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TRIBOLOGICAL PROPERTIES OF LOW AND HIGH DENSITY POLYETHYLENE REINFORCED BY SILICON CARBIDE NANOFIBERS

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ABSTRACT
The purpose of the present work is to investigate the effect of silicon carbide nanofibers (SiCNF) of 0.1, 0.3, 0.5, 0.7 and 1.0 wt. % contents reinforcing low density polyethylene (LDPE) and high density poly ethylene (HDPE) on the tribological properties of the composites when applying normal loads of 5 N, 10 N and 15 N and sliding against steel. The hardness of the tested composites is measured by Shore D Durometer. Friction coefficient and wear of SiCNF/LDPE and SiCNF/HDPE composites are measured at room temperature.

The experimental results show that by increasing the content of SiCNF, the hardness of LDPE composites increases, while for the hardness of HDPE composites there was a slight increase up to 1.0 wt. % SiCNF. Friction coefficient of LDPE composites tends to increase with increasing normal load, while minimum values are detected at 1.0, 1.0 and 0.3 wt. % SiCNF for 5N, 10N and 15N respectively. Friction coefficient of HDPE composites tends to increase with the increase of normal load, while the minimum values for HDPE composites are detected at 0.3 wt. % SiCNF content for 5 N, 0.3 wt. % for 10 N, while for 15 N appears at 0.1 wt. %. Minimum scar width occurs in SiCNF/LDPE composites at 0.1 wt. % content for 5N and 15N, white it occurs at 0.7 wt. % for 10N normal load. Minimum scar width occurs in HDPE composites at 0.1 wt. % SiCNF, 0.7 wt. % and 0.3 wt. % SiCNF for 5 N, 10 N and 15 N respectively.

KEYWORDS
Silicon carbide nanofiber, reinforcement, high and low density polyethylene, LDPE, HDPE, composites, hardness, wear, scar, friction coefficient, normal load.

INTRODUCTION
The applications of polymer matrix composites extend to include new areas in the aerospace, automotive, and chemical industries, [1]. It was necessary to improve the strength and stiffness by controlling the filling and matrix materials in order to increase

wear resistance, [2]. Most of machine elements such as gears, cams, impellers, brakes, clutches, belt conveyors and bearings are subjected to friction and wear. Filling and reinforcing polymeric matrix by particles and fibres of high mechanical properties can enable the composites to withstand higher load, lower friction coefficient and wear, [3, 4]. It was found that the wear behavior of polymer matrix composites can be reduced by introducing fibers and fillers into the polymer matrix, [5 - 17]. It was concluded that SiC fillers in the composite effectively reduce the plough and the adhesion between the two relative sliding parts. In a study of dry sliding of a glass–epoxy (GE) composite, filled with both silicon carbide SiC and graphite (Gr), against steel disc, It was observed that wear rate was significantly decreased with glass–epoxy containing SiC, [18]. SiC particles of 220 grit were used as filler in epoxy resin reinforced by silk fibres, [19, 20]. The application of the proposed material was aimed to be in orthopedic as implantable material in the bone fixation. It was found that its mechanical properties match the femur bone's tensile and flexural strength.

EXPERIMENTAL

Materials

Experiments have been carried out using test specimens composed of low density polyethylene (LDPE) and high density polyethylene (HDPE) as matrix materials and filled by silicon carbide nanofiber (SiCNF) as a reinforcement. LDPE and HDPE have been prepared from powder materials molded in conventional dies.

Preparation of Test Specimens

Test specimens had been fabricated from LDPE and HDPE powders (as received) by pressing into molds and heated. Dies had been fabricated from steel Dimensions had been determined considering shrinkage coefficient that had been calculated by molding well-pressed polymeric powder in a vertical pipe with known height. Silicon carbide nanofibers had been added in different contents of 0.1, 0.3, 0.5, 0.7 and 1.0 wt. % to LDPE as well as to HDPE. The mixed powders of LDPE and HDPE were conventionally molded in dies heated up to melting points and left to cool down and cure in room temperature. The produced specimens' dimensions are 20 × 20 × 3 mm, after curing, the sample were ejected, their dimensions had been confirmed, residues had been removed automatically sanded and adhered to a steel strip as shown in figure 1.

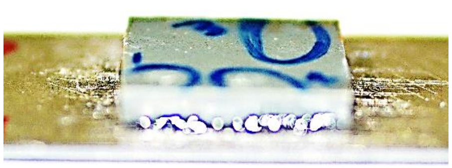

Fig. 1 Test specimen adhered to holder strip

Test Method

Hardness Test

Shore D Durometer instrument was used to measure hardness of specimens' surfaces, as durometer measures material's resistance to permanent indentation, it was used to measure in the upright position towards specimen surface.

Friction Test

Evaluation of the friction coefficient of the composite was done by using tribometer tester to measure friction force though subjecting specimens to different normal loads while the outer cylindrical bearing steel sliding against them. Friction force readings average was taken from 60 readings during one-minute test. Test rig shown in Fig. 2 consists of a variable speed motor rotating a shaft with chuck that holds a small shaft with fixed tapered outer race of bearing 30203. The tapered outer race rotates against specimens that held by clamps and subjected to normal loads. For each normal load, the friction coefficient is determined by dividing the friction force on the normal load applied to experiment, as μ= F/N, where μ is the friction coefficient, F is the friction force and N is the normal load. Experiments were carried out at 200 rpm rotating speed, normal loads of 5 N, 10 N and 15 N and test duration of one-minute.

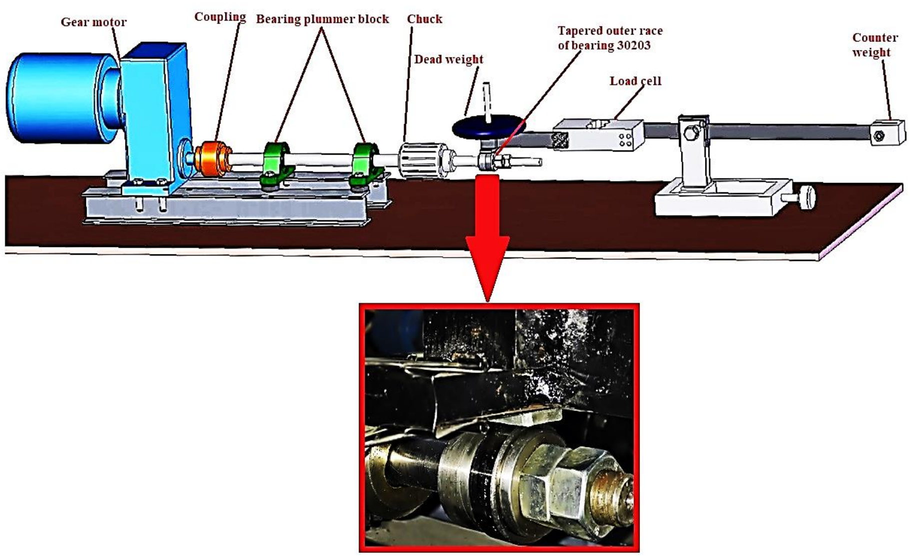

Fig. 2 Monitoring test rig with a tapered outer race of bearing 30203 rotating against composite specimen

RESULTS AND DISCUSSION

HARDNESS

Figure 3 shows the effect of silicon carbide nanofibers (SiCNF) on the hardness of the tested specimens made of LDPE composites. Hardness showed clear overall increasing trend with the increase of silicon carbide nanofibers. The improvement of hardness may be attributed to the strength enhancement and Young's modulus of SiCNF. Also, the role of heating/cooling procedure effect shall be considered as it might increase the hardness values due to overlapping and stacking, which might reduce the movement of polymer molecules leading to the increase of material resistance to scratch, cut and plastic deformation.

Figure 4 shows the correlation between hardness for the different percentages of added SiCNF to HDPE composites. The lowest hardness value appears at 0.1 wt. % SiCNF content, while the highest hardness value is detected at 1.0 wt. % SiCNF. The hardness increases with the increase of SiCNF from 0.1 wt. % to 1.0 wt. %. That behaviour may be due to the same reasons mentioned for LDPE, while hardness decreased from the reading measure at the pure sample maybe a result of inhomogeneous dispersion of SiCNF in HDPE polymer which reduced the reinforcing effect of SiCNF.

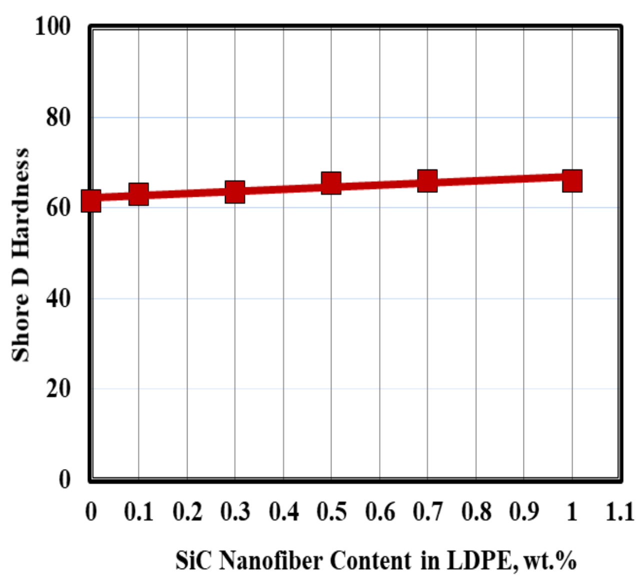

Fig. 3 Effect of SiCNF content on the surface hardness of SiCNF/LDPE composites.

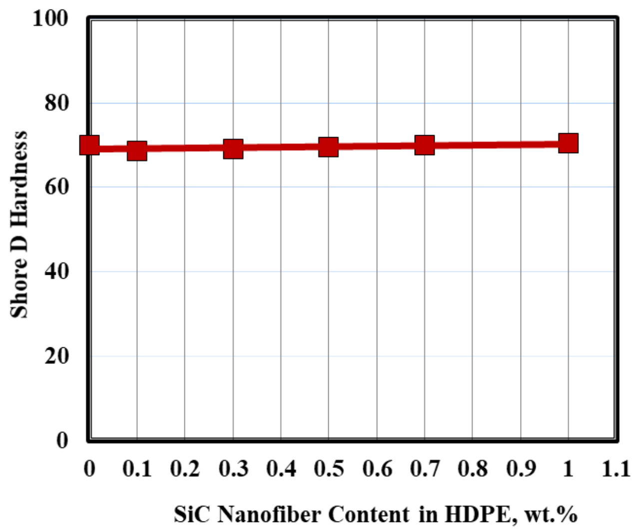

Fig. 4 Effect of SiCNF content on the surface hardness of SiCNF/HDPE composites.

Friction

Figures 5 and 6 show the effect of silicon carbide nanofibers (SiCNF) on the friction coefficient (μ) of the tested composites. For LDPE composites, Fig. 5, it can be noticed that when applying a normal load of 5 N to LDPE composites, the friction coefficient tends to decrease with adding SiCNF, while the lowest value of friction coefficient is seen at 1.0 wt. % of SiCNF and the highest friction coefficient value appears at 0 wt. %. SiCNF. When a normal load of 10 N was applied, the friction coefficient showed the minimum value at LDPE sample with 1.0 wt. % SiCNF content, where the highest friction coefficient value is observed at 0.5 wt. %. A similar trend of friction coefficient is observed when applying 15 N normal load while it shows its minimum value at 0.3 wt. % SiCNF content, while the highest at 0.7 wt. % SiCNF. The decreasing and increasing friction coefficient behavior may be attributed to the correlation between contact area and load, as the normal load increases, the contact area increases, hence the interacting surfaces produce particles work as third body that decreases friction coefficient, in addition to the strength improvement of surface.

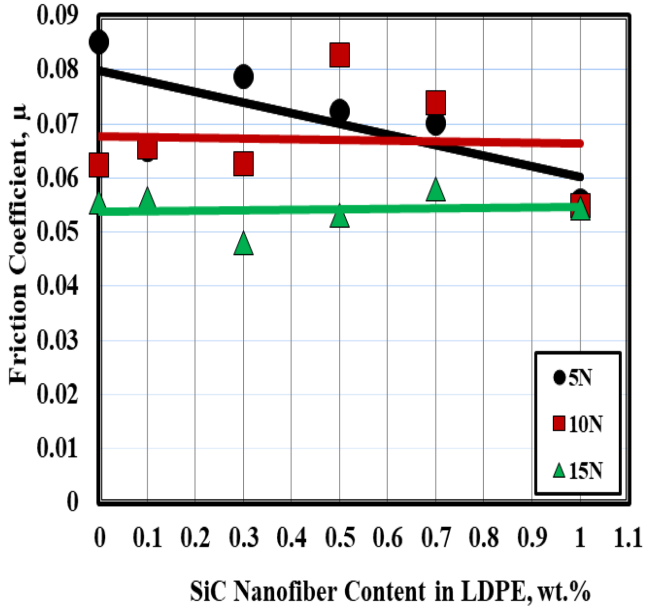

Fig. 5 Effect of SiCNF content on the friction coefficient of SiCNF/LDPE composites.

Figure 6 illustrates the friction coefficient with increasing the content of SiCNF reinforcing HDPE specimens. When HDPE composites were applied to 5 N normal load during experiment, friction coefficient shows its minimum value for HDPE specimen reinforced by 0.3 wt. % SiCNF, while the highest value is observed at 0.1 wt. % content. For experiments performed under normal load of 10 N, the minimum friction coefficient value appears at the unfilled HDPE, then at 0.3 wt. % SiCNF content, while the maximum value was displayed at 0.5 wt. %. For 15 N normal load, the minimum values of friction coefficient of HDPE composites are observed at 0.1 wt. % and 0.3 wt. % respectively, where both values were less than the friction coefficient value showed by pure HDPE samples. The maximum friction coefficient value was shown at HDPE composite with 0.7 wt. % of SiCNF content. The friction coefficient overall behavior at 5 N tended to decrease while when increasing the normal load to 10 N and 15 N, the friction coefficient tends to increase with normal load and filler content.

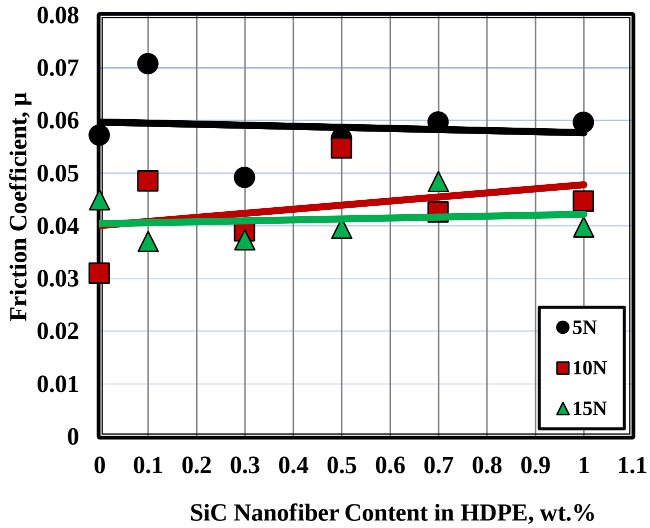

Fig.6 Effect of SiCNF content on the friction coefficient of SiCNF/HDPE composites.

Wear scar width in the current study is alternatively representing wear. The correlations observed between scar width and silicon nanofiber (SiCNF) content respecting different applied loads are shown in figures 7 and 8 for LDPE composites and HDPE composites respectively. In figure 7, LDPE composite with a 1.0 wt. % SiCNF content shows the minimum scar width when 5 N normal load was applied , while the widest scar appears at 0.3 wt. %. For 10 N normal load, the minimum wea scar width is at 0.7 wt. % and the maximum scar is at 0.3 wt. %. Maximum scar width at 15 N normal load can be observed at 0.3 wt. % and the minimum scar width appears at 0.1 wt. % SiCNF. The minimum value at 5 N load observed for LDPE reinforced by 1.0 wt. % SiCNF may be attributed to increase of wear resistance of the composite, while the maximum value of wear scar width occurred at 10 N load was observed at 0.3 wt. % SiCNF. This observation may refer to the wear increase as result of the separation of silicon carbide nanofibers from LDPE matrix. In addition to that, it may be due to the inhomogeneous dispersion of fillers.

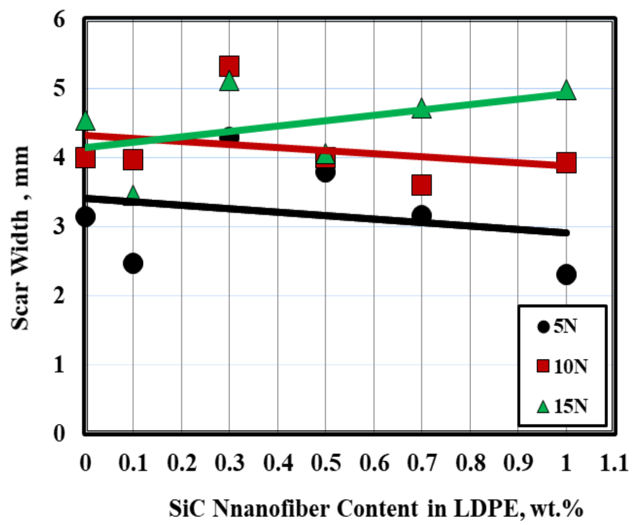

Fig. 7 Effect of SiCNF content on the scar width of SiCNF/LDPE composites.

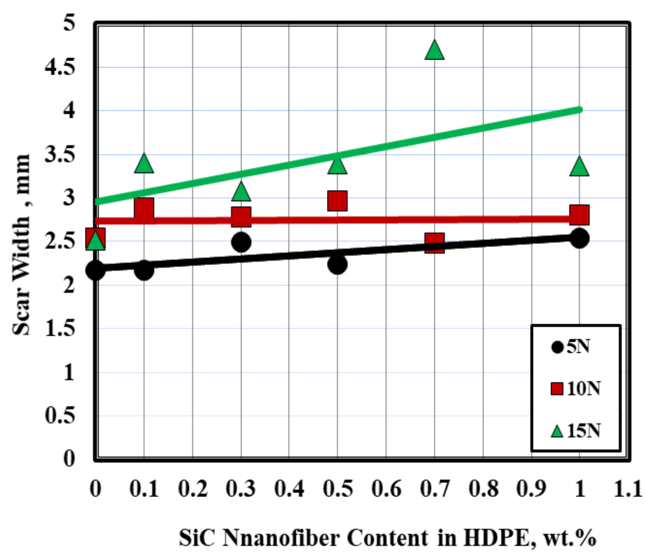

Fig. 8 Effect of SiCNF content on the wear scar width of SiCNF/HDPE composites.

Figure 8 shows the relationship between wear scar width and silicon carbide nanofiber of different weight contents reinforcing HDPE at different values of normal loads. For 5 N normal load, the minimum wear scar width value appears at the unfilled HDPE followed by value at 0.1 wt. % SiCNF, while the maximum wear scar width appears at 1.0 wt. % SiCNF. Applying 10 N normal load shows the minimum scar width at 0.7 wt. % SiCNF and widest scar at 0.5 wt. % SiCNF. Experiments had been performed under normal load of 15 N show a minimum wear scar width at unfilled HDPE followed by 0.3 wt. % SiCNF and maximum scar width at 0.7 wt. % SiCNF. The increase of normal load is correlated to the wear scar width trend increase. This behavior may be due to the agglomerates that cannot effectively transfer stress. The local agglomerates formed stress point that leads to the generation of fracture source, which increases wear. The increasing trend of wear scar width along the increase of silicon carbide content might be explained on the basis that at those loads, the high content of SiCNF wear might be increased due agglomeration of SiCNF inside the HDPE matrix.

CONCLUSIONS

Based on the experimental results of this study, the following points can be concluded:

1. Hardness of LDPE composites increases by the increase of SiCNF content.

2. Hardness of HDPE composites slightly increases with the increase of SiCNF content.

3. Friction coefficient of LDPE composites tends to increase with increasing normal load.

4. Friction coefficient of HDPE composites tends to increase with the increase of normal load.

5. Minimum scar width occurs in SiCNF/LDPE composites at 0.1 wt. % content for 5N and 15N, white it occurs at 0.7 wt. % for 10N normal load.

6. Minimum scar width occurs in HDPE composites at 0.1 wt. % SiCNF, 0.7 wt. % and 0.3 wt. % SiCNF for 5N, 10N and 15 N respectively.

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