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FRICTION COEFFICIENT AND WEAR DISPLAYED BY THE SCRATCH OF POLYETHYLENE REINFORCED BY COPPER WIRES

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ABSTRACT
The friction and wear of polyethylene matrix composites reinforced by unidirectional continuous copper wires are discussed in this work.

On the basis of experimental results, it was found that friction coefficient displayed by the scratch of PE reinforced by copper wires 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.

Copper wires reinforcing PE experienced decreasing wear trend with increasing number of wires. Normal load showed significant effect on wear of PE, where the variations were more pronounced. The decrease in friction coefficient and wear 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 the matrix. This effect is considered as result of crystal phase change in the structure, where the elastic part of polymer viscoelasticity decreased causing significant decrease in the microhardness of the tested polymeric materials.

KEYWORDS
Friction coefficient, wear, scratch, polyethylene, copper wires.

INTRODUCTION
Abrasive wear caused by sandy soil of steel specimens coated by epoxy resin was investigated. Epoxy coatings were filled by metallic particles such as aluminium, copper, iron and tin of 30 – 50 µm particle size. Also, epoxy coatings were reinforced by copper, steel and tinned steel wires of different wire diameters, [1]. It was found that wear of composites reinforced by copper wires slightly decreased down to minimum then significantly increased with increasing wire diameter. Perpendicular orientation represented the lowest wear followed by 45° cross plied, cross plied and parallel wire orientations. It seems that reinforcing epoxy coating by copper wires increased the tensile strength of the coating in the direction of the wires. Epoxy composites reinforced by steel wires showed relatively higher wear than that reinforced by copper wires. The minimum wear was observed for epoxy reinforced by wire diameter ranged from 0.2 to 0.4 mm for all the tested wire orientations. When the steel was coated by tin and used as reinforcement inside epoxy coatings, significant decrease in wear was observed. Tin coatings provided steel wires by an increased elastic deformation which can absorb the

impact and withstand the abrasive action of sandy particles. It was observed that coating steel surface by epoxy reinforced by tinned steel wires displayed lower wear than that observed for uncoated steel.

Tillage tools are made of low-carbon steel, which may be heat treated and hardened, or high carbon steel, [2]. Abrasive wear resistance of tillage tools depends on, among other factors, the stress-strain properties of the material and the amount of plastic deformation caused by wear process. Ductile materials undergo severe plastic deformation during wear. It is well known that, tillage tools require strength and toughness to resist impact, and hardness to resist wear.

Cast irons have good wear resistance but relatively poor toughness, while steels have adequate strength and toughness, but relatively poor wear resistance. Metallic-glass coating could be used to increase the hardness of the steels and retain the softer core to help absorb impacts, [3]. Abrasive wear resistance of heat treated high carbon steel was found to increase with hardness in sandy and clay soils, [4 - 6]. In soils containing considerable amount of large stones, wear rates were found to be twenty times higher in stony soil than in sandy soil and seven times greater than in clay soil.

It was observed that, the use of unfilled polytetrafluoroethyrene (PTFE) filled with glass fibres as tillage tools reduced the friction between the soil and the tools, [7]. However, this material would wear eight to ten times more rapidly than steel thus not being practical. Experiments were carried out to investigate abrasive wear of tillage tools coated by thermoplastic composites, [8]. Polyamide coatings showed promising results especially if both the concentration and grain size of the filling materials were carefully selected. Addition of iron and aluminium oxide particles to polyamide showed a considerable reduction in wear.

The effect of different filling materials, namely, silicon oxide, iron, copper, glass fibre and aluminium oxide on friction and wear of polyamide was investigated, [9, 10]. It was found that addition of glass fibre of concentration up to 10 wt. % as well as sand, (10 - 20) pm, and concentration of 5 wt. % reduced friction and improved wear resistance. Polyamide fibres as filling material in polyamide coatings enhanced abrasive wear resistance. The enhancement increased with increasing fibre concentration and decreasing fibre diameter, [11]. Bi-directional cross plied reinforcement displayed considerable wear reduction. Tin coated steel wire as short fibres reinforcing polyamide coatings displayed minimum wear rate. The best performance was observed for the perpendicular short fibres.

Alumina ceramics were used successfully to reduce wear of subsoiler components used in agricultural soils, [12]. Adhesive bonding of high performance epoxy resin was found to be suitable to attach ceramics to tillage tool surface. Epoxy resins are used in a number of tribological applications such as automotive and chemical industries. They are applied as bearing material in a cast form filled by graphite or molybdenum disulphide and as a thin film lining of filled epoxy applied to bearing surface, [13 - 19]. Friction and wear of epoxy resins composites reinforced by different types of fibre materials were investigated, [14, l5]. It was observed for graphite fibre, Kevlar fibre and glass fibre composites that the lowest wear and friction were obtained for fibre oriented normal to the sliding surface. The tribological performance of slip resistant material made of epoxy resin filled by abrasive grain like silicon oxide, aluminium oxide and

silicon carbide of different particle size and concentration was tested, [19]. The friction and wear of the tested materials sliding against steel counterface was investigated. Generally, wear resistance of epoxy filled by silicon oxide displayed the best wear resistance.

The aim of the present work is to test friction coefficient and wear displayed by scratch of polyethylene reinforced by copper wires of different diameters.

EXPERIMENTAL

Scratch tester shown in Fig. 1 was used. It consisted of a rigid stylus mount, a diamond stylus of apex angle 90° and hemispherical tip. The stylus was mounted to the loading lever through three jaw 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 a load cell mounted to the loading lever and connected to display digital monitor. The test specimen was held in the specimen holder which mounted in a horizontal base with a manual driving mechanism to move specimen in a straight direction. The test specimens were scratched by an indenter. The scratch force was measured during the test and used to calculate friction coefficient. The test was conducted under dry conditions at room temperature. An optical microscope was used to measure scratch width with an accuracy of ± 1.0 µm.

The test specimens were polyethylene of 5.0 mm thickness. The copper reinforcing wires were copperof 0.21, 0.28, 0.5, 0.57 and 0.85 mm diameters. The numbers of wires reinforcing the test specimens were 0, 3, 6, 9, 12 and 15. The test specimens were molded in die with of 30 × 100 mm^2, where the wires were installed, Fig. 2. Friction force was measured by using load cell, while wear resistance was measured by optical microscope to measure scratch width. The scratched surface is shown in Fig. 3.

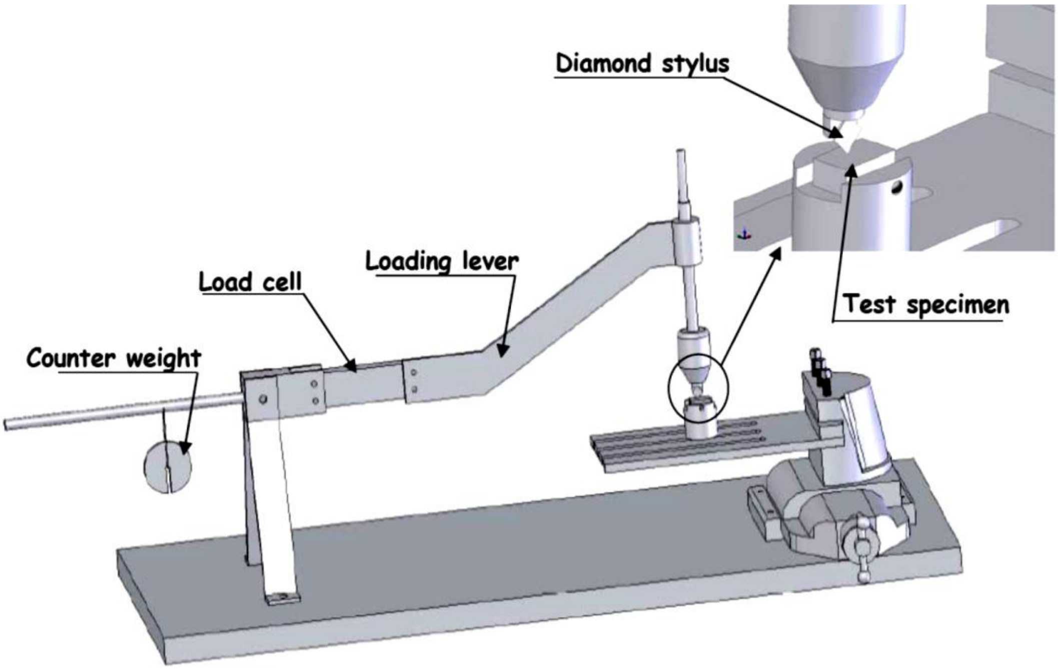

Fig 1 Arrangement of scratch test rig.

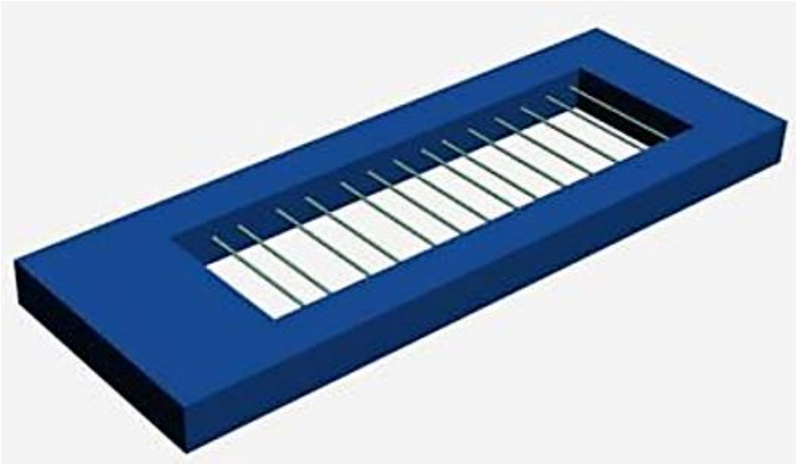

Fig. 2 Die of the test specimens reinforced copper wires.

Fig. 3 Test specimen after scratch.

RESULTS AND DISCUSSION

Friction coefficient displayed by the scratch of PE reinforced by 0.21 mm diameter copper wires, Fig. 4, decreased with increasing number of copper wires. As the load increased friction coefficient increased. It seems that the presence of copper wires decreased the hardness of the PE so that the material removal by the indenter was easier. At 2 N load, friction coefficient decreased from 0.68 for PE free of reinforcement to 0.3 for PE reinforced by 15 wires of 0.21 mm diameter.

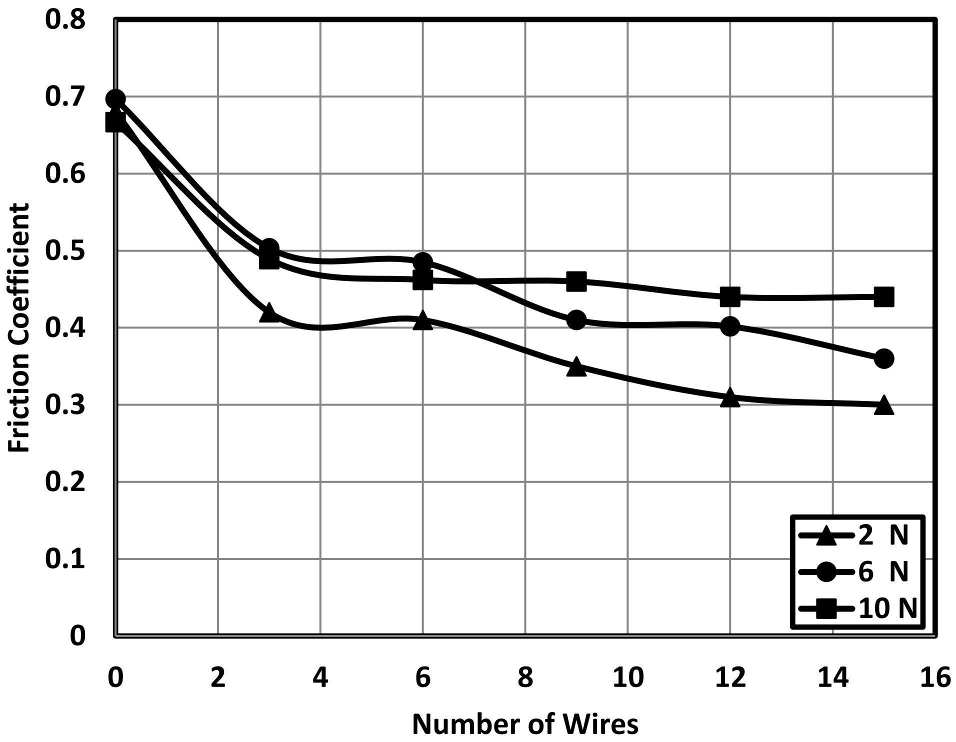

Fig. 4 Friction coefficient displayed by the scratch of PE reinforced by 0.21 mm diameter copper wires.

At 10 N load, the lowest friction values were 0.48, 0.42, 0.45 and 0.45 observed for PE reinforced by 0.28, 05, 0.57 and 0.85 mm diameter copper wires, Figs. 5, 6, 7 and 8 respectively. Based on that observation, it can be decided that the range of change of wire diameter had insignificant effect on friction coefficient. It was found that the physical and mechanical properties of polyamides are considerably affected by the degree of crystallization, which can be controlled by the change of cooling rate during the molding process. Presence of small particles such as fine silica dust in polyamide matrix can alter the nucleation and cause significant increase in tensile strength and hardness accompanied by reduction in the ductility and impact strength. It is essential to consider the variation of the morphology of the cast polymer because of the differences in the cooling rate from the surface to the centre, where the outer surface will be less crystalline due to the rapid solidification rate and may be less resistant to wear.

A single polymer chain may be partly in a crystalline lamella, and partly in the amorphous state. Some chains even start in one lamella, cross the amorphous region, and then join another lamella. No polymer is completely crystalline. Crystallinity makes the material strong, but it also makes it brittle. A completely crystalline polymer would be too brittle to be used as plastic. The amorphous regions give the polymer toughness, that is, the ability to bend without breaking.

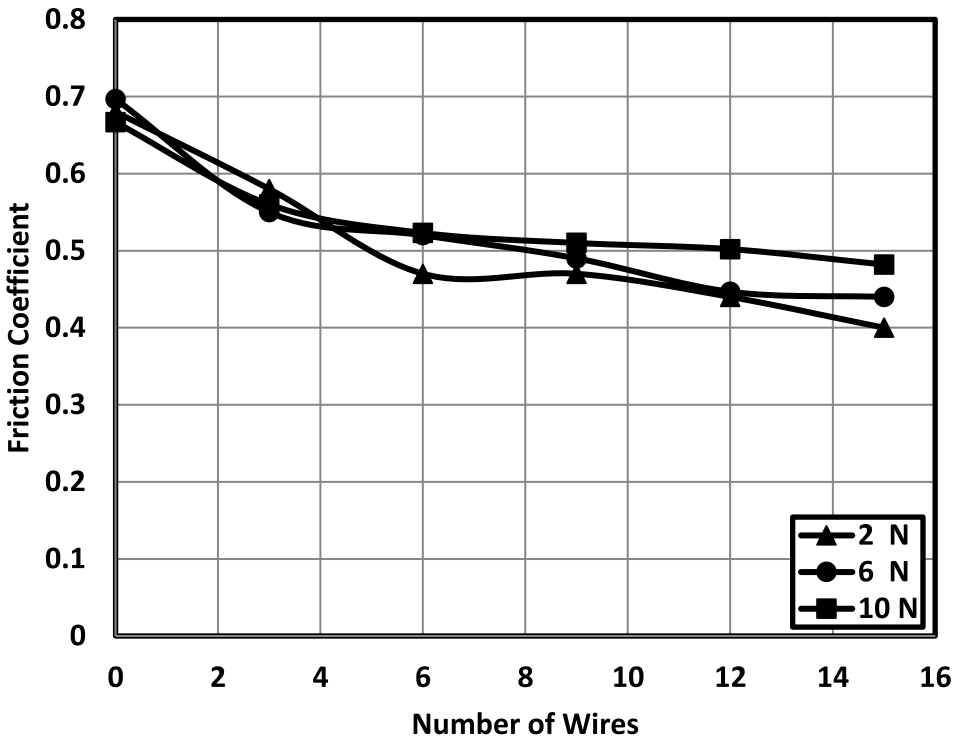

Fig. 5 Friction coefficient displayed by the scratch of PE reinforced by 0.28 mm diameter copper wires.

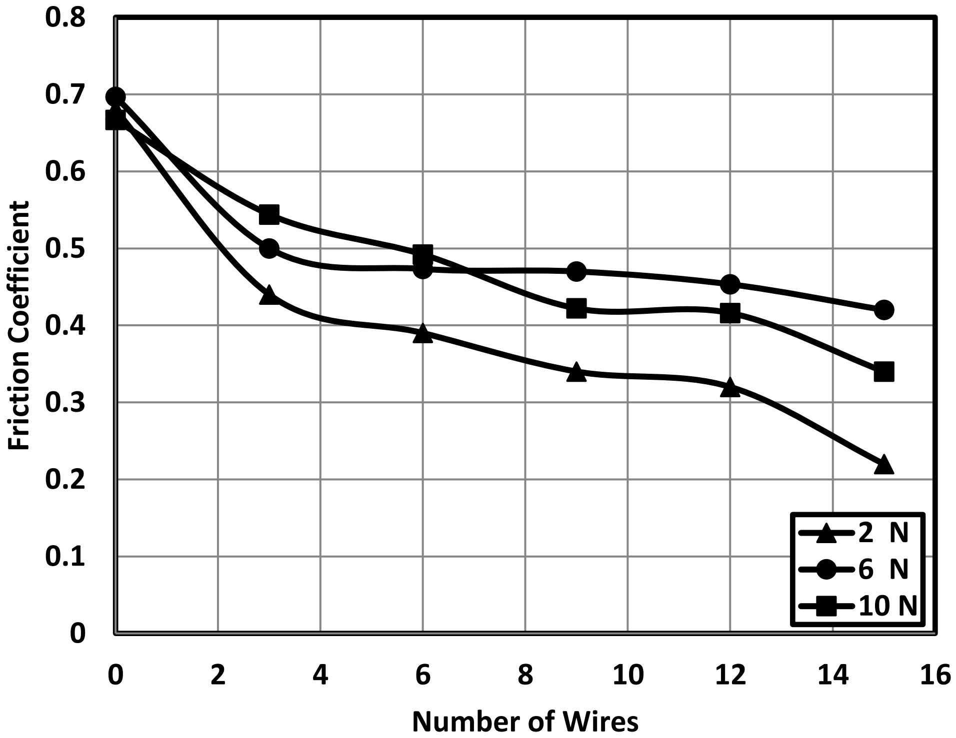

Fig. 6 Friction coefficient displayed by the scratch of PE reinforced by 0.5 mm diameter copper wires.

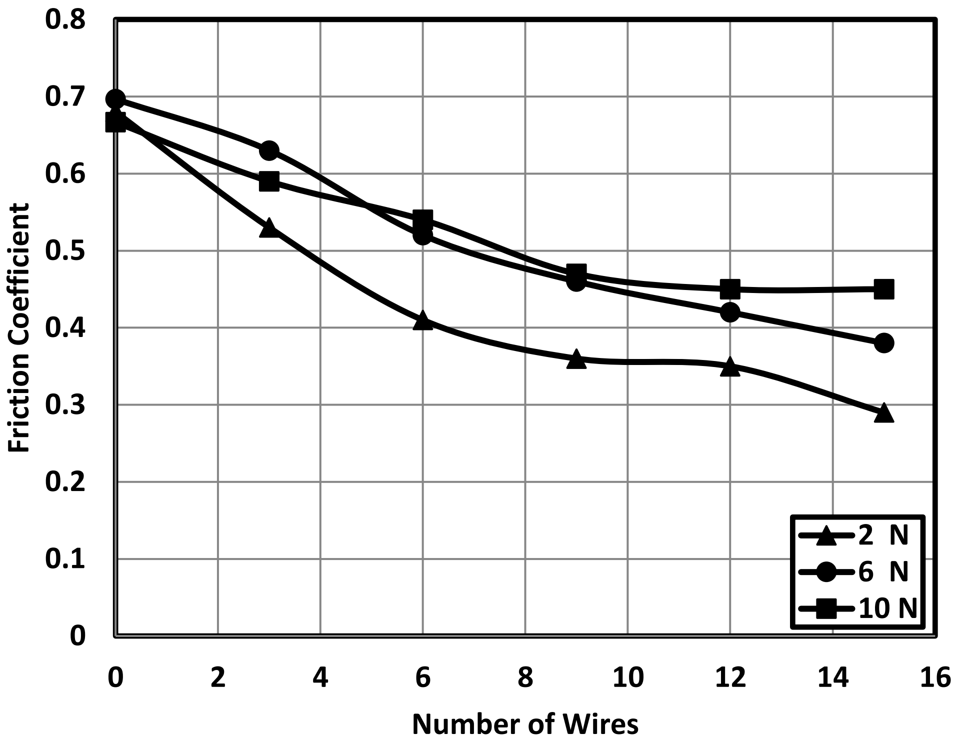

Fig. 7 Friction coefficient displayed by the scratch of PE reinforced by 0.57 mm diameter copper wires.

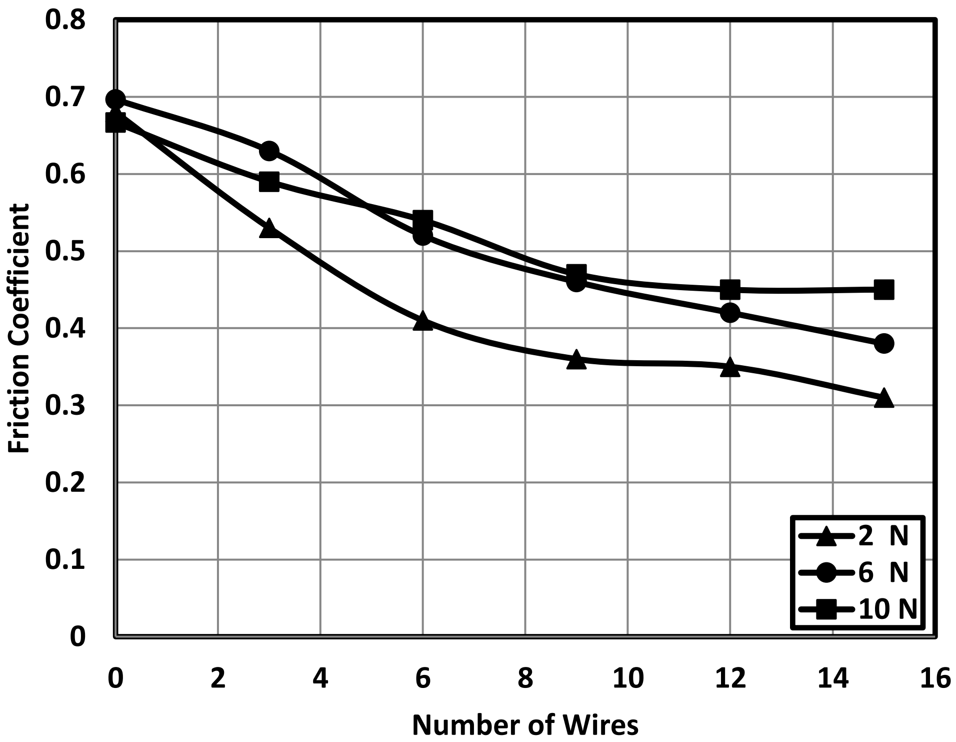

Fig. 8 Friction coefficient displayed by the scratch of PE reinforced by 0.85 mm diameter copper wires.

In semi-crystalline polymers the mode of crystallization influences the morphology and hence mechanical properties. Slow crystallization near the melting point results in larger, more perfect crystals; faster crystallization produces smaller spherulites with many more tie molecules. The presence of a spherulitic morphology requires a more complex model and the mechanical properties of most semi-crystalline materials are influenced by both crystalline and amorphous regions: degree of crystallinity is important, where crystalline regions are stiffer than amorphous regions. Taking polyethylene as a representative semi-crystalline polymer, values can be obtained for the Young's moduli of the various phases which contribute to the overall modulus.

The wear displayed by the scratch of PE reinforced by copper wires is shown in Figs. 9 - 13. The copper wires experienced decreasing trend with increasing number of wires. This behavior was attributed to the function of the matrix that supported the wires and transmitted the load to them by shear at the wire-matrix interface which represented the weakest zone in the matrix. As the adhesion between the matrix and wires increased the wear of the matrix decreased. Other explanation depends on the retarding action of the wires against the motion of the indenter. Besides, the influence of the cooling rate on the hardness and the mechanical properties of the polymers could affect the wear. Normal load showed significant effect on wear of PE, where the variations were more pronounced.

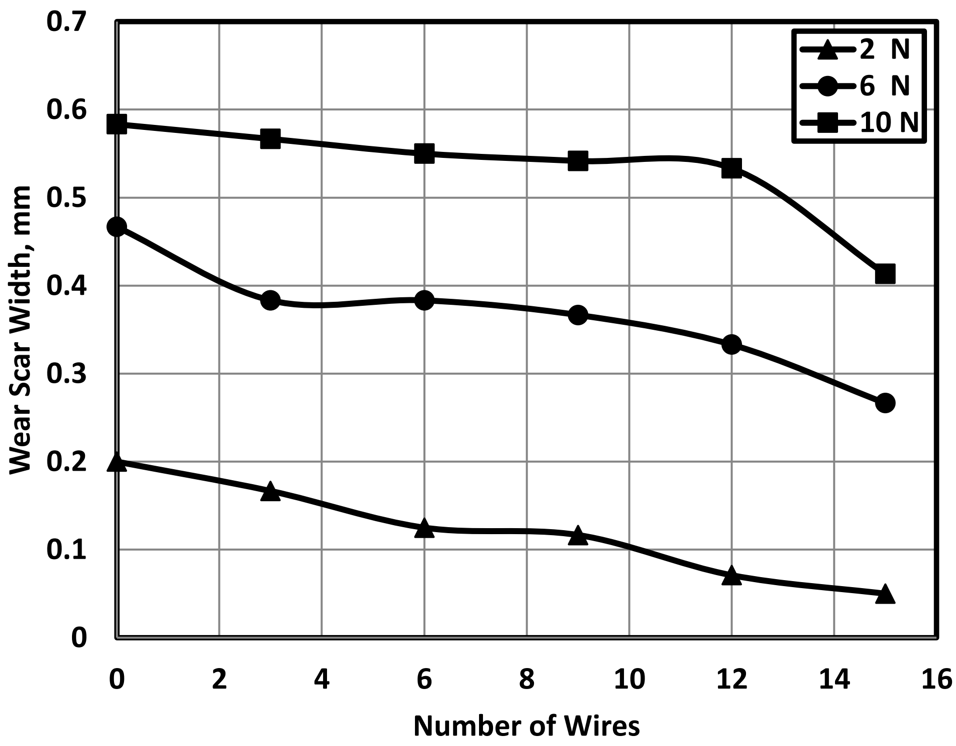

Fig. 9 Wear displayed by the scratch of PE reinforced by 0.21 mm diameter copper wires.

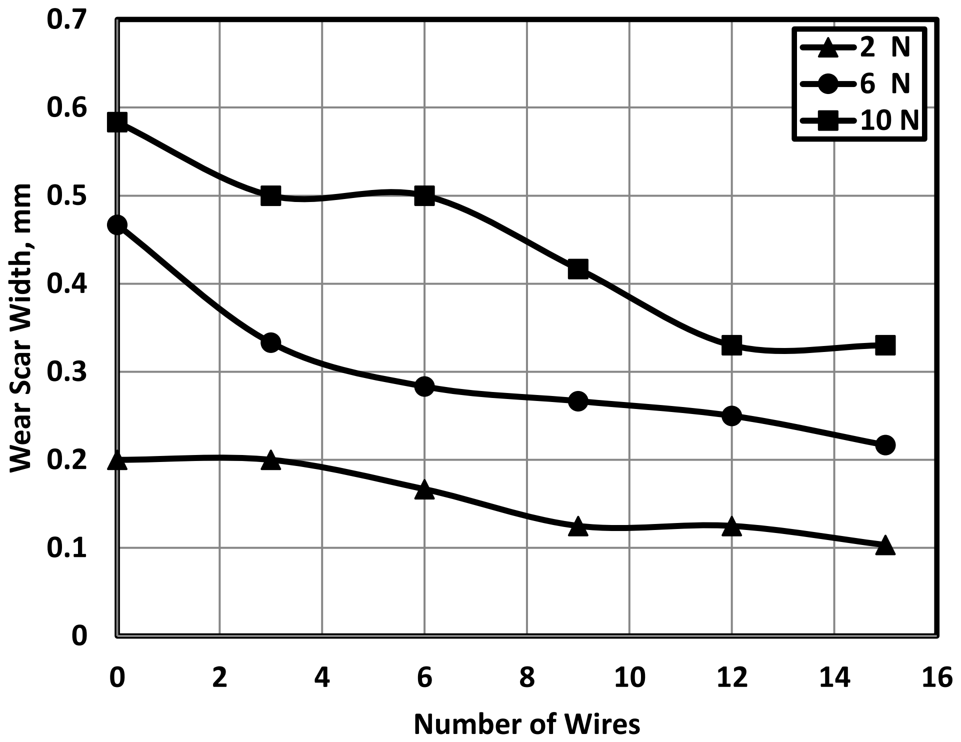

Fig. 10 Wear displayed by the scratch of PE reinforced by 0.28 mm diameter copper wires.

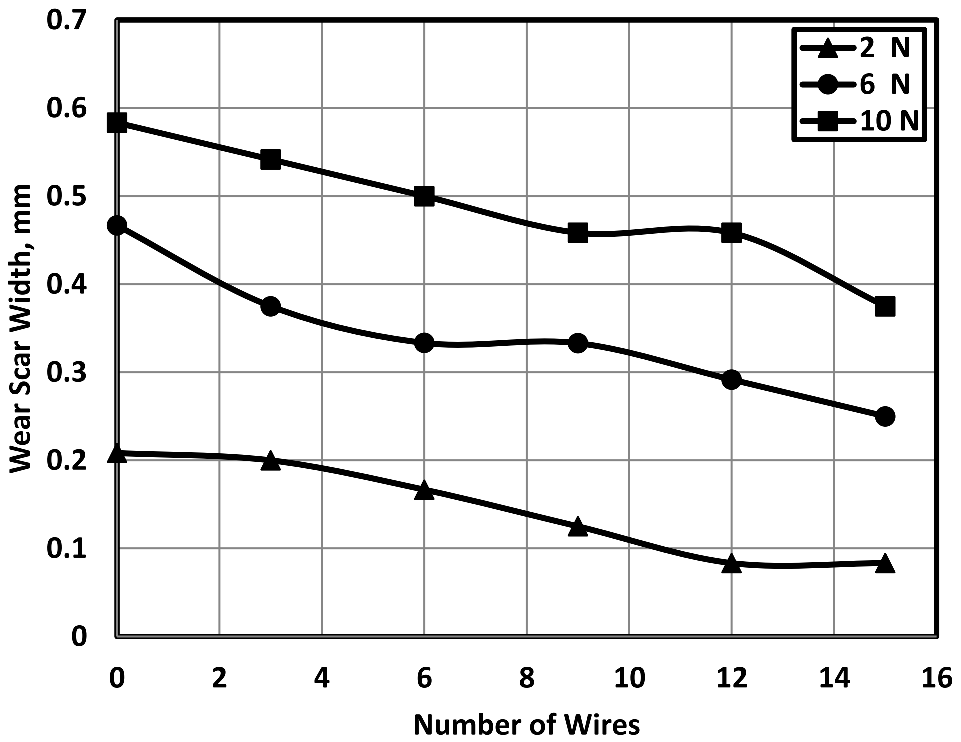

Fig. 11 Wear displayed by the scratch of PE reinforced by 0.5 mm diameter copper wires.

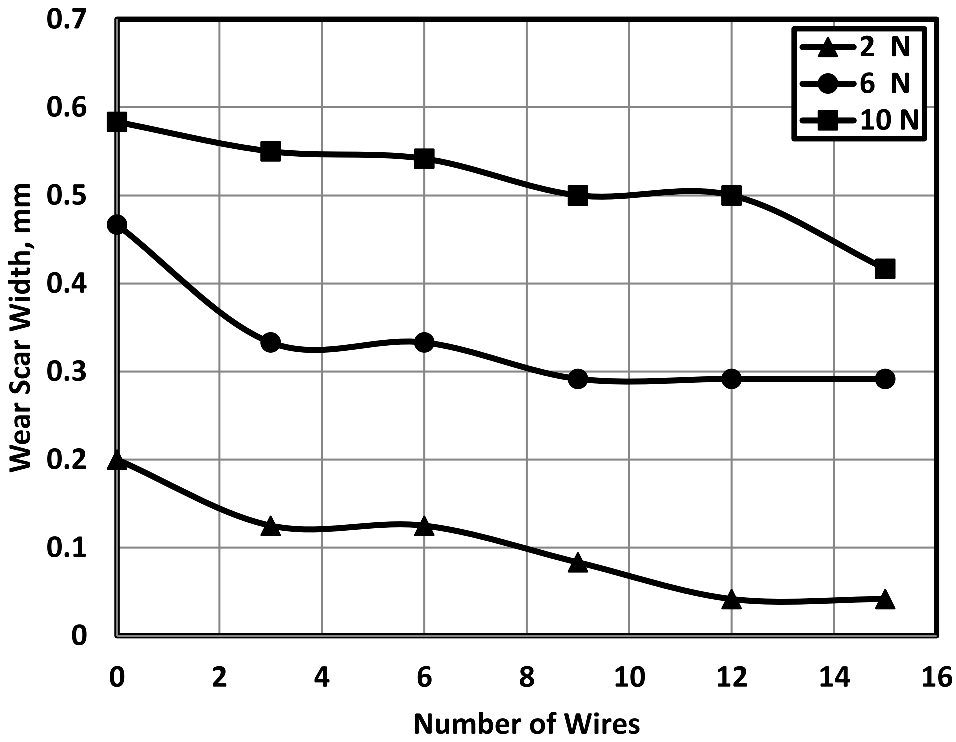

Fig. 12 Wear displayed by the scratch of PE reinforced by 0.57 mm diameter copper wires.

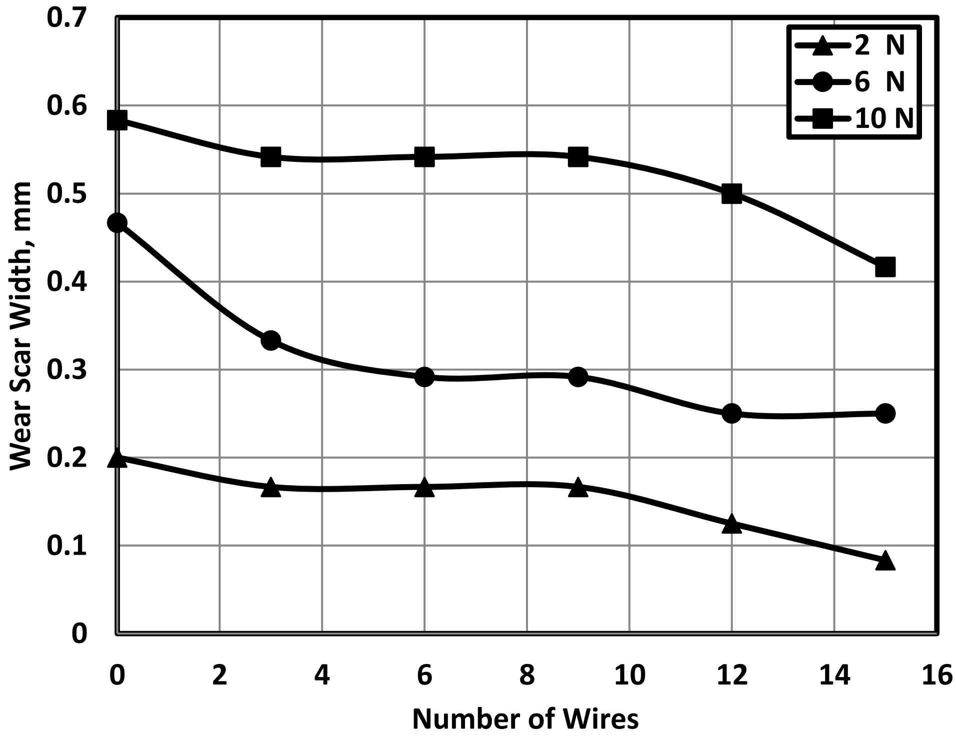

Fig. 13 Wear displayed by the scratch of PE reinforced by 0.85 mm diameter copper wires.

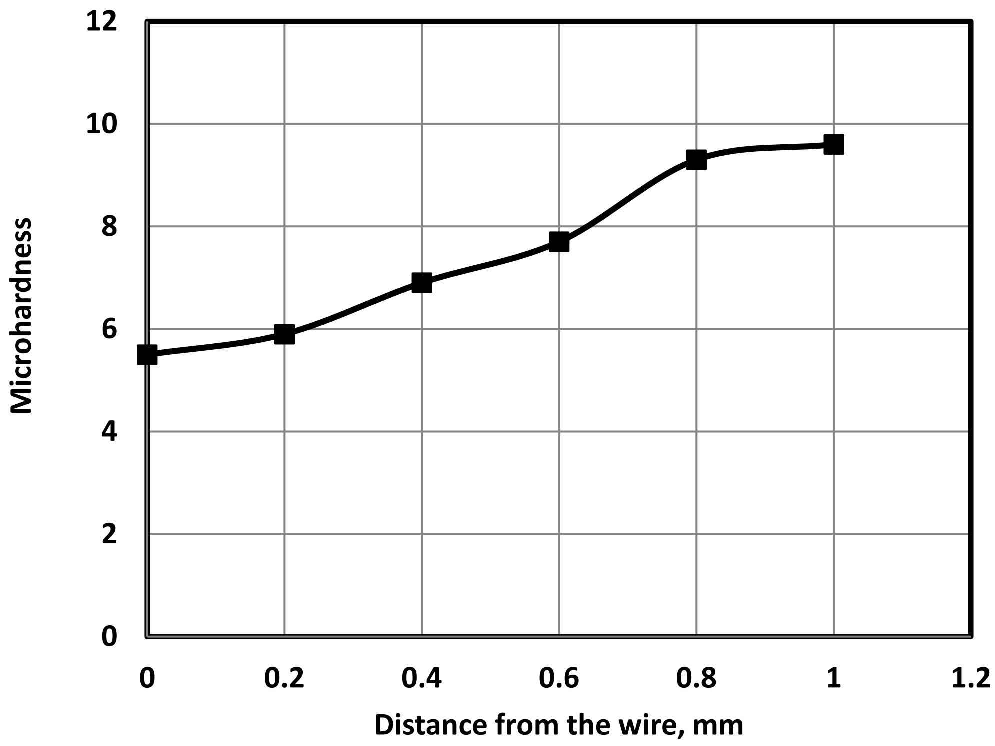

Fig. 14 Variation of Microhardness of the PE composites versus the distance from the copper wire.

The microhardness of the PE composites has been measured to investigate the effect of the metallic reinforcement on the cooling rate of coating during preparation. The variation in the coating hardness as function of the distance from the wire is illustrated in Fig. 14. It has been observed that the hardness decreased as the indenter got closer to the wire. The variation of the hardness may be from the change of the cooling rate where the zone near the copper wire was cooling faster and causing a decrease in the hardness of PE. Besides, presence of copper reinforcement could restrain the deformation of the PE matrix where the external load applied through the matrix was transferred to the wires by shear at the interface. Besides, plastic deformation, grooving and smearing of surface caused by scratch were reduced due to the strengthening effect of the reinforcement. It seems that the function of the matrix is to support the wires and transmit the load to them by shear at the wires-matrix interface which represents the weakest zone in the composites. As the adhesion between the matrix and fibre increased, wear of the composites decreased.

CONCLUSIONS

Friction coefficient displayed by the scratch of PE reinforced copper wires decreased with increasing number of copper wires. As the load increased friction coefficient increased. It seems that the presence of copper wires decreased the hardness of the PE so that the material removal by the indenter was easier. Wire diameter had insignificant effect on friction coefficient.

Wear displayed by the scratch of PE reinforced by copper wires experienced decreasing trend with increasing number of wires. This behavior was attributed to the function of the matrix that supported the wires and transmitted the load to them by shear at the

wire-matrix interface which represented the weakest zone in the matrix. As the adhesion between the matrix and wires increased the wear of the matrix decreased. Besides, the retarding action of the wires against the motion of the indenter could be responsible for wear decrease.

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