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EFFECT OF REINFORCING POLYPROPYLENE BY STEEL WIRES ON FRICTION COEFFICIENT AND WEAR

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ABSTRACT
The effect of reinforcing polypropylene (PP) by unidirectional continuous steel wires on friction coefficient and wear was discussed in this work. Scratch test was carried to evaluate the tribological performance of the proposed composites. The tested composites were sheets PP of 5.0 mm thickness. The steel reinforcing wires were 0.3, 0.5, 0.6, 0.7 and 0.8 mm diameters. The numbers of wires reinforcing the test specimens were 0, 3, 6, 9, 12 and 15. The wires were distributed parallel to the direction of motion.

It was observed that friction coefficient displayed by the scratch of PP reinforced by steel wires decreased with increasing number and diameter of steel wires. The presence of steel wires decreased the hardness of the PP so that the material removal by the indenter was easier, where PP was affected by the rate of cooling during molding. Besides, reinforcing PP by steel wires increased the rate of cooling causing softening of the PP matrix and decreased the hardness. It can be concluded that presence of steel wires experienced wear decreasing. In addition to that, the influence of the cooling rate on the hardness and the mechanical properties of the polymers affected the wear. Normal load showed pronounced effect on wear of PP.

KEYWORDS
Polypropylene, Steel wires, friction coefficient, wear.

INTRODUCTION
The scratch of polyethylene (PE) and PP reinforced by the metallic wires such as steel and copper was carried out, [1 – 3]. It was found that friction coefficient decreased with increasing number of metallic wires due to the decreased hardness of the polymeric materials. The wire diameter had no effect on friction coefficient for PE reinforced by copper wires, while friction coefficient displayed by the scratch of PP decreased with increasing the wire diameter. Wear of copper wires reinforcing PE decreased with increasing number of wires. The increase of the number as well as the diameter of steel wires wear decrease.

Polyurethane (PU) coating on steel sheet reinforced by steel wires of different diameters was tested using sand blast test rig, [4 – 6]. It was found that wear of the tested coating decreased drastically with increasing steel wire diameter due to the strengthening effect. While, as the PU coating thickness increased, wear increased. Besides, wear of PU reinforced by gridded steel wires decreased with increasing wire diameter. It seems that gridded wire reinforcement strengthened the coating and increased the bonding force between polyurethane and steel wires. The erosion of epoxy glass fibre composites (Epoxy/GF) was studied by sand blasting, [7]. The impact angles (30°, 60°, and 90°), distance from the sand jet and oil content (2.5, 5, 7.5, 10 wt. %) filling epoxy matrix were tested. It was proved that oil content influenced material behavior. The sand erosion testing, of transparent polymeric coatings deposited on steel sheets, was investigated, [8]. Sand blast erosion test rig was designed and manufactured for the test. It was found that the lowest wear was observed for 0.08 mm coating thickness. Heat treatment of the coatings caused significant wear decrease down to minimum.

The effect of silicon oxide (SiO_2), iron (Fe), copper (Cu), glass fiber (GF) and aluminium oxide (Al_2O_3) on friction and wear of polyamide (PA) was investigated, [9, 10], where addition of GF as SiO_2 reduced friction and improved wear resistance. PA fibers as filling material in PA coatings increased abrasive wear resistance, [11]. The best performance was observed for the perpendicular short fibers.

Steel specimens coated by epoxy resin was investigated by abrasive wear caused by sandy soil. Epoxy coatings were filled by metallic particles of 30 – 50 µm particle size such as aluminium (Al), Cu, Fe and tin (Sn). Besides, epoxy coatings were reinforced by copper, steel and tinned steel wires of different wire diameters, [12]. It was found that Cu wires slightly decreased wear. 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. Besides, it was revealed that coating steel surface by epoxy reinforced by tinned steel wires displayed lower wear than that observed for uncoated steel.

The tribological performance of slip resistant material made of epoxy resin filled by silicon oxide, Al_2O_3, SiC, saw dust, cellulose fibers and rubber of different particle size and concentration was tested, [13, 14]. 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.

Epoxy resins 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, [15 - 20]. Friction and wear of epoxy resins composites reinforced by different types of fibre materials were investigated. It was observed for graphite fibre, Kevlar fibre and GF composites that the lowest wear and friction were obtained for fibre oriented normal to the sliding surface.

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

EXPERIMENTAL

Experiments were carried out by the scratch tester, Fig. 1. The load was applied by weights of 2, 4, 6, 8 and 10 N. Scratch force was measured by load cell assembled to the loading lever and connected to 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 straight direction. The test specimens were scratched by diamond stylus of apex angle 90° and hemispherical tip. The scratch force was measured during the test 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 made of polypropylene of 5.0 mm thickness, 100 mm length and 30 mm width. The steel reinforcing wires were of 0.3, 0.5, 0.5, 0.6, 0.7 and 0.8 mm diameters. The test specimens were reinforced by 0, 3, 6, 9, 12 and 15 steel wires. The wires were distributed parallel to the direction of motion. The test specimens were molded in die of 5 × 30 × 100 mm^3, where the wires were installed, Fig. 2.

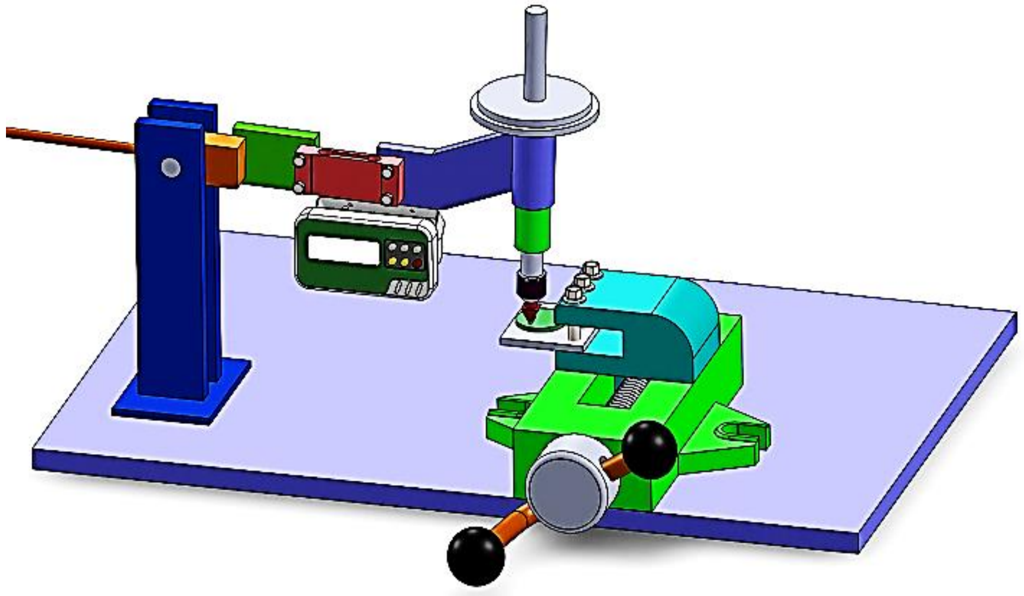

Fig. 1 Details of the scratch test.

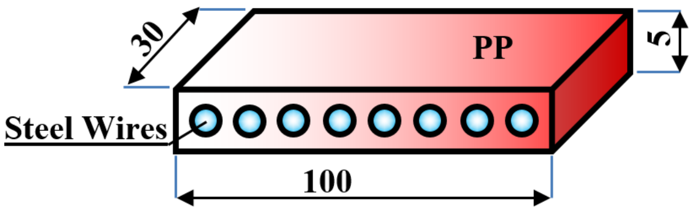

Fig. 2 Test specimen reinforced by steel wires.

RESULTS AND DISCUSSION

Figure 3 shows friction coefficient displayed by the scratch of PP reinforced by 0.8 mm diameter steel wires, where friction coefficient drastically decreased with increasing number of steel wires. It seems that PP was affected by the rate of cooling during molding. It seems that steel 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 polymeric matrix and decreasing the hardness that showed lower friction during scratching. It was observed that as the diameter of the steel wire increased, the values of the friction coefficient increased due to the increase of the rate of cooling, Fig. 4. It is shown that as the load increased, friction coefficient increased due to the increased material removed during scratch. It seems that the presence of steel wires decreased the hardness of the PP so that the material removal by the indenter was easier. Friction coefficient values were 0.62, 0.67 and 0.69 for PP free of wires at 2, 6 and 10 N load, while those values were 0.22, 0.47 and 0.54 for PP reinforced by 15 steel wires of 0.8 mm diameter at 2, 6, 10 N load.

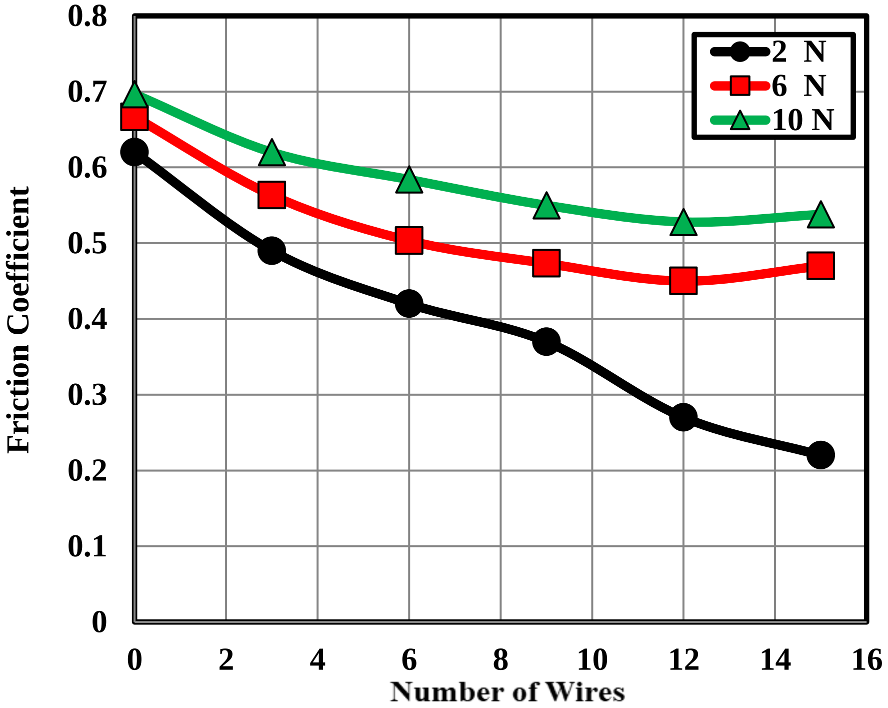

Fig. 3 Friction coefficient displayed by the scratch of PP reinforced by steel wires of 0.8 mm diameter.

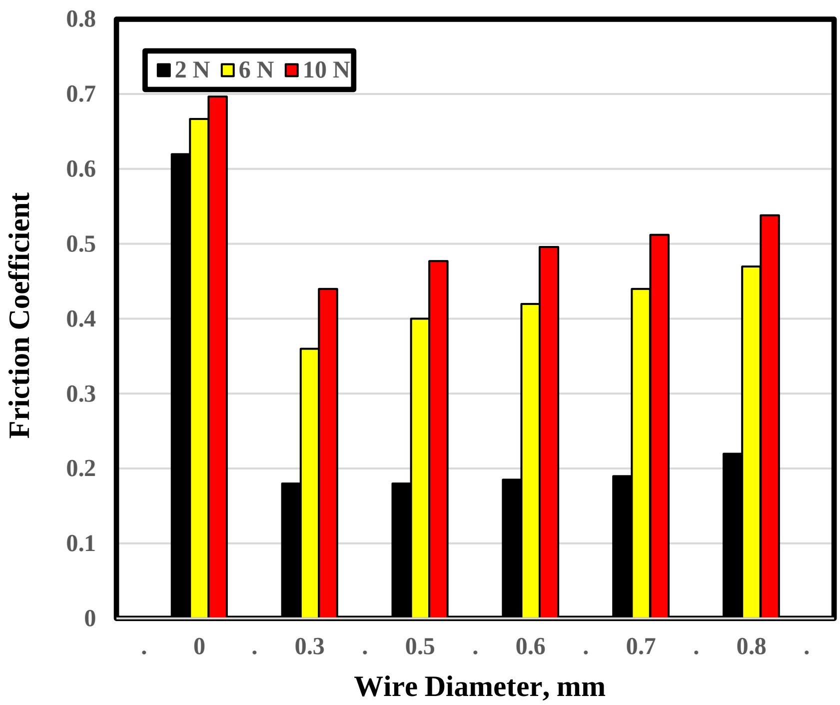

Fig. 4 Friction coefficient displayed by the scratch of PP Reinforced by 15 steel wires of different diameter.

The microhardness of the PP composites was measured to investigate the effect of the proposed reinforcement on the cooling rate of the composites during molding. The distribution of hardness as function of the distance from the wire is illustrated in Fig. 5. 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 steel wire cooled faster and caused a decrease in the hardness.

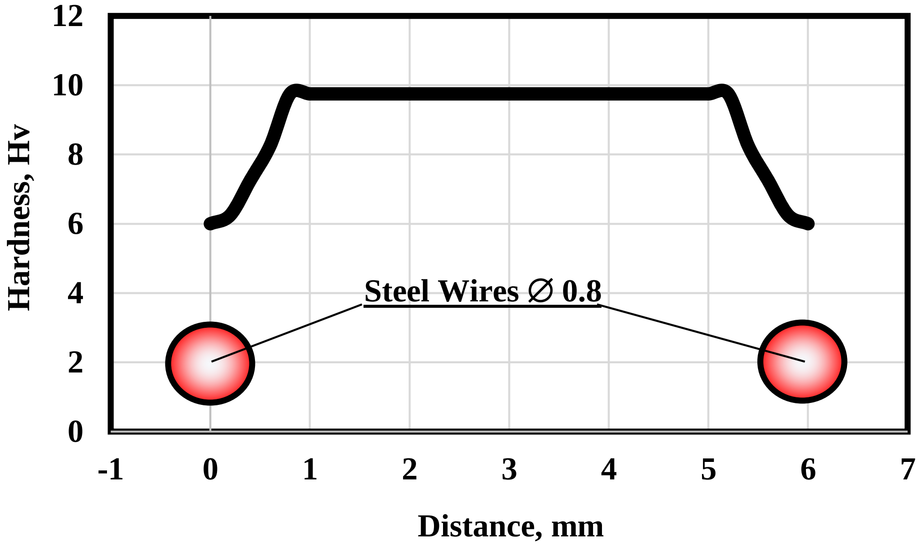

Fig. 5 Hardness distribution as function of the distance from the steel wire of 0.8 mm diameter.

Wear displayed by the scratch of PP reinforced by steel wires is shown in Figs. 6 - 9. The steel wires experienced wear decreasing trend with increasing number of wires

due to the function of the matrix that contained and transmitted the load to the wires by shear at the wire-PP interface that 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 as well as their strengthening effect could decrease wear. In addition to that, the influence of the cooling rate on the hardness and the mechanical properties of the polymers could affect the wear. Normal load showed pronounced effect on wear of PP.

Wear of PP matrix reinforced by wires of copper of 0.6 mm diameter is shown in Fig. 6. Wear of test specimens slightly decreased with increasing number of wires, where the minimum value was observed at 12 wires. It seems that worn materials removed from PP were affected by strengthening action of steel wires. The same trend was observed for 0.8 mm steel wire diameter, where the minimum wear was displayed by composites reinforced by 9 wires, Fig. 7. Besides, wear significantly increased with increasing normal load. Besides, steel reinforcement could restrain the deformation, plastic deformation, grooving and smearing of surface caused by scratch of the PP matrix. Wear displayed by the scratch of PE reinforced by 9 and 12 steel wires are shown in Figs. 8 and 9 respectively. The increase of the number of steel wires caused significant wear decrease. This behaviour may be from the strengthening effect of steel wires as well as the effect of cooling rate. It was observed that increasing the wires diameter of steel and increasing their number caused wear reduction. The best results have been observed for steel wires of 0.8 mm diameter. The possible explanation for the wear decrease observed for PP could be related to the relatively low hardness that enabled the indenter to be easily embedded in the surface and to increase its ability to make plastic deformation in the surface more than material removal.

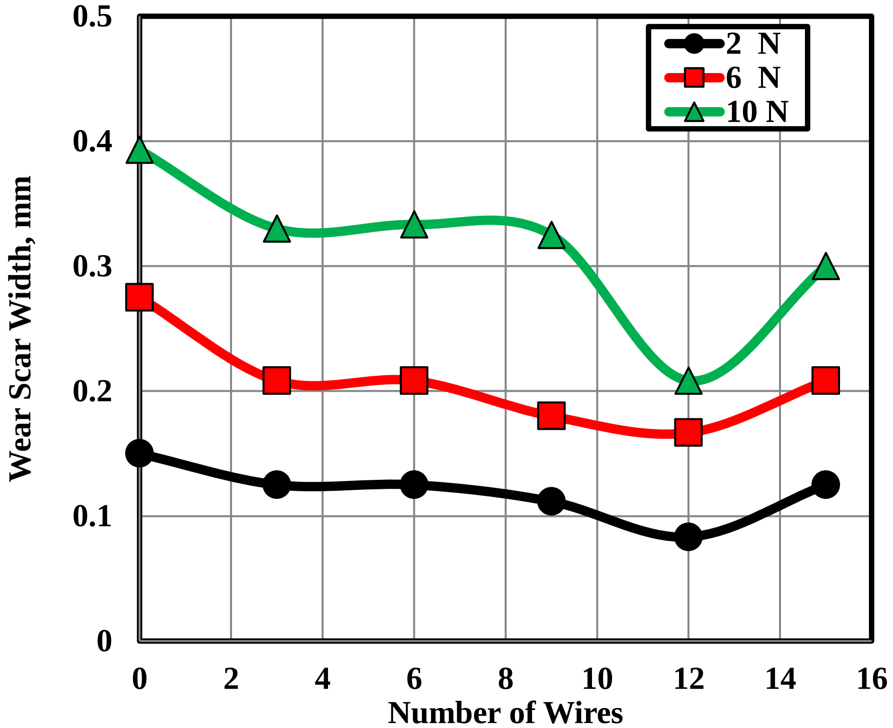

Fig. 6 Wear displayed by the scratch of PE reinforced by 0.6 mm diameter steel wires.

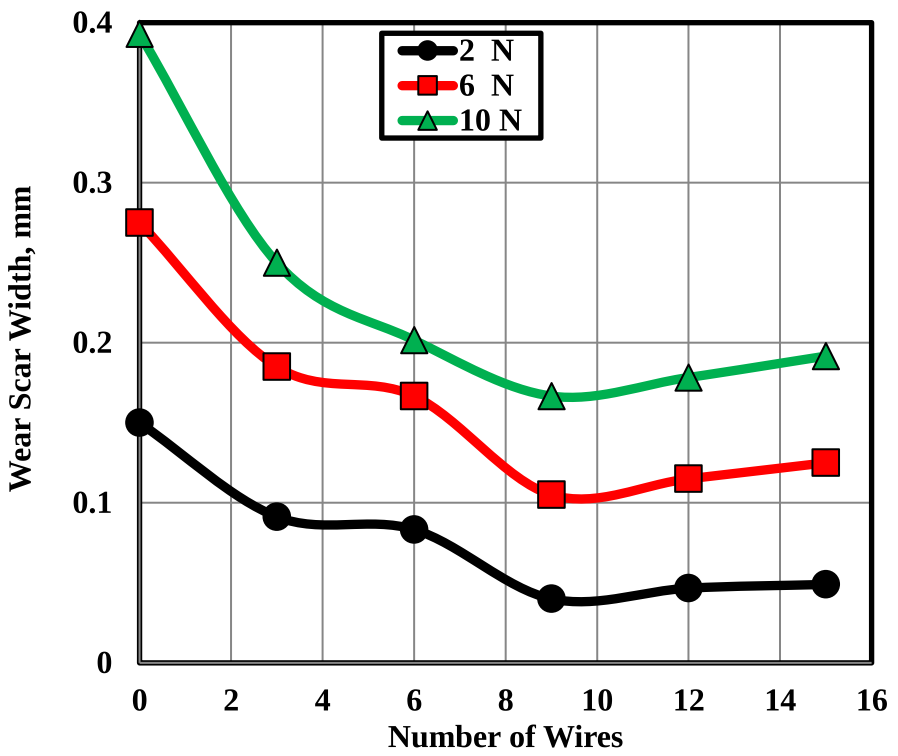

Fig. 7 Wear displayed by the scratch of PE reinforced by 0.8 mm diameter steel wires.

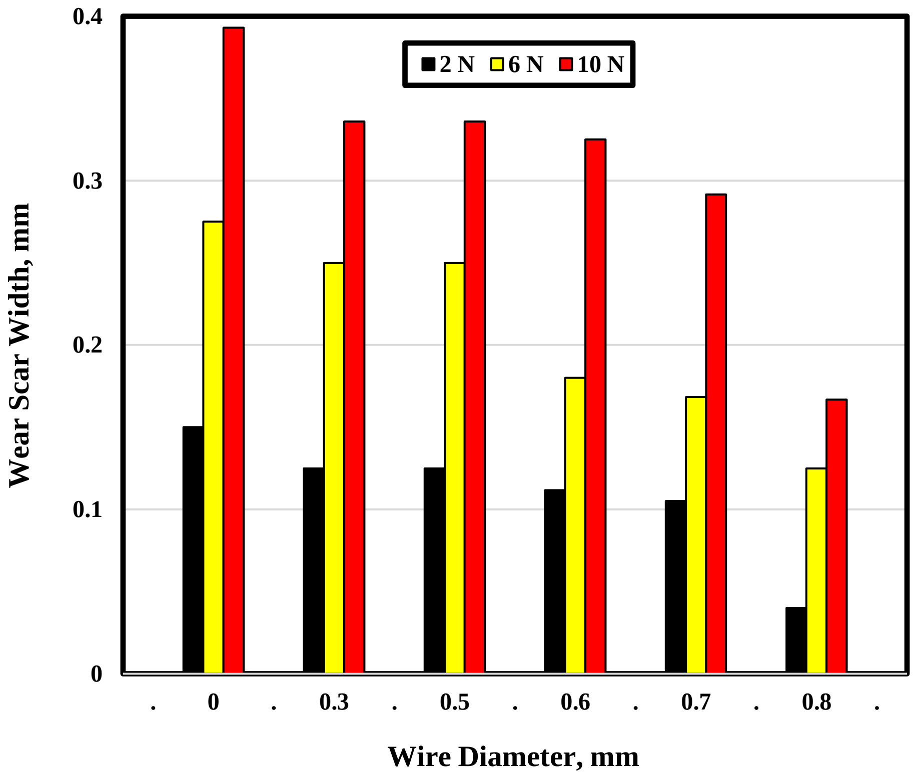

Fig. 8 Wear displayed by the scratch of PE reinforced by 9 steel wires.

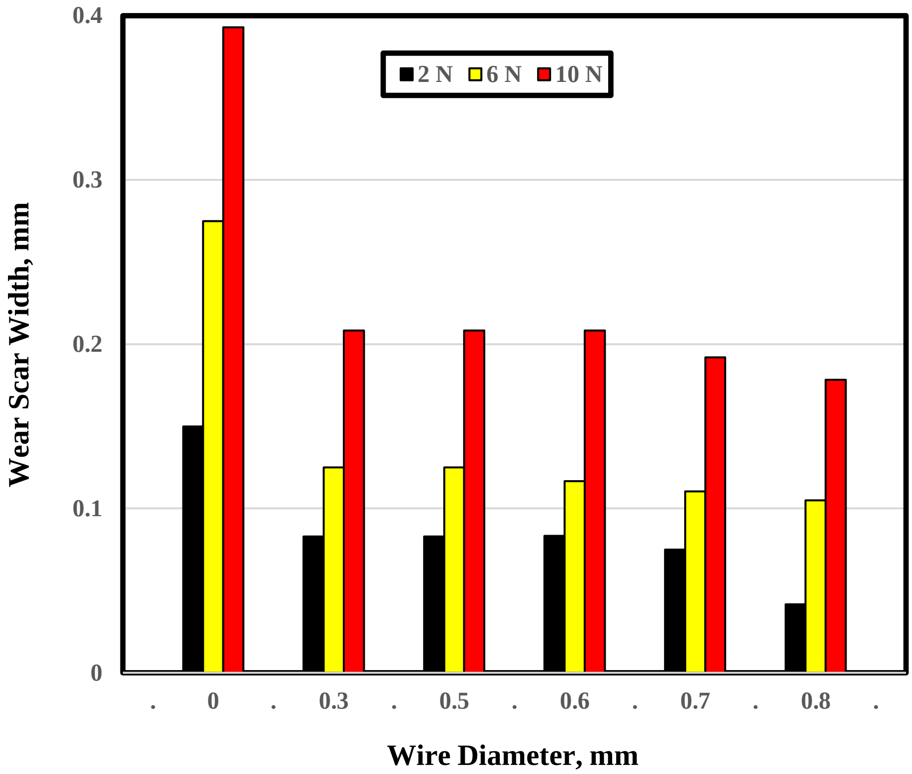

Fig. 9 Wear displayed by the scratch of PE reinforced by 12 steel wires.

It is well known that thermal preconditioning has strongly influenced the mechanical and tribological properties of polymers such as polyvinyl chloride (PVC), polystyrene (PS) and polymethylmethacrylate (PMMA) test samples. It was found that the quenched specimens exhibited uniform tensile deformation while annealed samples showed brittle behavior. The presence of the steel wires and the difference in the thermal properties enhanced the ability of the polymeric composites to be influenced by the cooling process after molding.

CONCLUSIONS

1. Friction coefficient displayed by the scratch of PP reinforced by 0.8 mm diameter steel wires drastically decreased with increasing number of steel wires.
2. As the diameter of the steel wire increased the values of the friction coefficient increased.
3. As the load increased friction coefficient increased.
4. The presence of steel wires decreased the hardness of the PP so that the material removal by the indenter was easier.
5. Presence of steel wires experienced wear decreasing trend with increasing number of wires.
6. Wear of test specimens decreased with increasing number of wires.
7. Wear significantly increased with increasing normal load.
8. Increasing the steel wires diameter caused wear reduction.

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