Effect Of Aluminum Oxide Nanofibers On The Abrasive Wear Of Polyvinyl Chloride Coating

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***Abstract*—Aluminum oxide nanofibers (Al_2O_3) filled polyvinyl chloride (PVC) coating was used in order to improve the wear resistance of PVC. The effect of Al_2O_3 nanofibers and oil content on wear of surfaces subjected to abrasive contaminants was studied. Steel specimens coated by the tested composites and oil. An abrasive wear tester was developed to simulate the abrasion caused by sand 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 ± 0.001 g. Wear and embedment of sand particles were analyzed using optical microscopy after the test. Based on the experimental results, it was found that, where oil content increased, the wear decreased. This can be attributed to the improvement of the oil over the running surface by the addition of the oil content in the matrix. Al_2O_3 nanofibers enhanced the wear resistance and the hardness of the coating. The high adhesion for Al_2O_3 nanofibers increased the accordance between the PVC and the nanofibers and showed a considerable mitigation in the wear due to the high hardness of Al_2O_3. Minimum wear was obtained using PVC with 7 and 9 wt. % Al_2O_3 nanofibers content and 10 wt. % oil content.**

Keywords—wear; polyvinyl chloride; aluminum oxide; oil; embedment.

I. INTRODUCTION

In a study investigated the abrasive wear of surfaces subjected to abrasive contaminants. It was found that, the increase of oil content decreased the wear. Minimum wear was observed in PE filled with aluminum oxide content and 10% oil content. The addition of aluminum oxide particles to PE enhanced the wear resistance and the hardness of the matrix. Increasing of oil content enables the sand particles to be easily embedded in the surface of the coating, [1]. Where, nanoparticles of aluminum oxide were used as filling material in PVC coating. Steel specimens were used as substrate coated by the tested composites and oil. It was concluded that, Aluminum oxide particles as filling material in PVC coating enhanced abrasive wear resistance. The increase of oil content caused a decrease in wear. The size and the shape of the sand particles affect on the embedment of the sand particles in the surface of the coating. Minimum wear was obtained using PVC with 9% aluminum oxide particles content and 10 % oil content. Increasing of oil content enhanced the embedment of the sand particles, [2]. In another study investigated the abrasive wear of steel specimens coated by polyethylene (PE) coating in a sandy soil. Aluminum oxide (Al_2O_3) nanofibers were employed as fillers in PE for fabricating the tested composites. It was found that, Aluminum oxide fibers enhanced the wear resistance and the hardness of the coating. Where, the high adhesion for Al_2O_3 nanofibers increased the accordance between the PE and the nanofibers and showed a considerable mitigation in the wear due to the high hardness of Al_2O_3. Increase of oil impregnating PE enhanced the embedment of sand particles. Where, the oil decreased the hardness of the coating by increasing the plasticity of it. The high abrasive action of sand particles facilitates the embedment. So the sand particles embedded in the surface of the specimen and increased the abrasion resistance of the coating appreciably, by forming a protective wear layer of hard sand particles on the surface of coating. Embedment of the sand particles for the smaller size particles is higher than the larger particles. Difference in embedment is probably due to their different angularity and the smaller particles are more angular, [3]. Nanocomposites are the emerging materials of the 21st century in view of their possessing design uniqueness without any compromises, certain unusual property combinations that are not found in conventional composites, as well as a wide spectrum of applications. Polymerbased layered compound nanocomposites have special place in view of their best property enhancement, [4]. 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, [5]. Polyvinyl chloride is a versatile thermoplastic which has a range of applications in domestic as well as industrial uses by virtue of its high abrasion and solvent resistance, [6]. 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, [7]. PVC is now the second most commonly used plastic material in terms of volume. Great achievements have been made in modifying its structure behavior and properties by including miscellaneous additives, [8]. Aluminas are important industrial chemicals that have found wide application as adsorbents, ceramics, abrasives, and as catalytic materials, [9]. Oxide ceramics such as Al_2O_3 ceramic coatings, having superior hardness, chemical stability and refractory character, are commonly utilized to resist wear by friction and solid particle erosion, [10]. Alpha phase alumina is the strongest and stiffest of the oxide ceramics. Its high hardness, excellent dielectric proper- ties, refractoriness and good thermal properties make it the material of choice for a wide range of applications, [11]. Nano-Al_2O_3 particles 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, [12]. The wear of specimens coated with PE containing fillers of different hardness showed a good correlation between wear and fillers hardness. PE coatings gave a relatively soft matrix of plastic materials, which enhanced the embedment of sand particles. The embedment increased the abrasion resistance, [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 PVC filled with nanofibers of aluminum oxide (Al_2O_3) was studied.

II. 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 had the form of a pin with 40 mm length, 8 mm outer diameter and 4 mm inner diameter, Fig. 1. Motion was transmitted to the disc via the drill chuck. 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 ± 0.001 g. The specimens were coated with PVC filled with 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. % nanofibers of aluminum oxide content and 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. % oil content. The sequence of the operations followed in the experimental work is shown in Fig. 2.

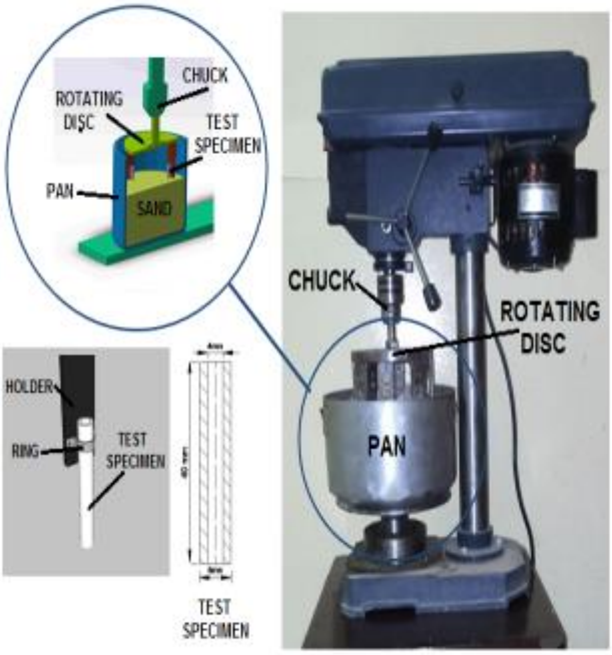

Fig. 1. *Layout of Sand Test Rig.*

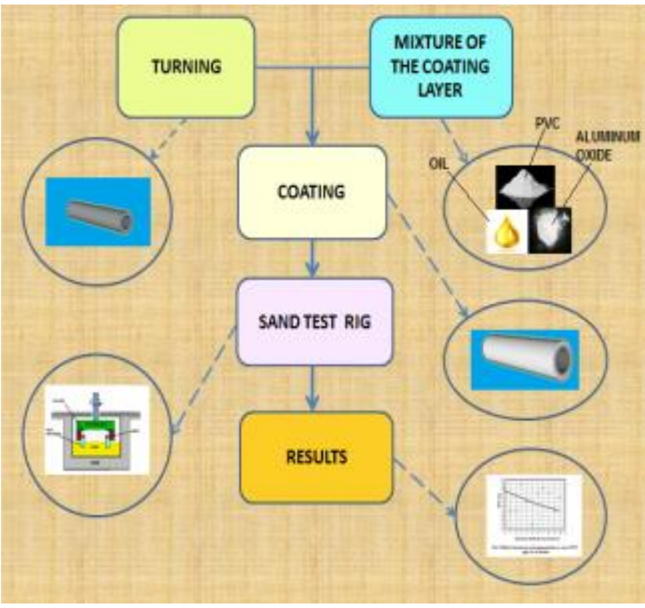

Fig. 2. *The sequence of the operations followed in the experimental work.*

III. RESULTS AND DISCUSSION

Figure 3 indicates that the increase of concentration of Al_2O_3 caused a decrease in wear. This can be attributed to the high wear resistance of Al_2O_3 nanofibers. The compatibility of Al_2O_3 nanofibers with PVC lead to the inseparability of Al_2O_3 nanofibers due to its good adhesion. Moreover, the higher surface area for nanofibers increases the adherence of the Al_2O_3 nanofibers into the PVC and increases the wear resistance of the matrix trend owing to the high wear resistance of Al_2O_3 nanofibers. The best results have been observes for PVC with 10 wt. % Al_2O_3 content.

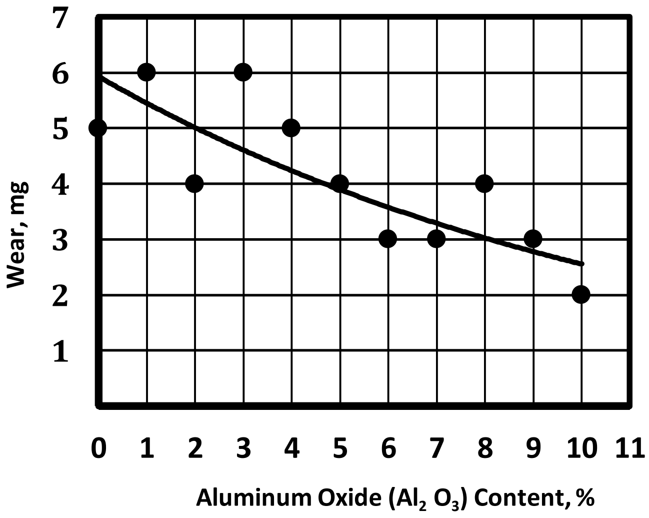

Fig. 3. *Effect of aluminum oxide nanofibers on wear for PVC*.

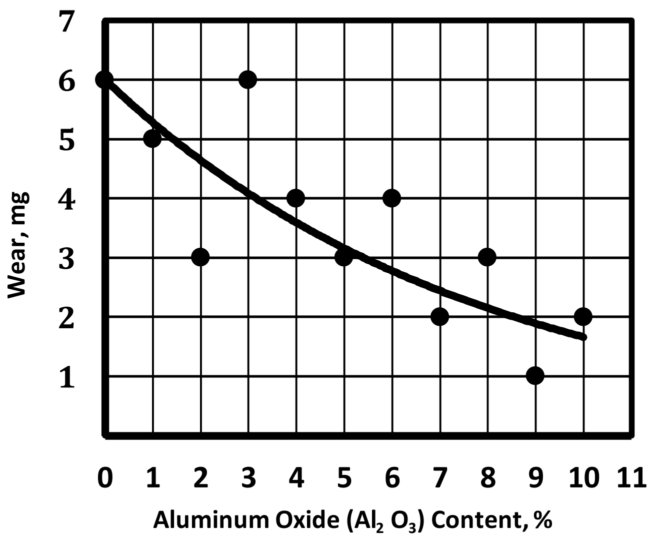

Fig. 4. *Effect of aluminum oxide nanofibers on wear of PVC with 1% oil content.*

The addition of Al_2O_3 nanofibers to PVC shows decreasing in the wear. As observes in Fig. 4, Al_2O_3 nanofibers enhanced wear resistance of the coating. This enhancement increased with increasing Al_2O_3 concentration. The higher surface area for nanofibers plays a noticeable role in enhancement the adherence between the nanofibers and PVC, Fig. 5. Where, the higher adhesion between the matrix and fibers tend to make the fibers to be inherent with the coating and increased the wear resistance of the coating as result of the high wear resistance of Al_2O_3. Furthermore, the specimens covered by PVC with Al_2O_3 and impregnated by 1 wt. % oil gave good wear results as compared to PVC with Al_2O_3 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 running surface by the addition of the oil content in the matrix. As the oil gets into the contact surfaces, forms film of oil and reduces the wear. Wear was 1 mg at 10 wt. % Al_2O_3 content and 1 wt. % oil content, where wear was 2 mg at 10 wt. % Al_2O_3 content without oil, Fig. 3.

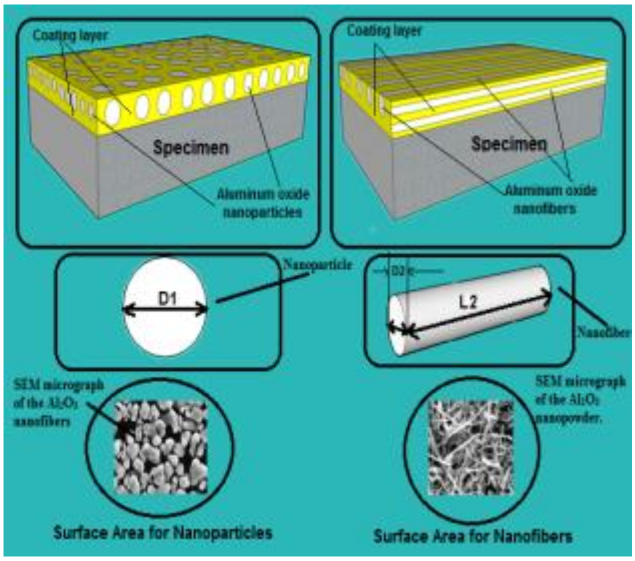

Fig. 5. *The Surface Area for Nanofibers and Nanoparticles Aluminum Oxide.*

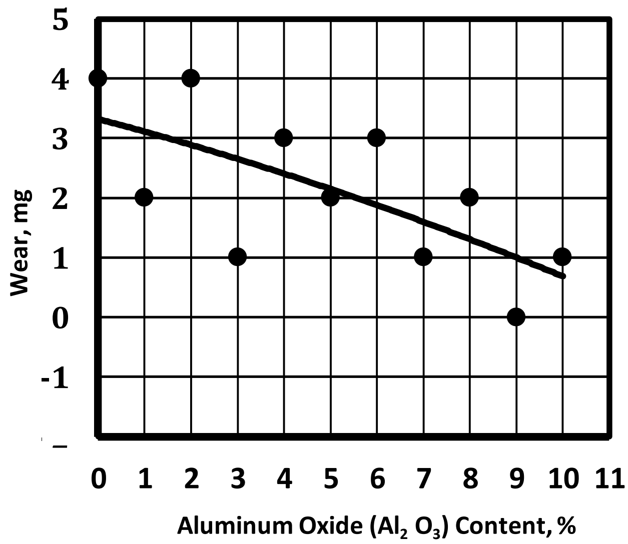

Fig. 6. *Effect of aluminum oxide nanofibers on wear of PVC with 2% oil content.*

Figure 6 clearly demonstrates the effect of Al_2O_3 on wear of impregnating PVC by 2 wt. % oil content. It is evident that the wear of PVC with Al_2O_3 and 2 wt. % oil content is lower than the wear of PVC with Al_2O_3 and 1 wt. % oil content. The minimum wear was zero at PVC with Al_2O_3 and 9 wt. % oil content. 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. Moreover, the specimens covered by PVC with Al_2O_3 and

2 wt. % oil content gave good wear results. It seems that increasing aluminum oxide decreased the wear. As the high wear resistance of Al_2O_3 causes a significant improvement in the surface of the coating and increases the wear resistance of the matrix.

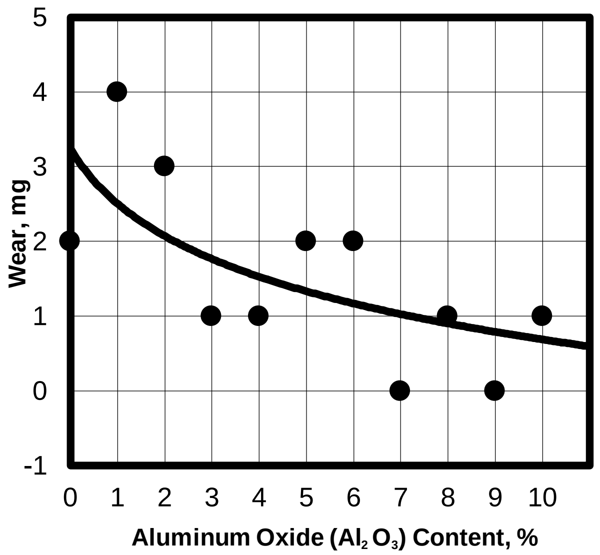

Fig. 7. *Effect of aluminum oxide nanofibers on wear of PVC with 3% oil content.*

The same trend was observed for PVC with Al_2O_3 and 3 wt. % oil content, Fig. 7. It seems that increasing Al_2O_3 content decreased the wear. As the high wear resistance of Al_2O_3 causes a significant improvement in the surface of the coating and increases the wear resistance of the matrix. Impregnated PVC by 3 wt. % oil content improved the wear resistance. 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 because it covers the surfaces and protects it from wear.

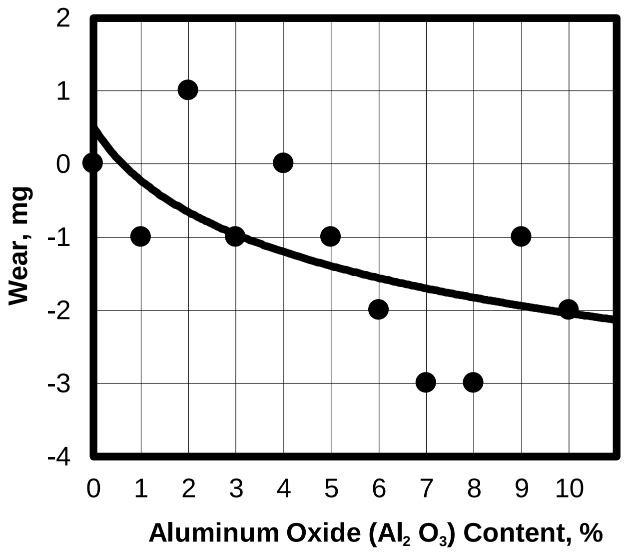

Fig. 8. *Effect of aluminum oxide nanofibers on wear of PVC with 4% oil content.*

The embedment of the abrasive sand particles in the surface of the coating offers an explanation for the observed initial increase of weight recorded, Fig. 8. The value of -3 mg at 7 and 8 wt. % Al_2O_3 content indicated that the weight increased after test. This behavior means the embedment of sand particles in the surface of the coating was higher than the material removed from coating. The embedment of sand particles in the surface of the coating was higher than the material removed from coating. The micro-scope examination illustrated that the sand particles embedded in the surface of the coating, Fig.9. 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, Fig. 10. On the other hand, the effect of oil content on the wear of PVC with Al_2O_3 content also is revealed in Fig. 8. For PVC with Al_2O_3 and 4 wt. % oil content, the wear is remarkably lowered as compared to the value of the wear of PVC with Al_2O_3 content with 3 wt. % oil content. This can be related to the low hardness of the matrix because increasing oil content, which enables the hard particles of sand to be embedded in the surface of specimen.

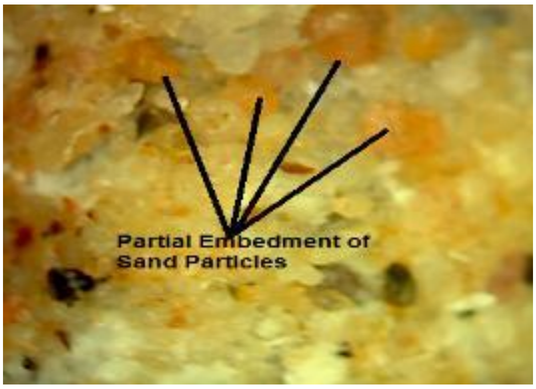

Fig. 9. *Partial Embedment of Sand Particles.*

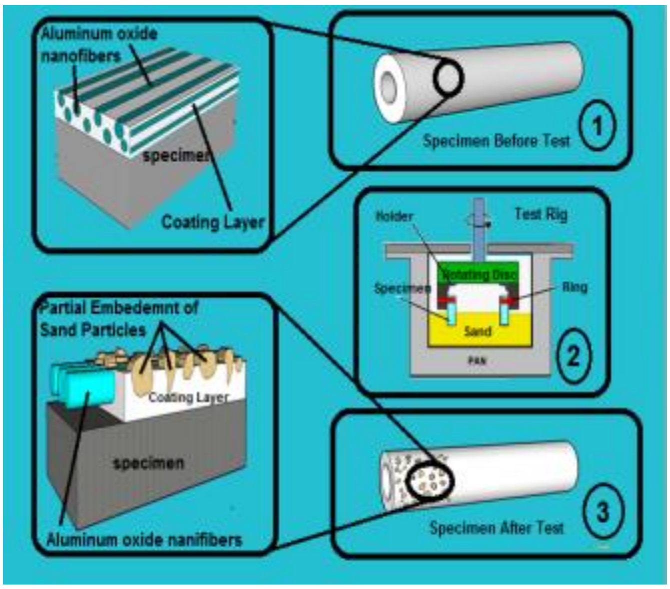

Fig. 10. *Sand Embedment*.

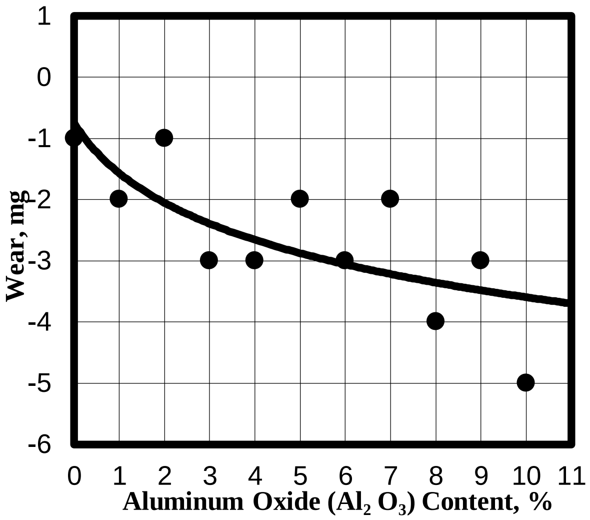

Fig. 11. *Effect of aluminum oxide nanofibers on wear of PVC with 5% oil content.*

The weight increased after test as observes in all results. It is clearly seen that the embedment is higher than the embedment in PVC with Al_2O_3 content and 4 wt. % oil content, Fig. 11. The wear was -5 mg at 10 wt. % Al_2O_3 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. Where, the oil decreased the hardness of the coating, by increasing the plasticity of it and the high abrasive action of sand particles facilitates the embedment, Fig, 12. So the sand particles embedded in the surface of the specimen and increased the abrasion resistance of the coating appreciably, by forming a protective wear layer of hard sand particles on the surface of coating. The size of sand particles affect on the embedment and the level of embedment of the smaller particles is higher than the larger particles. This can be due to the smaller particles is more angular.

It is well known that factors such as particle shape, size and hardness affect on the embedment of abrasive particles. According to Fig. 13, in all cases, embedment of sand particles is revealed. The wear was -10 mg at 9 wt. % Al_2O_3 content. The decrease in hardness of the coating caused by the high percentage of oil increased embedment of the sand particles in the surface of the coating leading to a significant reduction wear. 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. The size of sand particles affect on the embedment, Fig. 14 and the level of embedment of the smaller particles is higher than the larger particles. This can be due to the smaller particles is more angular.

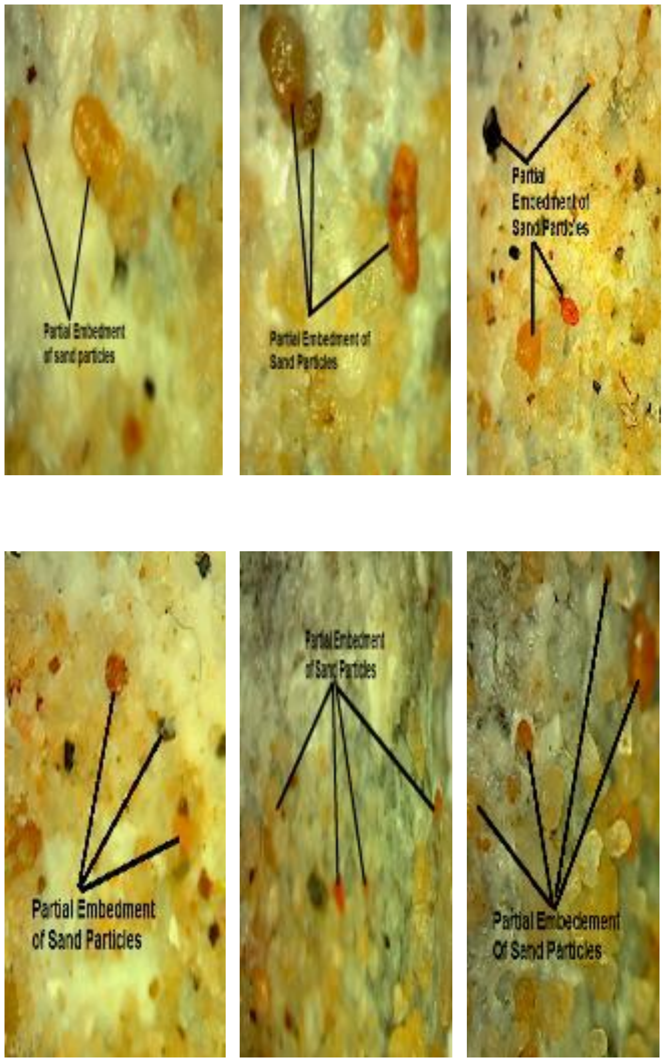

Fig. 12. *Embedment of Sand Particles*.

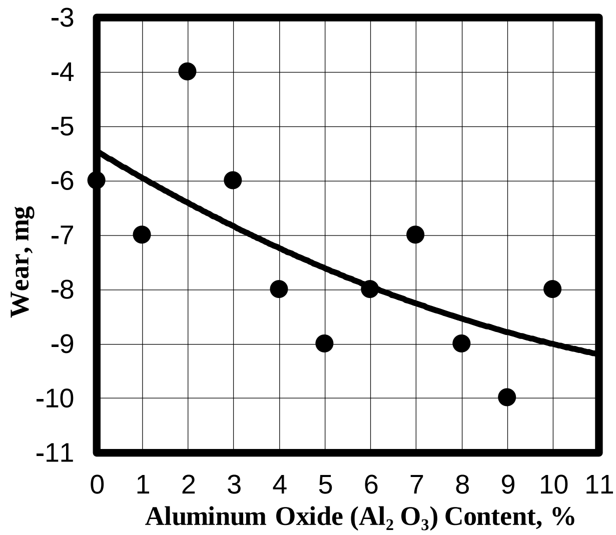

Fig. 13. *Effect of aluminum oxide nanofibers on wear of PVC with 6% oil content.*

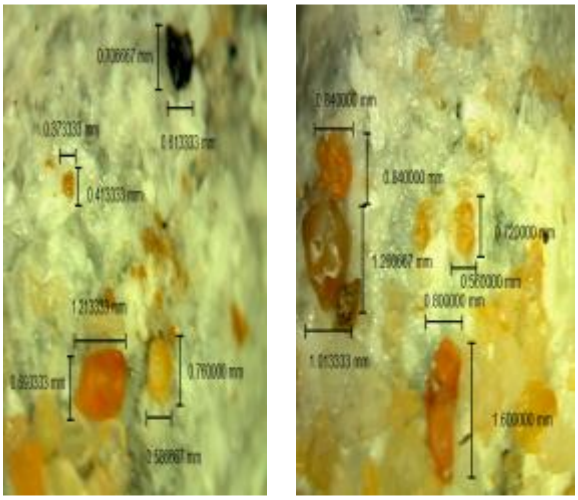

Fig. 14. *Effect of Sand Particles Size on Embedment.*

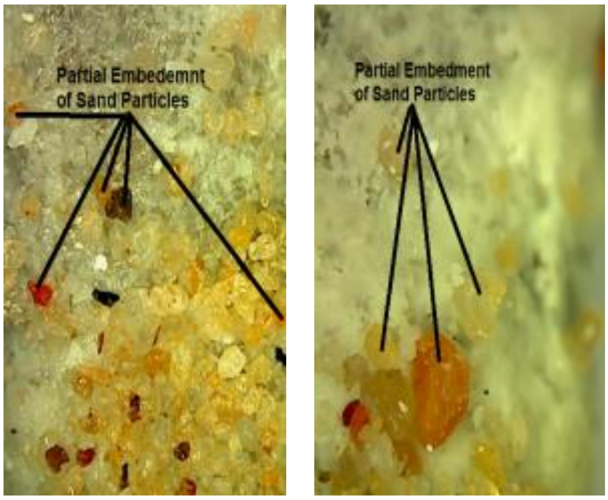

Fig. 16. *Embedment of Sand Particles*.

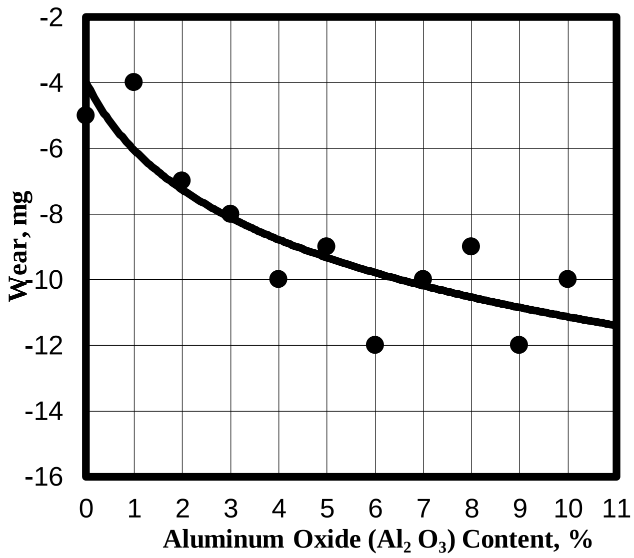

Fig. 15. *Effect of aluminum oxide nanofibers on wear of PVC with 7% oil content.*

Figure 15 observes that, embedment displayed in all results. This behavior confirms that, increasing the oil content causes a main role in the wear resistance of the coating surface. Where, the increasing of oil content decreased the hardness of the surface and enhanced the embedment of sand particles. Moreover, embedment is attributed to the fact of the higher hardness of the sand particles. The microscope examination illustrated the embedment of sand particles in the surface of the coating, as shown in Fig. 16. According to Fig. 15, wear was -12 mg at 6 and 9 wt. % Al_2O_3 nanofibers content. The negative sign indicated the increase of the weight caused by embedment of the sand particles.

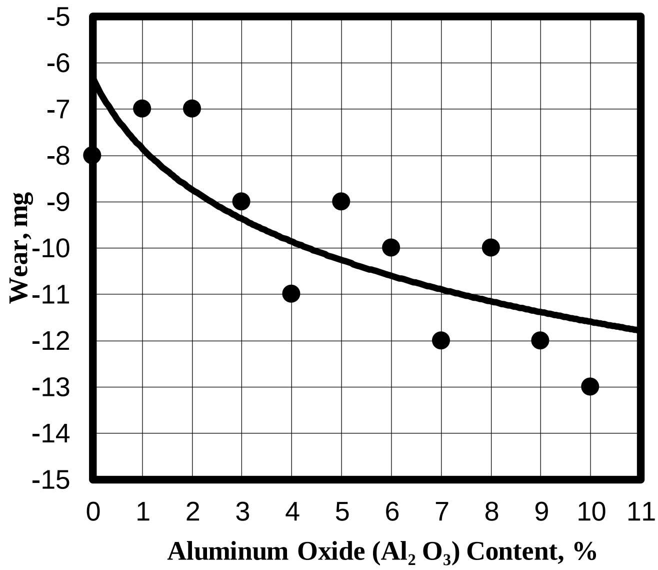

Fig. 17. *Effect of aluminum oxide nanofibers on wear of PVC with 8% oil content.*

Taking into account the size and the shape of sand particles, it is clearly illustrated that the wear decreased further as oil content increased, Fig. 17. Wear is remarkably lowered as comparing to the value of the wear of PVC with Al_2O_3 content and 7 wt. % oil content. The microscopic examination of the specimen surfaces confirmed the presence of the sand particles embedded in the surface, Fig. 18. Wear was -13 mg at 10 wt. % Al_2O_3 content. This can be related to the good lubricating properties of oil, which builds a film at the contact zone and reduces wear, Fig, 19. Moreover, 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.

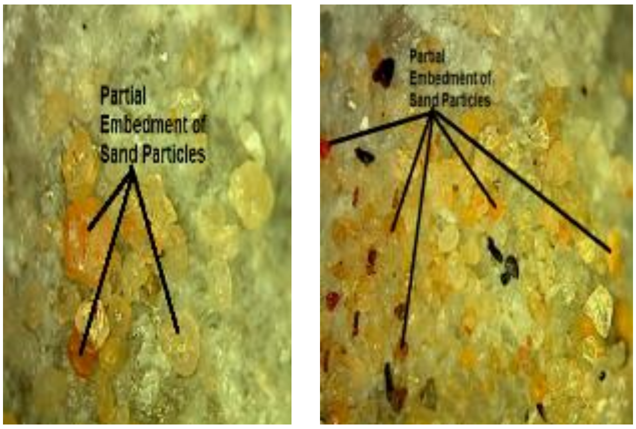

Fig. 18. *Sand Embedment*.

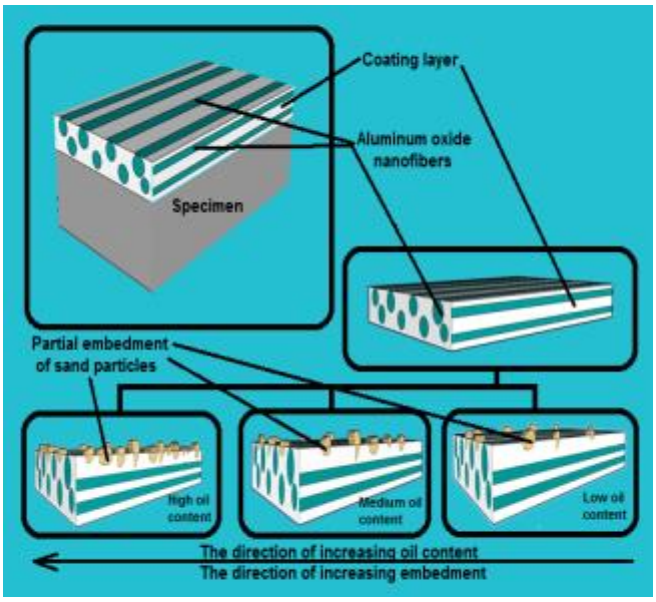

Fig. 19. *Effect of Oil on The Sand Embedment.*

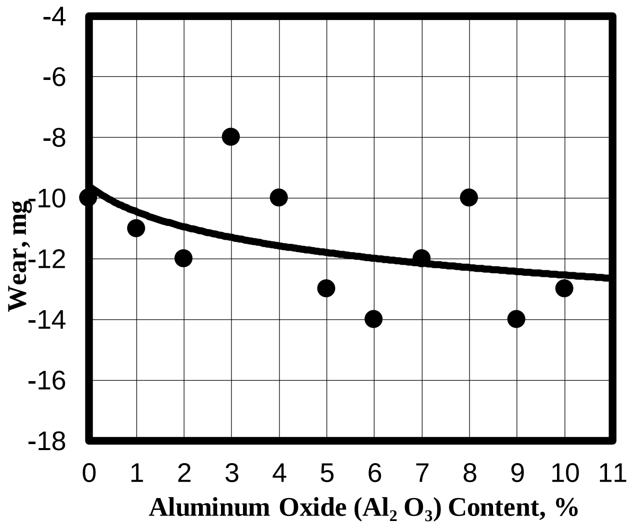

Fig. 20. *Effect of aluminum oxide nanofibers on wear of PVC with 9% oil content*.

PVC with Al_2O_3 content and 9 wt. % oil content showed promising results, Fig. 20. It is clearly seen that, the embedment is higher than the embedment in PVC with Al_2O_3 content and 8 wt. % oil content. The wear was -14 mg at 6 and 9 wt. % Al_2O_3 content. The negative sign indicated the increase of weight causes by embedment of sand particles. 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.

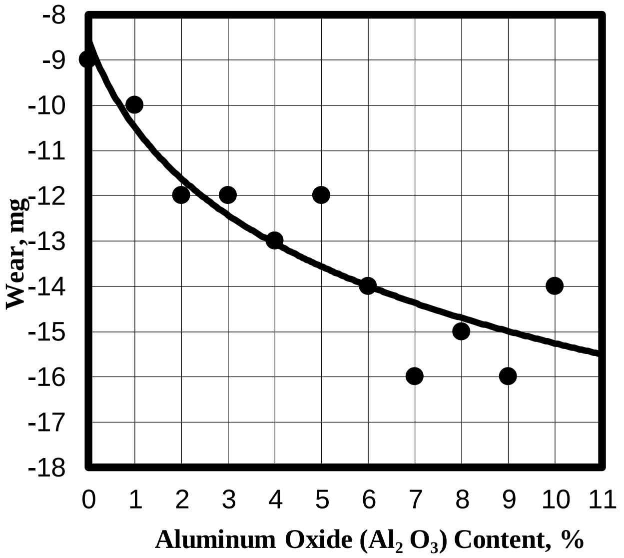

Fig. 21. *Effect of aluminum oxide nanofibers on wear of PVC with 10% oil content*.

Minimum wear illustrated in PVC with 10 wt. % oil content and Al_2O_3 nanofibers, Fig. 21. Wear was -16 mg at 7 and 9 wt. % Al_2O_3 content. The percentage of the sand particles embedment is higher due to the high percentage of oil content which decreased the hardness. The decrease in hardness increased embedment of the sand particles in the surface of the coating leading to a significant reduction wear. The specimens covered by PVC and Al_2O_3 content and 10 wt. % oil content gave good wear results as compared to other specimens. 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. 22.

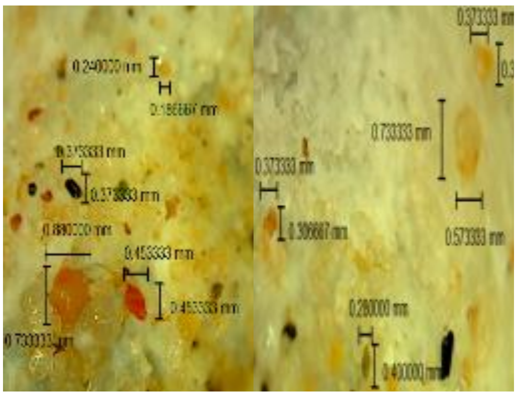

Fig. 22. *Embedment of Sand Particles*.

IV. CONCLUSIONS

1. Where oil content increased, the wear decreased. This can be attributed to the improvement of the oil over the running surface by the addition of the oil content in the matrix.

2. Minimum wear was obtained using PVC with 7 and 9% aluminum oxide nanofibers content and 10 % oil content.

3. Aluminum oxide nanofibers enhanced the wear resistance and the hardness of the coating.

4. The high adhesion for Al_2O_3 nanofibers increased the accordance between the PVC and the nanofibers and showed a considerable mitigation in the wear due to the high hardness of Al_2O_3.

5. Increase of oil impregnating PVC enhanced the embedment of sand particles.

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