EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 13, No. 1, January 2016, pp. 15 - 29 **ISSN 2090 - 5882**

THE TRIBOLOGICAL BEHAVIOR OF POLYETHYLENE FILLED BY NANOPOWDER OF ALUMINUM OXIDE

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ABSTRACT
The present study investigates the abrasive wear of surfaces subjected to abrasive contaminants. Polyethylene (PE) filled with nanoparticles of aluminum oxide were used as coating for steel specimens. Their effect on wear of moving surfaces contaminated by sand is discussed. An abrasive wear tester was constructed 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. The test specimens were immersed at a fixed depth in a pan full of sand. The specimens were coated with PE filled with aluminum oxide (Al_2O_3) and oil content. The 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, the addition of aluminum oxide particles to PE enhanced the wear resistance and the hardness of the matrix. The increase of oil content decreased the wear. PE coating filled by aluminum oxide particles content and 10wt. % oil content showed zero wear.

KEYWORDS
Wear, polyethylene, aluminum oxide, oil, sand, embedment.

INTRODUCTION
Nanoparticles have been used as fillers in polymeric composites for improving the tribological performance of the material, [1]. Tribological properties of polymer composites can also be greatly enhanced with the addition of nanoparticles, such as nano-Al_2O_3, [2]. A polymer nanocomposite is defined as a composite material with a polymer matrix and filler particles that have at least one dimension less than 100 nm, [3]. In desert areas, abrasive particles entering the machines cause serious wear of the sliding components, [4, 5]. Abrasive wear of composite materials is a complicated surface damage process, affected by a number of factors, such as microstructure, mechanical properties of the target material and the abrasive, loading condition, environmental influence, etc. Microstructure is one of the major factors; however, its effect on the wear mechanism is difficult to investigate experimentally, [6, 7]. Aluminum alloys are very promising for structural applications in aerospace, military, and transportation industries due to their light weight, high strength-to-weight ratio, and resistance to corrosion, [8]. Aluminum oxide is famous for its hardness and is often used as grinding medium. As considered by Schwartz and Bahadur, it would not be asuitable filler in the microscale particulate form due to its angularity which tends to

abrade the mating counterface. The material in the nanoscale particulate form has much lower angularity and thus is not that abrasive. Kishore and Kumar found that the addition of aluminum oxide powder of size <1µm into epoxy increases the sliding wear resistance of the material. Polyethylene is very high wear resistance even when water is present, moderate coefficient of friction, good abrasive wear resistance and relatively low temperature limit, [9]. polyethylene has been widely used in bearing applications due to its good chemical stability biocompatibility, and friction-reducing and antiwear ability It has also been used as some components or parts of machines in chemical engineering, textile engineering, transportation engineering, agricultural engineering, food processing, and the paper making industry, because of its excellent chemical corrosion resistance, water-repellent function, adhesion resistance, and self-lubricity, [10]. One way to improve the mechanical and wear properties of PE is the use of inorganic fillers, such as kaolin, aluminum oxide, zirconium oxide and so on, [11]. In material embedment and abrasion, factors such as particle shape, size and hardness affect the level of grit embedment, difference in grit embedment is probably due their different angularity, the particle grit size effect on the particle embedment and smaller particles are more angular, [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].

In the present work, the wear of polyethylene (PE) filled by nanoparticles of aluminum oxide and oil is discussed.

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. The tests were carried out at a speed of 280 rev/min. The test specimens were immersed at a fixed depth in a pan full of sand, Fig. 2. The test time was 15 min. Experiments were carried out at 25 °C. The wear was measured by digital balance with an accuracy of ± 10 mg. The specimens were coated with polyethylene filled with 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. % nanopowder of aluminum oxide content and 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 wt. % oil content, Fig. 3. The sequence of the operations followed in the experimental work is shown in Fig. 4.

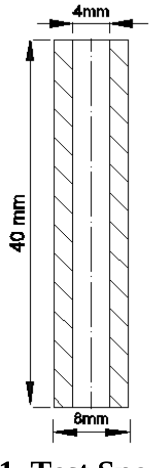

Fig. 1. Test Specimen.

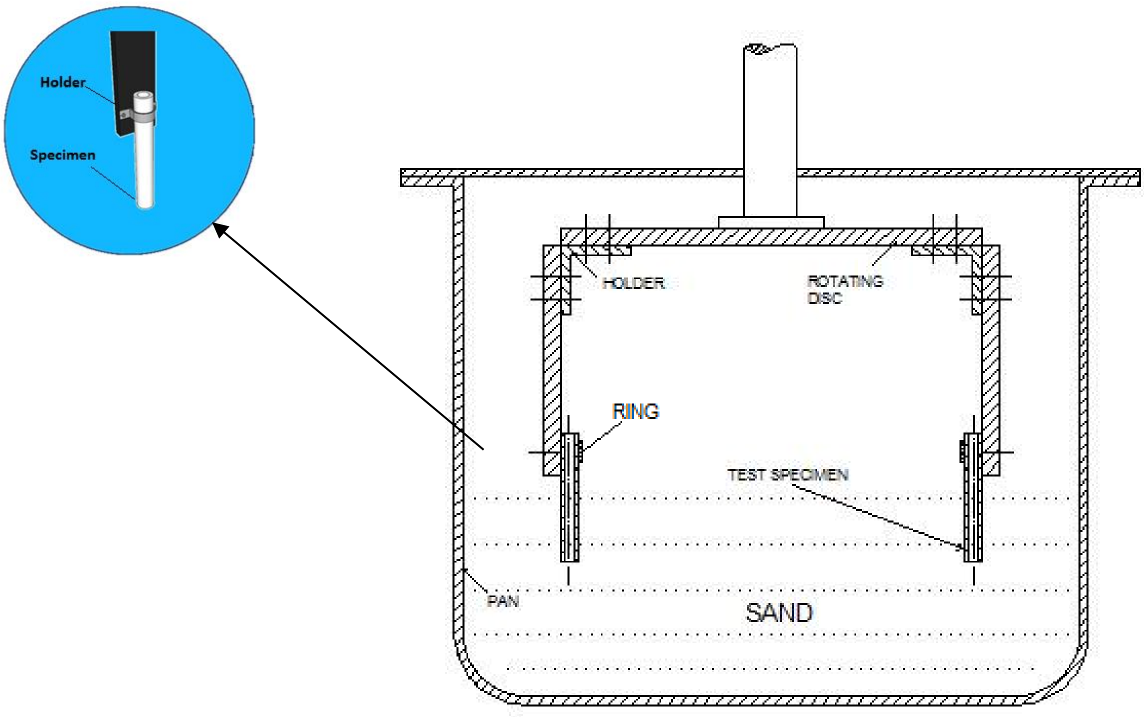

Fig. 2 Layout of Sand Test Rig, [14].

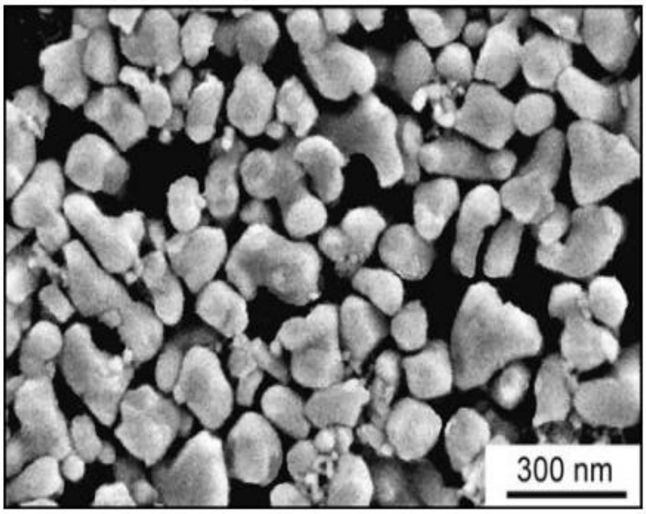

Fig. 3 SEM micrograph of the Al_2O_3 nanopowder, [15].

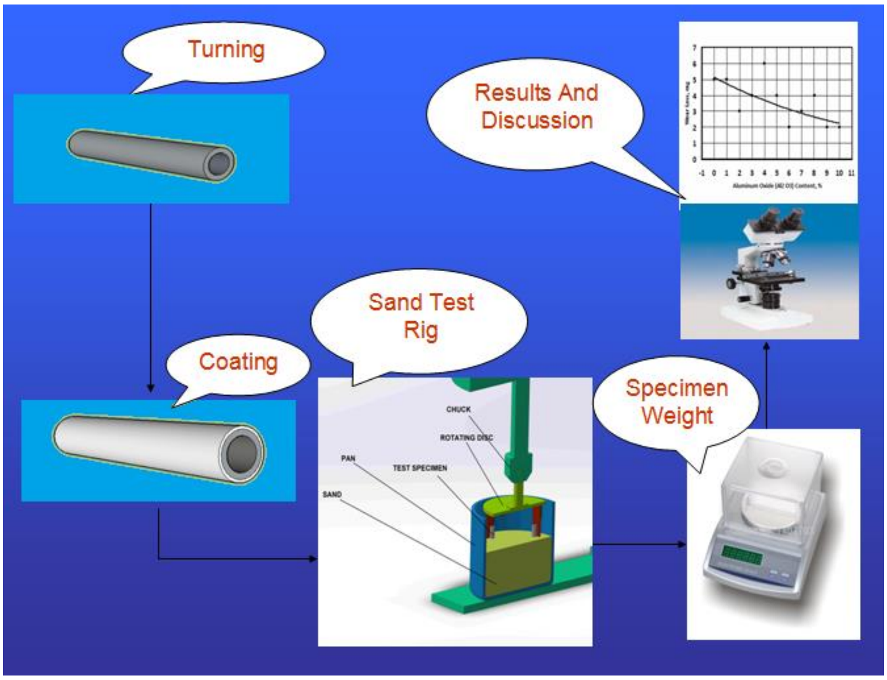

Fig. 5 The sequence of the operations followed in the experimental work.

RESULTS AND DISCUSSION

The Effect of addition of aluminum oxide particles to PE illustrated in Fig. 6. As seen, the increase of concentration of aluminum oxide caused a decrease in wear. The best results have been observed for PE filled by 10, 8 wt. % aluminum oxide content. This can be attributed to the high wear resistance and high hardness of aluminum oxide. Where, the addition of aluminum oxide particles into PE increases the wear resistance and the hardness of the matrix.

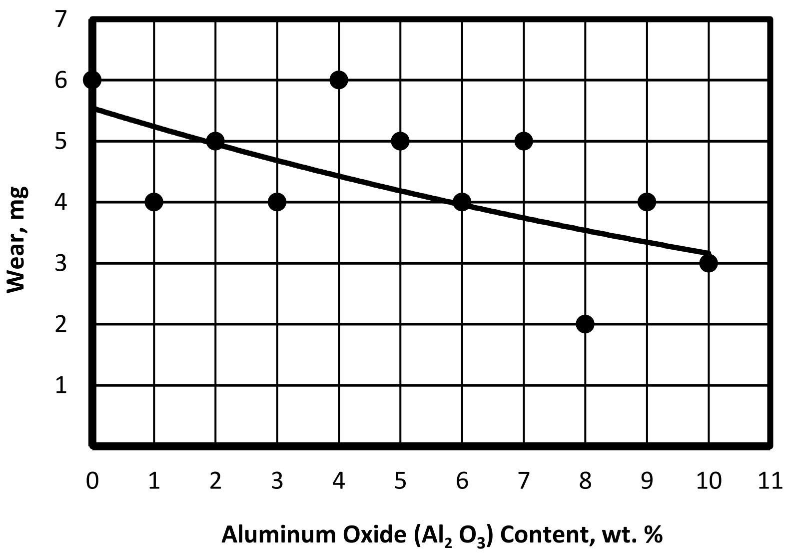

Fig. 6 Effect of aluminum oxide nanopowder on wear of PE.

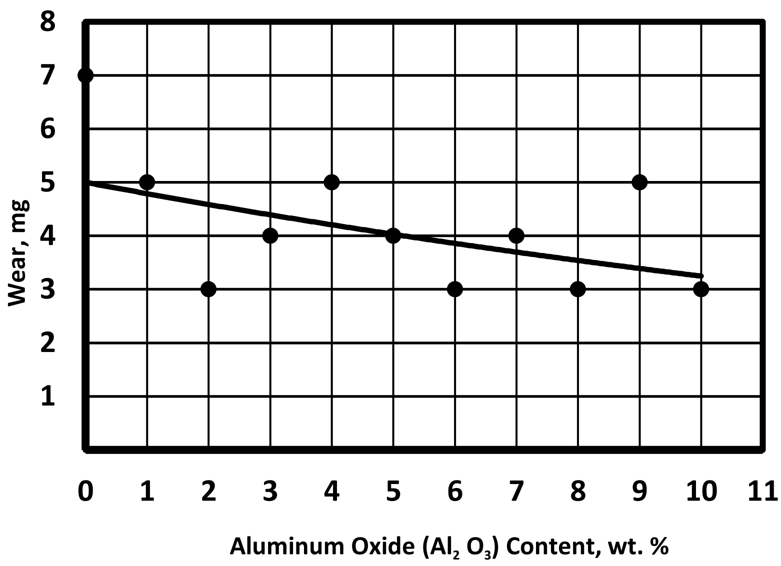

Fig. 7 Effect of aluminum oxide nanopowder on wear of PE filled by 1wt. % oil content.

It can be concluded from Fig. 7 that the PE filled with aluminum oxide particles and impregnated by 1 wt. % oil showed significant wear resistance. Also, aluminum oxide as filling material in PE coating enhanced the wear resistance of the matrix. Furthermore, the specimens covered by PE with aluminum oxide particles and impregnated by 1 wt. % oil gave good wear results as compared to PE with aluminum oxide particles 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 3 mg at 2 wt. % aluminum oxide content and 1 wt. % oil content, where wear was 5 mg at 2 wt. % aluminum oxide content without oil.

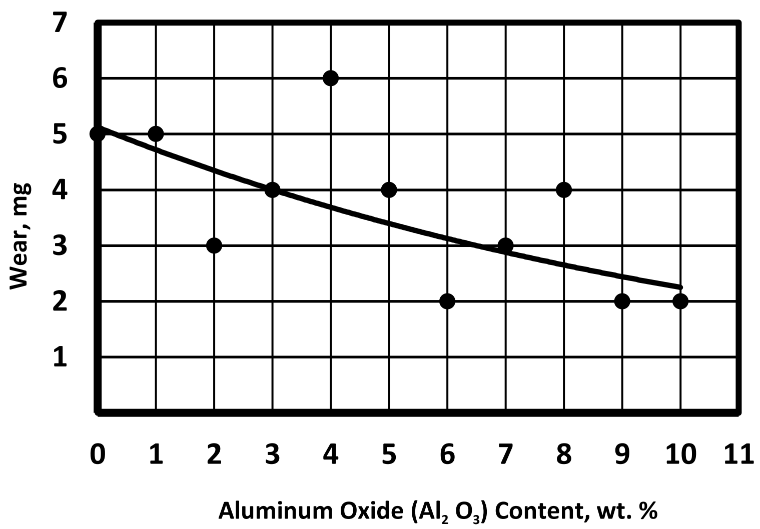

Fig. 8 Effect of aluminum oxide nanopowder on wear of PE filled by 2 wt. % oil content.

Figure 8 indicated the relation between wear and aluminum oxide content in PE filled by 2 wt. % oil content. As the aluminum oxide content increases wear decreases. The

minimum wear was 2 mg at 6, 9, 10 wt. % aluminum oxide content. Filling PE coating by aluminum oxide particles has been achieved to develop the wear resistance and the hardness of the coating trend owing to the high wear resistance and hardness of aluminum oxide. It is evident that the wear of PE filled by aluminum oxide and 2wt. % oil content is lower than the wear of PE filled by aluminum oxide and 1wt. % oil content. As the minimum wear was 3 mg at PE filled by aluminum oxide and 1wt. % oil content. This can be interpreted on the better distribution 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.

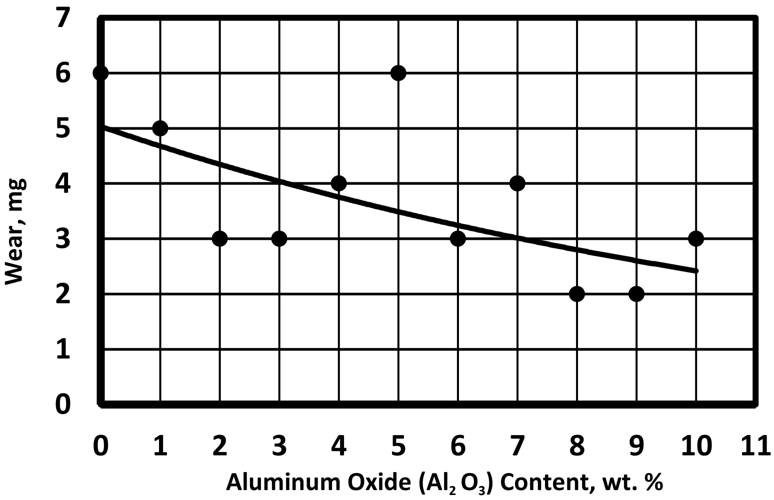

Fig. 9 Effect of aluminum oxide nanopowder on wear of PE filled by 3 wt. % oil content.

The same trend was observed for PE with aluminum oxide content and 3 wt. % oil content, Fig. 9. It seems that increasing aluminum oxide content decreased the wear. As the high wear resistance and hardness of aluminum oxide causes a significant improvement in the surface of the coating and increases the wear resistance of the matrix. Impregnated PE 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.

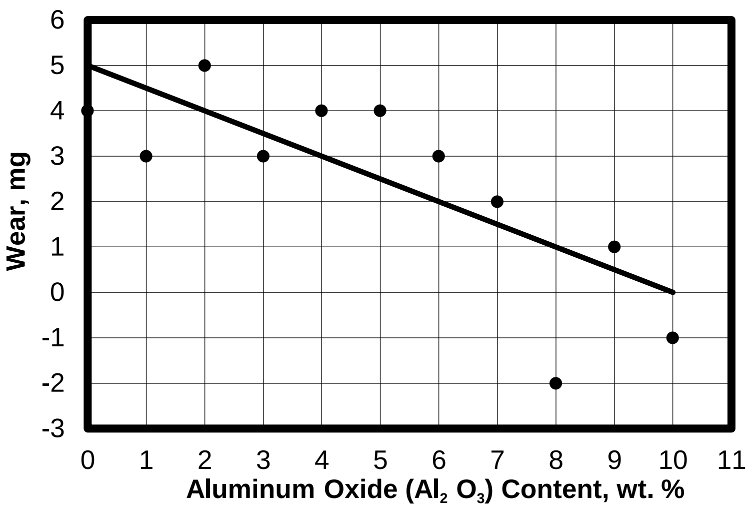

Fig. 10 Effect of aluminum oxide nanopowder on wear of PE filled by 4 wt. % oil content.

The embedment of the abrasive sand particles in the surface of the coating offers an explanation for the observed initial increase of weight recorded for both results of PE with 8, and 10 wt. % aluminum oxide content filled by 4 wt. % oil content, Fig. 10. As wear values were -2 and -1 mg at 8 wt. % and 10 wt. % aluminum oxide contents and the negative sign indicated that the weight increased after test. This means that the sand particles were embedded in the surface of the coating, Fig. 11. The microscopic examination of the specimen surfaces confirmed the presence of the sand particles embedded in the surface, Fig. 12. Here, 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 PE with aluminum oxide content also is revealed in, Fig. 10. For PE with aluminum oxide content and 4wt. % oil content, the wear is remarkably lowered as compared to the value of the wear of PE with aluminum oxide content and 3wt. % 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.

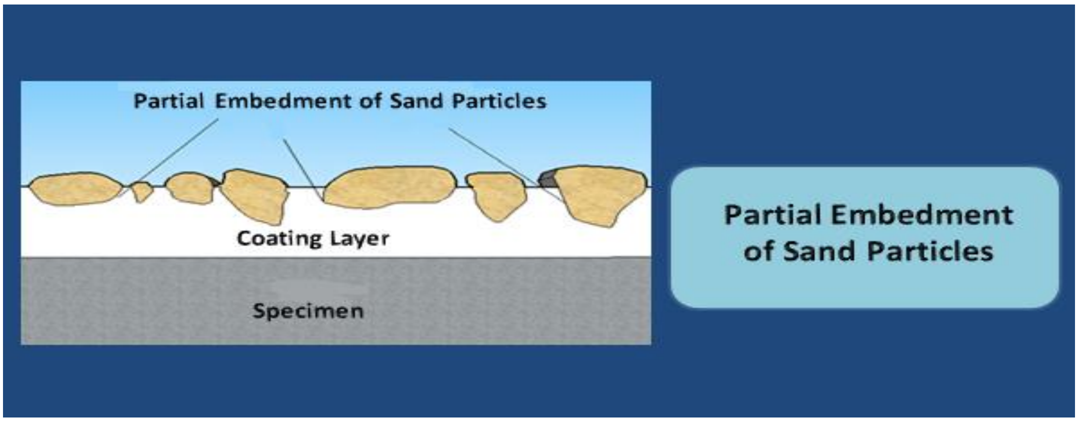

Fig. 11 Schematic illustration the embedment of sand particle.

Figure 13 clearly demonstrates the Effect of aluminum oxide content on wear of impregnating PE filled by 5 wt. % oil content. The specimens covered by PE with aluminum oxide particles content and 5 wt. % oil content gave good wear results as compared to the specimens covered by PE with aluminum oxide particles content and 4wt. % oil content. Wear was -4 mg at 9 wt. % aluminum oxide content. This behavior means that the embedment is higher than in PE with 4 wt. % oil content, where minimum wear was -2 mg, Fig. 10. As 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 wear resistance of the sand particles. To have more information about embedment of sand particles on the surface of the specimens, wear and embedment of sand particles was analyzed using optical microscopy after the test. A careful survey of Fig. 14 indicates that embedment of the sand particles for the smaller size particles are higher than the larger particles. Difference in embedment is probably due to their different angularity and the smaller particles are more angular.

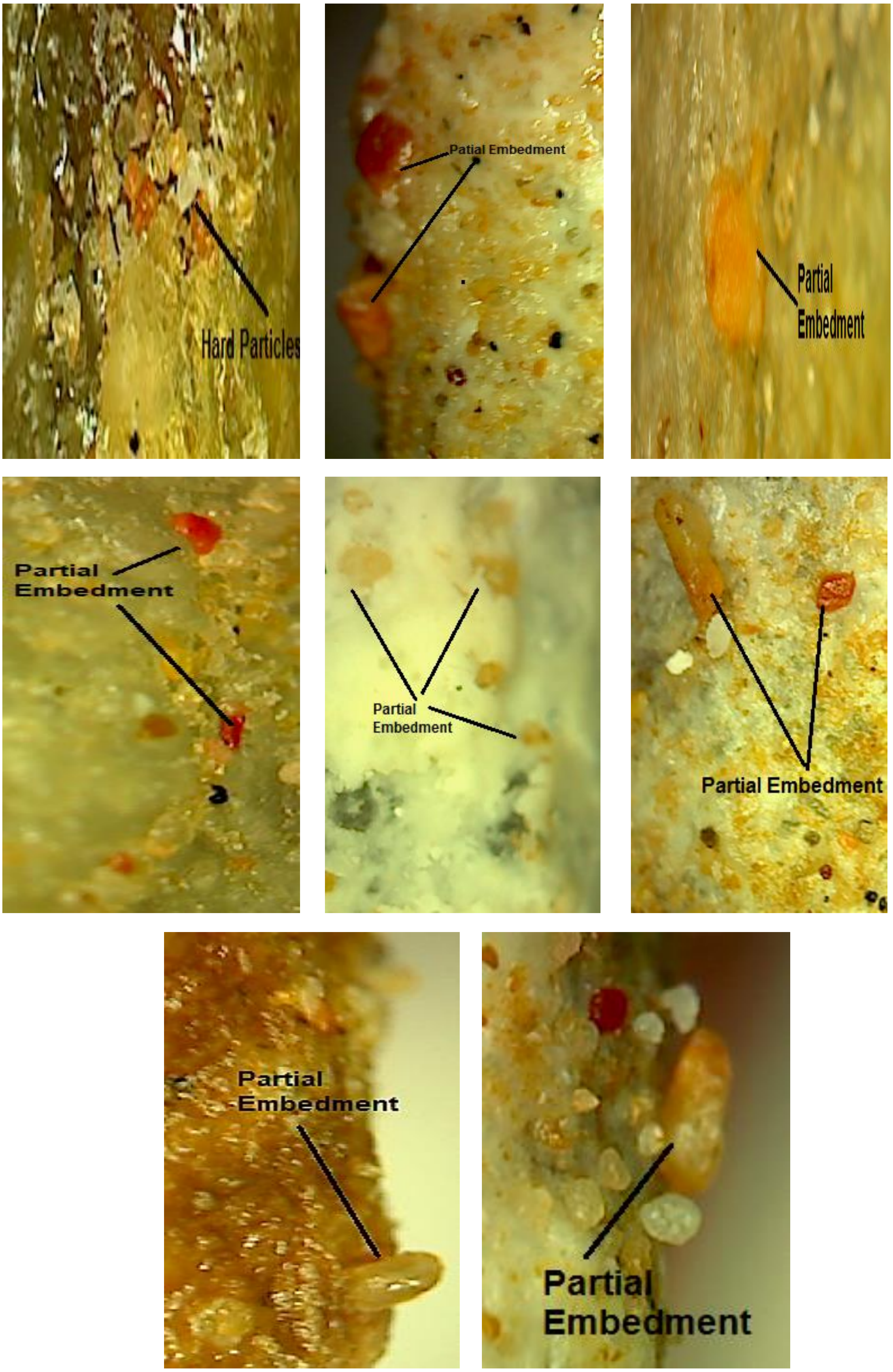

Fig. 12 Photomicrographs of embedment of sand particles

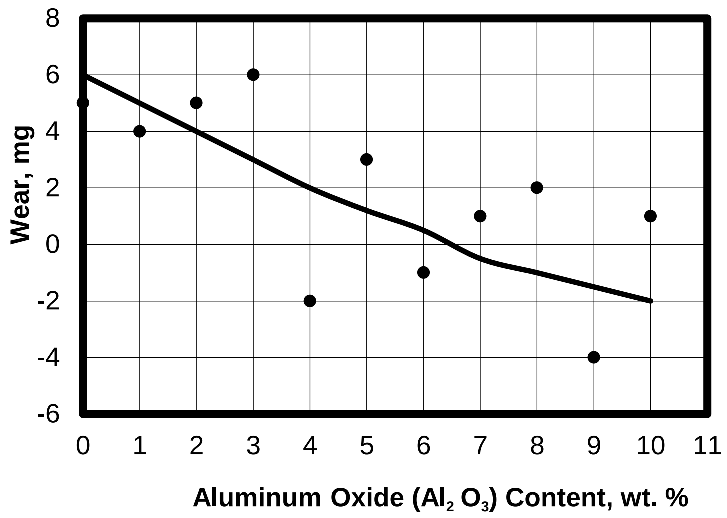

Fig. 13 Effect of aluminum oxide nanopowder on wear of PE with 5 wt. % oil content.

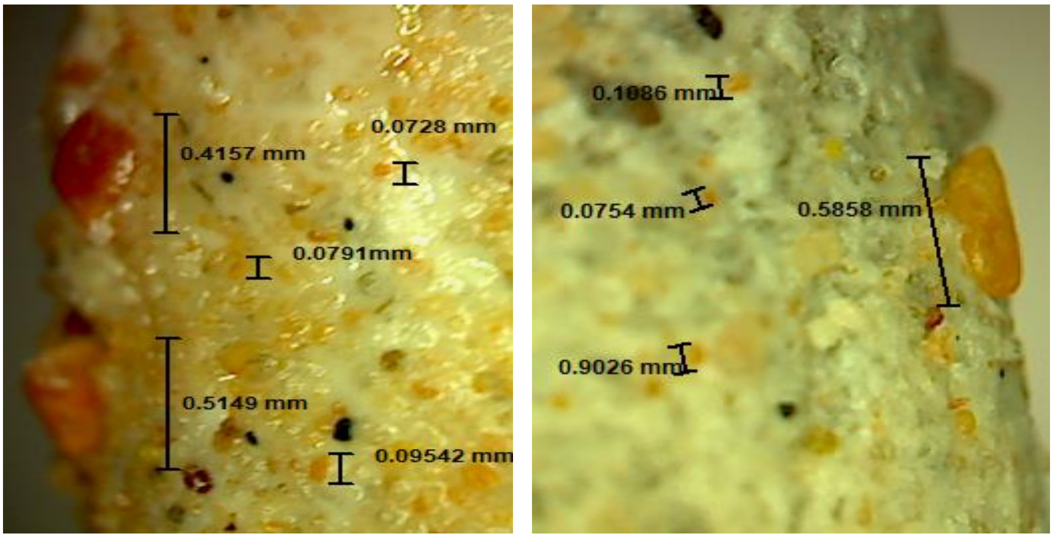

Fig. 14. Effect of sand particles size on the embedment.

It is well known that factors such as particle shape, size and hardness affect the embedment of abrasive particles. According to Fig. 15, increasing the oil content causes a significant improvement in the surface of the coating as the wear decreased with increasing oil content. In most cases, embedment of sand particles is revealed. The best of results was -5 mg for wear because 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. On the other hand, embedment of sharp particles is higher than the spherical particles, Fig. 16, as the sharp edge of these particles facilitates the embedment in the surface, Fig. 17.

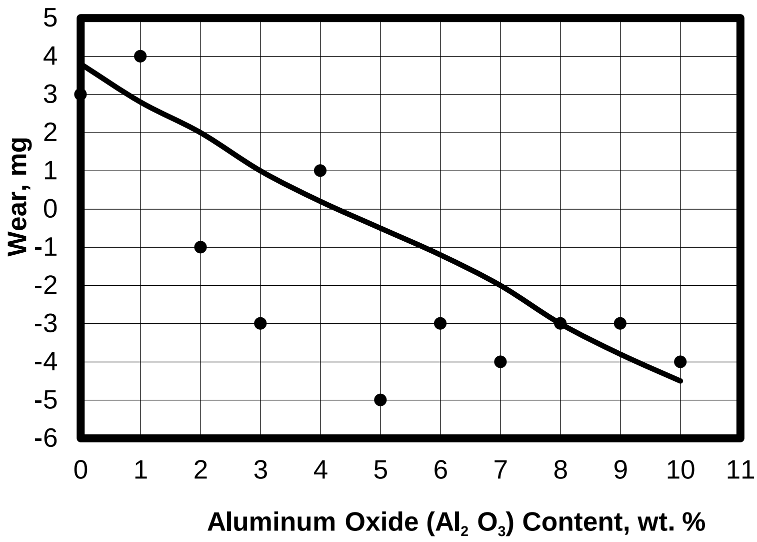

Fig. 15 Effect of aluminum oxide nanopowder on wear of PE with 6wt. % oil content.

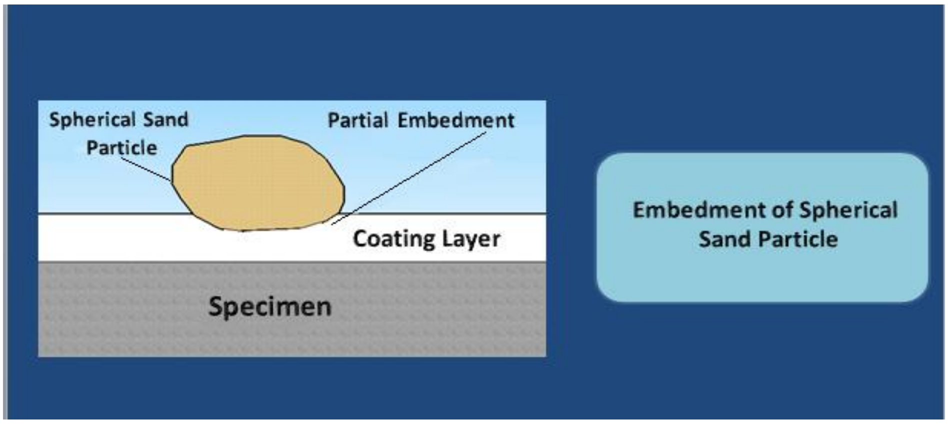

Fig. 16. Schematic illustration the embedment of spherical sand particle.

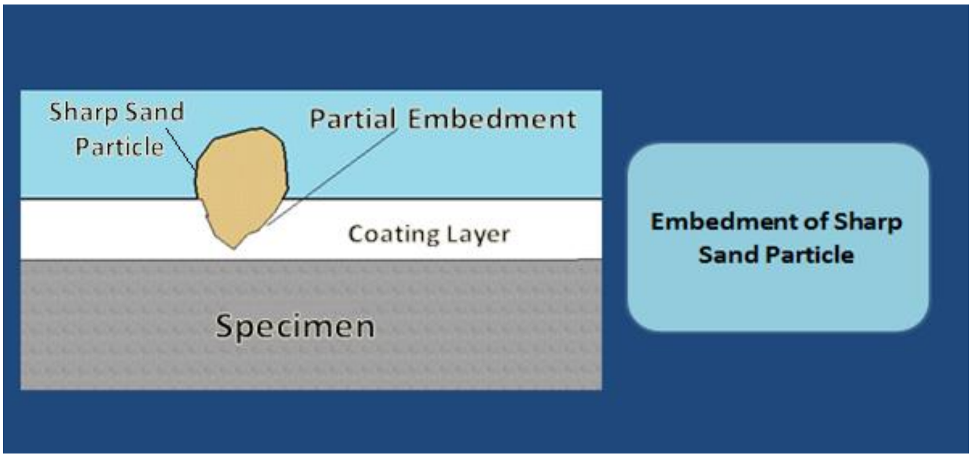

Fig. 17. Schematic illustration the embedment of sharp sand particle.

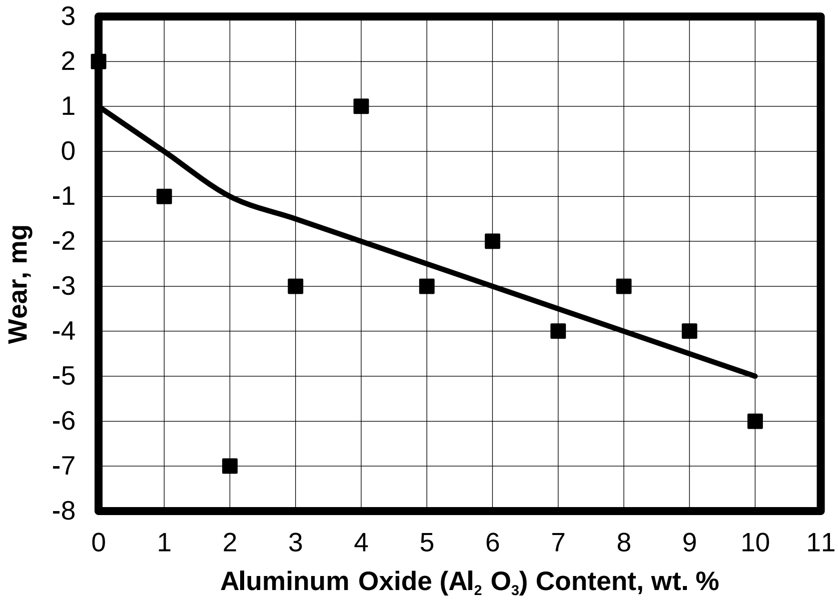

Fig. 18 Effect of aluminum oxide nanopowder on wear of PE filled by 7 wt. % oil content.

Fig. 18 indicates that the wear decreased further as oil content increased. Wear was -7 mg at 2 wt. % aluminum oxide content. The increasing of weight because the high percentage of sand embedment in the surface. A possible explanation for the higher embedment is could be related to the low hardness of the matrix because the high percentage of the oil, which enables the hard abrasive particles to be easily embedded in the surface of the coating and increase the abrasive resistance and protect the coating surface from more wear, Fig. 19.

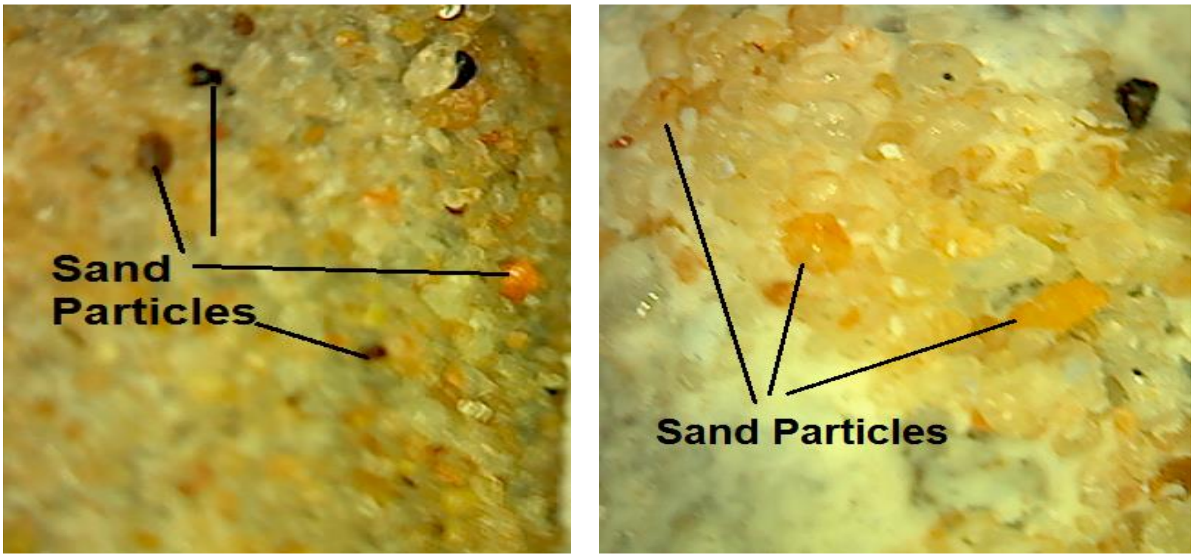

Fig. 19. Sand Embedment.

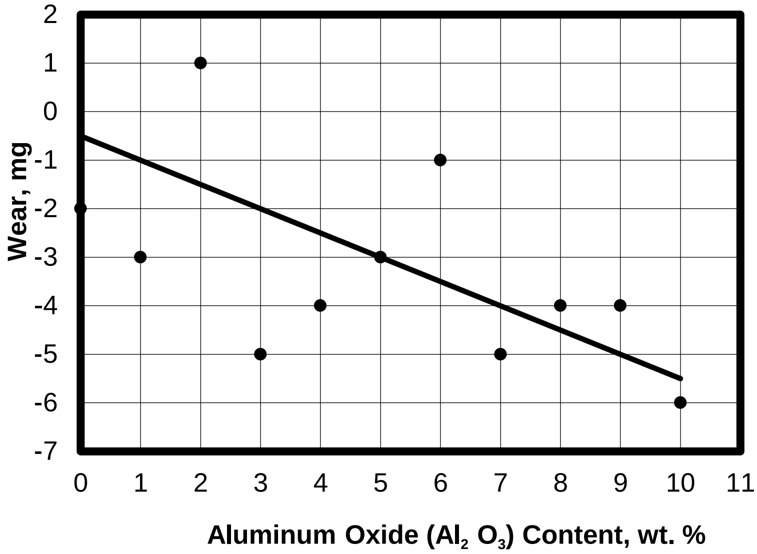

Fig. 20 Effect of aluminum oxide nanopowder on wear of PE filled by 8 wt. % oil content.

As presented in Fig. 20, embedment displayed in all results expect only at 2 wt. % aluminum oxide content. The high percentage of the oil content, 8wt. % oil content, plays a remarkably role on the embedment of the sand particles. This behavior confirms that when the oil content increased wear decreased. The decrease in hardness of the coating causes by the high percentage of oil increased embedment of the sand particles in the surface of the coating leading to a significant reduction wear.

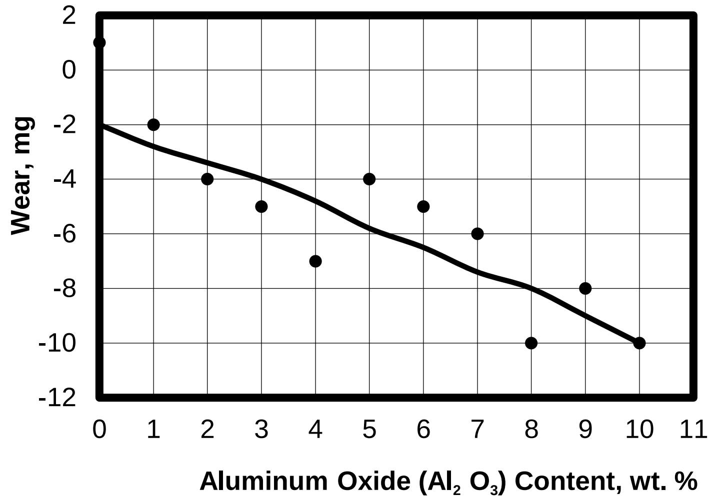

Fig. 21 Effect of aluminum oxide nanopowder on wear of PE filled by 9 wt. % oil content.

The weight increased after test as observed in all results expect only at zero wt. % aluminum oxide content. PE with aluminum oxide content and 9 wt. % oil content showed promising results. It is clearly seen that the embedment is higher than the embedment in PE with aluminum oxide content and 8wt. % oil content. The wear was -10 mg at 8 and 10 wt. % 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. As 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. The microscope examination illustrated the embedment of sand particles in the surface of the coating, Fig. 22. The size of sand particles affects 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.

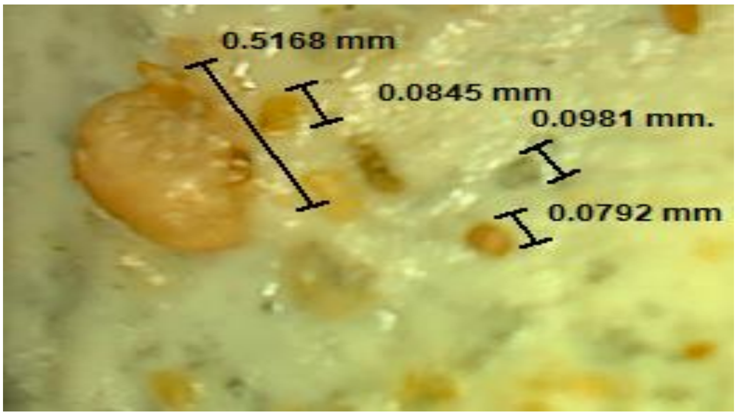

Fig. 22 Effect of sand particles size on embedment.

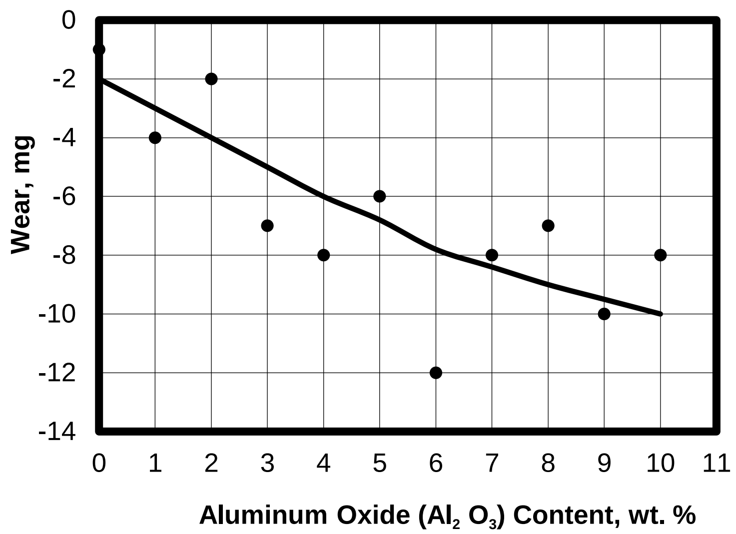

Fig. 23 Effect of aluminum oxide nanopowder on wear of PE filled by 10 wt. % oil content.

Minimum wear illustrated in PE filled by 10 wt. % oil content and aluminum oxide content, Fig. 23. Wear was -12 mg at 6 wt. % aluminum oxide content. The sand particles embedment is higher due to the high content of oil which decreases the hardness of the matrix and enables the hard particles of sand to be easily embedded in

the surface, allowing for growth of the protective wear layer of sand particles. The specimens covered by PE and aluminum oxide content and filled by 10 wt. % oil gave good wear results as compared to other specimens.

CONCLUSIONS

1. Minimum wear was observed in PE filled by aluminum oxide and 10 wt. % oil

2. The addition of aluminum oxide particles to PE enhanced the wear resistance and the hardness of the matrix.

3. The increase of oil content decreased the wear.

4. The size and the shape of sand particles play a remarkable role on the sand particles embedment.

5. Increasing of oil content enables the sand particles to be easily embedded in the surface of the coating.

6. The best result was obtained using PE filled by 6 wt. % aluminum oxide content and 10 wt. % oil content.

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