COMPORTAREA LA FRECARE ŞI UZURĂ A COMPOZITELOR PE BAZĂ DE HDPE ŞI TALC SAU CARBONAT DE CALCIU FUNCŢIE DE DISTANŢA DE ALUNECARE ŞI SARCINA APLICATĂ
FRICTION AND WEAR PERFORMANCE OF HDPE/TALC- CALCIUM CARBONATE POLYMER COMPOSITES AGAINST SLIDING DISTANCE AND APPLIED LOAD

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In comparison to metals, generally unfilled polymers have low thermal conductivity and low wear resistance. Therefore, various filler and reinforcements are frequently added to the unfilled polymers to improve their tribological and thermal properties. So, filled polymers are preferred for many industrial sectors such as aircraft, automotive, electrical/electronic and household application. Friction and wear behaviour is one of the most important properties of polymer and its composites. Therefore, many studies on friction and wear properties of polymer and its composites have been carried out.

In the present work, the friction and wear properties of high density polyethylene/talc and high density polyethylene/calcite polymer composites were studied. Fillers proportions in the HDPE were 5, 10, 15, and 20 wt%. The morphologies of the fracture surfaces of specimens were observed with a scanning electron microscopy (SEM). The result showed that the addition of fillers to the composite changed the friction coefficient and wear rate. For a specimens, wear loss increases with increasing load and sliding distance; meanwhile the friction (static and dynamic) coefficient increases. Wear rate of all HDPE composites is larger than that of pure HDPE. The static and dynamic friction coefficient of HDPE/talc (80/20) composite is slightly less than that of pure HDPE at each load. The modulus of elasticity, elongation, Izod impact strength and hardness values of the composites were also determined.

Keywords: Mechanical properties, friction, wear, high density polyethylene, talc, calcite, polymer composites, tribological behavior.

1. Introduction

Polymeric materials have been replacing metallic materials used as friction wear parts for many years. It is often found that, however, the single unmodified polymer could not satisfy the demands arising from situations where a combination of good mechanical and tribological properties is required. Therefore, it is necessary for improving polymer to provide it with outstanding properties using different methods, including copolymerizing, blending, filling with fibers and/or fillers, etc. Friction and wear behavior is one of the most important properties of polymer and its composites. Many studies on friction and wear properties of polymer and its composites have been carried out [1,3-10]. 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, polymer nanocomposites have attracted great interest. Nanocomposites offer new technological and economical benefits. The incorporation of nanometer-scale reinforcement (e.g., layered silicates of clay, nanofiber, nanotubes, and metal nanoparticles in polymeric materials) may dramatically improve selected properties of the related polymer [3].

Some polymer composites are a widely used for gear and bearing applications and its tribological properties have been studied by many researchers [4-5]. 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 [6]. 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 [6-9]. Lancaster [10], Hutchings [11] and Tewari et al. [12] reported that the friction between polymers can 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 most of the friction of polymer and is a result of breaking of weak bonding forces between polymer chains in the bulk of the material and the counter-face or the transfer film Although wear is an intrinsic material property, it also depends on operating parameters. A mathematical relationship between the wear of the investigated polymers and operating parameters is desirable in order to obtain a better understanding of the wear behavior. Lancaster [13], Dowson et al [14] and Viswanath et al [15] have developed various forms of equations/relationships for the wear of polymers.

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All these models have expressed wear volume as a function of either the operating parameters, such as load/contact pressure, speed, sliding distance, and most include properties such as hardness and surface roughness of the counter face, shear strength of the polymer. Some of the wear equations have related to volume loss to the operating parameters through a wear constant or a wear coefficient [16]. However, such models do not describe the influence of the individual operating parameters and their interactions on the wear. It is important to know the effect of the individual factors and their interactions on the wear behavior of materials for the potential applications. Such information is expected to add to an understanding of polymer wear, optimize the use of existing materials and aid the development of new materials for service in such conditions [17]. Zhang et al. [18] 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. Hashmi and co-workers investigated the friction and wear behaviours of the blends of ultra-high-molecular-weight polyethylene with polyphenylene, polyamide, or polyurethane [19]. Tanaka [20] and Bahadur et al. [21] have reported that tribological behaviour of polyamide, HDPE and their composites. They reported that their wear resistance and coefficient of friction are affected greatly by normal load, sliding velocity and temperature. Xianqiang et al. [22] studied the mechanical and tribological properties of the PET/HDPE microfibrillar reinforced composites. It has been found that, the wear resistance of HDPE was improved by the formation of microfibrillar composites.

The objective of present work is to investigate the tribological behavior of HDPE/talc and HDPE/calcite polymer composites. 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 7N load values for friction (at 100mm/min sliding speed).

2. Experimental

2.1. Compositions and Materials

Compositions of HDPE polymer composites that were formed are given in Table 1 and 2. High-density polyethylene (HDPE) (I 668 UV) was supplied by Petkim (Izmir-Turkey), with the following characteristics: specific gravity of 0,970 g/cm^3, melt flow rate of 5,2 g/10 min (190 ^{o}C – 2,16 kg), yield strength 28,0 MPa and notched Izod impact (at 23°C) 12 kJ/m^2, talc (Tital 10) was supplied Ankerpoort NV (Maastricht- Netherlands). Its density was 2,8 g/cm^3, average particle diameter was 4.7 μm and its moisture content was

0.2%. Calcium carbonate (calcite- CaCO$_3$) as nano powder (Calprec PR) was supplied by Cales de Llierca (Girona-Spain). Its purity is 98% and the particle diameter was 50 nm.

Table 1

Composition of the HDPE/Talc polymer composite formulations

Sample code	HDPE (wt %)	Talc (wt %)
HDPE	100	-
T5	95	5
T10	80	10
T15	85	15
T20	80	20

Table 2

Composition of the HDPE/calcium carbonate polymer composite formulations

Sample code	HDPE (wt %)	Calcium Carbonate (wt %)
HDPE	100	-
C5	95	5
C10	90	10
C15	85	15
C20	80	20

2.2. Sample Preparation

Prior to processing talc and calcium carbonate were dried in a Yamato vacuum oven ADP-31 (Yamato/VWR Scientific Products, Japan) at 105 ^{o}C for 24 hours. 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. Polymer composites with various proportions of HDPE were produced at temperature between 180 – 220 ^{o}C and at 20-30 bar pressure. The rotation rate was 25 rpm, using a Microsan extruder (Microsan Instrument Inc. Kocaeli - Turkey). Extrusion and injection conditions are given in Table 3.

Table 3

Extrusion and injection conditions of the HDPE polymer composites

Process	Extrusion	Injection
Temperature (^{o}C)	180–220	180–220
Pressure (bar)	20-30	110–140
Waiting time in mold (s)	-	15
Screw speed (rpm)	25	25
Mould temperature (^{o}C)	-	40

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.

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

2.4.1. Static and dynamic coefficient of friction

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. The static coefficient of friction μs is given by the equation (1) and the dynamic frictional force using the equation (2) [23].

$$\mu s = F_S/F_P \qquad (1)$$
$$\mu_D = F_D/F_P \qquad (2)$$

[μs: static coefficient of friction, F_S: static frictional force (N), F_P: normal force (N), μ_D: dynamic coefficient of friction, F_D: dynamic frictional force]

2.4.2. Wear rate

The wear tests were done according to the DIN 53 516 method with Devotrans DA5 (Devotrans, Istanbul-Turkey) abrasion test equipment. The friction coefficients and wear rates reported in the present study were the averages of at three measurements. The thickness of the test specimens was 7,0 mm and diameter was 15,5 mm. The mass loss of the specimen was measured after the wear test in order to calculate the specific wear rate by the following eguation:

$$Ws = (\Delta m)/\rho.F_N.L \ (mm^3/Nm) \qquad [\Delta m: \text{ mass loss},$$
ρ:density, F_N: normal load, L:sliding distance]

2.5. Microscopy

The fractured surfaces of the composites were coated to an approximate thickness of 10 nm of a gold/palladium alloys to prevent electrical charging by Polaron SC 7620 (Gala Instrumente GmbH, Germany). The surfaces of the prepared samples were observed by the JEOL-JSM 5910 LV (JEOL Ltd., 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).
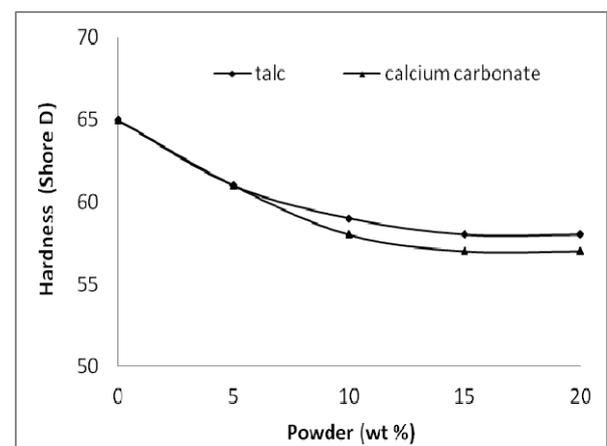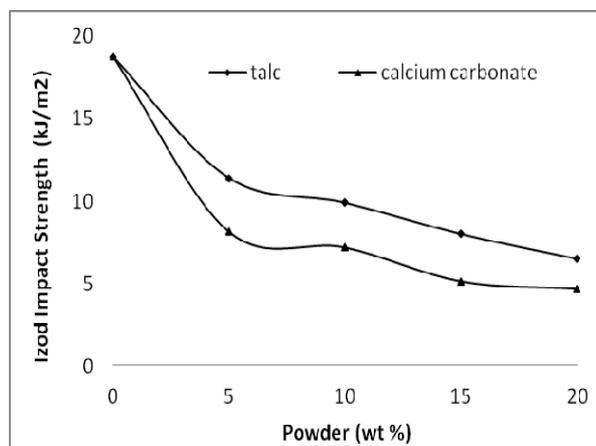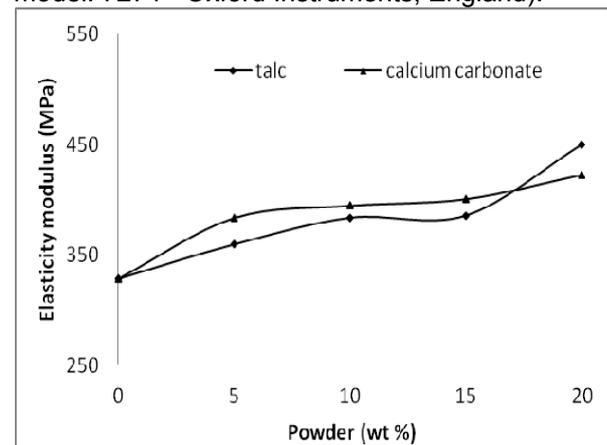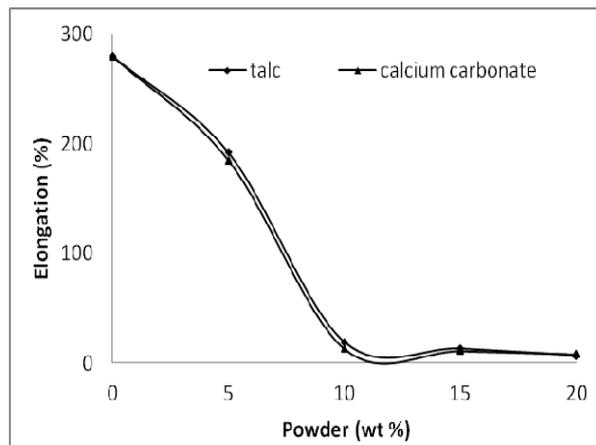

Fig. 1 - Mechanical properties of the HDPE polymer composites.

3. Result and discussion

3.1. Mechanical properties of talc and calcium carbonate 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.

From Figure 1 it can be seen that the elongation of HDPE/talc and calcite composites decrease with increasing filler content. The same trend is taken on for the Izod impact strength. The notched Izod impact strength of HDPE composites (all groups) was lower than pure HDPE. The embrittlement of the composites resulted from the weak interfacial adhesion between fillers and high density polyethylene matrix. In comparison with the Izod impact strength of virgin HDPE, the Izod impact strength decreased by 75 % for the

composites with a 20 wt % calcium carbonate concentration. On the other hand, the elasticity modulus of HDPE/talc and HDPE/calcium carbonate composites shows an increment as the filler concentration increases from 0 to 20 wt %.

3.2. Wear properties of talc and calcium carbonate 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 relationship between the values of sliding distance and wear loss are obtained and are presented in Table 4.

Table 4 shows the wear loss for various specimens sliding distance against the sand paper (#60) under 10N load and 0.32 m/s abrasion speed.

Table 4

Sliding distance-wear loss relationship of HDPE polymer composites

Sliding distance (m) (applied load:10 N)				
	20	40	60	80
Sample code		Wear loss (mg)		
HDPE	29	69	73	85
T5	43	104	114	137
T10	54	129	141	170
T15	67	154	170	215
T20	84	184	214	269
C5	46	86	114	129
C10	50	99	119	149
C15	57	122	149	180
C20	70	146	167	220

Table 5

Applied load-wear loss relationship of HDPE polymer composites

Applied load (N) (sliding distance:40 m)				
	5	10	15	20
Sample code		Wear loss (mg)		
HDPE	16	69	84	140
T5	32	104	152	217
T10	39	129	186	274
T15	42	154	238	337
T20	73	184	264	393
C5	28	86	125	198
C10	31	99	165	218
C15	36	121	192	259
C20	41	146	206	315

When the distance was more than 40 m and the load was more than 10 N , the wear loss began to increase rapidly. (Table 4-5). 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 exceeds 10 N and distance exceeds 40 m, the pressure on the wear surface is so big that the surface of HDPE 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 talc and calcite particles on increasing wear loss of specimen [7]. For example, HDPE/talc (80/20) or HDPE/calcite (80/20) have a low mechanical strength which are easily deformated. The contact area and wear loss of the counterpart are 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.

Figure 2 indicate that the results of the wear rate of HDPE/talc and HDPE/calcite polymer composites at different loads and sliding distances. Talc and calcite are soft mineral, and talc has a layered structure, which causes slipping between layers.

The basic talc crystal structure consists of a layer of magnesium-oxygen/hydroxyl octahedrals, sandwiched between two layers of silicon-oxygen tetrahedral. Figure 2 show that talc and calcite presents much larger wear rate than that of the pure HDPE, which could be attributed to the weakened adhesion between the fillers and polymer matrix in the presence of an excessive amount of talc and calcite particulates. 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. Wear rate increased with the increase of the sliding distance up to 40m but it decreased within the sliding distance change from 40 to 80 m. On the other hand, wear rate increased gradually with the increase of the load up to 20N except that the wear rate of the pure HDPE decreased within the load from 10 to 20 N. It was inconsistent that the sliding distance and applied load affected on the wear rate of HDPE 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 [24]. A high level of filer may decrease the hardness of the matrix and weaken the adhesion
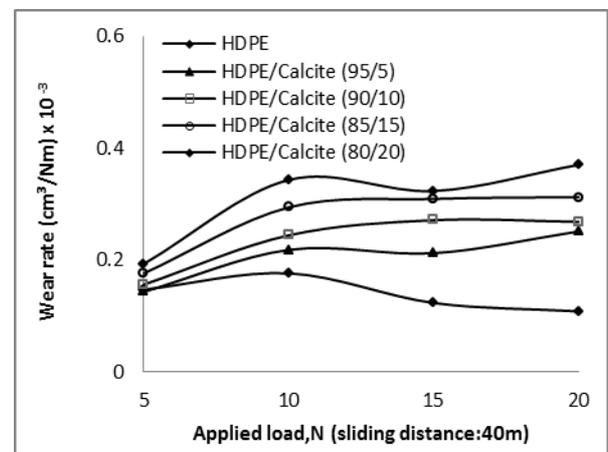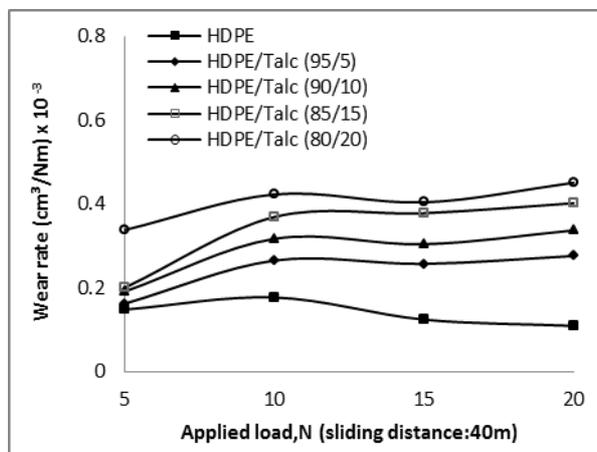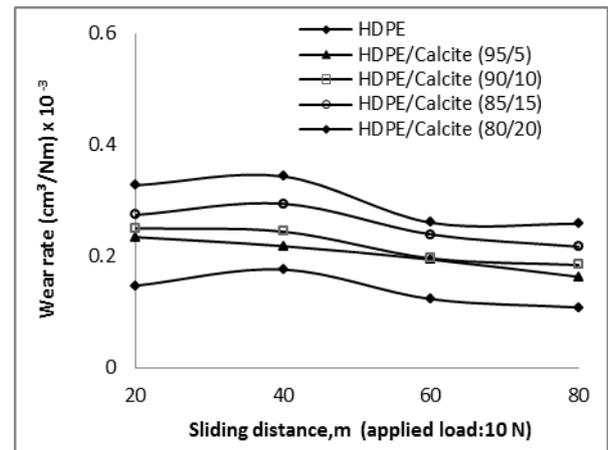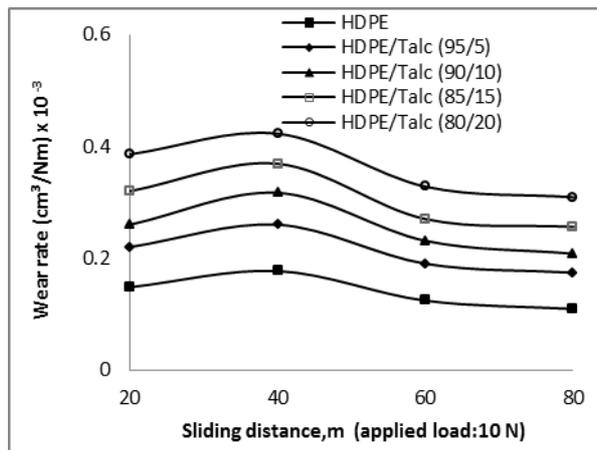

Fig. 2 -Wear rates of the HDPE polymer composites against load and distance.

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 composites. So, a high level of the filler led to the high wear rate of the composites. On the other hand, a low level of filler may increase the hardness of the matrix and bonding strength between the filler and polymer matrix. This should result in fewer polymer matrices being pulled out and reduced the wear rate. Therefore, the talc and calcite were not suitable for the high load tribological application. Moreover, the pure HDPE showed the good wear-resistance.

3.3. Friction coefficients of the talc and calcium carbonate filled HDPE

Figure 3 shows the friction coefficient for various specimens sliding under load. Speed was 100 mm/min. It is seen that the static friction coefficients of the HDPE/talc polymer composites were lower than that of the pure HDPE. 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 bonding strengths between the HDPE matrix and fillers changed with the content of the fillers, which accounted for the differences in the tribological properties of the HDPE filled with the varied content fillers.

3.4. Morphological properties of the talc and calcium carbonate filled HDPE

SEM patterns of the fractured surfaces of the composites are represented in Figure 4. Figure 5 shows the EDS survey spectra of the polymer composites. SEM micrographs of the fractured surfaces of the composites can provide information about the interfacial compatibility between the filler and HDPE matrix. The image also shows the random distribution of fibers in the matrix. Adhesion between filler and HDPE were obtained, this result produces a positive effect on the elastic modulus, but agglomeration was observed (C20).

4. Conclusions

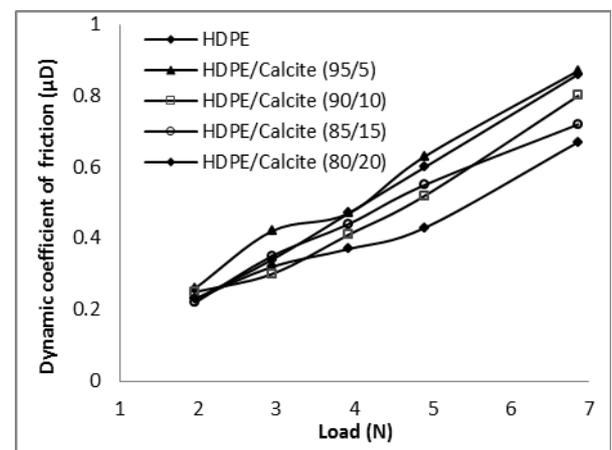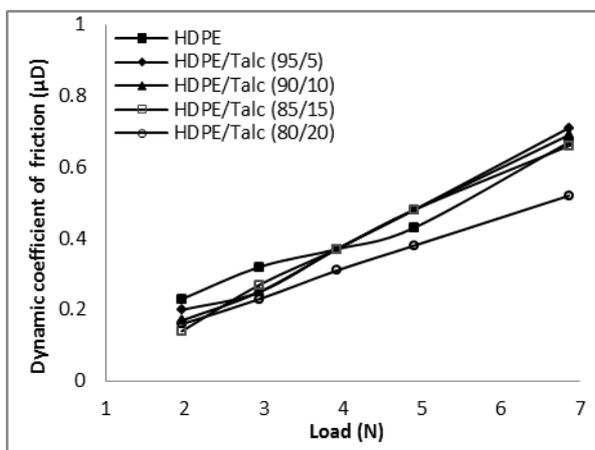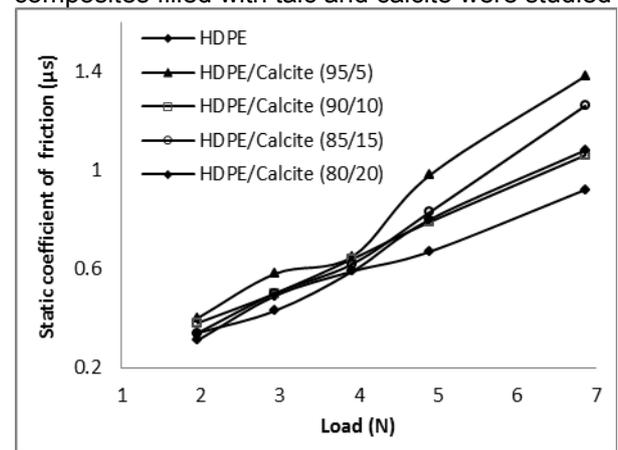The tribological properties of HDPE composites filled with talc and calcite were studied
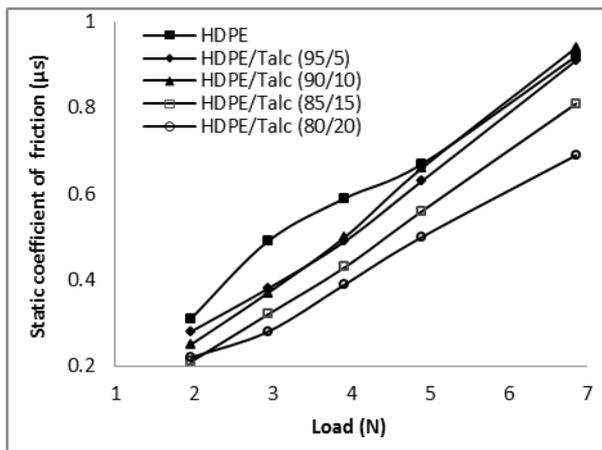
Fig. 3 - Friction coefficients of the HDPE polymer composites against load.
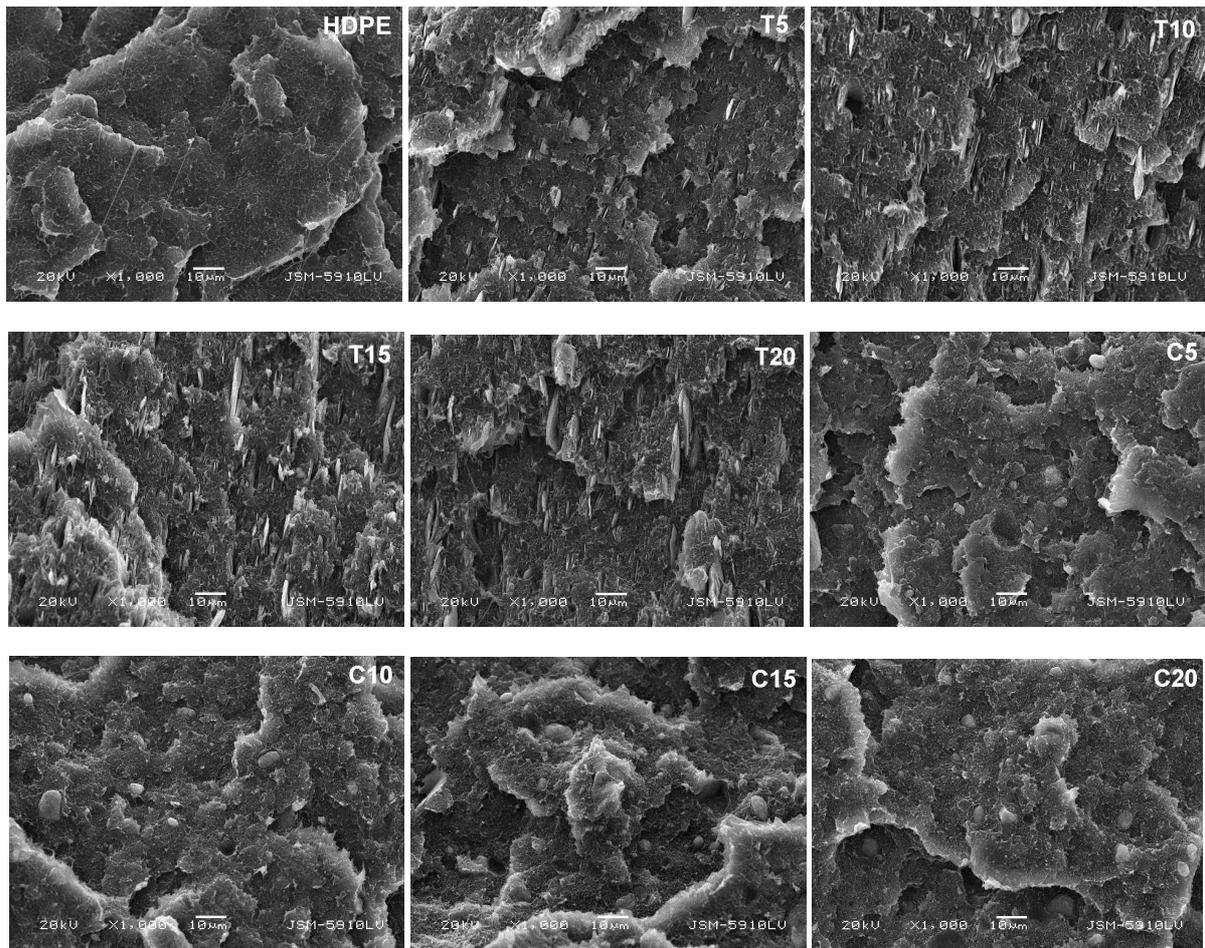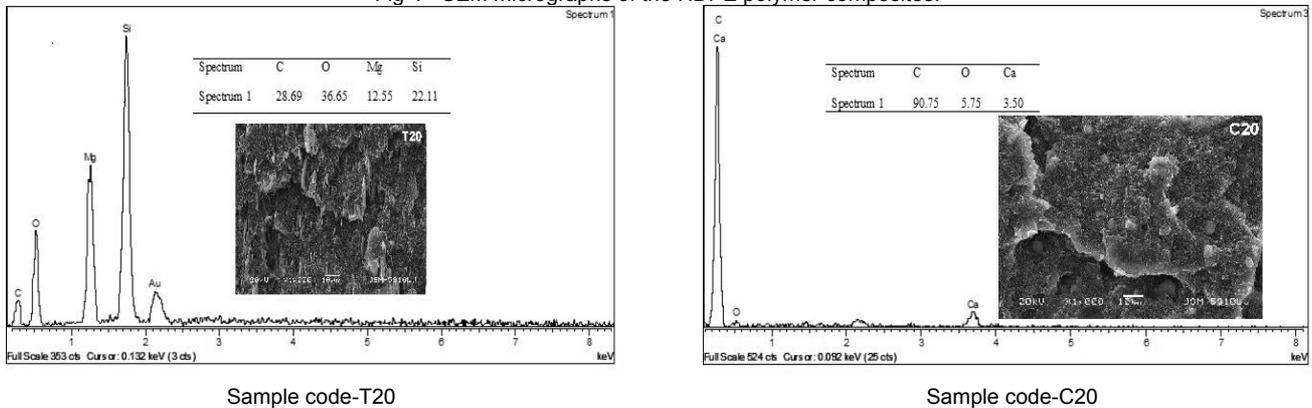
Fig 4 - SEM micrographs of the HDPE polymer composites.

Sample code-T20   Sample code-C20

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

at different loads and distance under dry sliding. The effects of talc and calcite content on the wear and friction behaviour were discussed. From the above, the following conclusions could be drawn:

   a. The embrittlement of the composites resulted from the weak interfacial adhesion between fillers and high density polyethylene matrix

   b. The wear loss of HDPE and its composites increases with increasing load and distance.

   c. With the addition of fillers to the composite, the wear rate and friction coefficient significantly changed. The composites filled with a low level content of fillers showed lower wear rate. While the composite with a high level content of fillers had higher wear rate.

   d. 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.

   e. Wear rate increased with the increase of the sliding distance up to 40m 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 20N except that the wear rate of the pure HDPE decreased within the load from 10 to 20 N. It was inconsistent that the sliding distance and applied load affected on the wear rate of HDPE polymer composites.

f. The bonding strengths between the polymer matrix and fillers changed with the content of the fillers, which accounted for the differences in the tribological properties of the composite filled with the varied content fillers.

g. The result s showed that the coefficients of friction increases linearly with the load increase for HDPE and its composites.

h. The micrograph shows that filler particulates are thoroughly distributed in the matrix but agglomeration was observed.

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