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TRIBOLOGICAL PROPERTIES OF HEAT TREATED LOW DENSITY POLYETHYLENE REINFORCED BY COPPER WIRES

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ABSTRACT
The present work investigates friction and wear displayed by the scratch of low density polyethylene (LDPE) composites reinforced by unidirectional continuous copper wires of 0.3 mm diameter. This is a simulation of bearing material. Influence of heat treatment processes such as (annealing, hardening and tempering) on their friction and wear was studied.

It was found that friction coefficient displayed by the scratch of LDPE reinforced by copper wires increased as the load increased due to increased material removed during scratch. Friction coefficient decreased with increasing number of wires up to eight wires then started to increase at 10 wires. It seems that, the presence of copper wires decreased the hardness of the polymeric materials so that the material removed by the indenter was easier. At 10 wires, friction became between the scratching tool and wires themselves due to narrow area between wires that caused the increase of the friction coefficient. The influence of heat treatment on friction was investigated. As the unheated specimens showed the highest friction coefficient, Tempered LDPE composites reinforced by unidirectional continuous copper wires specimens displayed the lowest friction values followed by hardened and annealed specimens. Friction coefficient increased with increasing normal load by annealing and hardening while it decreased by tempering.

As the number of copper wires increase, wear scar width of the LDPE composites slightly decreased. The wear decrease of the tested specimens can be explained on the basis that presence of copper wire reinforcement can restrain the deformation of the polymer composites. Besides, plastic deformation, grooving and smearing of surface can be decreased by the strengthening effect of the reinforcement as well as the retarding action of the wire against the motion of the indenter. The heat treatment of tested composites investigate that Tempered specimens displayed the lowest wear scar width values while untreated ones showed the highest wear scar width values. Wear scar width increased with increasing normal load by annealing at 90 °C and hardening at 120 °C

while it decreased by tempering at 110 °C. Annealed specimens displayed relatively higher wear scar width than hardened and tempered specimens.

KEYWORDS
Friction coefficient, wear, scratch, low density polyethylene, copper wires, annealing, hardening, tempering.

INTRODUCTION

Over the past decades, polymer composites have been increasingly used as structural materials in aerospace, automotive, and chemical industries, because they provide potential lower weight alternatives to traditional metallic materials. Among these applications, numerous are related to tribological components, such as gears, cams, bearings, and seals, where the self-lubrication properties of polymers and polymer based composites are of special advantage, [1]. The feature that makes polymer composites promising in industrial applications is the possibility to tailor their properties by adding special fillers with different volume fractions, shapes, and sizes. To tailor the mechanical and/or tribological performance of polymers, short-cut fibers and/or fabrics have been incorporated into some polymer matrices, [2].

Scratch resistance of polymers is an important property for engineering application especially in automotive industry, [3]. Scratch resistance of polymers depends mainly on the nature of the polymer itself and the operating parameters such as applied load, shape, size and the nature of the indenter, its attack angle, scratch velocity, state of the interfacial lubrication. Several papers are available reporting on the influence of operating parameters on the scratch behavior of polymers, [4 - 8]. The influence of indenter geometry, test temperature, loading rate, and strain rate on the scratch behaviour of polymethylmethacrylate was investigated. The effect of indenter geometry and test temperature, on the friction behaviour of ultra-high-molar-weight-polyethylene (UHMWPE) in single point and multi asperity scratch tests, was studied, [4]. It was observed that the friction coefficient increased with increasing the indenter attack angle for the single point scratch test. The abrasive and erosive wear behavior of various polyamides were studied, [9, 10]. It is possible to produce useful polymers by joining different polymers. Blending is combining of two polymer molecules to form new copolymer with different characteristics, [11]. Polymer blends are considered an alternative method to improve friction and wear behavior to extend the range of polymer applications.

The friction and wear of polyethylene (PE) matrix composites reinforced by unidirectional continuous steel and copper wires of different diameters were discussed, [12, 13]. On the bases of experimental results, it was found that friction coefficient displayed by the scratch of reinforced PE decreased with increasing number of wires. As the load increased friction coefficient increased. It seems that the presence of metallic wires decreased the hardness of the polymeric materials so that the material removal by the indenter was easier. Wire diameter had insignificant effect on friction coefficient. The friction and wear of polypropylene matrix composites reinforced by unidirectional continuous copper wires are discussed, [14]. It was found that friction coefficient

displayed by the scratch of PP reinforced by copper wires showed slight decrease with increasing number of wires, where the load had insignificant effect on friction coefficient. The change of wire diameter had slight effect on friction coefficient. The hardness decreased close to the wire due to the change of the cooling rate, where the zone near the copper wire was cooling faster and causing a decrease in polymer hardness.

Wear of the tested composites slightly decreased with increasing number of wires. Increase of wire diameter showed insignificant effect on wear that significantly increased with increasing normal load. The wear decrease of the tested composites can be explained on the basis that the presence of wire reinforcement can restrain the deformation of the polymer matrix. Besides, plastic deformation, grooving and smearing of surface can be decreased by the strengthening effect of the reinforcement as well as the retarding action of the copper wire against the motion of the indenter.

Heat treatment of the polymers is considered one of the most effective methods of modification to widen their applications. Heat treatment of polymers improves their mechanical and tribological properties, [15, 16]. This effect is a result of crystal phase increase in the polymer structure, where the elastic part of polymer viscoelasticity increases causing significant increase in compressive strength and heat conductivity. The physical and mechanical properties of polyamides are affected by the degree of crystallization, which can be controlled by the change of cooling rate during the production process.

In the present research, the friction coefficient and wear of LDPE composites reinforced by unidirectional continuous copper wires of 0.3 mm diameter are discussed in this work and the influence of heat treatment (annealing, hardening and tempering) on friction and wear was investigated.

EXPERIMENTAL

Specification and Preparation of Test Specimens

The dimensions of the test specimens prepared from LDPE were 20 × 40 mm² and 3.0 mm thickness and reinforced by copper wires of 0.3 mm diameter. The numbers of wires reinforcing the test specimens were 0, 2, 4, 6, 8 and 10. The wires were distributed perpendicular to the direction of motion. To prepare test specimens, LDPE with reinforcement of copper wires were molded in a die of 60 × 100 × 6 mm^3 at 150 °C temperature by using hydraulic press. The details of the specimens preparation and heat treatment have been discussed elsewhere, [16].

Test Method

Friction Test

Scratch tester shown in Fig. 1 was used in the experiments. It consists of a rigid stylus mount, a steel stylus of apex angle 90° and hemispherical tip. The stylus was mounted to the loading lever through three jaws chuck. A counter weight was used to balance the loading lever before loading. Vertical load was applied by weights of 2, 4, 6, 8 and 10 N. Scratch resistance force was measured using 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 specimens were scratched by steel indenter. The test was conducted under dry conditions at room temperature. The test specimen under scratch action is shown in Fig. 5. The scratch force was measured during the test and then friction coefficient was calculated. An optical microscope was used to measure scratch width with an accuracy of ± 1.0 µm. The evidence of the scratch test on the surface of the test specimen is shown in Fig. 2.

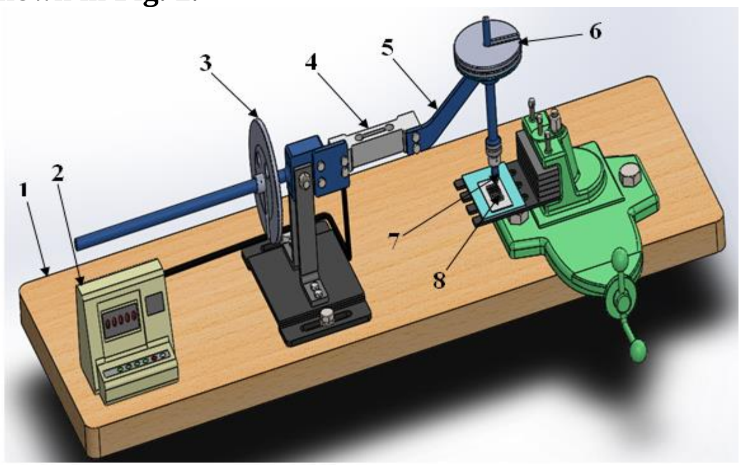

Fig. 1 Arrangement of scratch test rig; 1. Base, 2. Friction Force Screen, 3. Counter Weight, 4. Load Cell, 5. Loading Lever, 6. Normal Loads, 7. Scratching tool, 8. Test Specimen

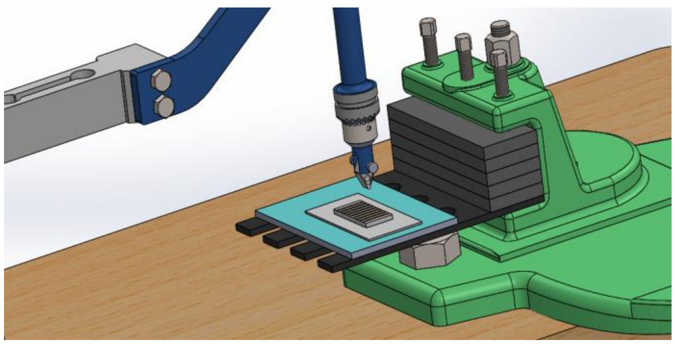

Fig. 2 The specimen under scratch action.

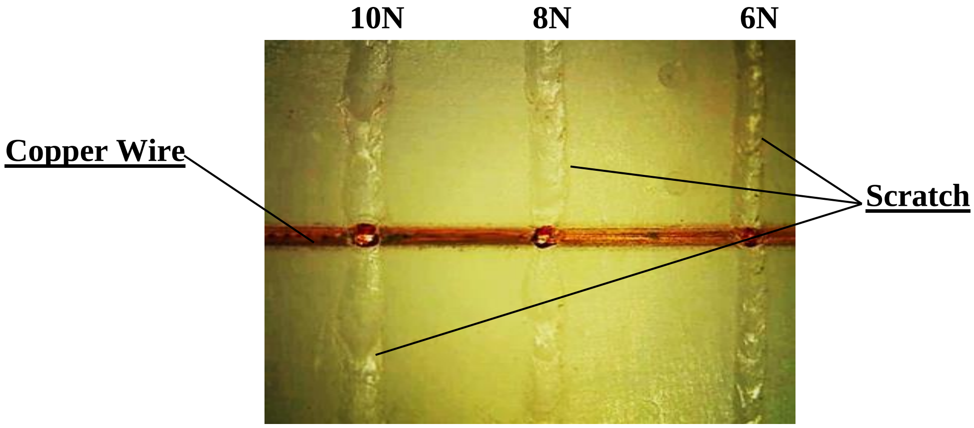

Fig. 3 Scratches on the surface of the test specimen.

Hardness Test

Shore D Durometer instrument was used. Hardness was measured in a various distances from copper wire.

RESULTS AND DISCUSSION

The results of the experimental work carried out in the present work are shown in Figs. 7 – 22. Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires, Figs. 4, 5 showed significant decrease with increasing number of wires up to 8 wires then it started to increase at 10 wires. This behavior may be attributed to the fact that, the copper wires as good heat conductor transferred heat during molding out of the polymeric materials. This process increased the rate of cooling causing softening of PE matrix. As the cooling rate increased hardness of the tested polymers decreased and consequently friction coefficient remarkably decreased as the material removal by the indenter was easier. As result of that, the increased number of copper wires decreased the friction coefficient while at 10 wires, the friction becomes between the scratching tool and wires themselves due to narrow area between wires caused increase of friction coefficient. At 10 N loads, friction coefficient decreased from 0.148 for unreinforced LDPE to 0.135 for LDPE reinforced by eight wires then increased to 0.140 for LDPE reinforced by 10 wires. The specimens without heat treatment displayed the highest friction coefficient.

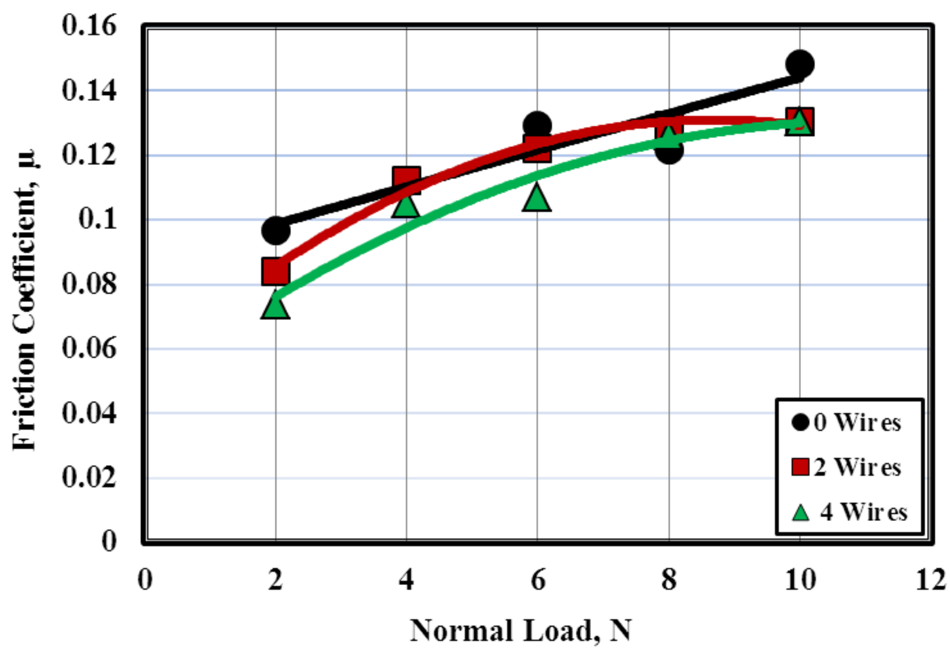

Fig. 4 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires.

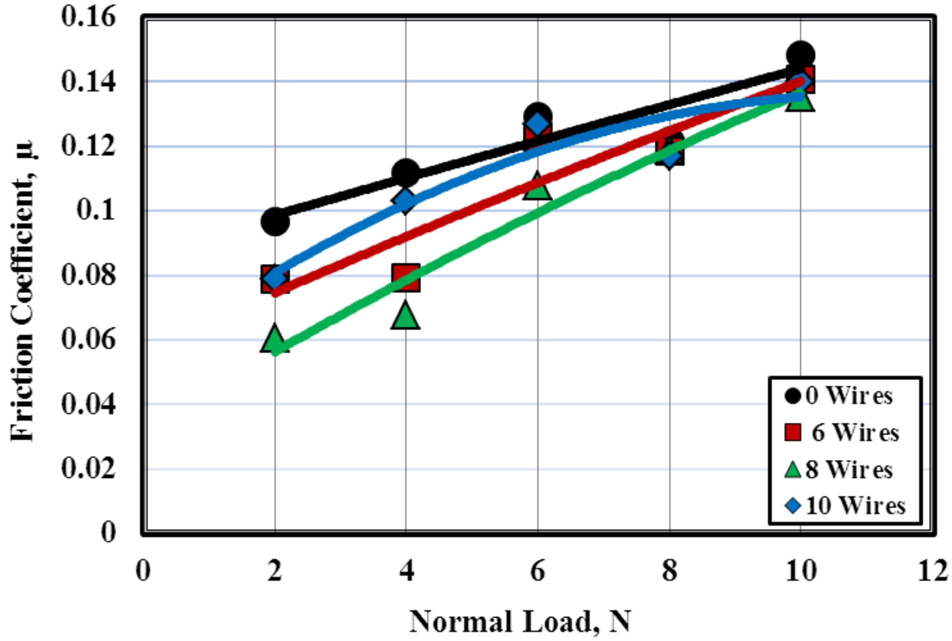

Fig. 5 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires.

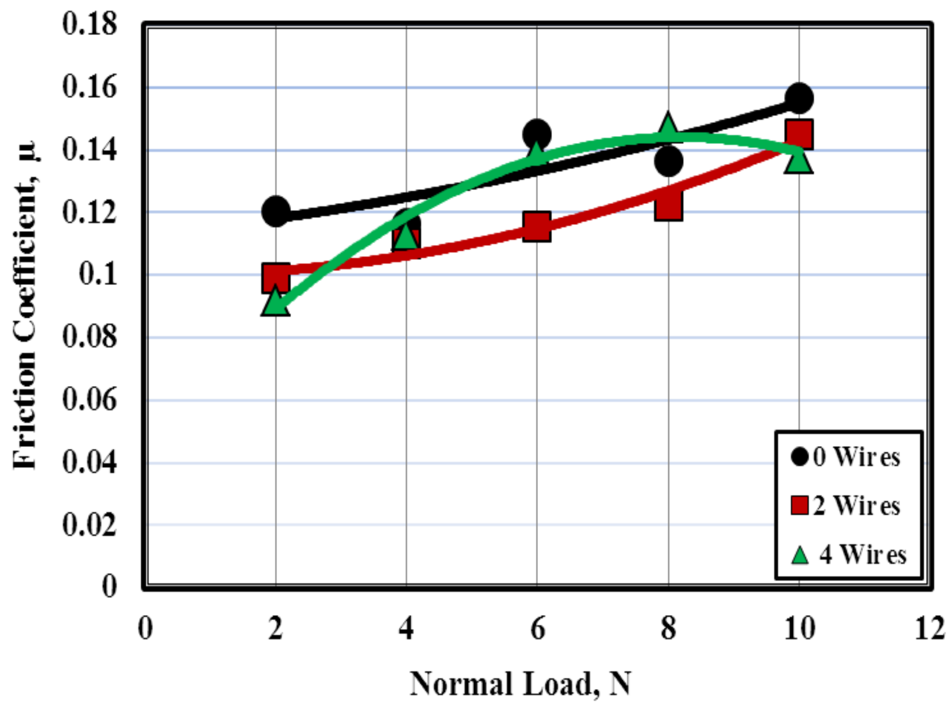

Fig. 6 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires and tempered at 90 °C.

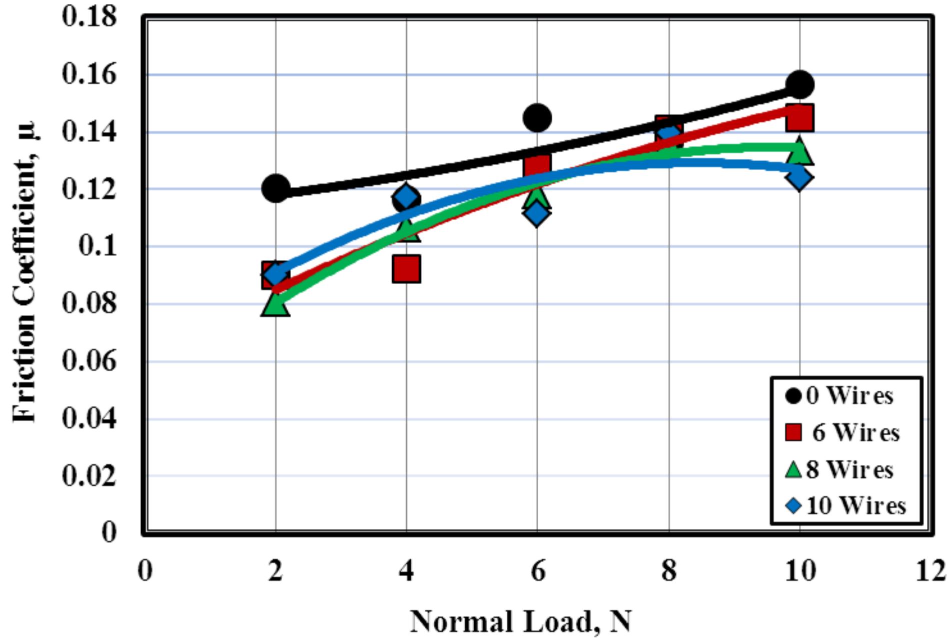

Fig. 7 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires and annealed at 90 °C.

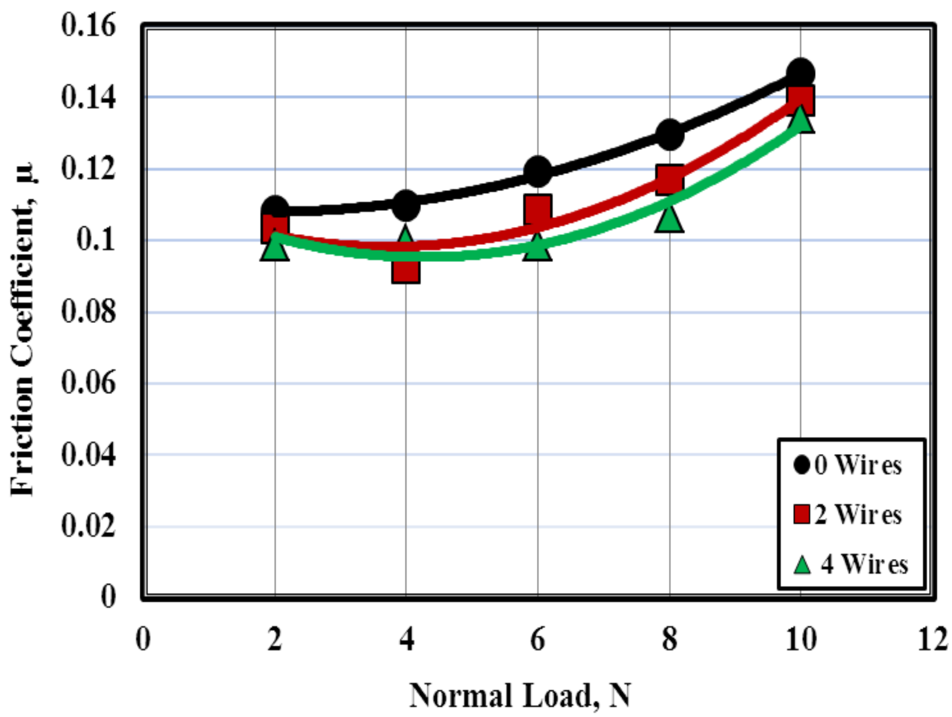

Fig. 8 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires and hardened at 120 °C.

The influence of heat treatment of the copper wires reinforcing LDPE composites on friction coefficient is illustrated in Figs. 6 - 11. Friction coefficient displayed by the scratch of LDPE composites that tempered at 110 °C recorded lower friction followed by those hardened at 120 °C and annealed at 90 °C. Unheated specimens showed the highest friction coefficient. It seems that the heat treatment was responsible for that behavior while the change in the friction caused by heat treatment can be attributed to the change of polymers crystallization. Heat treatment improves the mechanical and tribological properties of polymers. This effect is a result of crystal phase increase in the polymer structure, where the elastic part of polymer viscoelasticity increases causing significant increase in compressive strength and heat conductivity. The decreased in friction for tempered LDPE composite might be because of increasing the ductility by tempering.

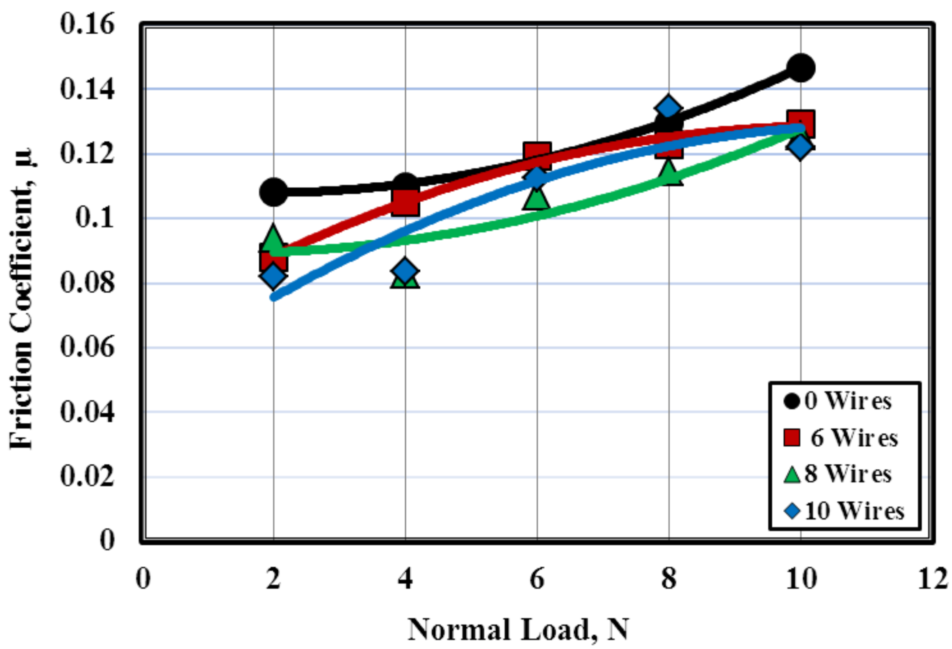

Fig. 9 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires and hardened at 120 °C.

WEAR

The wear displayed by the scratch of tested composites is shown in Figs. 15 - 16. It was observed that wear scar width decreased with increasing number of copper wires. The wear of the tested composites might be interpreted on the basis that the presence of copper wires reinforcement can restrain the deformation of polymer matrix where the external loads applied through the matrix is transferred to the wires by shear at the interface. Besides, plastic deformation, grooving and smearing of surface caused by the indenter can be decreased by the strengthening effect of the reinforcement as well as the retarding action of copper wire against the motion of the indenter. It is known that the function of the matrix is to support the wires and transmit the load to them by shear at the wire-matrix interface which represents the weakest zone in the coating. As the

adhesion between the matrix and wire increases, the wear of the coating decreases. The influence of heat treatment of the copper wires reinforcing LDPE composites on wear is illustrated in Figs. 17 – 22. Wear significantly increased with increasing normal load by annealing and hardening while it decreased by tempering. LDPE composites free of copper wires showed relatively higher wear than that reinforced by copper wires. The specimens without heat treatment displayed the higher wear scar width while tempered recorded the lower scar width. Annealed LDPE composites recorded the higher scar width. Annealed specimens displayed relatively higher wear scar width followed by hardened and tempered.

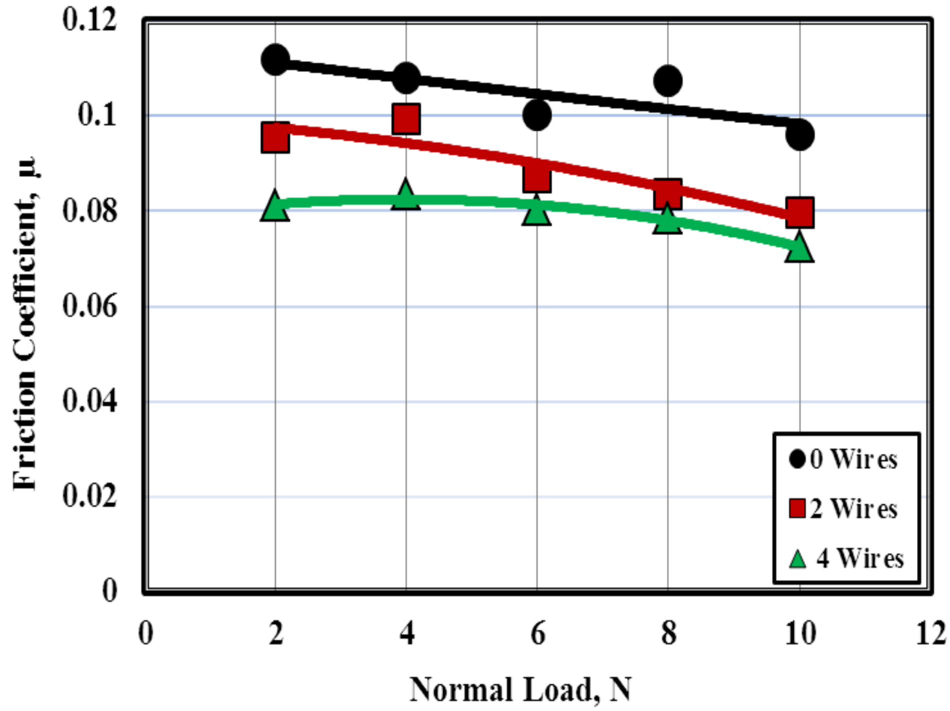

Fig. 10 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires and tempered at 110 °C.

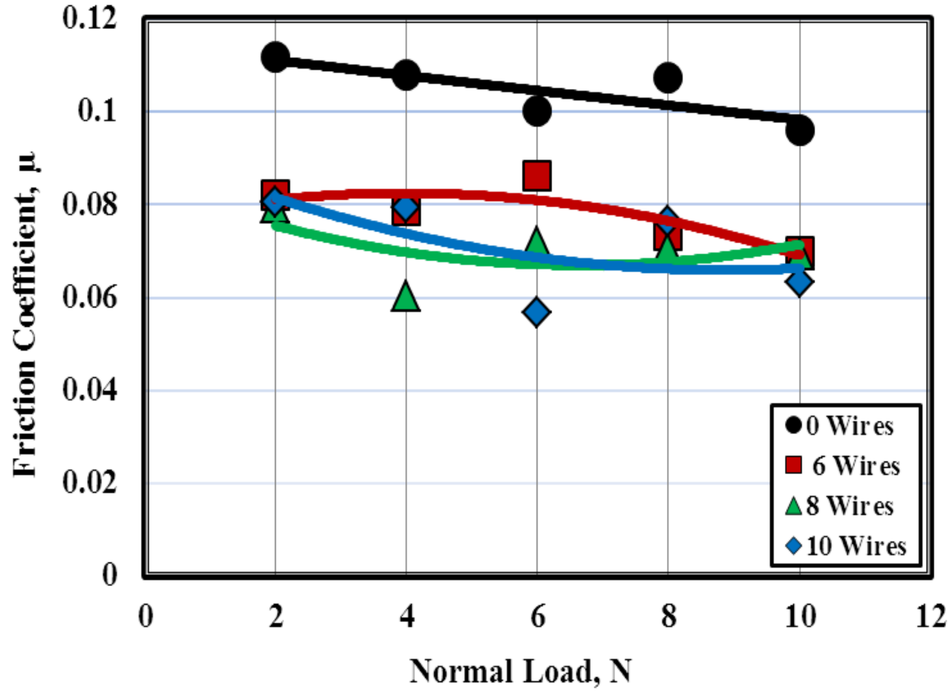

Fig. 11 Friction coefficient displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires and tempered at 110 °C.

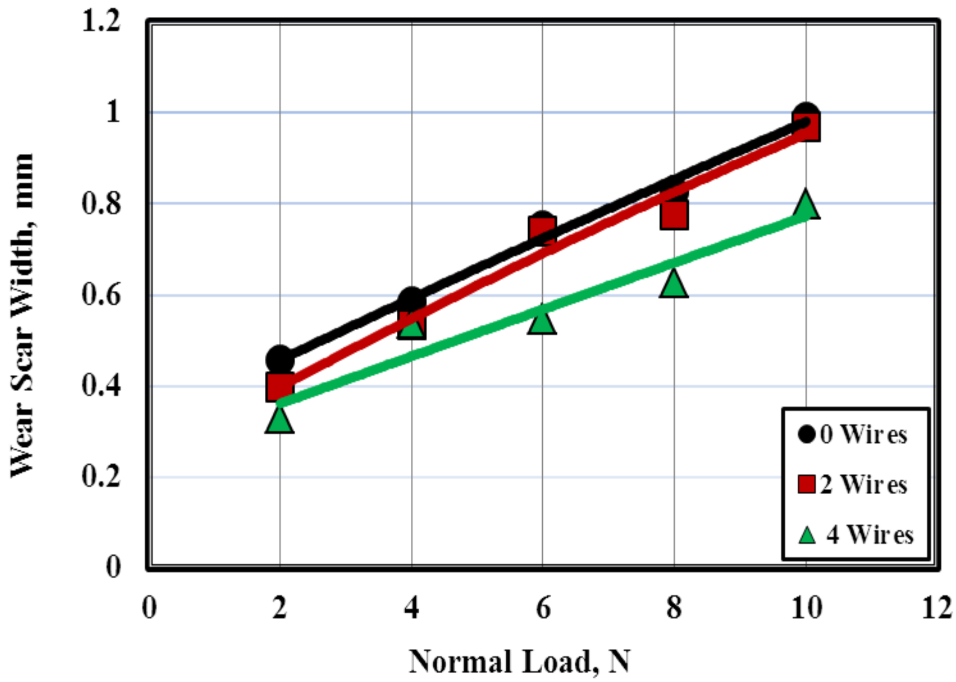

Fig. 12 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires.

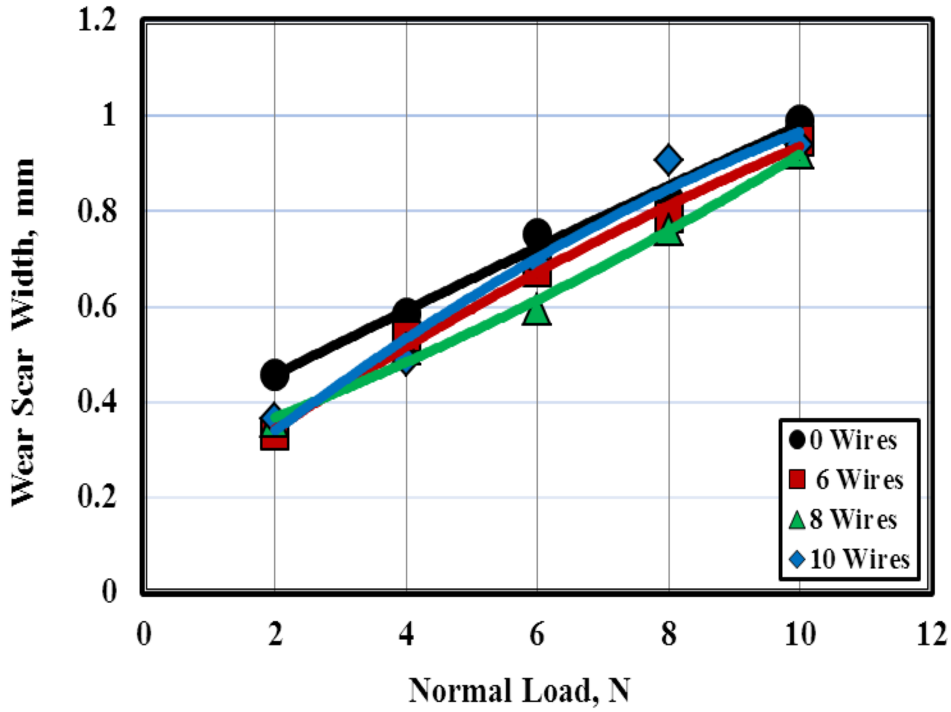

Fig. 13 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires.

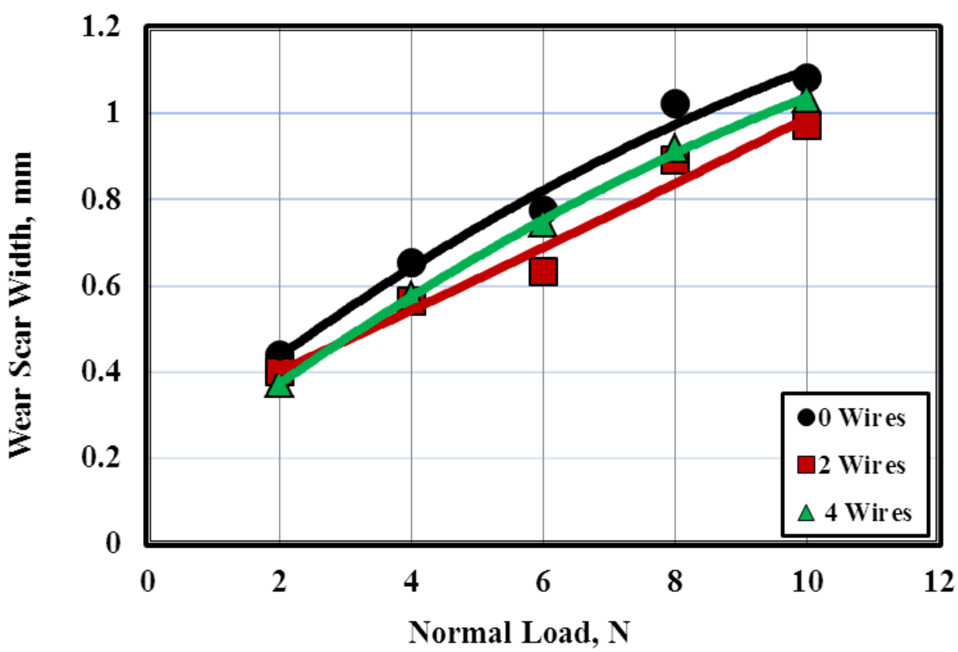

Fig. 14 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires annealed at 90 °C.

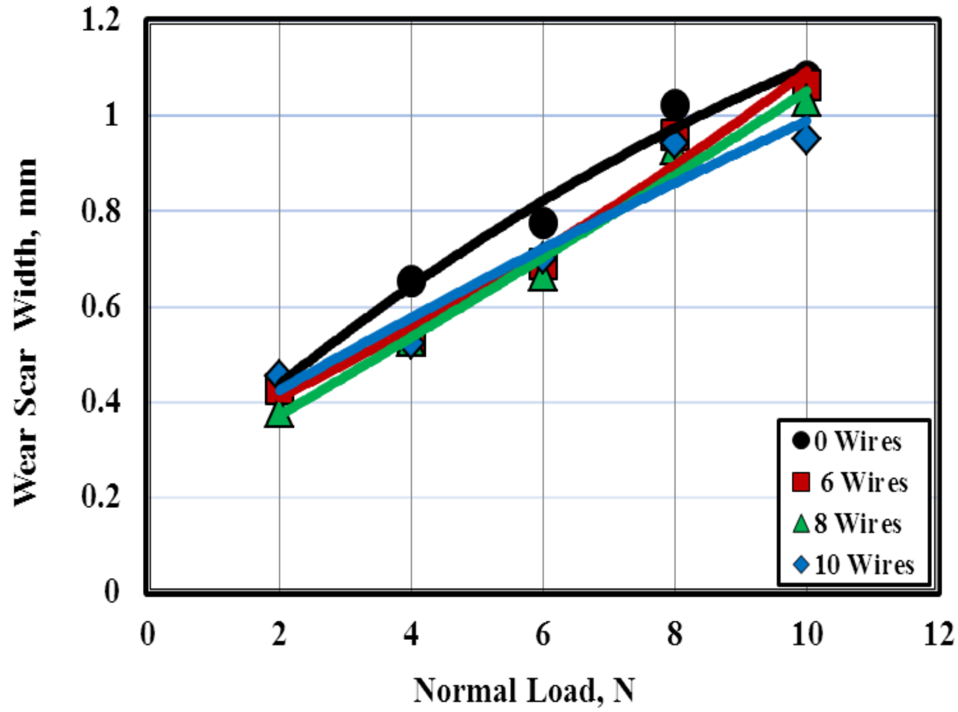

Fig. 15 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires annealed at 90 °C.

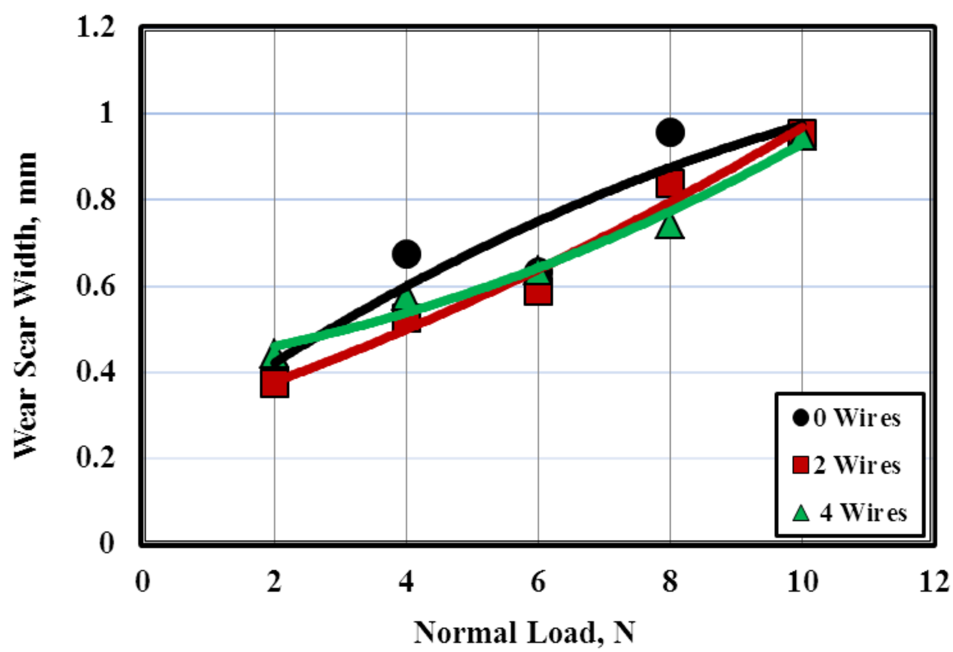

Fig. 16 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires hardened at 120 °C.

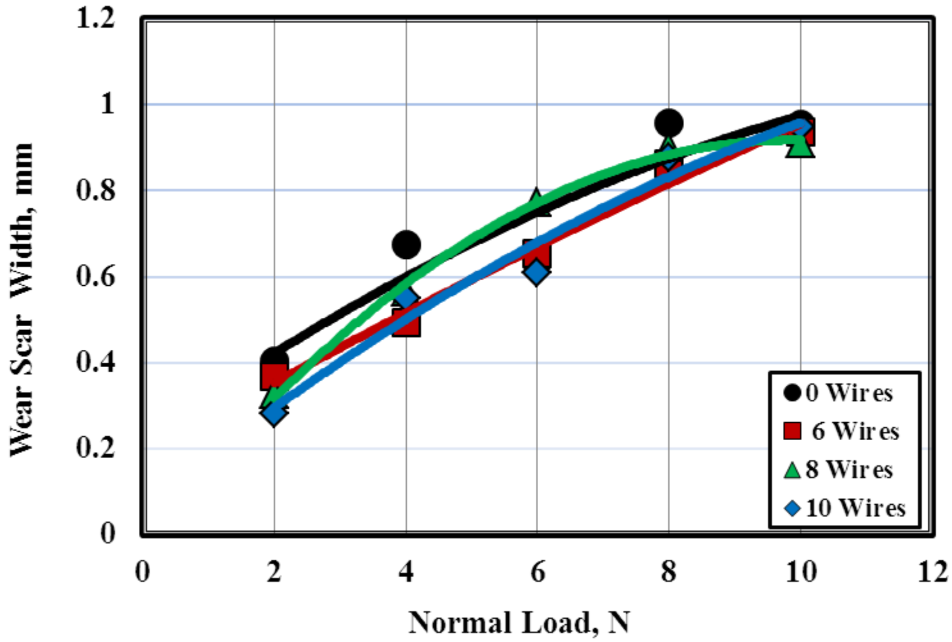

Fig. 17 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires hardened at 120 °C.

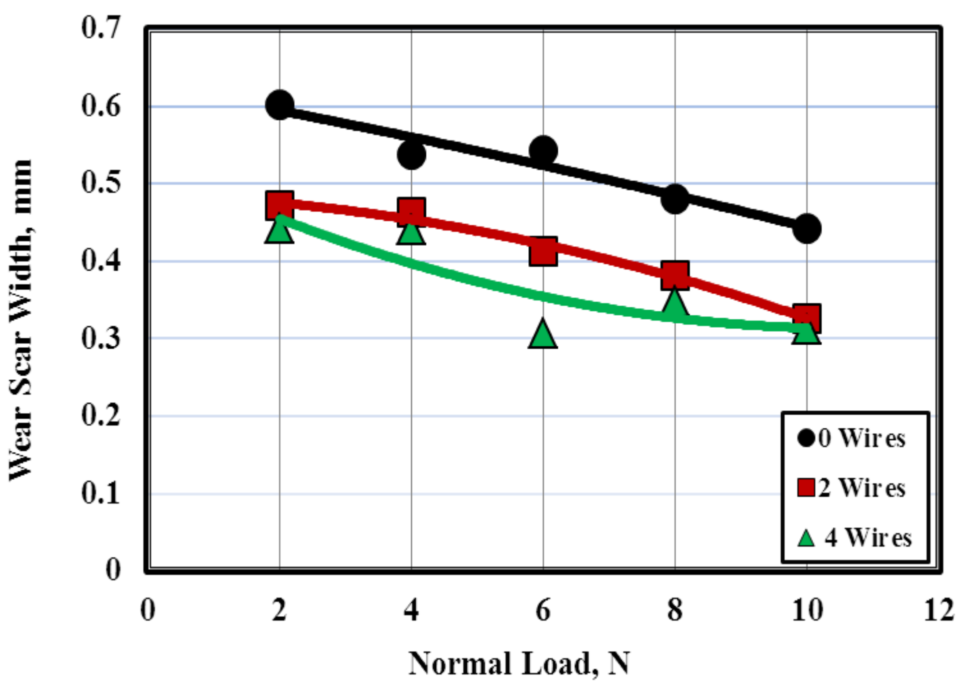

Fig. 18 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires tempered at 110 °C.

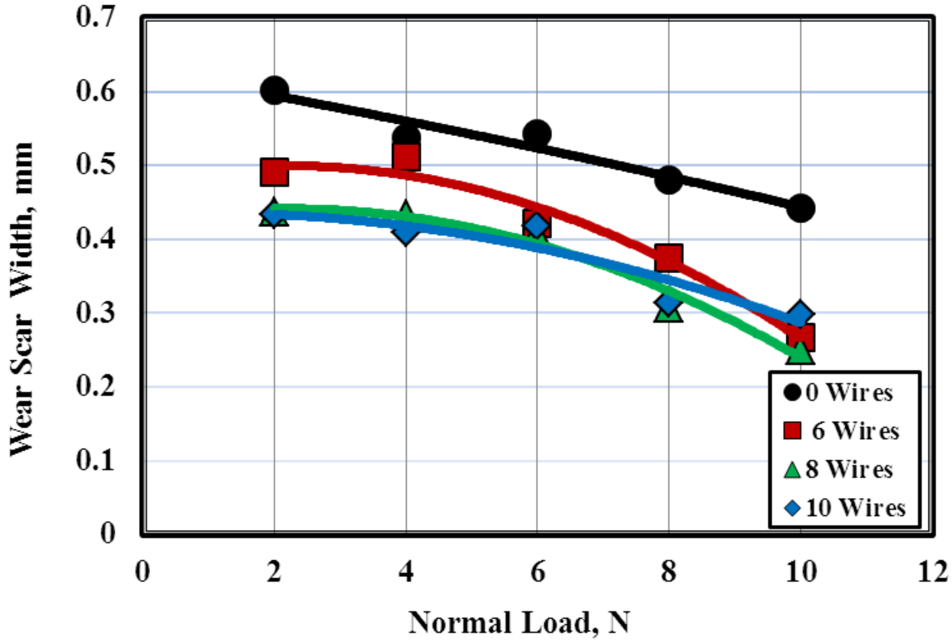

Fig. 19 Wear displayed by the scratch of LDPE reinforced by 0.3 mm diameter copper wires tempered at 110 °C.

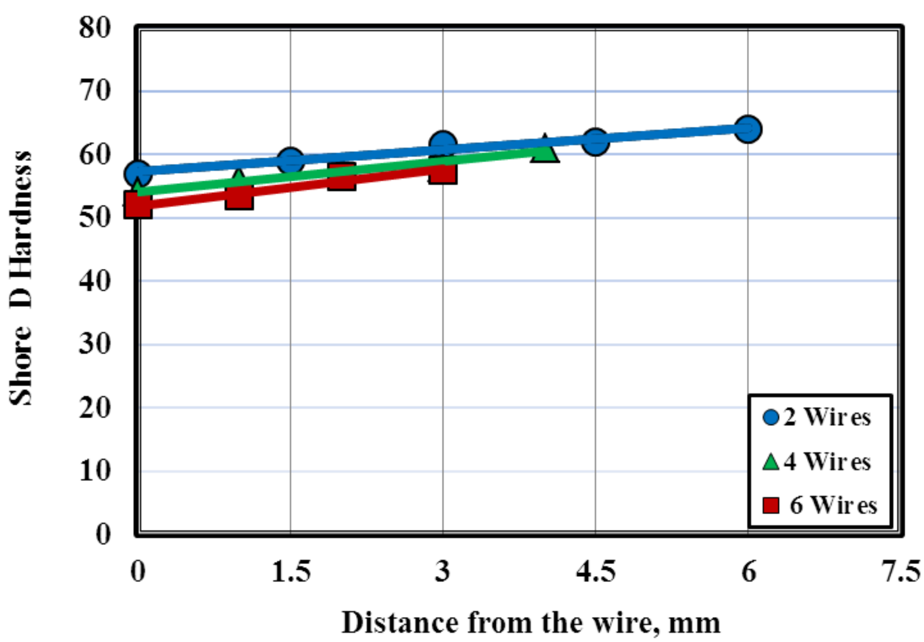

Fig. 20 Hardness distribution on the surface of LDPE composites reinforced by 0.3 mm diameter copper wires.

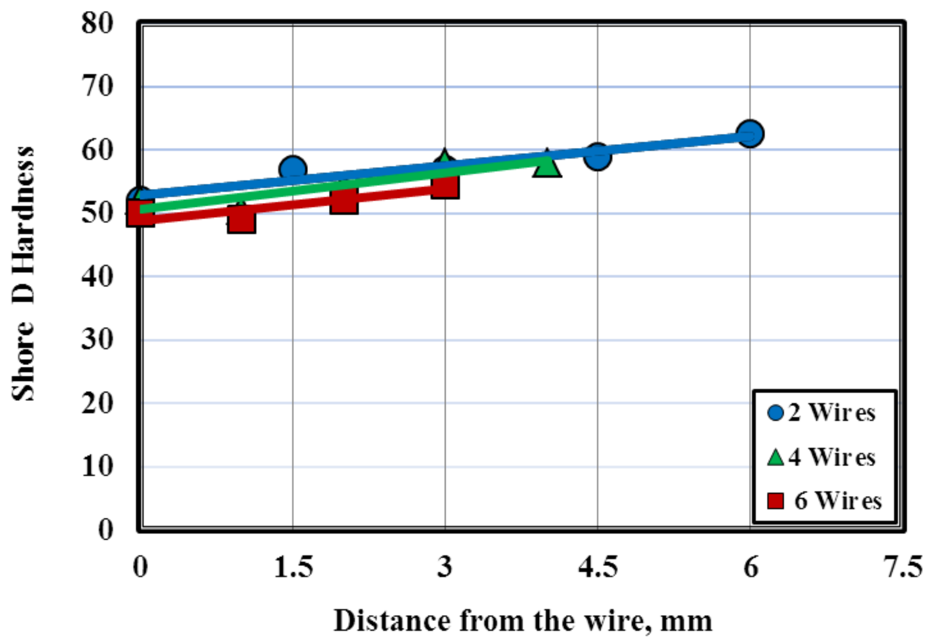

Fig. 21 Hardness distribution on the surface of annealed LDPE composites reinforced by 0.3 mm diameter copper wires.

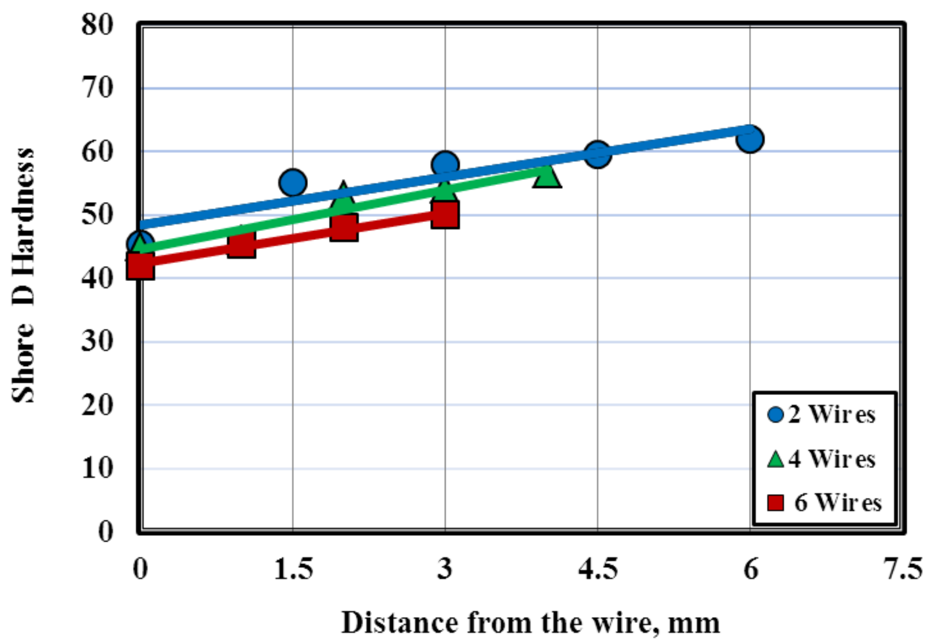

Fig. 22 Hardness distribution on the surface of hardened LDPE composites reinforced by 0.3 mm diameter copper wires.

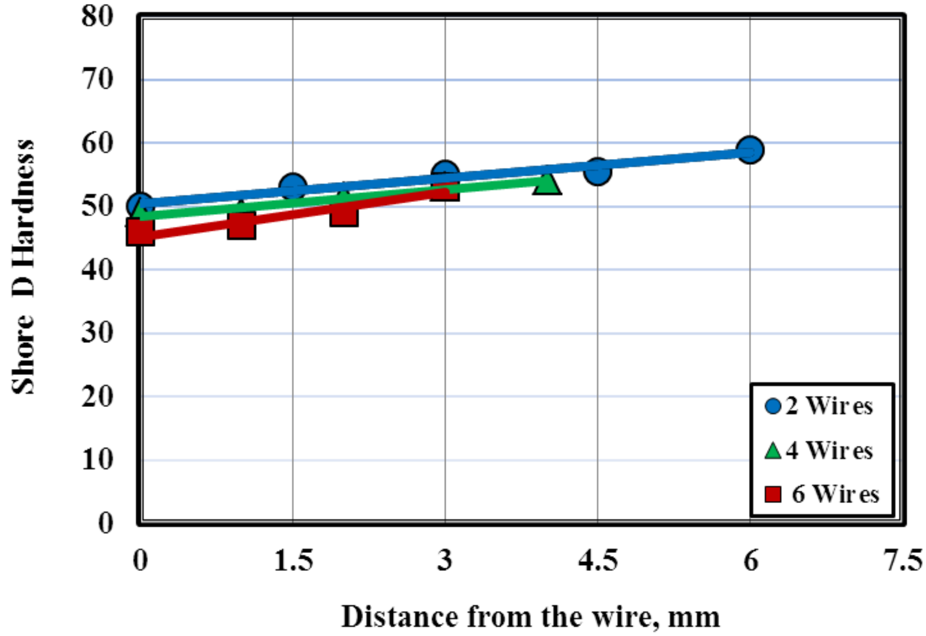

Fig. 23 Hardness distribution on the surface of tempered LDPE composites reinforced by 0.3 mm diameter copper wires.

Hardness

The hardness of LDPE has been measured to investigate the effect of the copper reinforcement on the cooling rate during preparation. It has been observed that the hardness decreases close to the wire. The variation of the hardness may be because of changing of the cooling rate where the polymer near the copper wire cooled faster causing a decrease in polymer hardness. The decrease in hardness increased the embedment of scratching tool in LDPE matrix causing a significant wear decrease. The highest value of hardness is the nominal hardness before reinforcing LDPE matrix by the copper wires, while the hardness decreased near the copper wire, [13]. As the hardness decreased, the plastic deformation accompanied to scratch increased, while the removed material decreased. When the volume of deformed material is close to that of removed material, the condition of zero wear is approached, due to all that the curves showed that as number of copper wires increased the hardness decreased. Figs. 19 - 23, showed the influence of heat treatment on hardness. The hardness of LDPE composites decreased with heat treatment. The tempered specimens showed the lowest hardness due to increased ductility by tempering while untreated specimens showed the highest values.

CONCLUSIONS

From this study, the followings can be concluded:

1. Friction coefficient displayed by the scratch of LDPE reinforced by copper wires decreased with increasing number of copper wires up to eight then started to increase at 10 wires. As the load increased friction coefficient increased.

2. Friction coefficient significantly increased with increasing normal load by annealing and hardening while it decreased by tempering.
3. Influence of heat treatment was investigated where tempered specimens displayed the lowest friction values, while as received ones showed the highest values.
4. Friction coefficient displayed by LDPE composites reinforced by unidirectional continuous copper wires recorded lower friction for tempered test specimens followed by hardened and annealed.
5. Wear scar width of the tested composites slightly decreased with increasing number of wires.
6. Tempered specimens showed the lowest wear scar width while untreated specimens showed the highest values.
7. Wear scar width significantly increased with increasing normal load by annealing and hardening while it decreased by tempering.
8. Wear displayed by LDPE composites reinforced by unidirectional continuous copper wires recorded higher wear scar width for annealed test specimens followed by hardened and tempered ones.

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