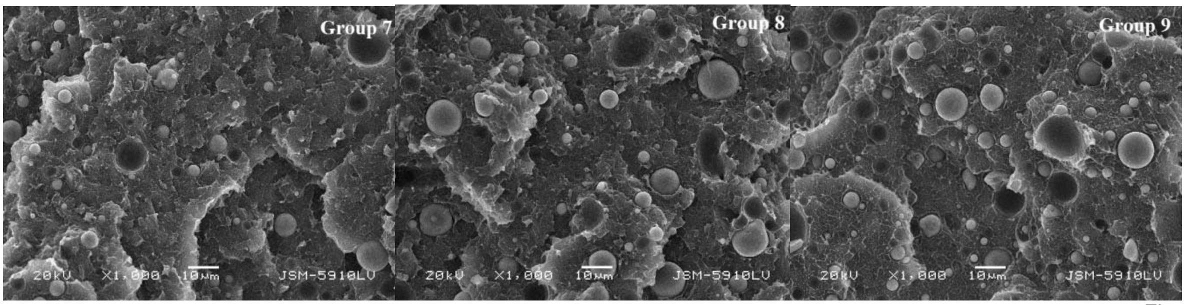


Fig. 4 (continue)

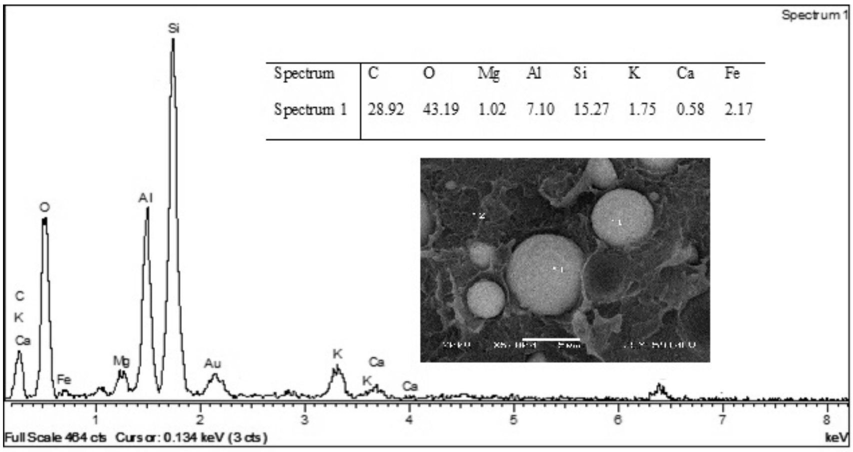


Fig. 5 - Energy dispersive X-ray spectroscopy (EDS) of the HDPE polymer composites.

4. Conclusions

Substantial improvements in the some mechanical properties were obtained by the addition of filler. For example, the results showed that the elasticity modulus of composites improved with increasing the filler content. On the other hand, % elongation and Izod impact strength values of the composites were decreased. The addition of fillers to the HDPE changed significantly the friction coefficient and wear rate of the composites. The wear loss of HDPE and its composites increases with increasing load and distance. Also, the sliding distance and applied load had a great effect on the wear rate of composites. The applied load is a more significant parameter than the sliding distance. HDPE filled with a high level content of fillers showed higher wear rate than pure HDPE under dry sliding. The micrograph shows that filler particulates are thoroughly distributed in the matrix but agglomeration was observed.

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