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Sand Erosion of Steel Coated by Polyurethane Reinforced By Metallic Wires

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Abstract

The present work discusses the possibility of coating steel sheets by polyurethane reinforced by copper, steel and nickel chrome wires. The abrasion resistance of polyurethane coatings of steel sheets has been investigated. The tested polyurethane composite coatings are proposed to decrease erosion wear of buildings and defeat sand erosion during dusty storms. Experiments have been carried out using sand blast test rig. Based on the experimental results, it was found that erosion wear decreases with increasing wire diameter, where the wire strengthens the eroded area. Besides, minimum value of wear of polyurethane coating reinforced by copper wires is observed when the substrate was coated by two layers. Ni Cr wires shows minimum wear when the substrate i coated by three layers.

Keywords

Erosion, Sand, Steel Sheets, Polyurethane Coating, Wear, Metallic Wires

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1. Introduction

Solid particles erosion of material surface has been a challenge to several fields of engineering. Despite of decades of investigations and research, the exact phenomenon of erosion of surface by the solid particles has not been fully understood. The solid particle erosion of epoxy glass fibre composites (Epoxy/GF) is investigated by sand blasting equipment, [1]. The impact angles (30°, 60°, and 90°), distance from the sand jet and oil content (2.5, 5, 7.5, 10) filling epoxy matrix are studied. The results show a strong dependency of oil content on the material behaviour form brittle to ductile. The morphology of eroded surface is observed under microscope and damage mechanisms are discussed. The sand erosion testing, of transparent polymeric coatings of steel sheets, was investigated, [2]. The tested coatings were aimed to coat the vehicle surfaces as well as lamp covers to defeat sand erosion during dusty storms. An air-sand erosion test rig was designed and manufactured for that purpose. Four types of transparent polymeric coatings were tested. Based on the experimental results, it is found that the lowest wear values were observed for coating thickness of 0.08 mm. At 90° angle of inclination, embedment of sand particle was indicated by the weight increase after test. Heat treatment of the coatings caused significant wear decrease. Wear decreased down to minimum then remarkably increased with increasing angle of inclination.

Solid particle erosion is a general term used to describe the mechanical degradation (wear) of any material subjected to a stream of erodent particles impinging on its surface. The effect of particle erosion on structural and engineering components has been recognized for a long time, [3]. The aim of solid particle impact testing is to investigate the resistance to erosion by solid particle impact of materials with a wide range of mechanical properties, and to explore the correlation between erosion rate and mechanical properties. An aircraft is most likely to encounter dust and

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sand during take-off and landing, and rain during ascent and descent, as cruising altitudes are generally above cloud levels, [4]. However, military aircraft and missiles may experience all types of conditions.

Erosion of polymers and polymer matrix composites includes two modes: brittle and ductile erosion depending on the variation in the erosion rate (ER) with impact angle. If ER goes through a maximum at 15° – 30° impact angles, the response of the eroding material is considered ductile. In contrast, if ER continuously has a maximum at 90° (normal impact), the eroding material is considered as brittle, [5]. Polyethylene (PE) was eroded by sand particles. Most erosion was found to occur at an angle of 20–30°, while the weight loss became zero at around 80°. Transitions in the wear response of the target materials have been related into changes in the erodent characteristics, like shape, hardness or size of the sand particles [6 - 8]. The operating environment in Middle East is particularly severe in terms of the high ambient dust concentrations experienced throughout the Eastern and Western Provinces, [9]. During severe dust storm conditions dust concentrations of the order of 100 to 500 times higher may be encountered. It was found that the vast majority of airborne in the Eastern Province are concentrated in the smaller sizes. 95 % of all particles are below 20 μm and 50 % of all particles are below 1.5 μm in size. The dusty storms continue for long times in Gulf area. The erosion of vehicles body has an accelerated rate, [10].

The friction and wear of polyethylene (PE) and polypropylene (PP) matrix composites reinforced by unidirectional continuous copper and steel wires were discussed, [11 – 13]. It was found that friction coefficient displayed by the scratch of PE and 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.

In the present work, the abrasion resistance of polyurethane coatings reinforced by metallic wires is investigated by sand blast. The tested polyurethane composite coatings are proposed to decrease erosion wear of buildings and defeat sand erosion during dusty storms.

2. Expermental

Experiments were carried out using sand blast test rig, Fig. 1. It consists of a box of aluminum frame of 120 × 120 × 60 cm^3 dimension. The sand blast gun is fixed to one side of the test chamber at a distance 70 cm far from its bottom. A hopper attached to the sand blast gun contains sand particles. The sand blast gun is connected to an air compressor used to compress atmospheric air up to 0.8 N/mm^2 maximum pressure. The air is stored in a pressure vessel of 25 liters capacity. The compressor is refilled automatically when the pressure decreases to 7 bars. A sand blast gun is used to eject air mixed with sand. When the trigger of the gun is pressed, the air passes from the pressure vessel and creates a suction ejecting the sand particles from the hopper. The average velocity of the air mixed with the sand particles is calculated (30 m/s). The box contains a vise works as specimen holder fixed on a plate of wood which moves through a guide attached to the box frame.

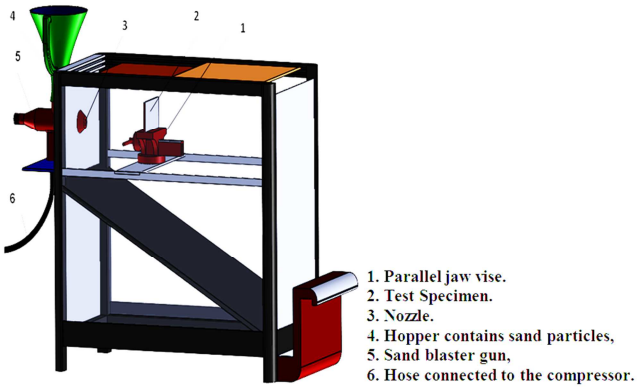

Fig. 1. Sand blast test rig.

Test specimens of steel sheets of 120 × 100 × 2 mm are coated by polyurethane and reinforced by metal wires of 0.4, 0.5 and 0.6 mm diameter, Fig. 2. The test specimens are sand blasted at 90° and the wear is evaluated by the weight loss after test. Two types of wire directions are used; unidirectional continuous and grid. The distance between wires is 4 mm.

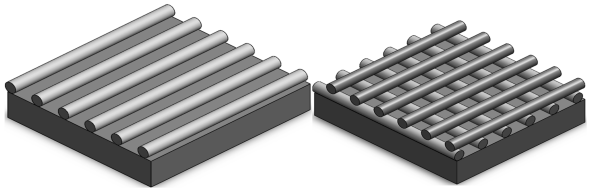

Fig. 2. Test specimens.

3. Results and Discussion

Wear of polyurethane coatings reinforced by copper wires is shown in Fig. 3, where wear decreases drastically down to minimum at 0.5 mm wire diameter then slightly increases with increasing wire diameter. This behavior means that presence of the wire strengthens the eroded area. But at 0.6 mm wire diameter, wear increases due to the separation of the wire from polymer coating leading to wear increase. The minimum value of wear is observed for three layers coating. The photomicrograph, Fig. 4, shows the separation of copper wire form the coatings due to effect of sand particles erosion on the surface of the coating confirming that the copper wire could withstand the erosion of the sand particles. The evidence of erosion shown indicates that sand particle penetrated the surface, removed the wire from its original location and the impact force eroded the coating of the wire, leading to wear increase. The erosion causes plastic deformation of the copper wire. Besides, embedment of the sand particles in the surface of the copper wire and separation of copper wire from polyurethane coating are clearly shown.

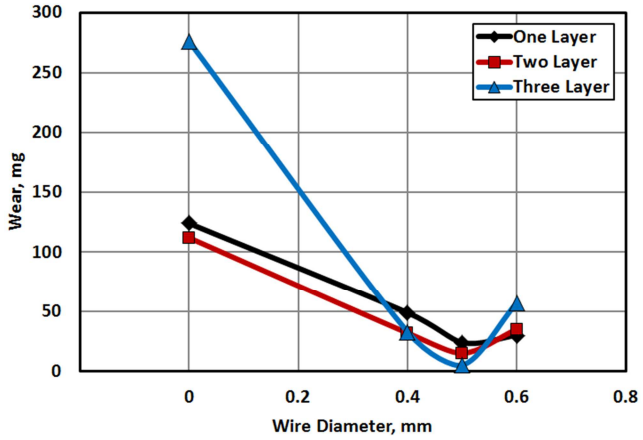

Fig. 3. Relationship between wear and copper wire diameter.

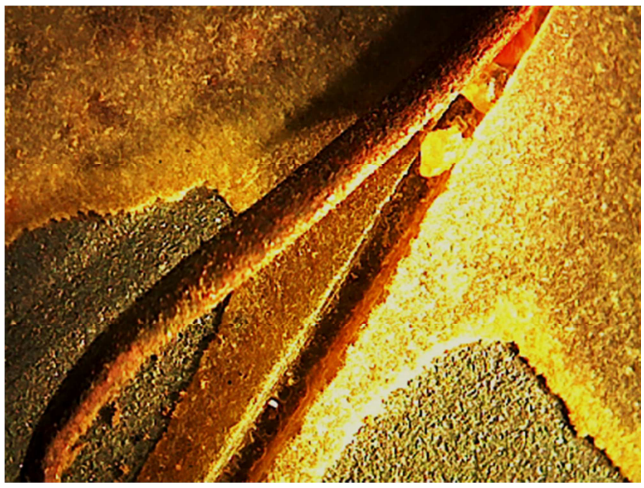

Fig. 4. Surface of the test specimen after erosion.

Schematic representation of the effect of erosion on the test specimens is illustrated in Fig. 5, where the copper wires are plastically deformed from their original location and embedded by sand particles. Besides the polyurethane coating is also eroded and embedded as a result of erosive and particles.

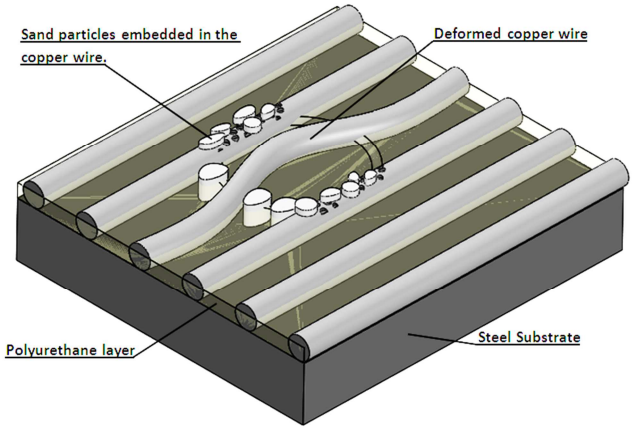

Fig. 5. Schematic representation of the effect of erosion on the test specimens.

For grid reinforcement by copper wires, Fig. 6, wear decreases with increasing wire diameter due to the increase of the bonding force caused by increasing the adhesion area. The number of wires increases for the grid distribution so that the adhesion area of wires increases and consequently the resistance against the impact force of sand particles increases. The minimum value of wear is observed at test specimens of three layers coating. Figure 7 shows the plastic deformation of copper wire and its removal from the coating matrix. Accumulation of polyurethane around the wires is clear. It seems that, grid distribution of copper wires increases the bonding force and consequently, wear decreases. In addition to that, plastic deformation in polyurethane layer close to the wire is observed, where transverse cracks are shown. Besides, sand particles severely penetrate polyurethane. The deformation of the upper wire in the grid is shown because it is subjected directly to the erosive action, while the lower wire does not deform and protects polyurethane from excessive wear.

Wear of coatings reinforced by steel wires is illustrated in Fig. 8. It is clearly shown that wear decreases drastically with increasing wire diameter. This behavior confirms that, steel wires could strengthen the eroded area and increase adhesion force. It seems that steel wires better resists erosion compared to copper wires. The evidence of the strengthening effect of steel wires is shown in Fig. 9, where an area of polyurethane is totally removed, while coating behind the steel wire is protected from erosion. In addition to that, steel wire is still adhered to the coating.

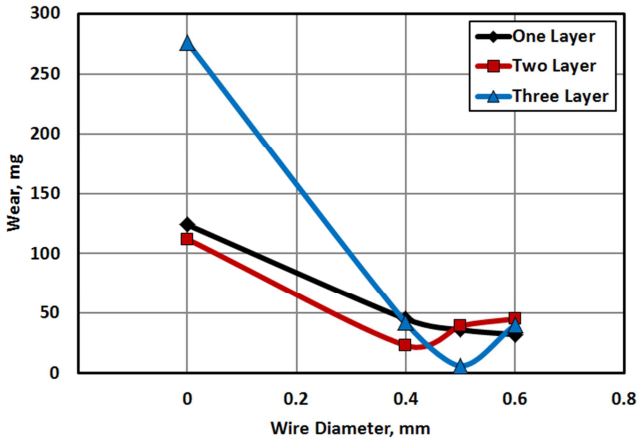

Fig. 6. Wear of coating reinforced by gridded copper wire diameter.

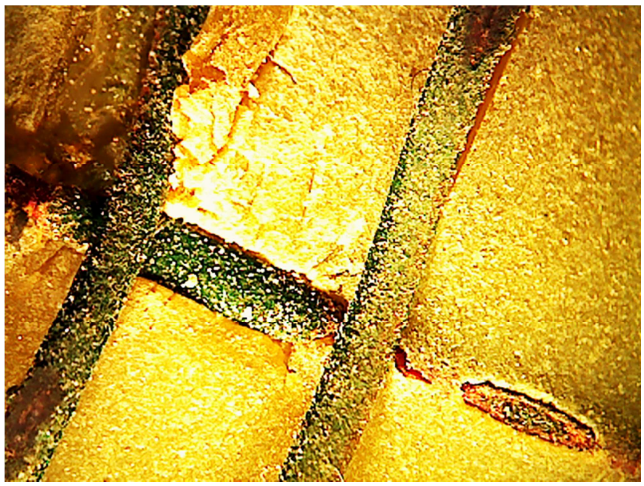

Fig. 7. Plastic deformation copper wire.

For grid distribution of steel wires, wear decreases with increasing wire diameter, Fig. 10. The minimum value of wear is observed when the substrate is coated by two layers. The accumulation of polyurethane around the wire is shown in Fig. 11, where the grid distribution of steel wires prevents the removal of polyurethane layer from the steel substrate, therefore, wear decreases.

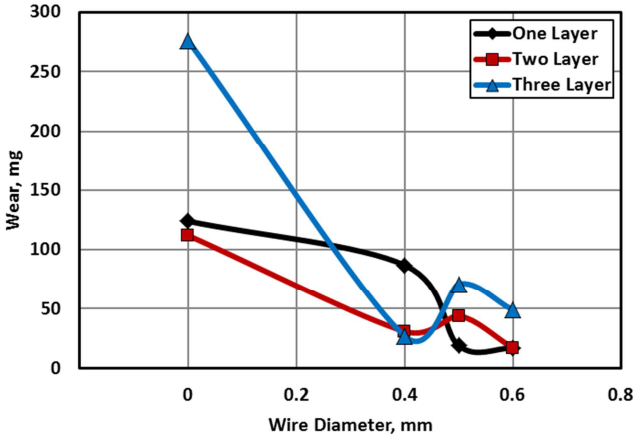

Fig. 8. Wear of coatings reinforced by steel wires.

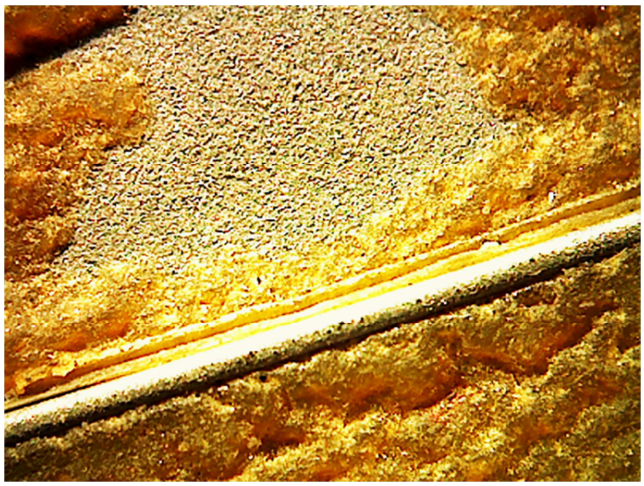

Fig. 9. Surface of the test specimen after erosion steel wire.

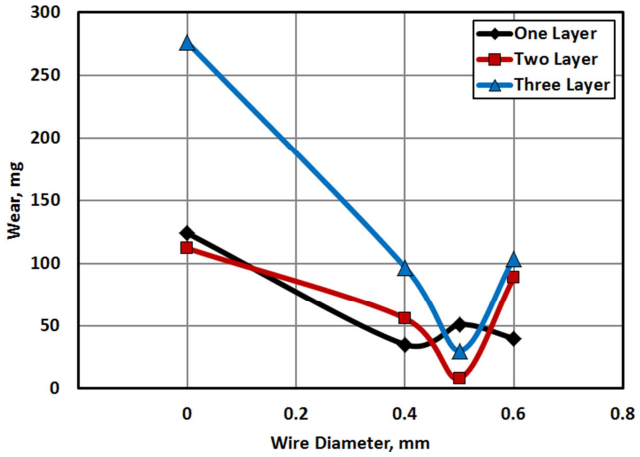

Fig. 10. Wear of coatings reinforced by grid distributed steel wires.

Fig. 11. Accumulation the polyurethane around the steel wire.

The following results deals with wear of coatings reinforced by stainless steel (Ni Cr) wires. Figure 12 shows that wear decreases drastically with increasing wire diameter. The behavior indicates that, when wire diameter increases, adhesion area increases and the resistance of the test specimens to impact force increases. The minimum value of

wear is observed for test specimens coated by two layers of polyurethane. The image below, Fig. 13, indicates the easy separation of the Ni Cr wire from polyurethane coatings in a manner that the coating is exposed completely to the erosion of sand particles. The severity of the action of sand particles is illustrated in Fig. 14, where sand particles erodes the coating layer and removes the wire from its location.

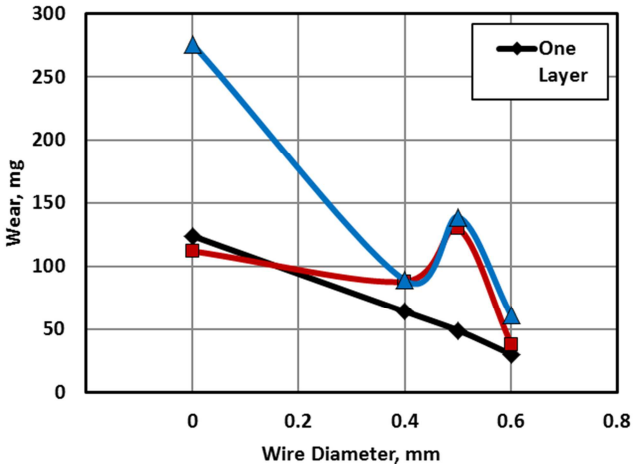

Fig. 12. Wear of coating reinforced by Ni Cr wires.

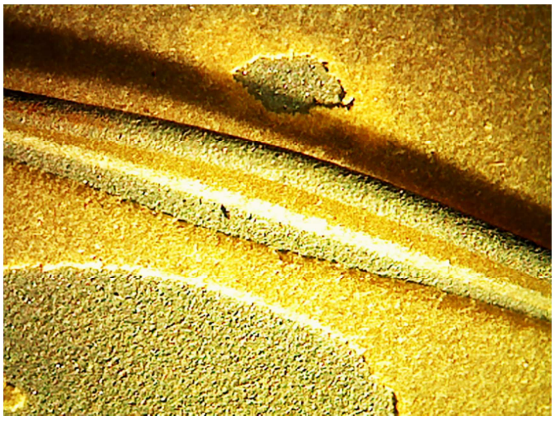

Fig. 13. Separation of Ni Cr wire from polyurethane coating.

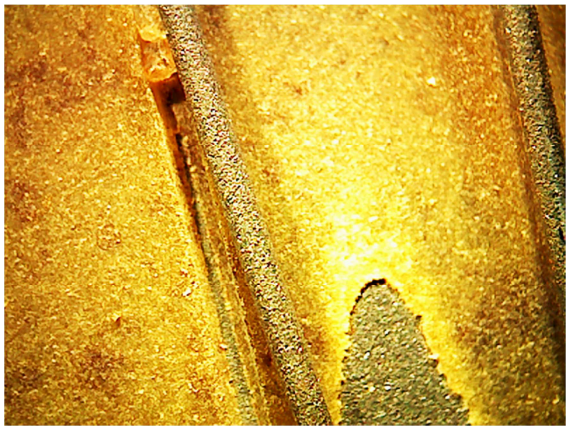

Fig. 14. Severity of sand particles erosion.

Wear displayed by polyurethane coating reinforced by gridded Ni Cr wires is shown in Fig. 15, where wear drastically decreases with increasing wire diameter. This behavior is attributed to the fact that the grid increases the bonding force between wires and polyurethane. Wear displayed by coatings reinforced by wire of 0.6 mm diameter shows the minimum wear. Evidence of wear of polyurethane coating reinforced by Ni Cr wires is shown in Fig. 16. The removal of polyurethane and the weak adhesion of wires in the coating are seen.

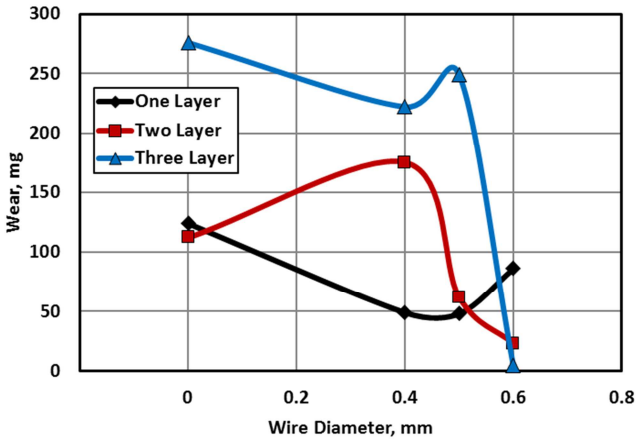

Fig. 15. Wear of coating reinforced by gridded Ni Cr wires.

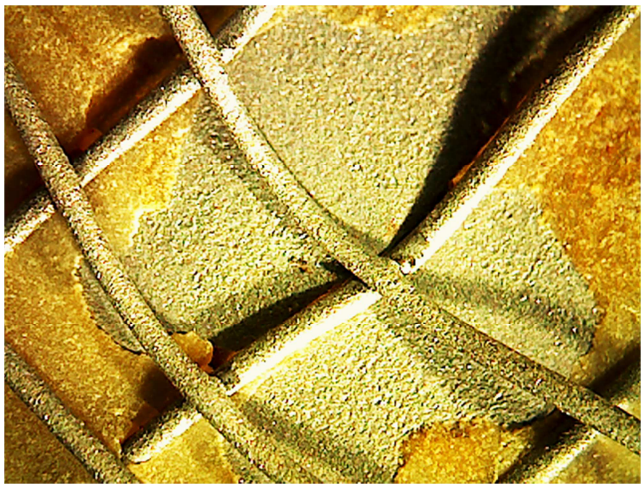

Fig. 16. Evidence of wear of polyurethane coating reinforced by Ni Cr wires.

4. Conclusion

1). Wear of polyurethane coatings reinforced by copper wires decreases drastically down to minimum at 0.5 mm wire diameter then slightly increases with increasing wire diameter. The minimum value of wear is observed for coating of three layers. The erosion caused plastic deformation of the copper wire. Grid reinforcement of copper displays lower wear than that observed for longitudinal wires.

2). Wear of coatings reinforced by steel wires decreases drastically with increasing wire diameter. Resistance of the composites reinforced by steel wires is higher than that observed for copper wires. The minimum value of wear is

observed when the substrate is coated by two layers.

3). The minimum value of wear of composites reinforced by stainless steel (Ni Cr) wires is observed for test specimens coated by two layers of polyurethane. Gridded Ni Cr wires of 0.6 mm diameter shows the minimum wear. Evidence of wear of polyurethane coating reinforced by Ni Cr wires confirms the weak cohesion of wires in the coating matrix.

References

[1] Atia A. M., Ali W. Y., "Erosion Behavior of Epoxy Composites Reinforced by Glass Fibre andFilled by Synthetic Oil", EGTRIB Journal, Vol. 13, No. 2, April 2016, pp. 50 – 59, (2016).

[2] Al-Qaham Y., Breemah A., Mohamed M. K. and Ali W. Y., "Sand Erosion Testing of Polymeric Coatings of Steel Sheets", Journal of the Egyptian Society of Tribology Vol. 9, No. 3, July 2012,pp. 40–52, (2012).

[3] Patnaik A., Satapathy A. and Biswas S., "Effect of Particulate Fillers on Erosion Wear of Glass Polyester Composites: A Comparative Study using Taguchi Approach, Malaysian Polymer Journal, Vol. 5, No. 2, p 49-68, (2010).

[4] Jilbert, G. H. and Field J.E., "Synergistic effects of rain and sand erosion", Wear, 243(1–2): pp. 6-17, (2000).

[5] Walley S. M., Field J. E., "The erosion and deformation of polyethylene by solid particle impact", Philosophical Transactions of the Royal Society, London A 321, PP. 277–303, (1987).

[6] N. M. Barkoula, J. Karger-Kocsis, Processes and influencing parameters of the solid particle erosion of polymers and their composites: a review, Journal of Materials Science 37 (18), PP. 3807–3820 (2002).

[7] G. W. Stachowiak, A. W. Batchelor, Engineering Tribology, Tribology Series 24, Elsevier, Amsterdam, PP. 586 (1993).

[8] I. M. Hutchings, Ductile-brittle transitions and wear maps for the erosion and abrasion of brittle materials, Journal of Physics D: Applied Physics 25A.212 (1992).

[9] Neaman, R. and Anderson, A., "Development and Operating Experience of Automatic Pulse-Jet Self-Cleaning Air Filters For Combustion Gas Turbines", ASME paper 80, GT, (1980).

[10] Elhabib O. A., Mohamed M. K., AlKattan A. A. and Ali W. Y. Reducing Wear of Vehicle Surface Caused by Sand Erosion Faculty of Engineering, Taif University, Saudi Arabia. International Journal of Scientific & Engineering Research, Volume 4, Issue 9, September-2013 2559 ISSN 2229-5518 IJSER © 2013 http://www.ijser.org

[11] Eman S. M, Khashaba M. I. and Ali W. Y., "Friction Coefficient and Wear Displayed by the Scratch of Polyethylene Reinforced by Steel Wires", International Journal of Materials Chemistry and Physics, Vol. 1, No. 3, 2015, pp. 378-383, (2015).

[12] Eman S. M., Khashaba M. I., Ali W. Y., "Friction Coefficient and Wear Displayed by the Scratch of Polypropylene Reinforced by Copper Wires", EGTRIB Journal, Vol. 13, No. 2, April 2016, pp. 38–49, (2016).

[13] Eman S. M, Khashaba M. I. and Ali W. Y., "Friction Coefficient and Wear Displayed by the Scratch of Polyethylene Reinforced by Copper wires", EGTRIB Journal, Vol. 12, No. 4, October 2015, pp. 15–27, (2015).