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

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

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

INTRODUCTION
The friction and wear of polyethylene (PE) matrix composites reinforced by unidirectional continuous steel and copper wires of different diameters were discussed, [1, 2]. On the basis 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.

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, [3]. 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, [4]. 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.

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, [5]. 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, [6]. 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, [7, 8]. 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, [9]. 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, [10]. 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, [11 - 17]. Friction and wear of epoxy resins composites reinforced by different types of fibre materials were investigated, [12, 13]. 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, [17]. 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 polypropylene (PP) reinforced by copper wires of different diameters.

EXPERIMENTAL

Scratch tester shown in Fig. 1 was used in the experiments. It consists 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 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 an indenter. The scratch force was measured during the test, then friction coefficient was calculated. 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.

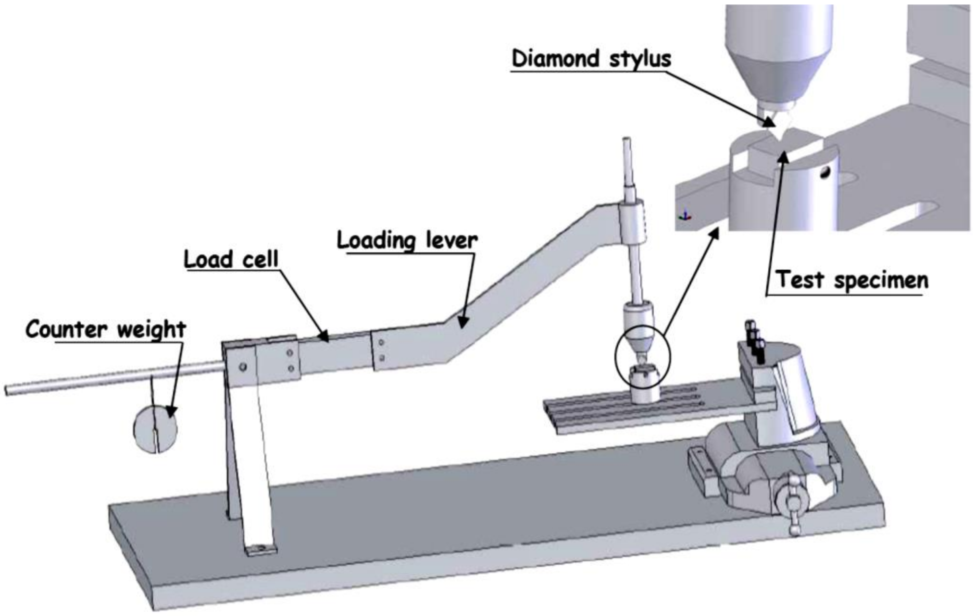

Fig 1 Arrangement of scratch test rig.

The test specimens were PP of 5.0 mm thickness. The copper reinforcing wires were of 0.21, 0.28, 0.5, 0.57 and 0.85 mm diameters. The numbers of wires reinforcing test specimens were 0, 3, 6, 9, 12 and 15. The wires were distributed parallel to the direction of motion. The test specimens were molded in die of 100 × 30 × 5 mm^3, where the wires were installed, Fig. 2. Friction force was measured by using load cell, while wear

resistance was measured by scratch width through optical microscope of ± 1.0 µm accuracy. The scratched surface is shown in Fig. 3.

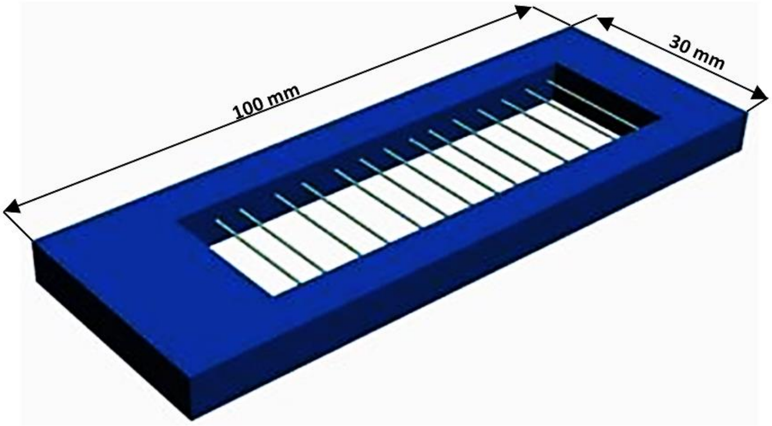

Fig. 2 Molding die of the test specimens.

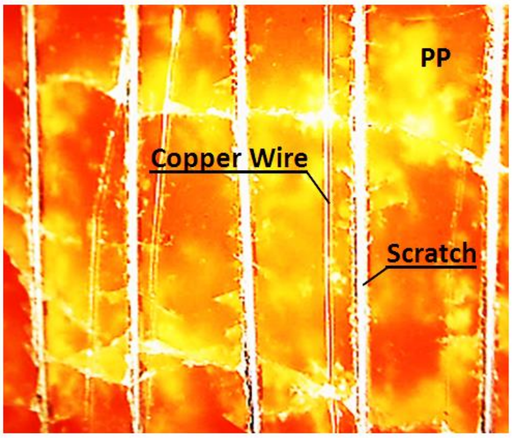

Fig. 3 Test specimens after scratch.

RESULTS AND DISCUSSION

Friction coefficient displayed by the scratch of PP reinforced by 0.21 mm diameter copper wires showed slight decrease with increasing number of wires, Fig. 4. It seems that the presence of copper wires decreased the hardness of the PP so that the material removal by the indenter was easier. At 2 N load, friction coefficient decreased from 0.68 for PP free of reinforcement to 0.5 for PP reinforced by 15 wires of 0.21 mm diameter. Friction coefficient showed relatively higher values than that observed for PE, [1]. The load had insignificant effect on friction coefficient.

The influence of the diameter of the copper wire reinforcing PP on friction coefficient is illustrated in Figs. 5 – 8. The lowest friction values were 0.34, 0.37, 0.46 and 0.43 observed for PP 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 seen that the change of wire diameter had slight effect on friction coefficient. This behavior can be explained on the basis that the physical and mechanical properties of polymers 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 polymeric 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.

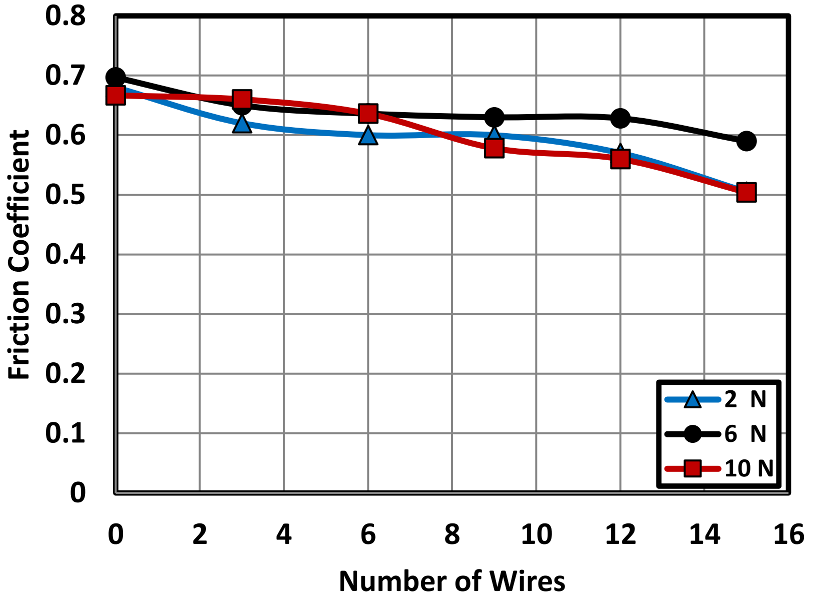

Fig. 4 Friction coefficient displayed by the scratch of PP reinforced by 0.21 mm diameter copper wires.

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.

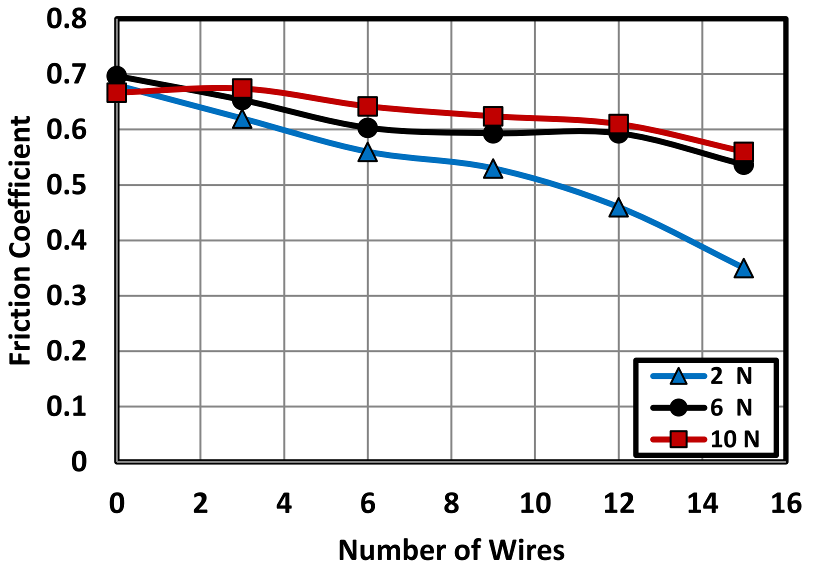

Fig. 5 Friction coefficient displayed by the scratch of PP reinforced by 0.28 mm diameter copper wires.

The microhardness of PP coatings was measured to investigate the effect of the copper wire reinforcement on the cooling rate of coating during preparation. It was observed that the hardness decreased as the indenter got closer to the wire, Fig. 9. The variation of the hardness may be attributed to the change of the cooling rate where the zone near the copper wire was cooling faster and causing a decrease in polymer hardness. The decrease in hardness increased the plastic deformation of coating surface leading to a significant wear decrease. The change of hardness due to the presence of the copper wires is shown in Fig. 10. The highest value of the hardness is the nominal hardness before reinforcing PP matrix by the copper wires, while the hardness decreased near the copper wires. As the hardness decreased the plastic deformation accompanied to scratch increased, while the removed material decreased, Fig. 11. When the volume of the deformed material is close to that of the removed material, the condition of zero wear is approached.

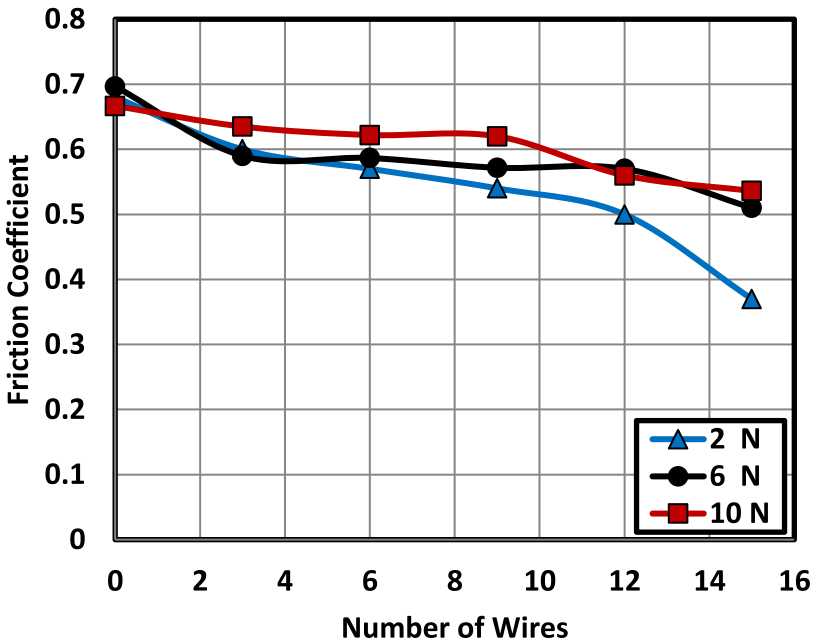

Fig. 6 Friction coefficient displayed by the scratch of PP reinforced by 0.5 mm diameter copper wires.

Wear of PP matrix reinforced by wires of copper of 0.21 mm diameter is shown in Fig. 12. Wear of test specimens slightly decreased with increasing number of wires. It seems that worn materials removed from PP were influenced by strengthening action of copper wires. The same trend was observed for 0.28, 0.5, 0.57 and 0.85 mm copper wire diameter, Figs. 13 - 16. PP composites, which consist of a reinforcing material of high strength and/or high modulus of elasticity like copper wires, showed relatively lower wear than that observed for PE composites free of copper wires. Increase of wire diameter showed insignificant effect on wear. Wear significantly increased with increasing normal load.

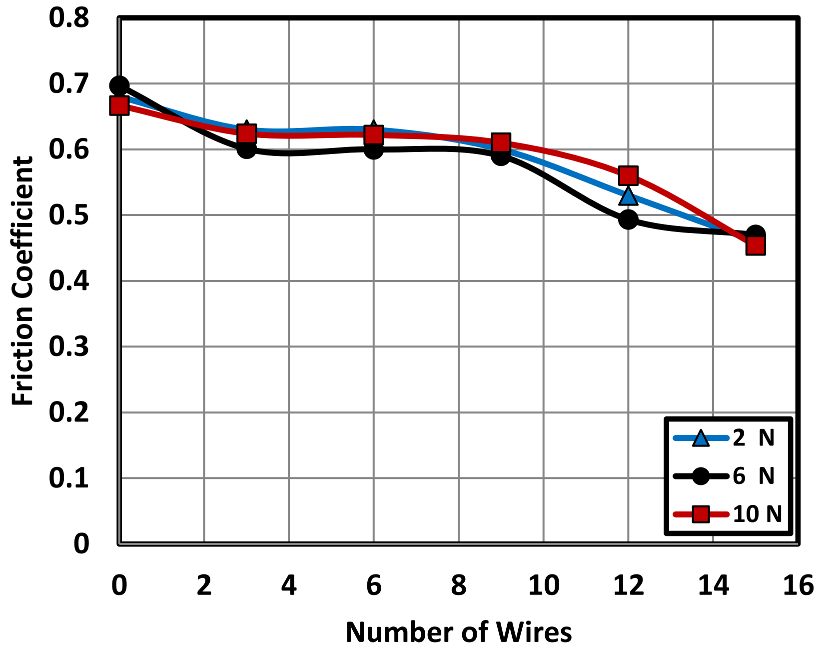

Fig. 7 Friction coefficient displayed by the scratch of PP reinforced by 0.57 mm diameter copper wires.

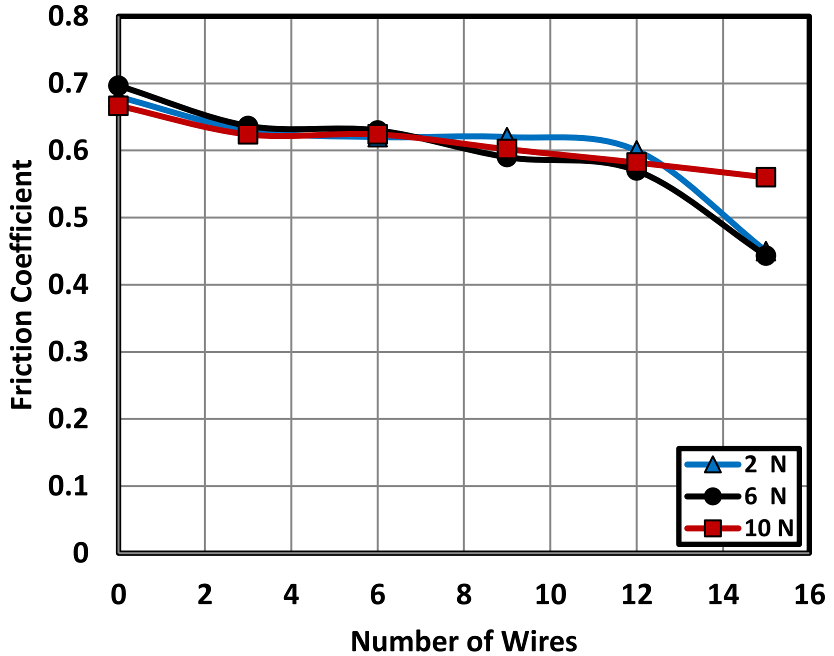

Fig. 8 Friction coefficient displayed by the scratch of PP reinforced by 0.85 mm diameter copper wires.

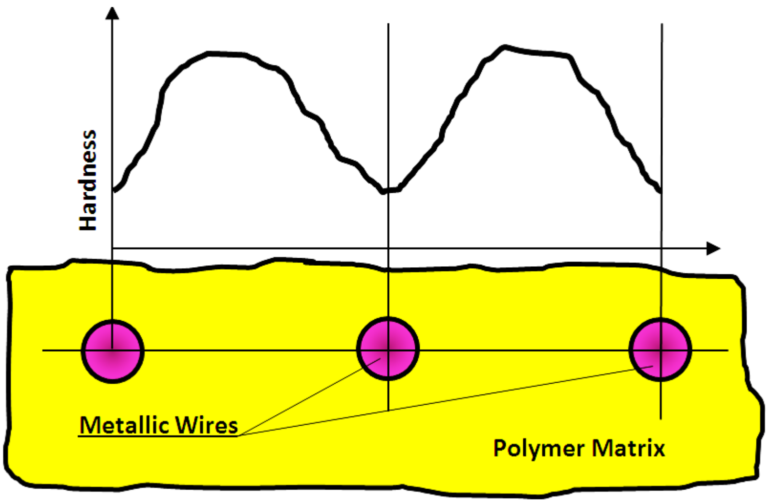

Fig. 9 Hardness change due to the caused by copper wires.

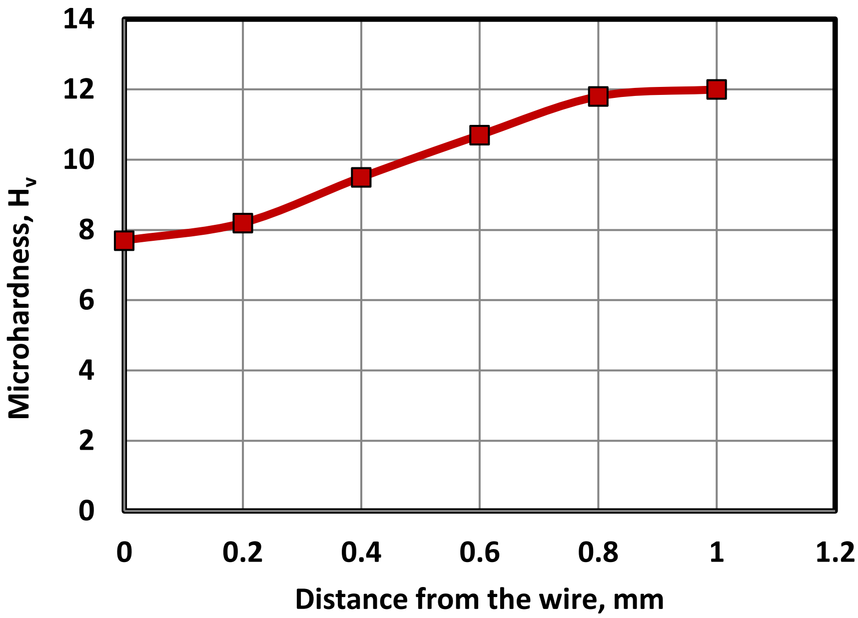

Fig. 10 Variation of microhardness of PP composites versus the distance from the copper wire.

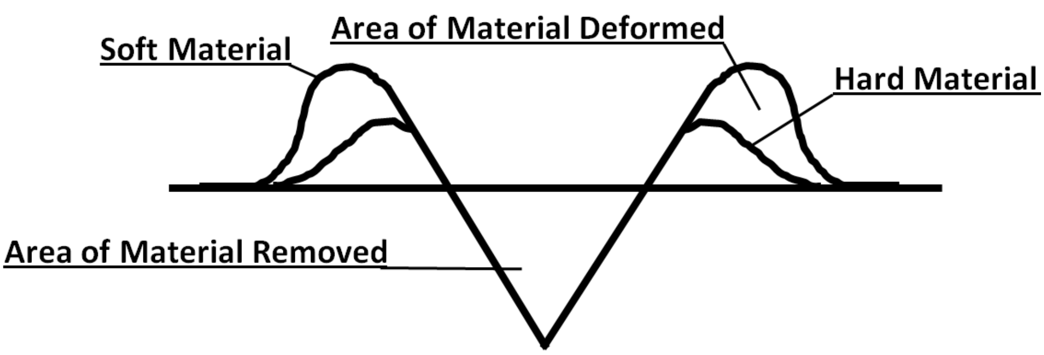

Fig. 11 Removed and deformed areas of the wear track after scratch.

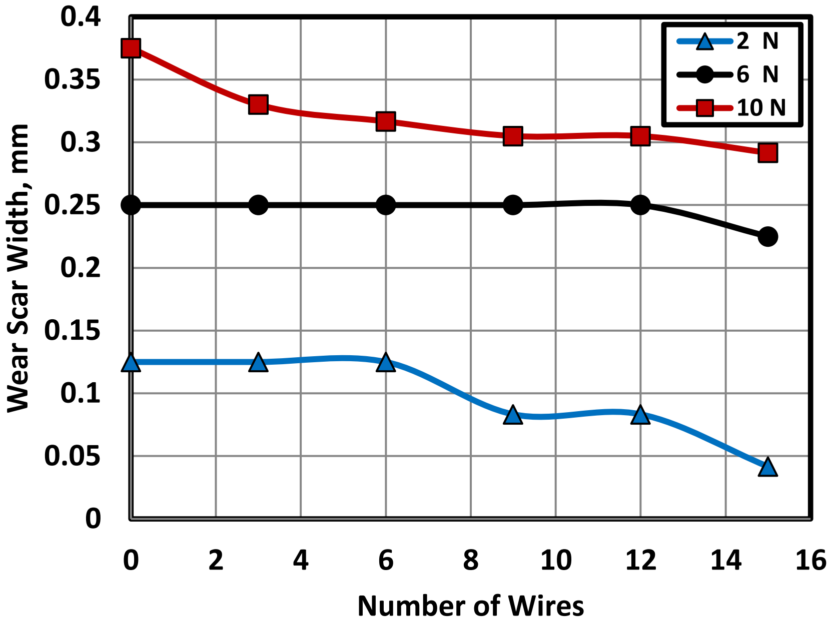

Fig. 12 Wear displayed by the scratch of PP reinforced by 0.21 mm diameter copper wires.

The wear of the tested composites can be interpreted on the basis that the presence of wire reinforcement can restrain the deformation of the polymer matrix where the external load 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 the 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.

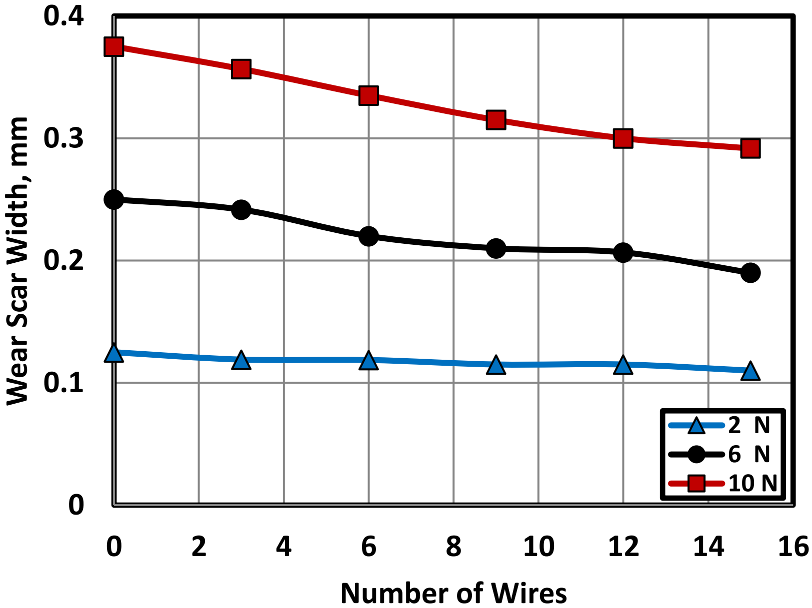

Fig. 13 Wear displayed by the scratch of PP reinforced by 0.28 mm diameter copper wires.

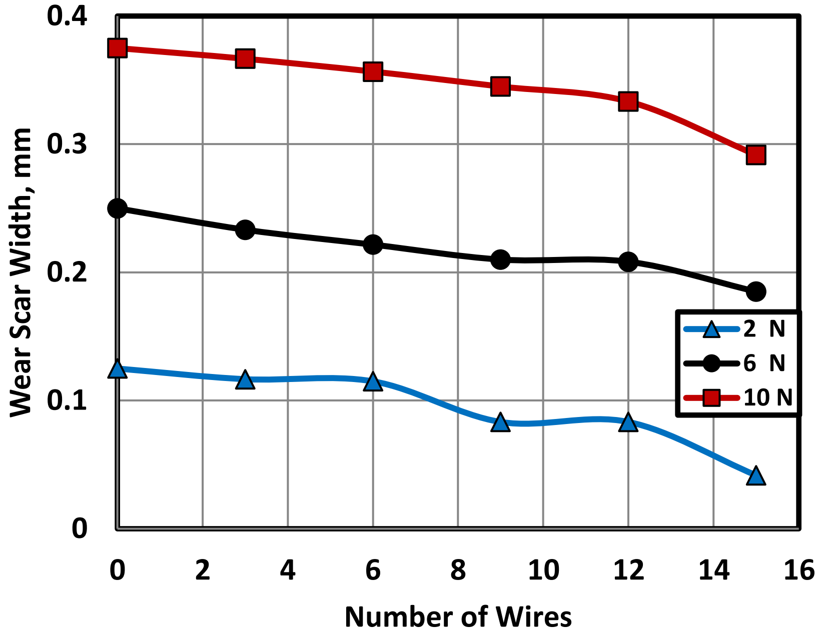

Fig. 14 Wear displayed by the scratch of PP reinforced by 0.5 mm diameter copper wires.

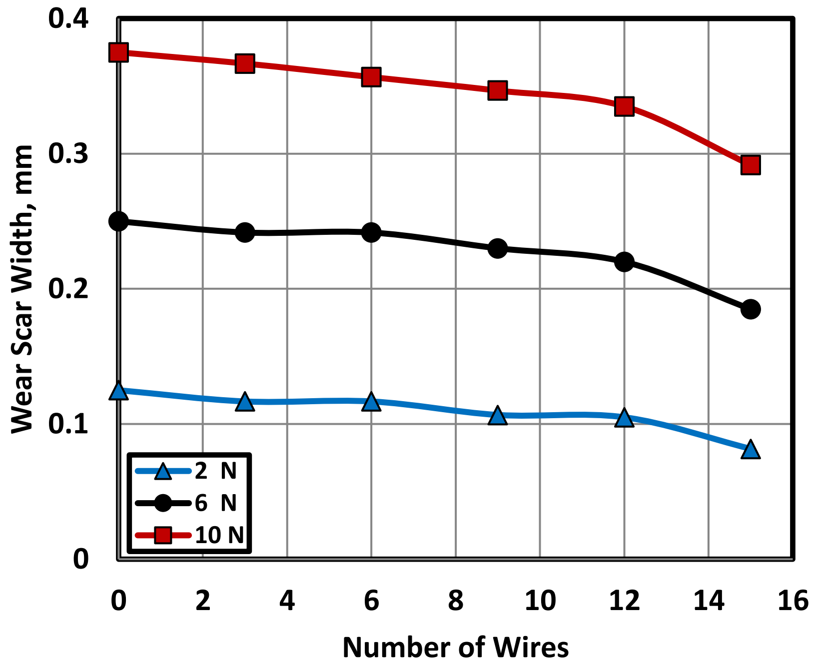

Fig. 15 Wear displayed by the scratch of PP reinforced by 0.57 mm diameter copper wires.

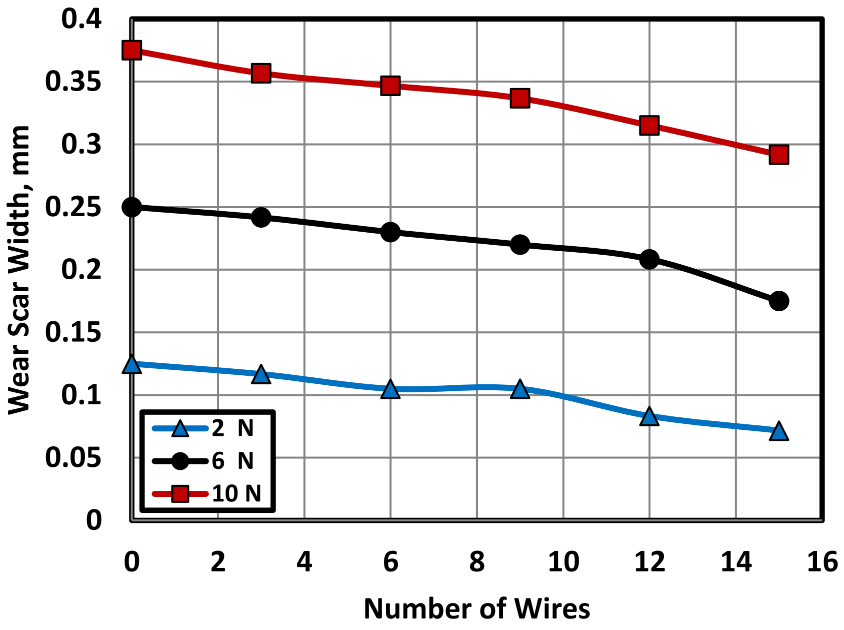

Fig. 16 Wear displayed by the scratch of PP reinforced by 0.85 mm diameter copper wires.

CONCLUSIONS

1. 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.
2. The wire diameter had slight effect on friction coefficient.
3. The hardness of the PP decreased close to the wire, this behaviour may be attributed to the change of the cooling rate where the zone near the copper wire was cooling faster and causing a decrease in polymer hardness.
4. Wear of the tested composites slightly decreased with increasing number of wires. Increase of wire diameter showed insignificant effect on wear. Wear significantly increased with increasing normal load.

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