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Reducing Wear of Vehicle Surface Caused by Sand Erosion

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Abstract-The present work discusses the possibility of coating the steel sheets by polyurethane to resist sand abrasion. The abrasion resistance of polyurethane coatings of steel sheets was investigated. The tested coatings were aimed to coat the vehicle surfaces as well as lamp covers to defeat sand erosion during dusty storms. Two types of tests were carried out. The first was air sand erosion, while the second was scratch test to measure the wear resistance of the proposed coating. The testes coatings were heated up to 50º and 75º C then left to cool in the furnace .Based on the experimental results, it was found that for the sand erosion test as the coating thickness increased wear decreased. Annealed polyurethane coatings up to 50 °C showed insignificant effect on wear. Annealed coatings up to 75 °C significantly decreased wear . The results of the scratch test, showed that friction coefficient displayed by 0.26 mm coating significantly increased up to maximum then decreased with increasing load. As received tested coating showed the higher wear, while the annealed coatings displayed lower wear. Friction coefficient decreased down to minimum then increased with increasing coating thickness. The lowest values of friction coefficient were observed for as received coatings. Wear drastically decreased down to minimum then increased with increasing coating thickness. The minimum wear was observed at coating thickness ranging from 0.48 to 0.68 mm. Annealing remarkably decreased wear, where coatings annealed at 75 °C displayed the lowest wear values.

KEYWORDS: Erosion, sand particles, steel sheets, transparent polyurethane coatings, thickness, angle of inclination, heat treatment, scratch, wear, friction coefficient.

1 INTRODUCTION

The sand erosion testing of transparent polymeric coatings of steel sheets was investigated, [1]. 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. The test rig was designed to allow constant velocity of sand particles to impact the coated steel sheets. Four types of transparent polymeric coatings (A, B, C and D) were tested. The evidence of erosion caused by sand particles in the coating surfaces was inspected before and after test by optical microscope. Based on the experimental results, it is found that the tested coatings (A) and (B) showed significant wear decrease. 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. Coating (C), at low angle of inclination, showed relatively high wear resistance. This means that the shear strength of the coating is relatively high. As the angle of inclination increased wear increased. Heat treatment of coating (C) slightly decreased wear, where minimum values were observed at 60° angle of inclination.

Frequently aircraft, tank and helicopter gas turbine engines are operated in a desert environment where the gas turbine compressor rotor blades and vanes are exposed to erosive media such as sand and dust. Base metal erosion leads to increased fuel consumption, efficiency loss, and can cause damage to compressor and turbine hardware. Erosion resistant coatings can be used to prolong the life of compressor airfoils in a sand erosion environment, [2]. The key features of two selected coating architectures are outlined. Selected erosion performance data with different erosion media are presented. Excellent mechanical properties of single layer nitride coating such as high hardness and Young's modulus make it a very attractive material for the protection against the different types of wear, [3]. Mechanisms of solid particle erosion of metals and brittle materials, such as Ti-N and other nitride coatings have been discussed. It was demonstrated that the erosion rate of brittle coating compared to ductile coatings is lower at low impact angle but is higher at high impact angle, [4]. Brittle/ductile multilayer systems have also been applied successfully in commercial applications.

The sand erosion rates of novel compositions of hard ceramics such as tungsten carbide, silicon nitride, silicon carbide, and partially stabilized zirconia have been tested in air-sand erosion facilities. A new testing facility that ensured stable and reproducible erosion testing with sand velocities and concentrations up to 250 m/s and 5 wt. % in air, respectively, was built, [5]. Special rig design features allowed accurate sand consumption monitoring during each test. High-speed photography was used to determine the sand velocity distribution at each test setting. High-speed visualization of the sand impact on the material surface demonstrated fragmentation of almost every sand particle in the range of velocities of 60 m/s and higher. The evidence of extensive fragmentation contributed to understanding the origin of the erosion resistance of hard ceramics.

Selection of materials capable of withstanding sand erosion is one of the major problems encountered when designing valves for oil and gas severe service applications, [6 - 8]. The erosion problem is particularly acute for gas choke valves where natural gas, initially compressed to 200 - 500 kp/cm^2, may reach sonic velocity within the choke trim. The enormous fluid velocity accelerates entrained sand particles that subsequently impinge onto walls of the valve parts as well as the downstream pipe work.

The angle dependence of the erosion rate was obtained by testing the materials at an impact angle of 30° with the sand velocity of 105 m/s. It is generally believed, [9, 10] that for brittle materials such as hard ceramics a maximum erosion rate occurs at 90°, whereas for ductile materials this occurs at oblique impact angles. The erosion rate increases with the sand concentration because of the increased opportunity of sand particles impacting the steel surface, [11]. It was proposed, [12], that during each impact, plastic deformation takes place at the vicinity of the impact when the yield strength of steel is locally exceeded. Multiple impacts could generate a plastically deformed layer near the eroded surface with the increased yield strength due to strain hardening, reducing the erosion rate.

A single correlation for sand erosion of a “family” of polyurethanes is presented. By “family” is meant a group of chemically similar compounds, [13]. The natural time of a viscoelastic fluid: its significance and measurement, observations regarding the number of dimensional parameters in viscoelastic constitutive equations has been used together with the Pi theorem to prepare a single dimensionless correlation for a group of materials with similar but different forms of constitutive equations, different forms of stress-deformation behavior. Results of a large number of erosion tests on artificially generated and relatively dense sand–mud mixtures are presented, [14]. Soil sample compositions are varied concerning clay–silt and sand–silt ratio, and clay mineralogy. An experimental approach to accelerated laboratory testing sand erosion in high pressure flow channels of complicated 3D configurations was developed, [15]. The channels were designed for erosion-resistant valves in natural gas and oil severe service applications. A testing facility that operated at 40 bar of nitrogen pressure with silica sand as an erodent was built and calibrated. The flow channels were manufactured from organic glass (PMMA) in separate plates that facilitated weight loss measurements in different parts of the channels as well as erosion visualization. The particular grade of glass was selected after testing erosion in a range of materials in order to find close resemblance to stainless steel in terms of both the erosion rate angle function and the velocity exponent.

The operating environment in Middle East is particularly severe in terms of the high ambient dust concentrations experienced throughout the Eastern and Western Provinces, [16]. 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.

In the present research, it is aimed to investigate polyurethane transparent coatings of different thicknesses and annealed at 50 and 75 °C to resist the erosive wear caused by sand particles. The angle of inclination of the test specimens, the thickness of the coating and the effect of heat treatment are investigated. Besides, scratch test was carried out to have specific information about abrasive wear resistance of the tested coatings.

2 EXPERMENTAL

An air compressor was used to compress atmospheric air to 0.8 N/mm^2 maximum pressure. The air was stored in a pressure vessel of 25 litres capacity. The compressor is refilled automatically when the pressure decreases to 7 bars. A sand blaster gun (1) was used to eject air mixed with sand. There were two hoses. The first hose (2) was connected to the bottom of the handle and to the compressor, while the second hose (3) was connected to the bottom of the barrel and attaches the underside of a reservoir that contains sand particles. When the trigger

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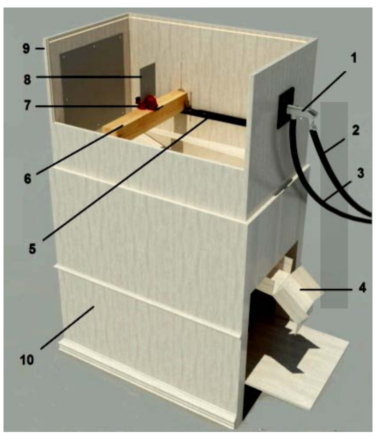
of the gun was pressed, the air passed from the pressure vessel created a suction ejecting the sand particles up to the hose from its reservoir through a 3 mm diameter nozzle. The average velocity of the air mixed with the sand particles were calculated (30 m/s, 108km/h). The details of the test rig are shown in Fig. 1.
The sand blaster gun was fixed to one side of a test chamber (9) which was a 450 mm height, 500 mm width and 780 mm long. The specimens were held by a parallel jaw vice (7) fixed inside the test chamber on adjustable beam that can be moved forward and backward from the nozzle depending on the distance needed. In this study the distance from the tip of the nozzle to the center line of the parallel jaw vice was fixed to 600 mm. The test chamber was placed on a stand with a fixed drain (5) to collect sand. The duration of the sand blast was 2.0 seconds. The sand was sieved before the test to control the particles size up to 2.0 mm. Sand was collected from the western desert in Saudi Arabia.



1. Sand blaster gun.
2. Hose connected to the compressor.
3. Hose connected to the reservoir.
4. To drain.
5. Linear bearings.
6. Beam.
7. Parallel jaw vise.
8. Specimen.
9. Test chamber.
10. Stand.

Fig. 1 Details of the sand erosion test rig.

The sand blaster gun was fixed to one side of a test chamber (9) which was a 450 mm height, 500 mm width and 780 mm long. The specimens were held by a parallel jaw vice (7) fixed inside the test chamber on adjustable beam that can be moved forward and backward from the nozzle depending on the distance needed. In this study the distance from the tip of the nozzle to the centre line of the parallel jaw vice was fixed to 600 mm. The test chamber was placed on a stand with a fixed drain (5) to collect sand. The duration of the sand blast was 2.0 seconds. The sand was sieved before the test to control the particles size up to 2.0 mm. Sand was collected from the western desert in Saudi Arabia.

The tested specimens were made of low carbon steel sheet (St. 37.11, DIN 1611), where their dimensions were 100 × 100 mm and 0.6 mm thickness. The test specimens were bended to 5 different inclination angles of 10°, 20°, 40°, 60°, 90°. The test specimens of 100 × 100 mm steel sheets coated by polyurethane coatingswere tested. Test specimens were subjected to heat treatment (annealing). The electrical lab furnace was used to heat the tested coatings at 50 and 75 °C for 4 hours then they were left to cool in the furnace for 4 hours.

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, 10 and 12 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 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.

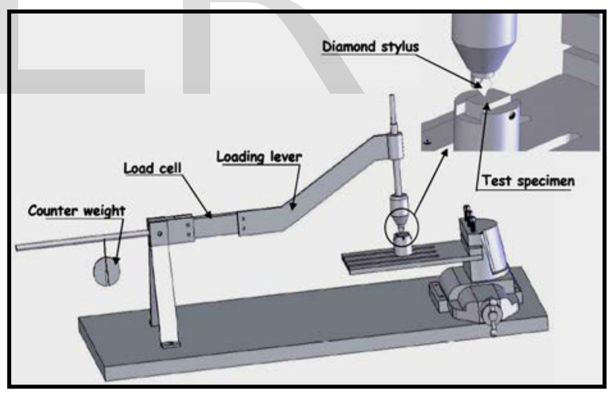


Fig. 2 Arrangement of scratch test rig.

3 RESULTS AND DISCUSSION

The wear of the tested coating caused by sand erosion is shown in Fig. 3. As the coating thicknesses increased wear decreased, where the highest thickness displayed minimum wear at 10° angle of inclination. This behavior might be attributed to the increase of embedment of sand particles in coating surface as its thickness increased. Wear increased with increasing angle of inclination. Annealing polyurethane coating up to 50 °C showed insignificant effect on wear, Fig. 4. The lowest wear values were displayed by the lowest angles of inclination. The highest wear was displayed by 60° angle of inclination.

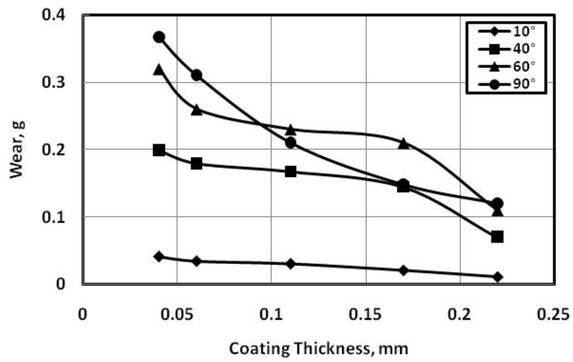


Fig. 3 Wear of coating caused by sand erosion.

Annealing the tested coating up to 75 °C significantly decreased wear, Fig. 5. The highest wear was observed for erosion at 60° angle of inclination, while the lowest wear was performed by 10° angle of inclination. It seems that annealing polyurethane increased the hardness of the polymer and wear consequently decreased.

The results of the scratch test of the tested coatings of 0.26, 0.48 and 0.80 mm thickness are shown in Figs. 6 – 13. Friction coefficient displayed by 0.26 mm coating thickness as a function of the load is shown in Fig. 6. Friction coefficient significantly increased up to maximum then decreased with increasing the load. As received tested coating showed the highest wear, while the annealed coatings displayed lower wear.

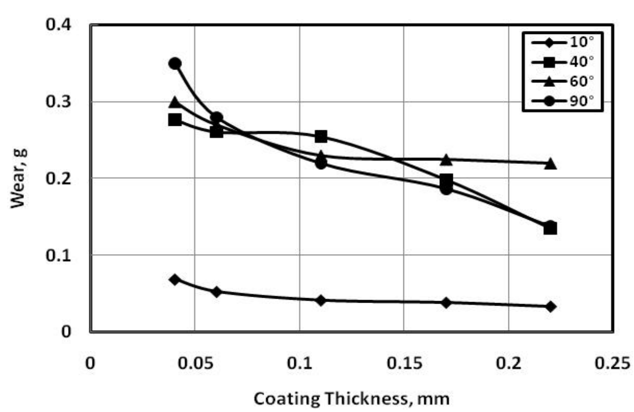


Fig. 4 Wear of coating after heat treated at 50 °C.

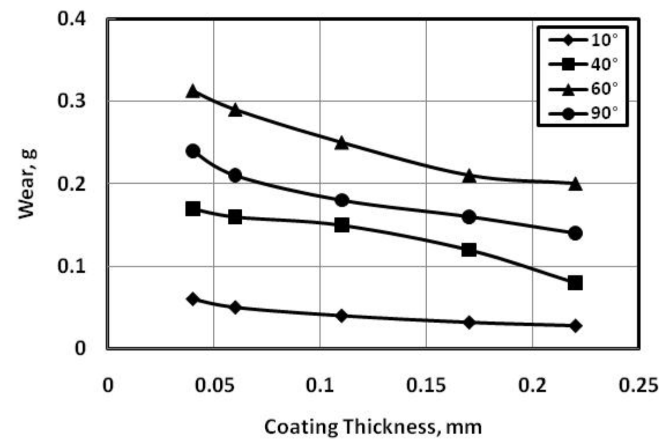


Fig. 5 Wear of coating after heat treated at 75 °C.

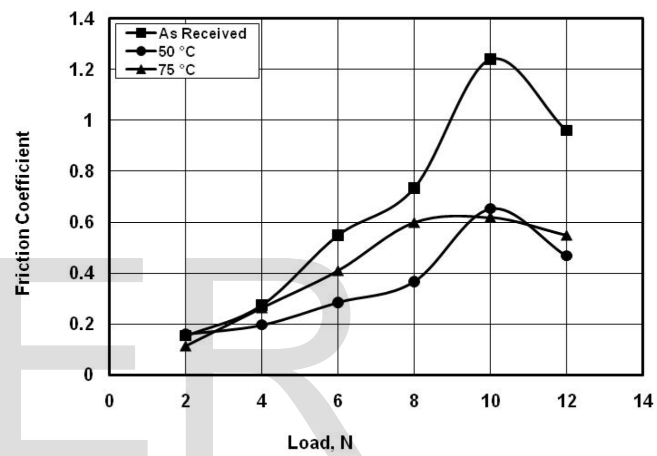


Fig. 6 Friction coefficient displayed by 0.26 mm coating thickness.

Wear displayed by coatings of 0.26 mm thickness is illustrated in Fig. 7. Wear increased with increasing load. Annealed tested coatings showed relatively lower wear than as received coatings. It was found that annealing of polymers increased hardness and improved mechanical properties, [17]. The increase of hardness of the polyurethane coatings might be the reason of decreasing wear.

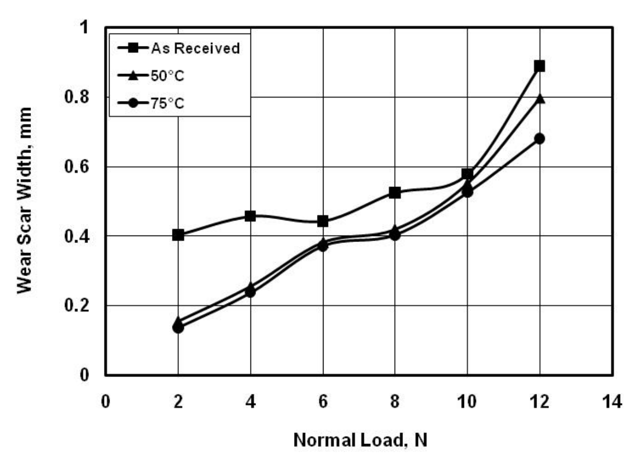


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Fig. 7 Wear displayed by 0.26 mm coating thickness.

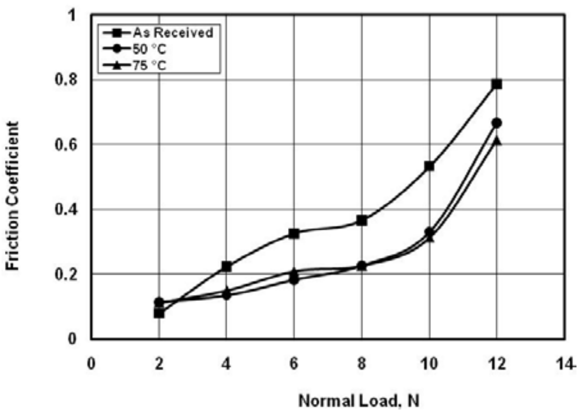

Fig. 8 Friction coefficient displayed by 0.48 mm coating thickness.

Increasing the coating thickness to 0.48 mm showed slight decrease in friction coefficient, Fig. 8. The annealed tested coatings represented lower friction values than as received coatings.

Drastic wear decrease was observed for 0.48 mm coatings compared to the behaviour of 0.26 mm coatings. Wear significantly increased with increasing normal load, Fig. 9. It seems that 0.48 mm thickness performed the best wear resistance. Annealed coatings showed relatively higher wear than as received coatings at 12 N load.

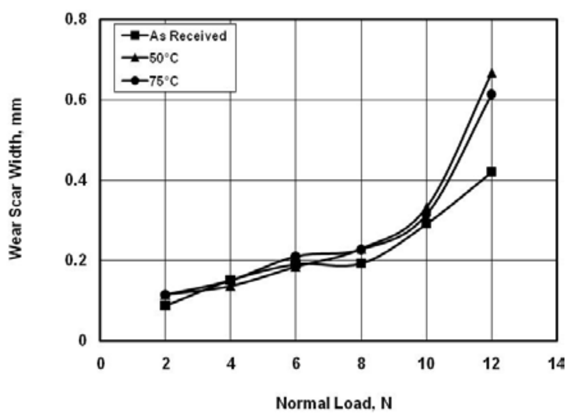

Fig. 9 Wear displayed by 0.48 mm coating thickness.

Further friction decrease was observed as the coating thickness increased up to 0.80 mm, Fig. 10. Annealing of the tested coating showed relative friction decrease, where annealed coatings at 75 °C displayed the lowest friction coefficient. The differences in values of frictioncoefficient observed for as received and annealed coatings reflected the dependence of the coating thickness on the annealing process.As the load increased the difference was more pronounced.

The same trend observed for friction was noticed for wear of the tested coatings, Fig. 11. Annealing provided the coatings by higher wear resistance against abrasion. The values of wear showed higher values than that predicted for 0.48 mm coatings.

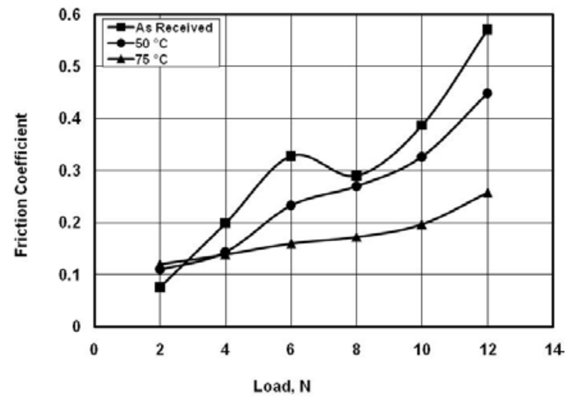

Fig. 10 Friction coefficient displayed by 0.8 mm coating thickness.

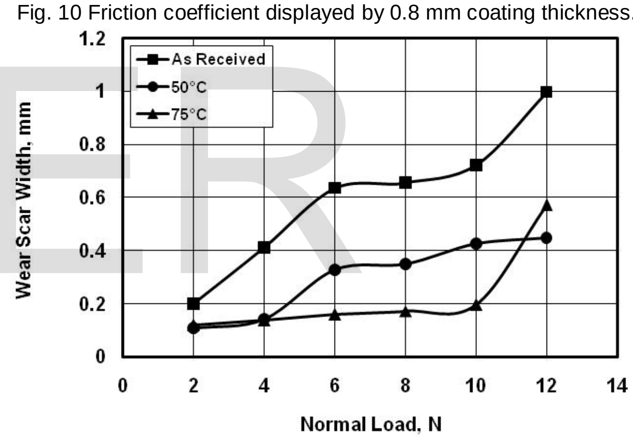

Fig. 11 Wear displayed by 0.80 mm coating thickness.

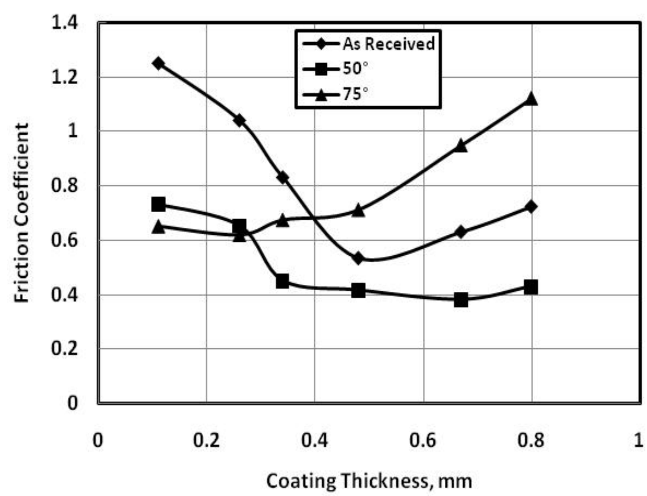

Fig. 12 Friction coefficient as a function of coating thickness.

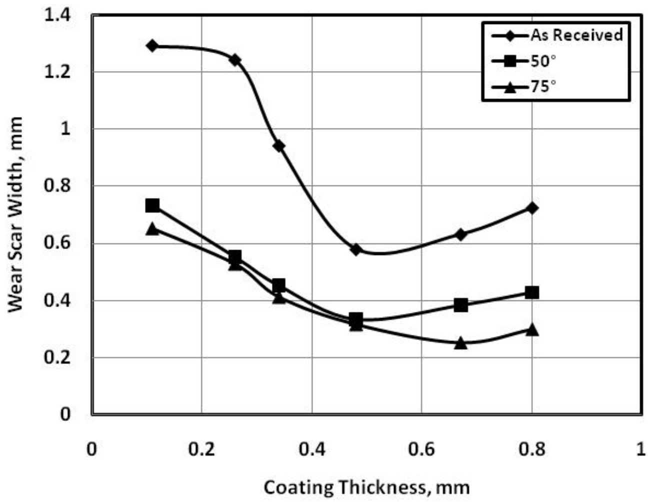

Fig. 13 Wear as a function of coating thickness.

The comparative performance of friction coefficient and wear at 10 N normal load for the all values of coating thickness is illustrated in Figs. 12 and 13 respectively. Friction coefficient decreased down to minimum then increased with increasing coating thickness, Fig. 12. The lowest values of friction coefficient was observed for as received coatings. At higher loads annealing caused significant friction increase.

Wear drastically decreased down to minimum then increased with increasing coating thickness, Fig. 13. The minimum wear was observed at coating thickness ranging from 0.48 to 0.68 mm. Annealing remarkably decreased wear, where coatings annealed at 75 °C displayed the lowest wear values.

4CONCLUSION

I. For the sand erosion test, it can be concluded that:
1. As the coating thickness increased wear decreased where the highest thickness displayed minimum wear at 10° angle of inclination. Wear increased with increasing the angle of inclination.
2. annealing polyurethane coating up to 50 °C showed insignificant effect on wear. The lowest wear values were displayed by the lowest angles of inclination. The highest wear was displayed by 60° angle of inclination.
3. Increasing the annealing temperature of tested coating up to 75 °C significantly decreased wear.

II. For the scratch test, it can be concluded that:
1. Friction coefficient displayed by 0.26 mm coating significantly increased up to maximum then decreased with increasing the load. As received tested coating showed the highest wear, while the annealed coatings displayed lower wear.
2. Increasing the coating thickness to 0.48 mm showed slight decrease in friction coefficient. The annealed tested coatings represented lower friction values than as received coatings. Drastic wear decrease was observed for 0.48 mm coatings compared to the behaviour of 0.26 mm coatings. Wear significantly increased with increasing normal load.
3. Further friction decrease was observed as the coating thickness increased up to 0.80 mm. Annealed coatings at 75 °C displayed the lowest friction coefficient. The values of wear showed higher values than that predicted for 0.48 mm coatings.
4. Friction coefficient decreased down to minimum then increased with increasing coating thickness. The lowest values of friction coefficient were observed for as received coatings. Wear drastically decreased down to minimum then increased with increasing coating thickness. The minimum wear was observed at coating thickness ranging from 0.48 to 0.68 mm. Annealing remarkably decreased wear, where coatings annealed at 75 °C displayed the lowest wear values.

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