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Friction Coefficient and Wear Displayed by the Scratch of Polyethylene Reinforced by Steel Wires

Eman S. M, Khashaba M. I., Ali W. Y.*

Faculty of Engineering, Minia University, El-Minia, Egypt

Abstract

The friction and wear of polyethylene (PE) matrix composites reinforced by unidirectional continuous steel wires of different diameters are discussed in this work. On the basis of experimental results, it was observed that friction coefficient displayed by the scratch of PE reinforced by steel wires showed that as the load increased friction coefficient increased due to the increased material removed during scratch. Besides, drastic decrease in friction coefficient was observed with increasing number of wires. It was observed that as the diameter of the steel wire increased, the values of the friction coefficient decreased due to the increase of the rate of cooling as result of the increased cross section area. The increase of the number and diameter of the steel wires reinforcing PE caused significant wear decrease. Wear significantly increased with increasing normal load. Wear values were influenced by the variation of steel wire diameter due to the variation of the cooling rate.

Keywords

Friction Coefficient, Wear, Scratch, Polyethylene, Steel Wires

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1. 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

* Corresponding author
E-mail address: wahyos@hotmail.com (Ali W. A.)

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 both 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 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.

Many efforts have been exerted to introduce new self-lubricating polymeric materials for bearing applications, where external lubricant such as oil or grease can be excluded and the design can be simplified and maintenance cost can be reduced. Polymeric composites consisting of polyamide (PA6) filled by different types of vegetables oils such as (almond oil, camphor oil, castor oil, cress oil, flaxseed oil, black seed oil, lettuce oil, olive oil, sesame oil, and sun flower oil) in concentration up to 10 wt. %, were tested, [20, 21]. It was found that, as the oil content increased friction coefficient decreased. It seems that friction decrease was displayed due to oil transfer from the specimen to the counterface forming a thin layer which was responsible for the friction decrease.

The aim of the present work is to investigate the effect of reinforcing PE by steel wires of different diameters on friction coefficient and wear displayed by the scratch test.

2. Experimental

Scratch tester shown in Fig. 1 was used. It consisted of an indenter of apex angle 90° and hemispherical tip. The indenter was mounted to the loading lever. 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 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 scratch force was measured during the test to calculate friction coefficient. 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.

The test specimens were PE of 5.0 mm thickness. The steel reinforcing wires were carbon steel of 0.1 wt.% carbon content and 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. The test specimens were molded in die of $30 \times 100 \times 5$ mm^3, Fig. 2. The evidence of the scratch test on the surface of the test specimen is shown in Fig. 3.

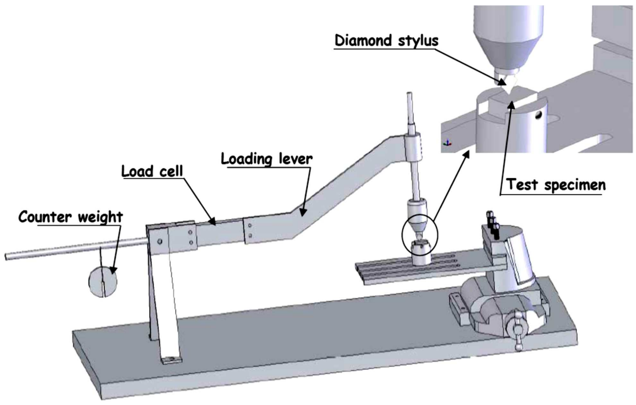

Figure 1. Arrangement of scratch test rig.

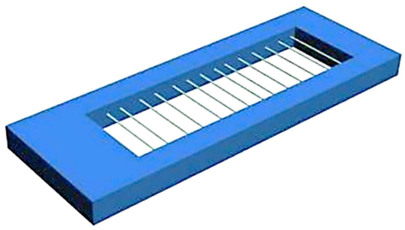

Figure 2. Molding die of the test specimens.

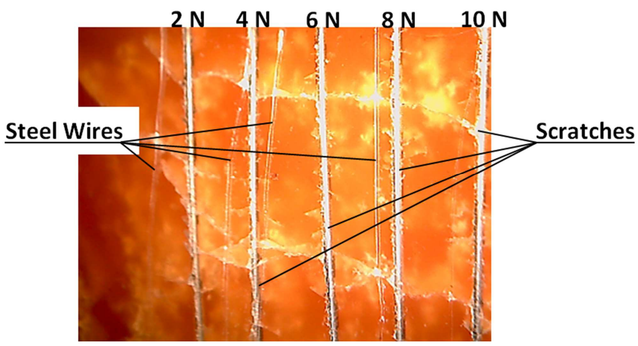

Figure 3. Photomicrograph of the test specimen.

3. Results and Discussion

Friction coefficient displayed by the scratch of PE reinforced by 0.3 mm diameter steel wires, Fig. 4, showed that as the load increased friction coefficient increased due to the increased material removed during scratch. This behavior can be explained on the basis that as the load increased, the indenter sank deeply in the PE matrix abrading relatively higher PE volume. The lowest friction value was displayed by PE reinforced by 15 wires at 2 N load. Besides, drastic decrease in friction coefficient was observed with increasing number of wires. This behavior is attributed to the steel wires which are considered as heat conductor that transferred heat during molding out of PE matrix. This process increased the rate of cooling that caused softening of the matrix. During scratching, the relatively low hardness of PE was the reason of the relatively lower values of friction coefficient.

The microhardness of PE has been measured to investigate the effect of the steel reinforcement on the cooling rate during preparation, Fig. 5. It has been observed that the hardness decreases close 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 causing a decrease in PE hardness. The decrease in hardness increased the embedment of indenter in PE matrix leading to a significant wear decrease. The variation of hardness due to the presence of the steel wires is illustrated in Fig. 6. The highest value of the hardness is the nominal hardness before reinforcing the PE matrix by the steel wires, while the hardness decreased near the steel wire. As the hardness decreased the plastic deformation accompanied to scratch increased, while the removed material decreased, Fig. 7. When the volume of deformed material is close to that of removed material, the condition of zero wear is approached.

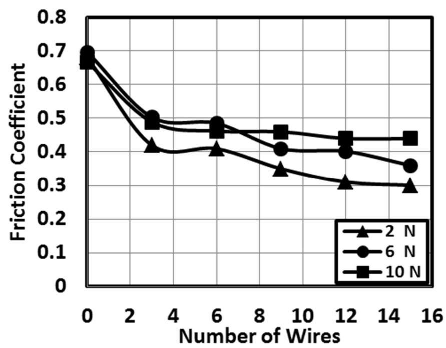

Figure 4. Friction coefficient displayed by the scratch of PE reinforced by 0.3 mm diameter steel wires.

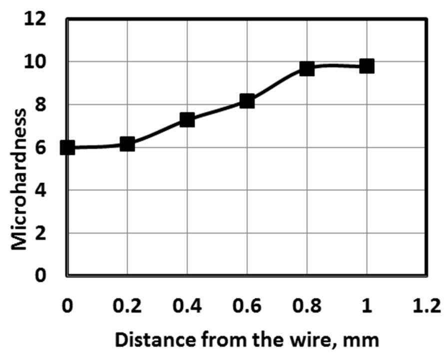

Figure 5. Microhardness distribution on the the surface of the PE composites.

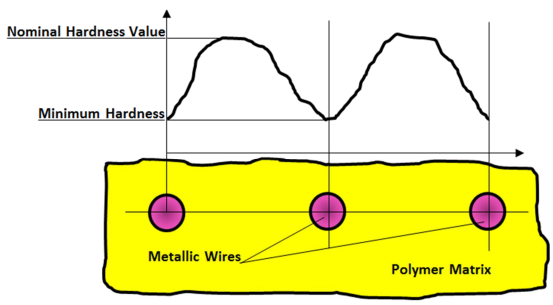

Figure 6. Hardness variation due to the steel wires.

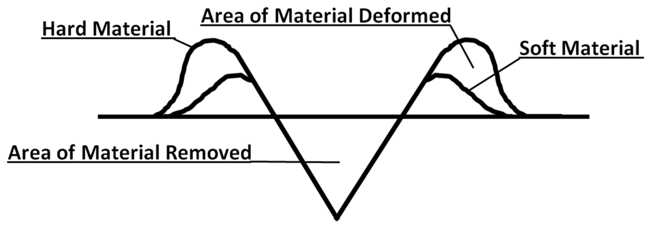

Figure 7. Illustration of the removed and deformed areas of the wear track.

The effect of number of wires reinforcing PE on friction coefficient for 0.5 mm steel wire diameter is shown in Fig. 8. Slight friction decrease was observed at 2 N load, where the lowest value was 0.32. The same trend was detected as the wire diameter increased up to 0.8 mm, Figs. 9–11. It is clearly seen that friction coefficient drastically decreased with increasing wire diameter up to 3 wires then slightly decreased. The minimum values were presented by PE reinforced by 15 wires of 0.8 mm diameter.

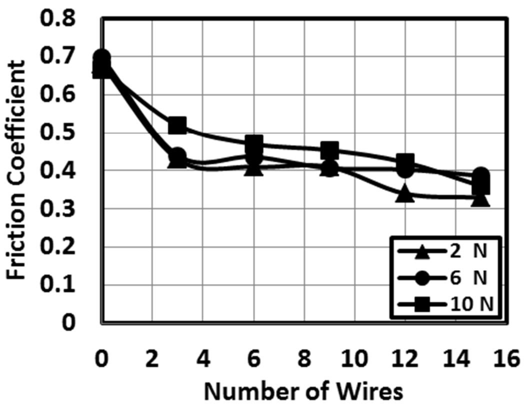

Figure 8. Friction coefficient displayed by the scratch of PE reinforced by 0.5 mm diameter steel wires.

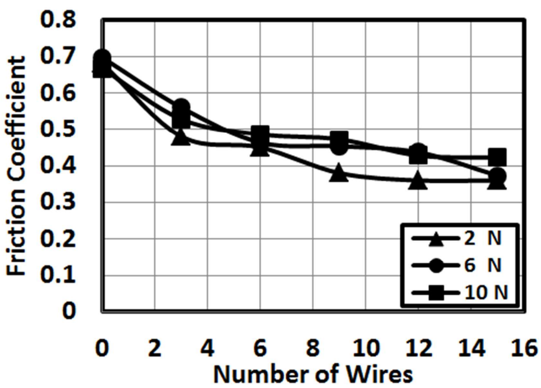

Figure 9. Friction coefficient displayed by the scratch of PE reinforced by 0.6 mm diameter steel wires.

Reinforcing PE materials by steel wires was achieved to develop the mechanical properties and increase the wear resistance. The increase of the number of steel wires caused significant wear decrease, Figs. 12-16. 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 significant wear decrease. The best results have been observed for steel wires of 0.8 mm diameter. A possible explanation for the wear reduction observed for PE could be related to the relatively low hardness which enabled the indenter to be easily embedded in the surface, where its ability to plastically deform the surface was more than to remove PE.

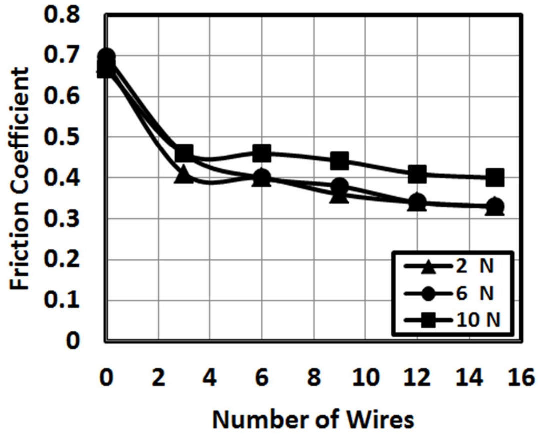

Figure 10. Friction coefficient displayed by the scratch of PE reinforced by 0.7 mm diameter steel wires.

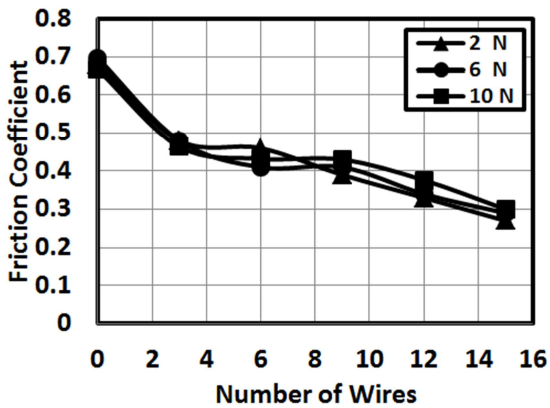

Figure 11. Friction coefficient displayed by the scratch of PE reinforced by 0.8 mm diameter steel wires.

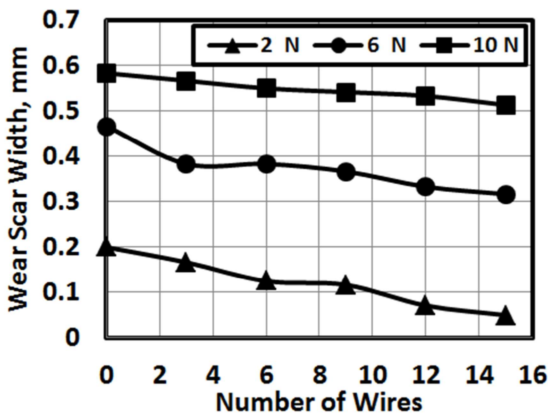

Figure 12. Wear displayed by the scratch of PE reinforced by 0.3 mm diameter steel wires.

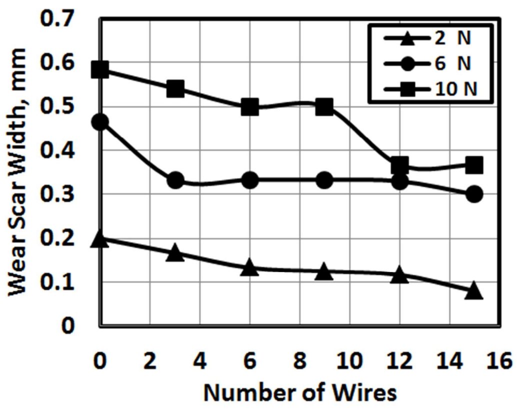

Figure 13. Wear displayed by the scratch of PE reinforced by 0.5 mm diameter steel wires.

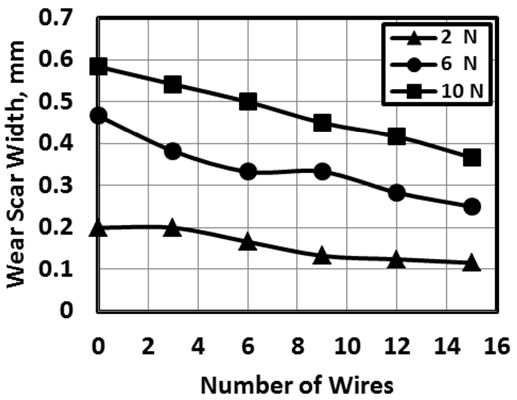

Figure 14. Wear displayed by the scratch of PE reinforced by 0.6 mm diameter steel wires.

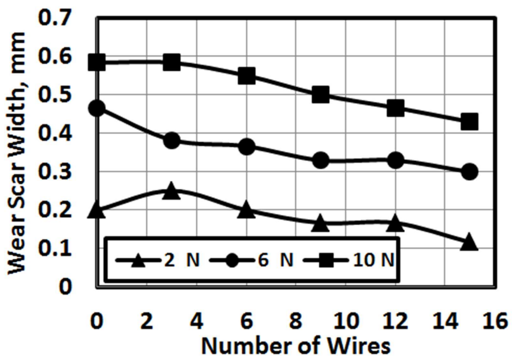

Figure 15. Wear displayed by the scratch of PE reinforced by 0.7 mm diameter steel wires.

Also presence of steel wire reinforcement could restrain the deformation of 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 the surface caused by indenter could be reduced due to the strengthening effect of the reinforcement. The steel wires experienced minimum values of wear because of the retarding action of the wires against the motion of the indenter. This can be interpreted on the bases 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 matrix. As the adhesion between the matrix and wire increases, the wear of the matrix decreases.

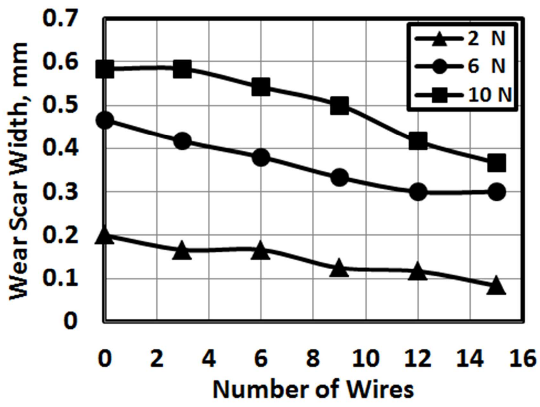

Figure 16. Wear displayed by the scratch of PE reinforced by 0.8 mm diameter steel wires.

4. Conclusions

1. Friction coefficient increased as the load increased. The lowest friction value was displayed by PE reinforced by 15 wires at 2 N load. Besides, drastic decrease in friction coefficient was observed with increasing number of wires. The microhardness of the PE decreased close to the steel wire. The variation of the hardness may be from the change of the cooling rate where the zone near the steel wire cooled faster causing a decrease in PE hardness which increased the embedment of indenter in the coating surface leading to a significant wear reduction. Friction coefficient drastically decreased with increasing wire diameter up to 3 wires then slightly decreased.

2. Increase of the number and the diameter of the steel wires reinforcing PE caused significant wear decrease. This behaviour may be from the strengthening effect of steel wires as well as the effect of cooling rate. A possible explanation for the wear decrease observed for PE could be related to the relatively low hardness which enables the indenter to be easily embedded in the surface, where its ability to plastically deform the surface was relatively high. Plastic deformation, grooving and smearing of surface caused by indenter could be reduced due to the strengthening effect of the reinforcement. The steel wires experienced minimum values of wear because of the retarding action of the wires against the motion of the indenter.

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