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ABRASIVE WEAR RESISTANCE OF POLYMERS REINFORCED BY SILICON CARBIDE NANOFIBERS

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ABSTRACT

Scratch test was carried out to investigate the abrasion wear resistance gained by the polymeric composites. They were polymethyl methacrylate (PMMA), low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) and epoxy epoxy reinforced by silicon oxide nanofibers (SiCNF). Experiments were carried out using normal loads of 5, 10, and 15 N. The experiments showed that PMMA composites displayed the highest friction and lowest wear values among the tested polymers, while the minimum friction values were observed at unfilled PMMA. The improvement in friction and wear may be attributed to the resistance to scratch gained by composites reinforced by SiCNF. The decreasing behavior can reflex the increase of abrasive wear resistance offered by SiCNF. Further increase of SiCNF up to 0.5 wt. % increased wear due to the drop in cohesion of the matrix. Friction coefficient increased to maximum showing that composites resisted scratch by the gained strength due to SiCNF reinforcement, while reached minimum values mostly at higher SiCNF content as result of the drop of the cohesion of the polymeric matrix. Besides, the deterioration of wear at SiCNF content higher than 0.5 wt. % may be attributed by the agglomeration of SiCNF inside the polymeric matrix that influenced the tribological behavior of composites. Homogeneous mixing and good dispersion procedures are recommended.

KEYWORDS

Silicon carbide nanofibers, reinforcement, polymethyl methacrylate, epoxy, low density polyethylene, high density polyethylene, polypropylene, composites, wear, friction coefficient.

INTRODUCTION

Composite materials are known to have high specific modulus, high specific strength, high resistance to corrosion, low weight and can be tailored to meet specific purpose, which give them advantage over traditional materials such as metals and ceramics, [1]. Polymer matrix composites (PMCs) are commonly used nowadays in industrial applications such as fishing boats, brake pads materials, flooring materials, [2 - 7]. They have wide range of applications in aerospace, marine, automotive, biomedical and low pressure pipes.

Polymethyl methacrylate (PMMA) is one of the most widely used industrial polymeric materials and still remains an active material for research. Because of its good biocompatibility, reliability, dimensional stability, absence of taste, odor, tissue irritation and toxicity, [8 - 11], teeth adhesion, insolubility in body fluids, relative ease of manipulation, good aesthetic appearance, and color stability, PMMA based materials are widely used as biomaterials. Nowadays, PMMA finds applications not only in dentistry but also in areas such as transparent glass substitutes, interior design, transparent dielectric films, [12 - 16], acrylic paints, and microcellular foams. Still, one of the most attractive applications of PMMA based materials is in various biomedical applications such as intraocular lenses, and bone cement in orthopedic surgery.

Wear generally originates from damage induced by rubbing bodies due to repeated applications of mechanical, impact and other kinds of forces, [17]. Therefore, the surface loses mechanical cohesion and debris is formed that is dislodged from the contact zone. Many wear mechanisms have been proposed, [18, 19], e.g., abrasive, adhesive, fatigue, corrosive, erosive and delamination, which show the complexity of the wear phenomena. Wear debris can also be generated by material transfer from one surface to another.

Scratching is an alternative to conventional wear testing to evaluate the abrasive wear resistance of materials, [20 - 23]. Scratch performance of polymers is determined by the material properties, test environment, and the stress field due to the scratching process. In addition, the surface tension of polymers has also been shown to play a role in influencing the scratch resistance.

Recently, 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), high density poly ethylene (HDPE), polypropylene (PP), polymethyl methacrylate (PMMA) and epoxy on the tribological behavior of the composites was investigated. Friction coefficient of SiCNF/PMMA and SiCNF/Epoxy composites was measured at room temperature, [24, 25]. It was found that friction coefficient of PMMA composites minimum values are detected at 0.7 wt. % SiCNF, while the minimum values of friction coefficient for epoxy composites were detected at 0.5 wt. % SiCNF content. Minimum scar width occurs in SiCNF/PMMA composites at 0.7 wt. % content.

In the present work, the effect of reinforcing low density polyethylene (LDPE), high density poly ethylene (HDPE), polypropylene (PP), polymethyl methacrylate (PMMA) and epoxy by SiCNF on the tribological behavior of the composites when scratched by hard indentor has been investigated.

EXPERIMENTAL

Test specimens were fabricated from low density polyethylene (LDPE), high density poly ethylene (HDPE), polypropylene (PP), polymethyl methacrylate (PMMA) and epoxy. Silicon carbide nanofibers were added in different contents of 0.1, 0.3, 0.5, 0.7 and 1.0 wt. %. The dimensions of the specimens were 20 × 20 × 3 mm.

Scratch test was performed by scratch tester. It is consisted of a rigid stylus mount to produce a scratch on a flat surface with a single pass, a diamond stylus of apex angle 90° and hemispherical tip as shown in Figs. 1 and 2. The loading lever mounted to the stylus through three-jaw chuck. A counter weight is used to balance the loading lever before process of loading. Weights of 5, 10 and 15 N are vertically applied. Scratch resistance force was measured using a load cell mounted to the loading lever and connected to display digital monitor. The test specimen was held in the specimen holder mounted in a horizontal base with a manual driving mechanism to move specimen in a straight direction. The test was conducted under dry condition at room temperature. An optical microscope was used to measure scratch width with an accuracy of ± 1.0 μm.

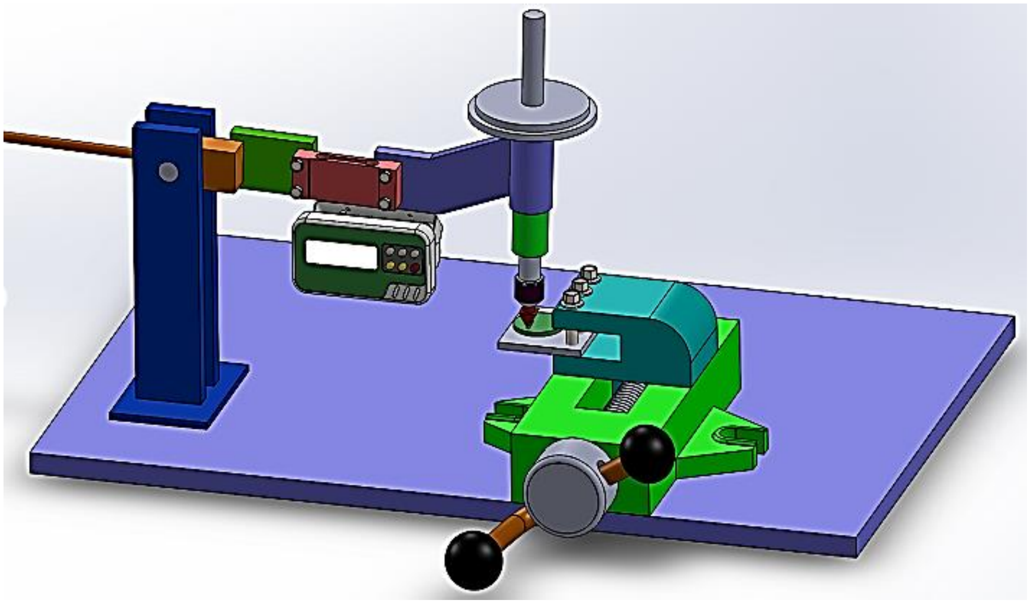

Fig. 1 Arrangement of scratch test rig.

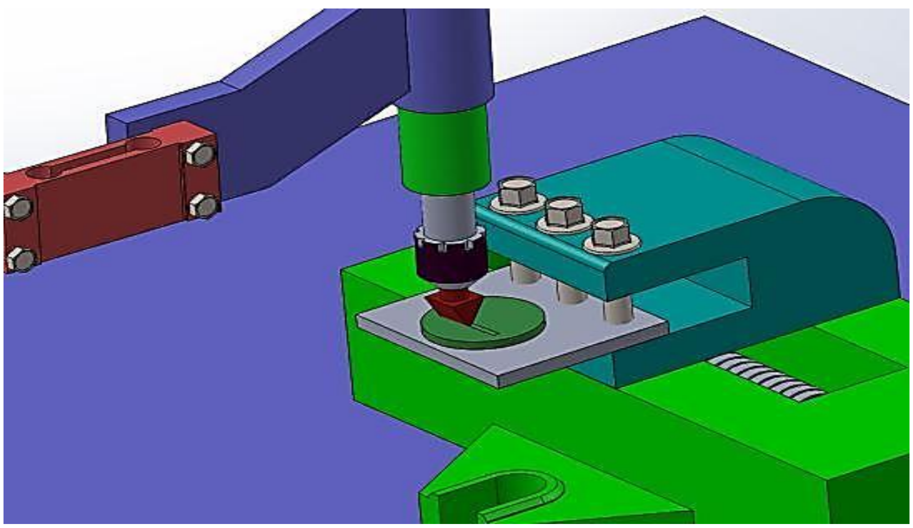

Fig. 2 Details of the scratch test.

RESULTS AND DISCUSSION

Friction coefficient displayed by LDPE reinforced by SiCNF showed decreasing trend with increasing SiCNF at 5 N applied load, Fig. 3. As the load increased up to 10 and 15 N, friction coefficient slightly increased up to maximum then slightly decreased with increasing SiCNF. The highest values of friction coefficient were displayed at 0.5 wt. % SiCNF content. They may be attributed to the resistance to scratching action gained by composites reinforced by SiCNF. The scar width displayed by LDPE composites slightly decreased down to minimum at 0.5 wt. % SiCNF content, Fig. 4, then slightly increased with further SiCNF increase. The decreasing behavior can reflex the increase of abrasive wear resistance offered by SiCNF.

Friction coefficient of HDPE composites showed the same trend observed for LDPE composites with relatively lower values, Fig. 5. As the load increased, friction coefficient decreased due to the plastic deformation offered by the scratch process, where the shear strength of the polymer decreased. The highest friction values were observed at 0.5 wt. % SiCNF content. Further increase of SiCNF caused drop in friction coefficient due to the decrease of the cohesion of the matrix of the composites. This assumption is confirmed by the wear results shown in Fig. 6, where the minimum wear was detected at 0.5 wt. % SiCNF content. Wear values were lower than that measured for LDPE and slightly increased as the SiCNF increased.

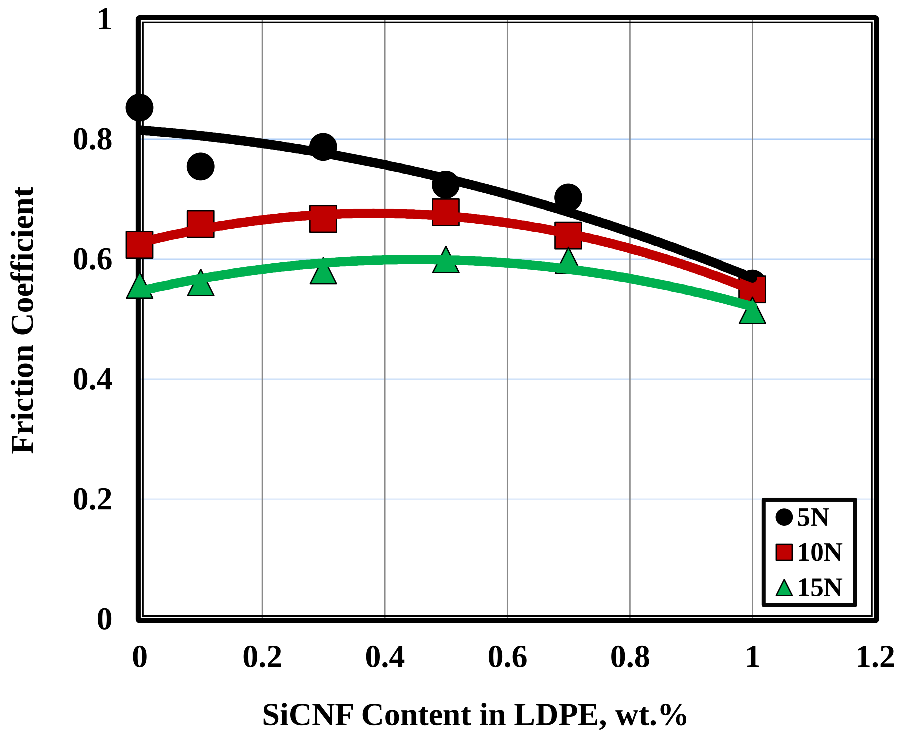

Fig. 3 Effect of SiCNF content on the friction coefficient of SiCNF/LDPE composites.

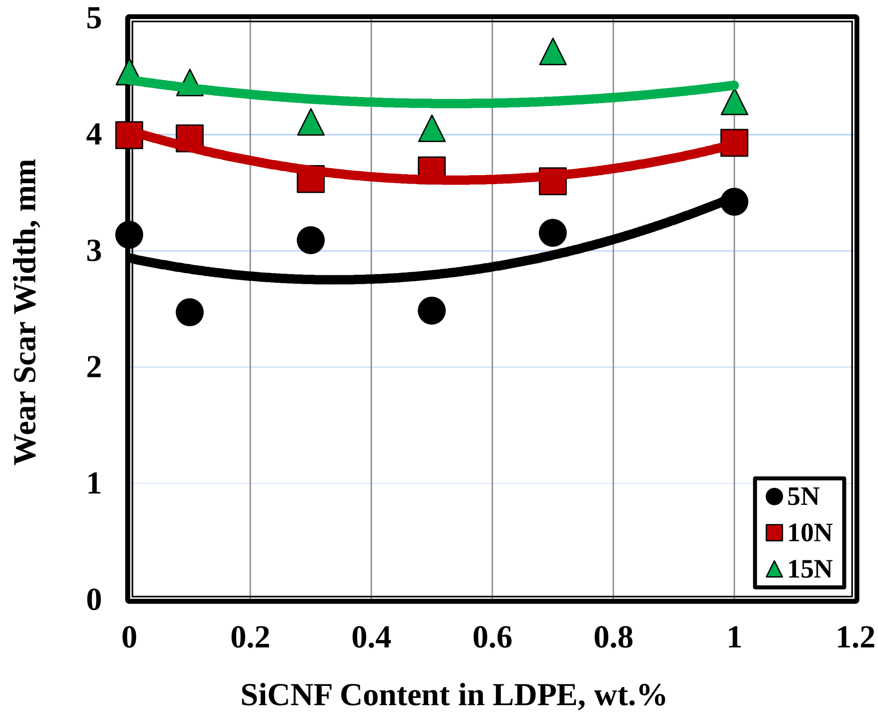

Fig. 4 Effect of SiCNF content on the scar width of SiCNF/LDPE composites.

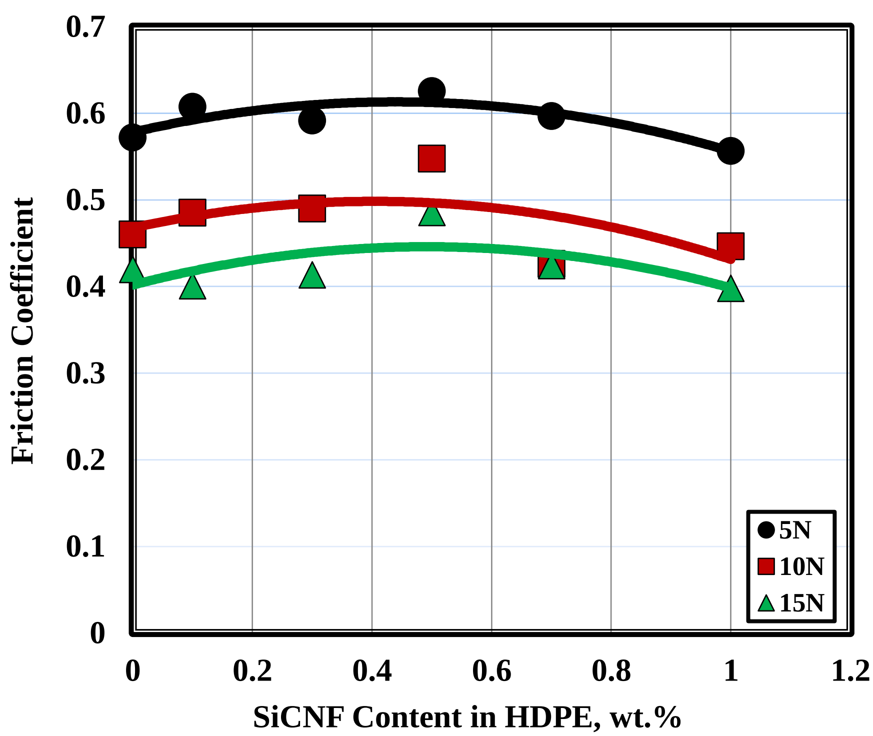

Fig. 5 Effect of SiCNF content on the friction coefficient of SiCNF/HDPE composites.

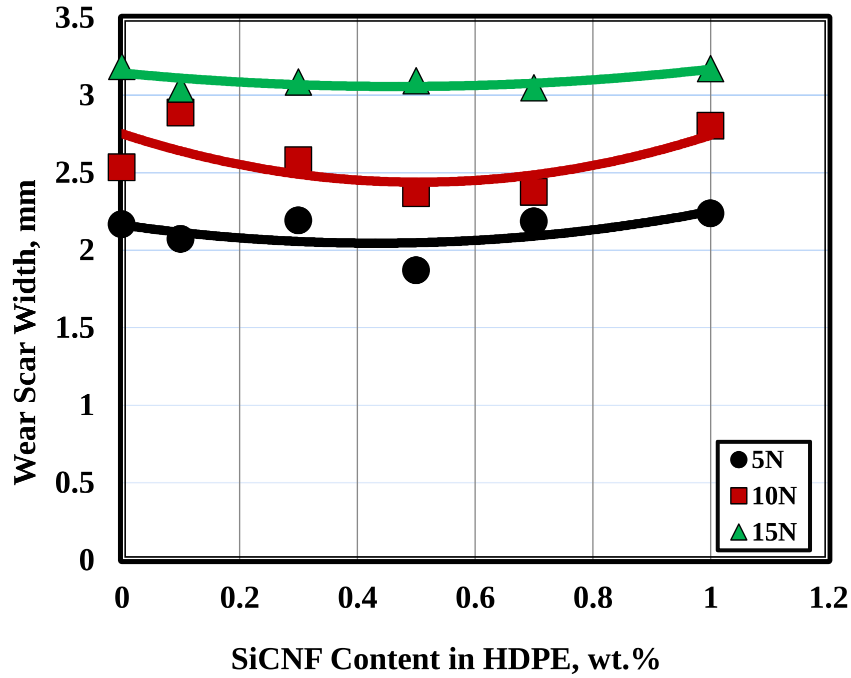

Fig. 6 Effect of SiCNF content on the scar width of SiCNF/HDPE composites.

Friction behavior of PP composites filled by SiCNF showed higher values than that presented by LDPE and HDPE. That result confirmed the relatively higher wear resistance of PP, Fig. 7. The highest friction coefficient values reached 0.8, 0.73 and 0.56 at 5, 10 and 15 N load respectively. Maximum friction coefficient values were displayed at 0.5 wt. % SiCNF. Friction coefficient increased to maximum showing that composites resisted scratching action by the gained strength due to SiCNF reinforcement, while reached minimum values mostly at higher SiCNF content as result of the drop of the cohesion of the polymeric matrix. Wear of PP composites represented lower values, Fig. 8. The lowest wear was shown at 0.5 wt. % SiCNF indicating the best cohesion gained by composite to resist scratching action. Scar width increases with the increase of normal load due to the contact area increase by increasing applied normal loads that caused softening while rubbing as shear stress reduces caused by the plastic deformation. Increase of scar width with the increase of SiCNF content can be referred to weak cohesion inside the polypropylene matrix.

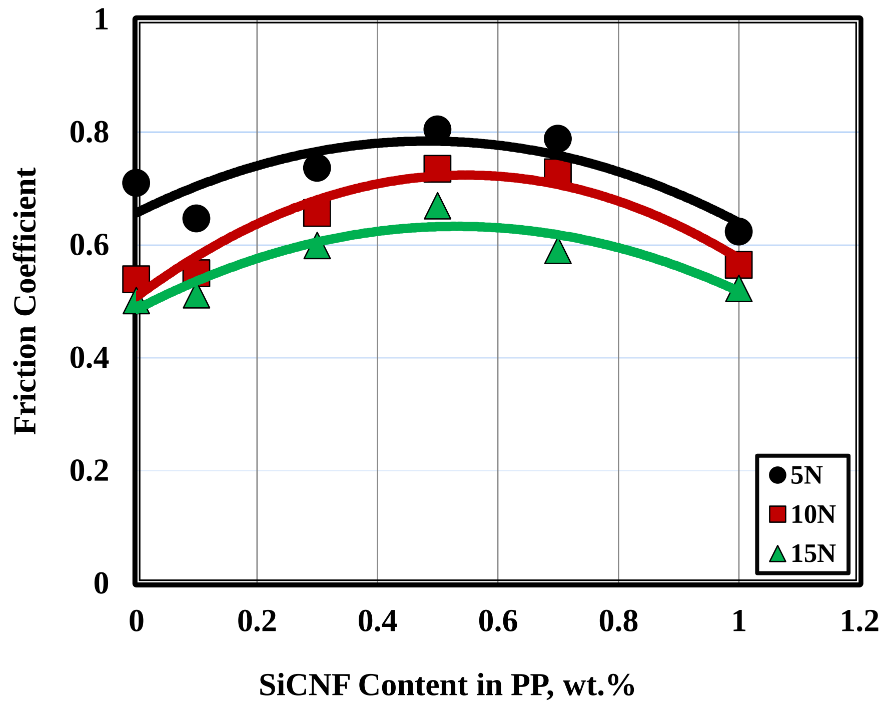

Fig.7 Effect of SiCNF content on the friction coefficient of SiCNF/PP composites.

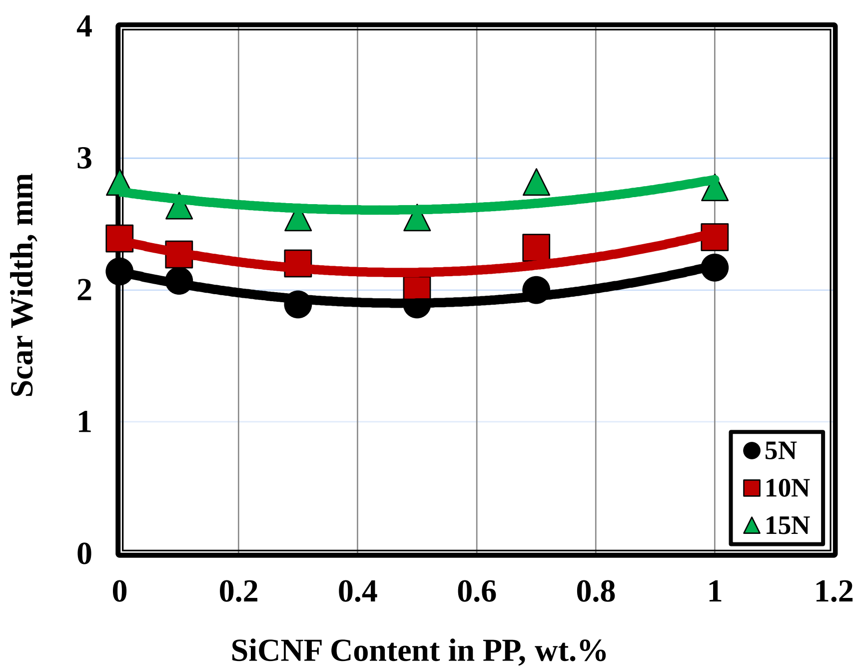

Fig. 8 Effect of SiCNF content on the wear scar width of SiCNF PP composites.

PMMA composites showed the highest friction and lowest wear values among the tested polymers, while the minimum friction values were observed at unfilled PMMA, Figs. 9 and 10. Friction increase indicated the increase of cohesion of the matrix of the tested

composites by increasing the reinforcement content up to 0.5 wt. %. Further increase of SiCNF would increase wear due to the drop in cohesion of the matrix.

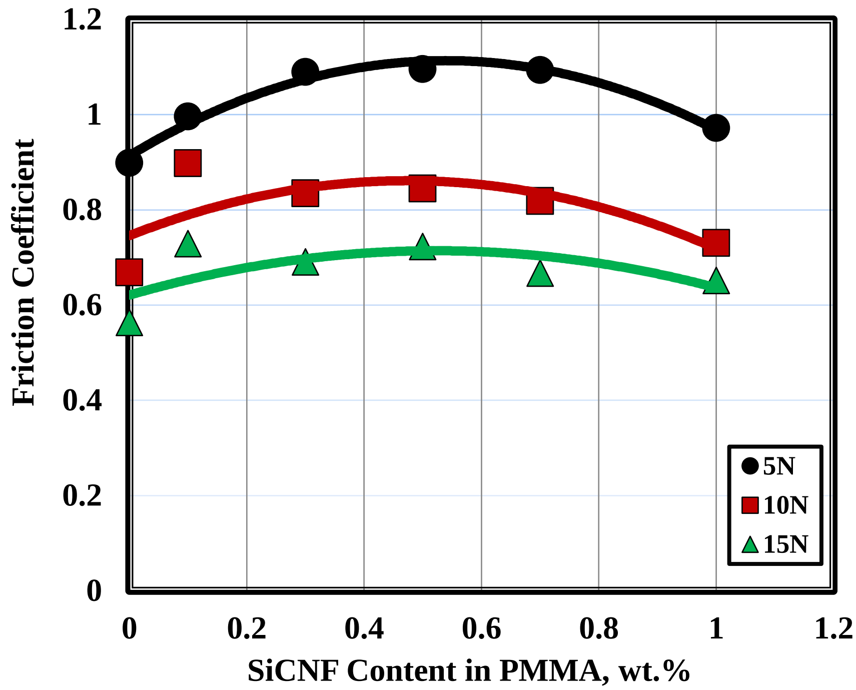

Fig. 9 Effect of SiCNF content on the friction coefficient of SiCNF/PMMA composites.

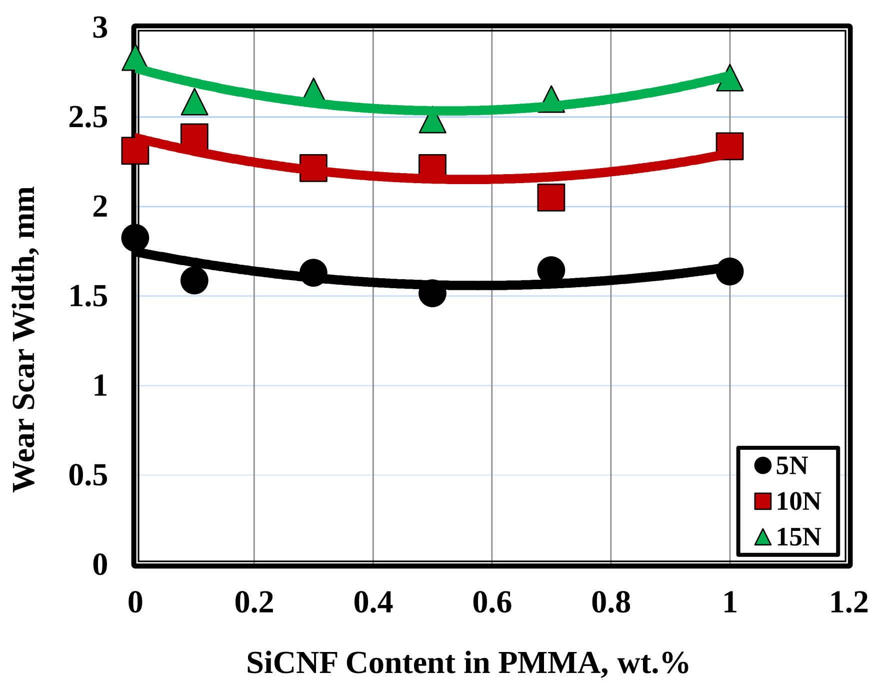

Fig. 10 Effect of SiCNF content on the scar width of SiCNF/PMMA composites.

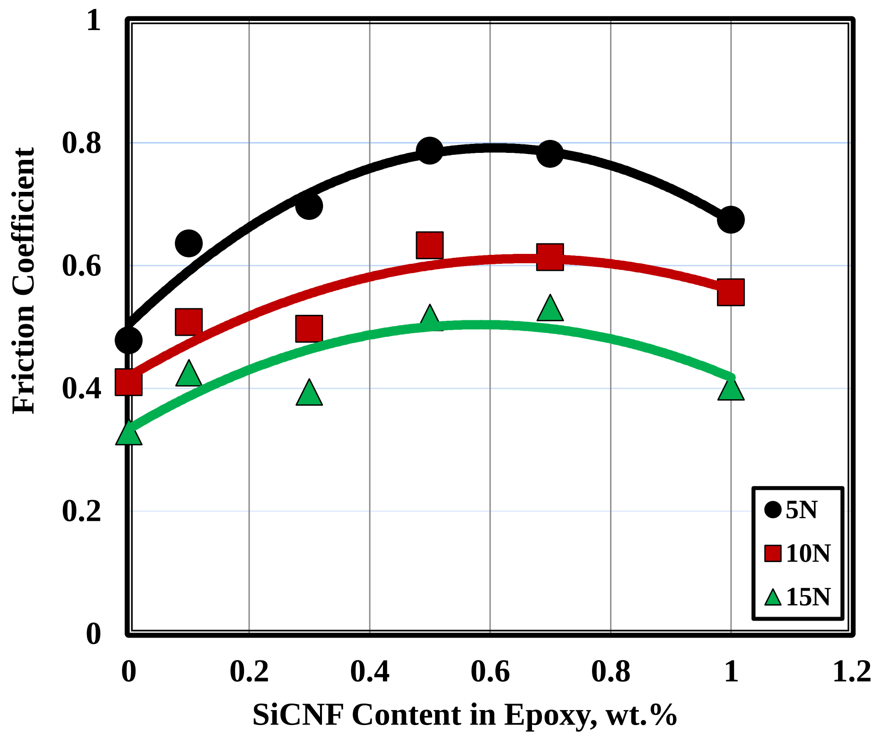

Fig. 11 Effect of SiCNF content on the friction coefficient of SiCNF/Epoxy composites.

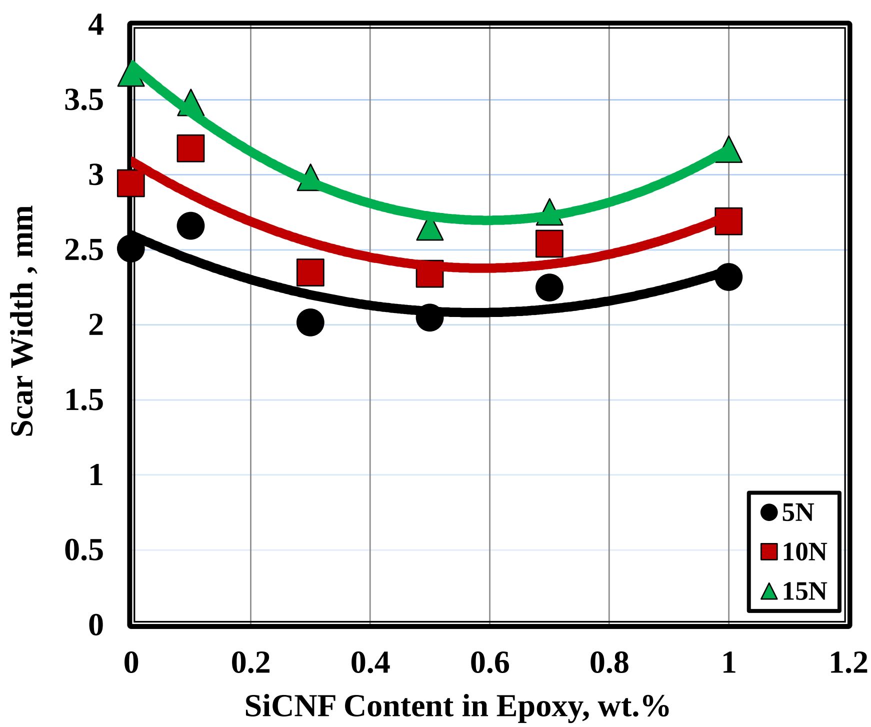

Fig. 12 Effect of SiCNF content on the scar width of SiCNF/Epoxy composites.

Figure 11 shows the friction coefficient variation with the increase of SiCNF content reinforced epoxy matrix, where the highest values of friction coefficient were watched 0.5 wt. %, while the lowest values were presented by unfilled composites. The decreasing trend of friction coefficient can be attributed to the increase of wear resistance gained by SiCNF reinforcing epoxy composites. Wear scar width occurred in epoxy composites after scratch test is shown in Fig. 12. It can be noted the deterioration of wear at SiCNF content higher than 0.5 wt. % may be attributed by the agglomeration of SiCNF inside the matrix composites that plays a role affecting the tribological behavior of composites. Homogeneous mixing and good dispersion procedures are recommended.

CONCLUSIONS

1. Friction coefficient displayed by LDPE reinforced by SiCNF slightly increased up to maximum then slightly decreased with increasing SiCNF. The highest values of friction coefficient were displayed at 0.5 wt. % SiCNF content. Wear slightly decreased down to minimum at 0.5 wt. % SiCNF content then slightly increased with further SiCNF increase. The decreasing behavior can reflex the increase of abrasive wear resistance offered by SiCNF.

2. Friction coefficient of HDPE composites showed the same trend observed for LDPE composites with relatively lower values. As the load increased, friction coefficient decreased due to the plastic deformation offered by the scratch process, where the shear strength of the polymer decreased. Minimum wear was detected at 0.5 wt. % SiCNF content. Wear values were lower than that measured for LDPE and slightly increased as the SiCNF increased.

3. Friction behavior of PP composites filled by SiCNF showed higher values than that presented by LDPE and HDPE. Wear of PP composites represented lower values. The lowest wear was shown at 0.5 wt. % SiCNF indicating the best cohesion gained by composite to resist scratching action.

4. PMMA composites showed the highest friction and lowest wear values among the tested polymers, while the minimum friction values were observed at unfilled PMMA.

5. The deterioration of wear at SiCNF content higher than 0.5 wt. % may be attributed by the agglomeration of SiCNF inside epoxy composites that plays a role affecting the tribological behavior of composites. Homogeneous mixing and good dispersion procedures are recommended.

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