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WEAR OF POLYVINYL CHLORIDE FILLED BY NANOPARTICLES OF ALUMINUM OXIDE

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ABSTRACT
The wear of polyvinyl chloride (PVC) filled with inorganic nanoparticles was studied. Nanoparticles of aluminum oxide (Al_2O_3) were used as filling material in PVC coating. Steel specimens used as substrate coated by the tested composites and oil. The effect of the matrix on wear of surfaces subjected to abrasive contaminants is discussed. An abrasive wear tester was developed to simulate the abrasion caused by a sandy soil against surfaces subjected to abrasive contaminants. Motion was transmitted to the disc via the drill chuck. The test time was 15 min. Experiments were carried out at 25 °C. Wear was measured by digital balance with an accuracy of ± 0.01 g. Wear and embedment of sand particles were analyzed using optical microscopy after the test. Based on the experimental results, it was found that, aluminum oxide particles as filling material in PVC coating enhanced the hardness and the wear resistance. The increase of the concentration of the oil caused a decrease in wear. Minimum wear illustrated in PVC with 9 wt. % aluminum oxide particles content and 10 wt. % oil content. Increasing of oil content enhanced the embedment of the sand particles.

KEYWORDS
Wear, polyvinyl chloride, aluminum oxide, oil, embedment.

INTRODUCTION
Many laboratories have launched projects on composites containing particles on the nanometre scale with varying success, [1]. Polymers and polymer–matrix composites have been finding great potentials in industry as a class of important tribo-engineering materials, not just for their ease in manufacturing and low unit cost, but also for their potentially excellent tribological performance in engineered forms, [2]. The polymers show very low surface free energy and also have the viscoelastic properties. It effects in drastic tribological differences when we consider adhesive and mechanical components of friction force. Therefore there are often and easily used as a background material to produce many composites with easily varied physicochemical properties. This makes polymers very promising materials with ability to control their frictional and wear behaviours sliding contacts, [3]. In some circumstances, wear resistance of materials is an extremely important evaluation index which directly determines service life of products. However, rigid PVC materials without plasticizers are typically brittle, and

some microcracks are easily generated and propagated under friction stress, which greatly hinders practical application of rigid PVC as wear-resistant materials in many fields. In that case, developing high wear-resistant PVC materials has attracted considerable attention from industrial and academic fields, [4]. Tribological properties of polymer composites can also be greatly enhanced with the addition of nanoparticles, such as nano-Al_2O_3, [5]. Alumina particles are important industrial chemicals that have found wide application as adsorbents, ceramics, abrasives, and as catalytic materials, [6]. Alumina coatings, as well as bulk alumina tiles, are commonly used to resist the wear caused by solid particle erosion and friction, [7]. Nano-Al_2O_3particles prove to be quite effective in lowering frictional coefficient and wear rate of epoxy composites sliding against steel. The severe abrasive wear of unfilled epoxy has been changed into mild fatigue wear with the addition of nano-Al_2O_3 particles, [8]. The wear resistance of PPS was reported to decrease with the addition of microscale Al_2O_3 particles. With Al_2O_3 particles reduced to nanosize, Schwartz and Bahadur reported that the wear resistance of PPS increased, [9]. Wear is defined as the unwanted loss of solid material from solid surfaces due to mechanical interaction, [10]. Wear by hard particles occurs in many different situations such as with earth-moving equipment, slurry pumps or pipelines, rock drilling, rock or ore crushers, pneumatic transport of powders, dies in power metallurgy, extruders, or chutes. More particularly in the moon probe project, the sand dust environment contains small, angular and irregularly shaped particles that have demonstrated high wear and abrasion on mechanical and sealing systems, [11]. One of the best alternatives to resolving the tribology problems of mechanical systems in sand-dust environments is to apply effective protective coating with best antiabrasion wear and friction reducing capacity on the moving parts, [12]. Sliding speed and applied pressure have significant influence on the level of particle embedment. At lower speeds more particle embedment occurs at lower pressures due to the slower mixing of particles, while at higher speeds more embedment occurs at higher pressures due to the particles fragmentation, [13]. The embedment of hard particles tends to increase the generation of wear debris, [14] because the embedded hard particles slide against the disc in greater proportion of time.

In the present work, the wear of Polyvinyl Chloride (PVC) filled by nanoparticles of aluminum oxide (Al_2O_3) was studied.

EXPERIMENTAL

An abrasive wear tester was constructed to simulate the abrasion caused by sand against surfaces subjected to abrasive contaminants. The tester was composed of a circular steel disc holder 180 mm in diameter capable of holding eight specimens of carbon steel (St 60). The specimens (Fig. 1) had the form of a pin with 40 mm length, 8 mm outer diameter and 4 mm inner diameter. Motion was transmitted to the disc via the drill chuck (Fig. 2). A speed of 280 rev/min was chosen. The test specimens were immersed at a fixed depth in a pan full of sand. The test time was 15 min. Experiments were carried out at 25 °C. Wear was measured by digital balance with an accuracy of ± 0.01 g. The specimens were coated with polyvinyl chloride filled with 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. % nanopowder of aluminum oxide content, Fig. 3, and 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. % oil content. Two-theta scale for aluminum oxide nanopowder is shown in Fig. 4.

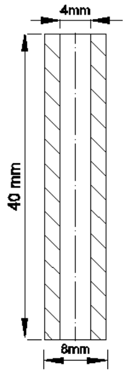

Fig. 1 Test Specimen.

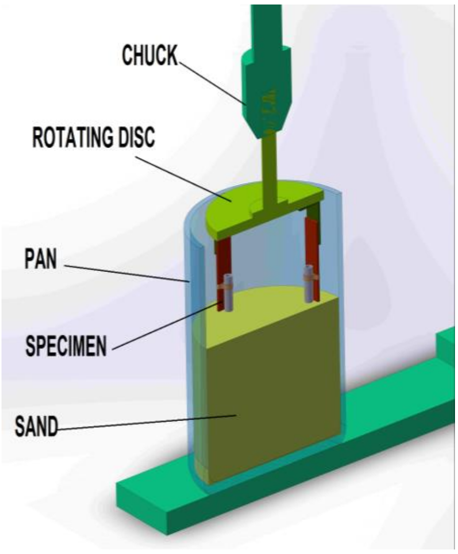

Fig. 2 Layout of the test rig.

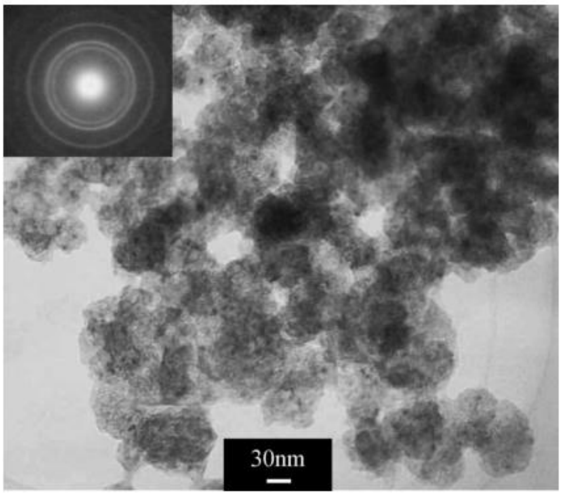

Fig. 3 SEM micrograph of Al_2O_3 nanopowder, [15].

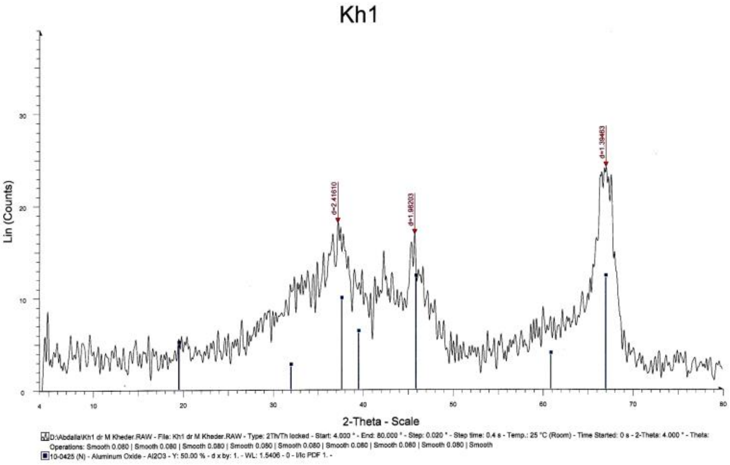

Fig. 4 2-theta scale for aluminum oxide nanopowder.

RESULTS AND DISCUSSION

Figure 5 indicated the relation between wear and aluminum oxide content. It seems that, increasing of aluminum oxide content caused a decrease in wear. Reinforcing PVC coating by aluminum oxide particles has been achieved to develop the wear resistance and the hardness of the coating trend to the high wear resistance and hardness of aluminum oxide. The best result has been observed for PVC with 10 wt. % aluminum oxide content.

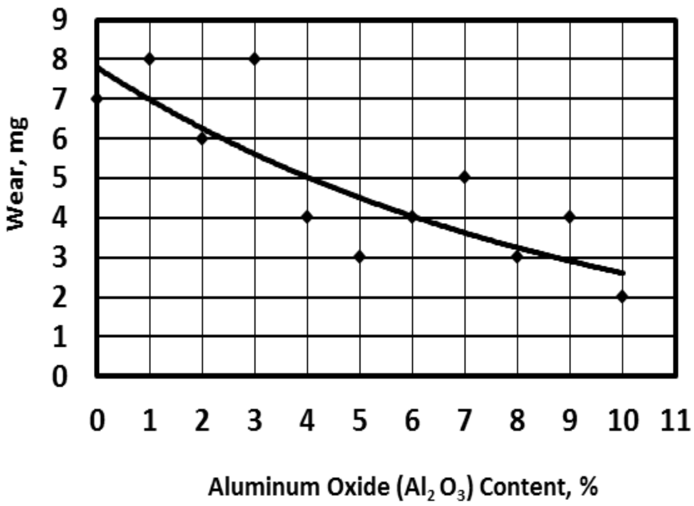

Fig. 5 Effect of aluminum oxide nanoparticles on wear of PVC.

The embedment of the abrasive sand particles in the surface of the coating offers an explanation for the observed initial increase of weight recorded for result of PVC with 3 wt. % aluminum oxide and 1 wt. % oil. The value of -3 mg at 3 wt. % aluminum oxide content indicated that the weight increased after test. This behavior means that weight of the sand particles embedded in the surface of the coating. The micro-scope examination illustrated the embedment of sand particles in the surface of the coating was higher than the material removed from coating, Fig. 7. Embedment of the sand particles in the surface of the test specimens can be expected due to the relatively higher wear resistance of the sand particles. On the other hand, the effect of oil content on the

wear of PVC with aluminum oxide content also is revealed in Fig. 6. For PVC with aluminum oxide and 1wt. % oil content, the wear is remarkably lowered as compared to the value of the wear of PVC with aluminum oxide content without oil. Wear was 2 mg at 9 wt. % aluminum oxide content and 1wt. % oil content, where wear was 4 mg at 9 wt. % aluminum oxide content without oil. This behavior means that when oil content increased, the wear decreased. This can be attributed to the improvement of the oil over the contact surfaces. As the oil gets into the contact surfaces, it forms film of oil and reduces wear.

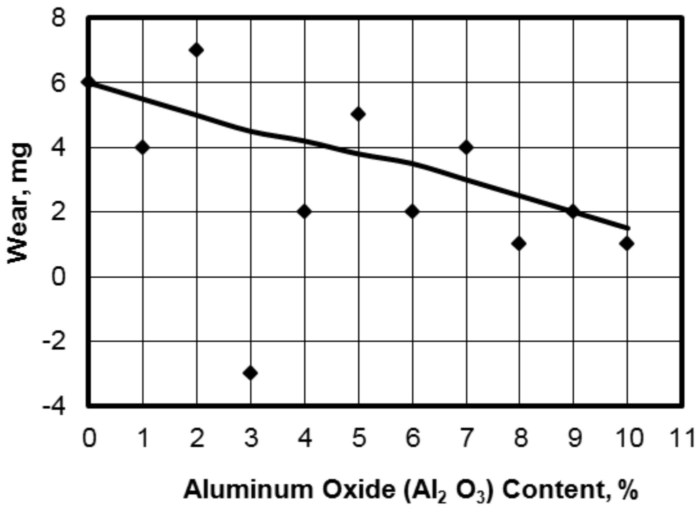

Fig. 6 Effect of aluminum oxide nanoparticles on wear of PVC filled by 1 wt. % oil content.

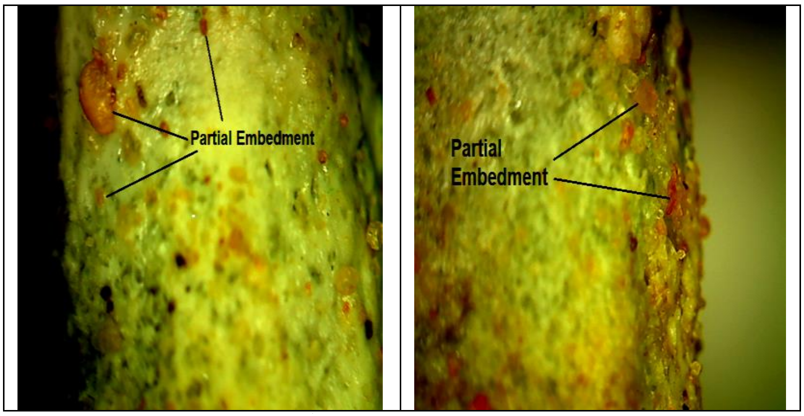

Fig. 7 Embedment of sand particles.

Figure 8 clearly demonstrates the effect of aluminum oxide on wear of impregnating PVC by 2wt. % oil content. The specimens covered by PVC with aluminum oxide particles content and 2wt. % oil content gave good wear results as compared to the specimens covered by PVC with aluminum oxide particles content and 1wt. % oil content. Wear was -4 mg at 5wt. % aluminum oxide content. This behavior means that the embedment is higher than the embedment in PVC coating with 1wt. % oil content.

Where, the increase of oil decreased the hardness of the surface and enhanced the embedment of sand particles.

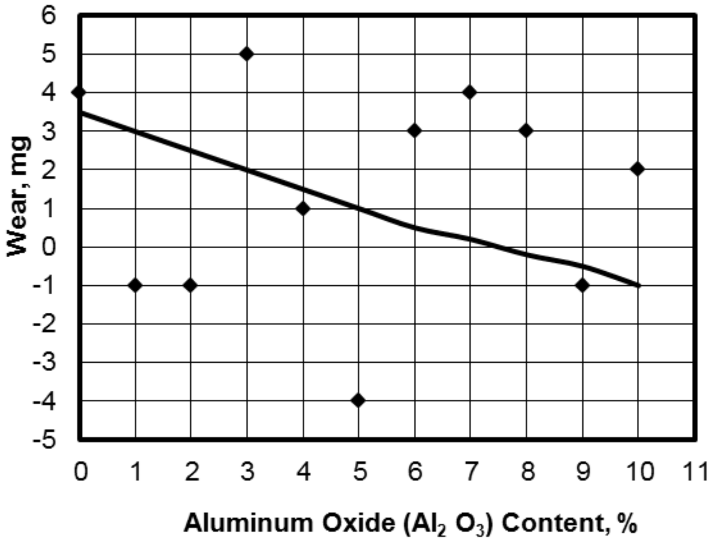

Fig. 8 Effect of aluminum oxide nanoparticles on wear of PVC filled by 2 wt. % oil content.

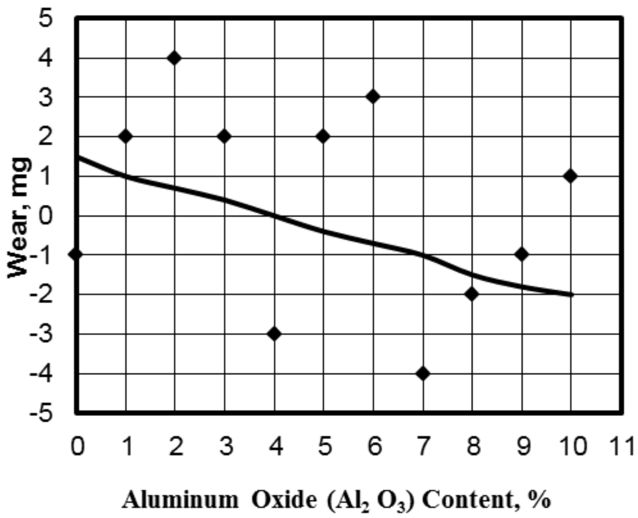

Fig. 9 Effect of aluminum oxide nanoparticles on wear of PVC filled by 3 wt. % oil content.

The same trend was observed for PVC with aluminum oxide and impregnated by 3 wt. % oil content. Where, the aluminum oxide increases the wear decreases. The minimum wear was -4 mg at 7 wt. % aluminum oxide content. As the high wear resistance and the high hardness of aluminum oxide increases the wear resistance and the hardness of the surface of the coating. Moreover, impregnated PVC by 3 wt. % oil content improved the wear resistance. That improvement may be attributed to the higher percentage of the oil which allows the oil to cover the contact surface and decreased the wear.

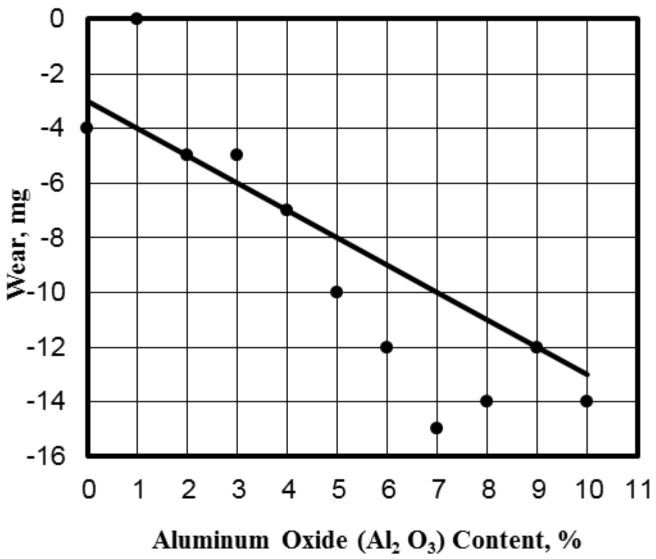

Fig. 10 Effect of aluminum oxide nanoparticles on wear of PVC filled by 4 wt. % oil content.

As presented in Fig. 10, embedment displayed in all results expect only at 1 wt. % aluminum oxide content. This behavior confirms that, increasing the oil content causes a remarkably role in the wear resistance of the coating surface. As the high percentage of oil content, increases the plasticity of the coating surface, and decreases the hardness of the coating matrix. Where, the hardness of the matrix decreases, the sand particles embedment increases. The best of results was -15 mg for wear. The microscopic examination of the specimen surfaces confirmed the presence of the sand particles embedded in the surface, Fig. 11.

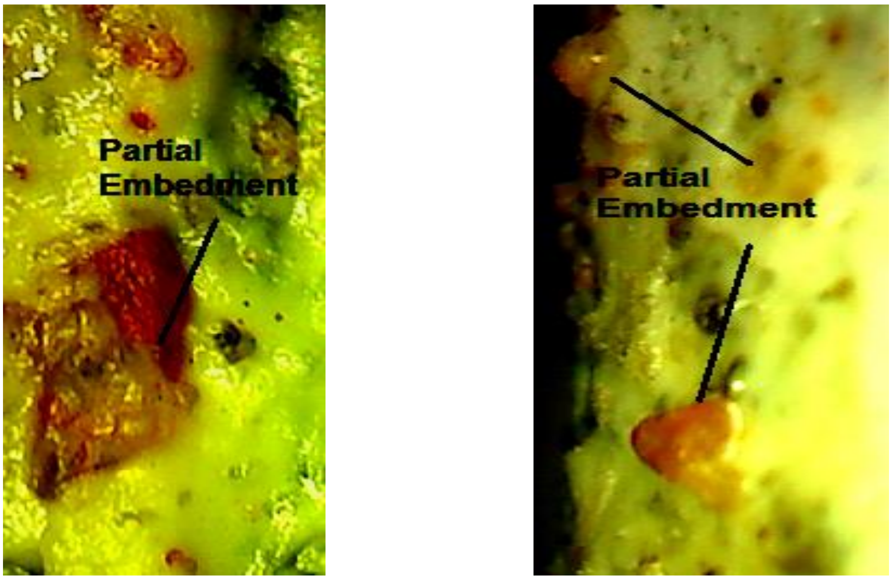

Fig. 11 Sand Embendment.

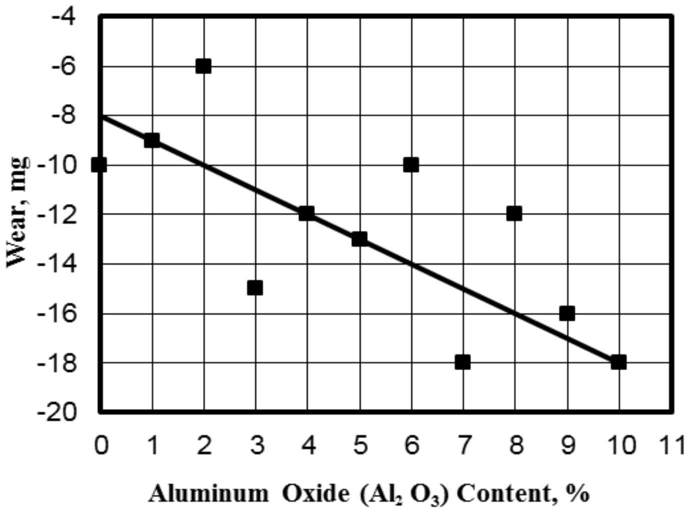

Fig. 12 Effect of aluminum oxide nanoparticles on wear of PVC filled by 5 wt. % oil content.

The weight increased after test as observed in all results. PVC with aluminum oxide particles and 7, 10 wt. % oil content showed promising results. It is clearly seen that the embedment is higher than the embedment in PVC with aluminum oxide content and 4wt. % oil content. The wear was -18 mg at 7 and 10wt. % aluminum oxide content. The negative sign indicated the increase of weight causes by embedment of sand particles. This phenomenon can be attributed to the oil which enhanced the embedment of sand particles. The high abrasive action of sand particles facilitates the embedment, Fig 13. So, the sand particles embedded in the surface of the specimen increased the abrasion resistance of the coating appreciably by forming a protective wear layer of hard sand particles on the surface of coating.

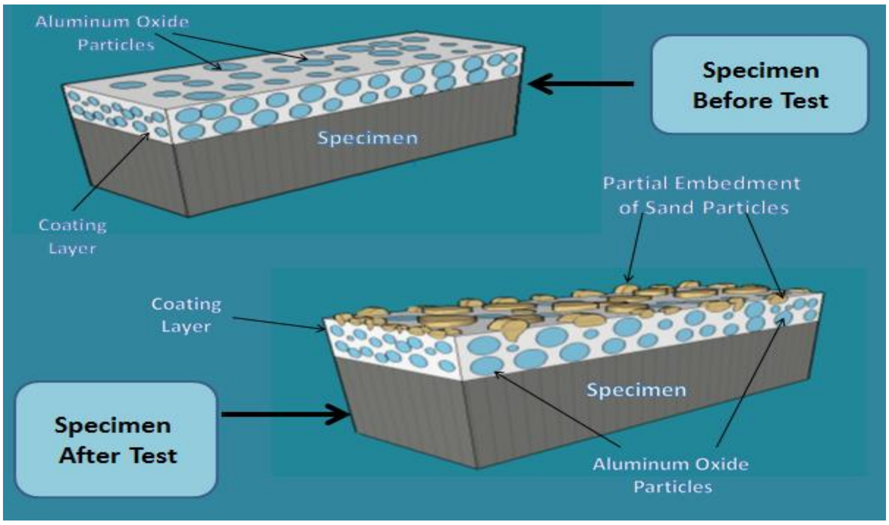

Fig. 13 Schematic illustration the embedment of sand particles.

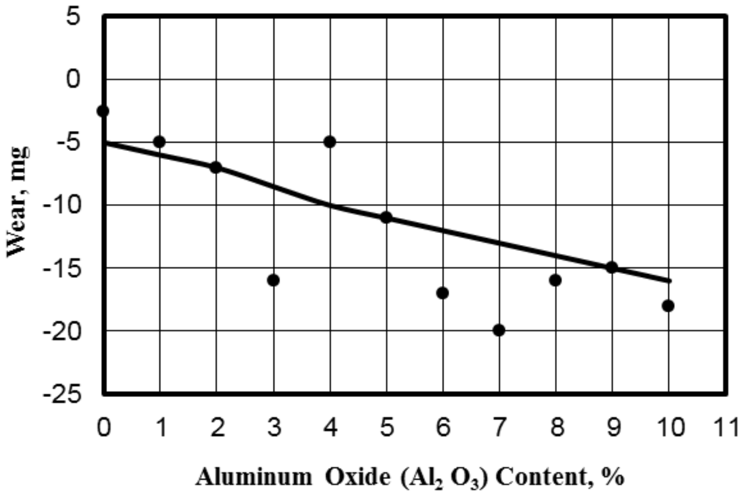

Fig. 14 Effect of aluminum oxide nanoparticles on wear of PVC filled by 6 wt. % oil content.

It is well known that particle shape, particles size and hardness affect on the embedment of abrasive particles. According to Fig. 14 increasing the oil content causes a significant improvement in the surface of the coating as the wear decreased with increasing oil content. In all cases, embedment of sand particles is revealed. The best of results was -20 mg for wear. The percentage of the sand particles embedment is higher due to the high percentage of oil content which decreases the hardness of the matrix and the hard particles of sand embedded in the surface. On the other hand, embedment of sharp particles is higher than the spherical particles as the sharp edge of these particles facilitates the embedment in the surface, Fig. 15.

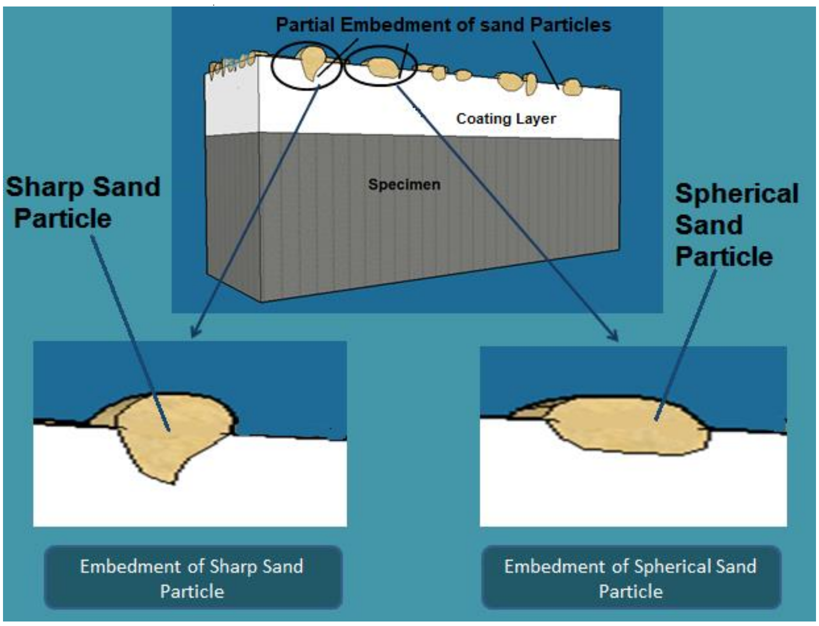

Fig. 15. Schematic illustration the effect of the sand particle size on embedment.

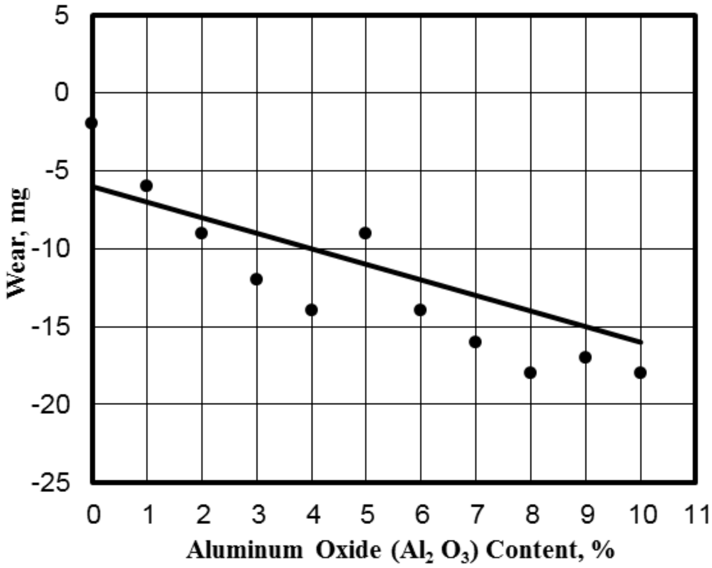

Fig. 16 Effect of aluminum oxide nanoparticles on wear of PVC filled by 7wt. % oil content.

The addition of aluminum oxide particles to PVC showed a considerable mitigation in the wear. As observed in Fig. 16, aluminum oxide particles enhanced the abrasive wear resistance of the coating. This enhancement increased with increasing aluminum oxide particles concentration. It is evident that embedment of sand particles revealed in all results. To have more information about the embedment of sand particles, the specimen surfaces are examined by microscope, Fig. 17. The size of sand particles affects the embedment and the intensity of embedment for the smaller particles are higher than the larger particles. This is can due to the smaller particles are more angular.

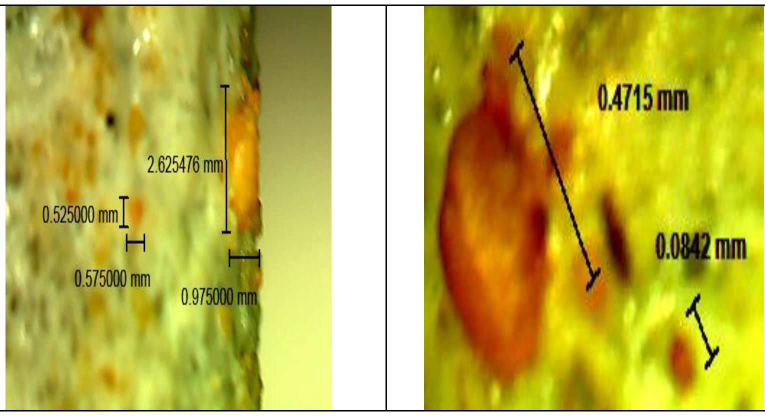

Fig. 17 Effect of sand particles size on embedment.

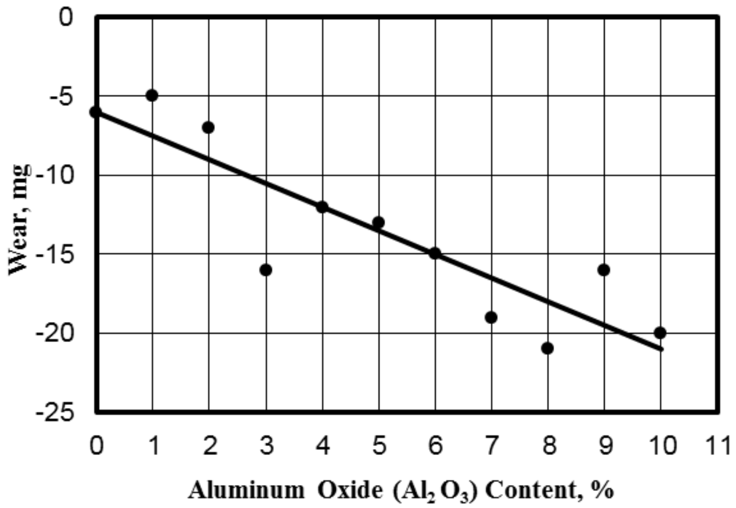

Fig. 18 Effect of aluminum oxide nanoparticles on wear of PVC filled by 8wt. % oil content.

It is well known that the embedment of the sand particles in the surface of the coating depends mainly on its hardness. According to Fig. 18, wear was -21 mg at 8wt. % aluminum oxide particles content. The negative sign indicated the increase of the weight caused by embedment of the sand particles. As the oil gets into the contact surfaces, forms oil film and reduce the wear. Furthermore, a possible explanation for the general decrease in wear could be related to the low hardness of the PVC coating because of the high percentage of oil content, where the low hardness of the coating surface caused by the increasing of the oil content enables the particles of sand to be embedded in the surface and protect the surface from excessive wear.

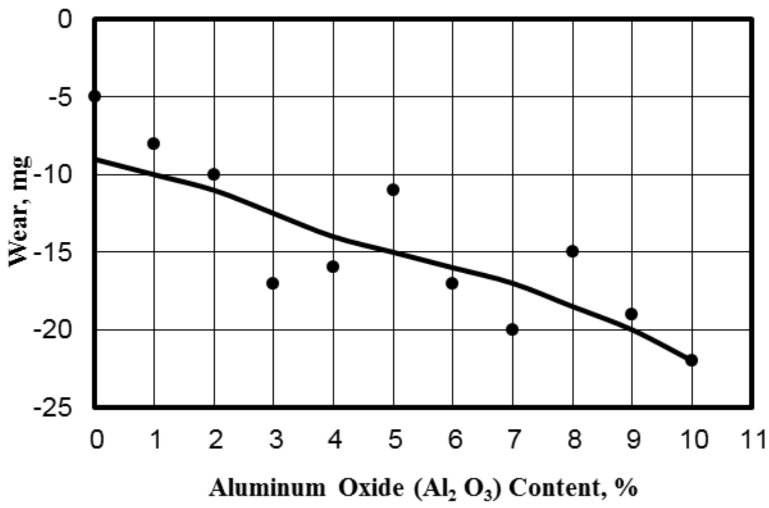

Fig. 19 Effect of aluminum oxide nanoparticles on wear of PVC with 9 wt. % oil content.

Taking into account the size and the shape of sand particles, it is clearly seen that increasing aluminum oxides particles decreased the wear, Fig. 19. This effect may be due to the effect of aluminum oxide nanoparticles into PVC increases the wear resistance

and the hardness of the coating. Wear was -22 mg at 10 wt. % aluminum oxide content. This can be interpreted on the better presence of the oil over the contact area due to the higher percentage of the oil. As the oil plays the role of the lubricant and tends to reduce the wear.

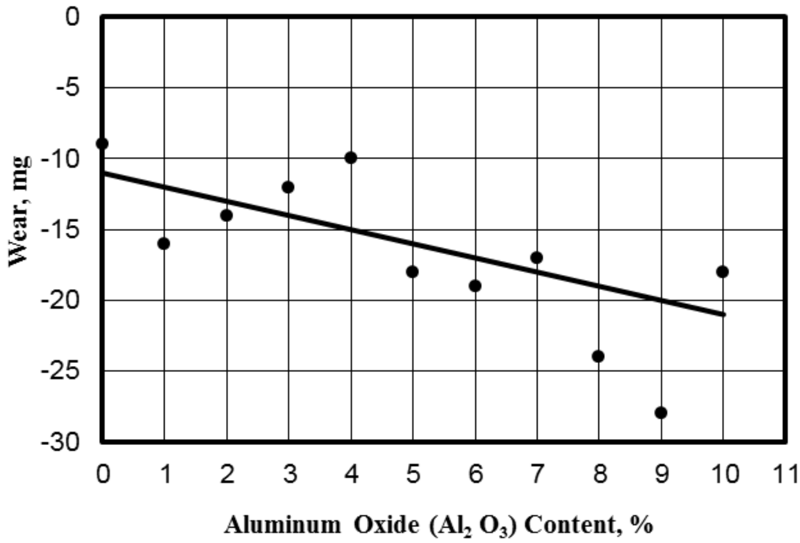

Fig. 20 Effect of aluminum oxide nanoparticles on wear of PVC with 10wt. % oil content.

Minimum wear illustrated in PVC with 10wt. % oil content and aluminum oxide particles, Fig. 20. Wear was -28 mg at 9 wt. % aluminum oxide content. The percentage of the sand particles embedment is higher due to the high percentage of oil content which decreased the hardness. So the sand particles embedded in the surface of the specimen. The decrease in hardness increased embedment of the sand particles in the surface of the coating and forming a protective wear layer of hard and particles on the surface of the coating leading to a significant reduction wear. The specimens covered by PVC and aluminum oxide content and 10 wt. % oil content gave good wear results as compared to other specimens. On the other hand, embedment of the sand particles in the surface of the test specimens can be expected due to the relatively higher hardness of the sand particles.

CONCLUSIONS

1. Aluminum oxide particles as filling material in PVC coating enhanced abrasive wear resistance.
2. The increase of oil content caused a decrease in wear.
3. The size and the shape of the sand particles affect the embedment of sand particles in the surface of the coating.
4. Minimum wear was obtained using PVC filled by 9 wt. % aluminum oxide particles and 10 wt. % oil.
5. Increasing oil content enhanced the embedment of the sand particles.

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