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EFFECT OF POLYMERIC POWDER ON THE FRICTION AND WEAR OF SAND CONTAMINATED GREASED SURFACES

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ABSTRACT

The present work aims to develop the abrasion resistance of surfaces lubricated by contaminated greases. The intended development can be achieved by reducing the effect of abrasive action of sand particles on the wear of the friction surfaces. Different polymeric thickeners in powder form, such as high density polyethylene (HDPE), low density polyethylene (LDPE), polyvinylchloride (PVC), polystyrene (PS), polyamide (PA6) and polymethylmethacrylate (PMMA), were added to lithium based grease.

Friction coefficient and wear resistance of cylindrical steel specimens were examined using a cross pin wear tester. The wear tester provided concentrated contact under mixed lubrication conditions. Wear was measured on the stationary test specimen by the wear scar diameter, using an optical microscope, with an accuracy of ±1 µm. The frictional torque generated between the rubbing surfaces was measured using a load cell attached to the stationary test specimen holder. The experiments were performed using clean and sand contaminated lubricating greases. Air Cleaner Fine Test Dust (ACFTD Arizona Sand) was added as a contaminant to the grease at a concentration of 10 wt.%.

The results show that the effect of the abrasive contaminants can be reduced by dispersing the grease by polymeric powders. However, the addition of polymer to lubricating grease at relatively high concentration (more than 35 wt. %) has no effect on the antiwear action of the lithium grease. Besides, the addition of polymeric powder of particle size relatively greater than that of the contaminant can be considered as a useful method of eliminating the cutting process of sand particles.

KEYWORDS

Friction coefficient, wear scar diameter, HDPE, LDPE, PMMA, PA6, PVC, PS, lithium based grease, sand.

INTRODUCTION

The operating environment in Middle East is particularly severe in terms of the high ambient dust concentrations experienced throughout the Eastern and Western Provinces. 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, [1]. Contaminants in the lubricating oils and greases are considered as one of the major reasons for machine elements failure, [2]. Solid contaminants can be classified into three groups. The first is the external contaminants that enter the lubricating oils and greases through air, fuel and fresh oil as well as fresh grease. The second is the contaminants generated due to friction and wear of the rubbing surfaces while the third item covers the contaminants introduced during manufacturing and assembly of different elements of the machine.

The majority of previous studies focused on the influence of the sand particles contaminated in the lubricating oils on the friction and wear of engineering surfaces. The effect of the liquid and solid contaminants on the friction and wear of the moving surfaces of internal combustion engines was discussed, [3]. The test results showed that friction coefficient caused by oil contaminated by sand showed maximum values for sand particles of 5 – 10 and 15 – 20 μm, while wear increased significantly with increasing particle size. Iron oxide, as lubricant contaminant, showed the highest values of friction and wear followed by carbon black and copper.

Wear is one of the surface damage that involves a progressive loss of material and affects the life time of machine elements such as gears and rolling element bearings. Rolling contact wear is a particular type of wear that results from the repeated mechanical stressing of the surface of a loaded body rolling against another, [4 - 7]. Greases with different compositions will lead to lubricating films exhibiting different thicknesses, which will determine rolling contact wear performance. When studying the relation between grease composition and the lubricating film thickness, several authors concluded that when the contact is being lubricated under fully flooded conditions, an increase both on the base-oil viscosity and percentage of soap concentration results in a greater film thickness [8, 9]. Experimental tests for the tested greases and correspondent base oils were carried out on a twin disc machine under pure rolling conditions, where base oil viscosity, percentage of soap concentration and the presence of additives were varied.

The failure mechanisms of the machine elements in a contaminated environment can be divided into two cases. The first mechanism involves surface denting in terms of scratches or pits resulting from the abrasion action of particles in bearing gap. The second mechanism comprises fluid starvation due to the accumulation of debris particles in the inlet zone of the bearing gap, which may lead to scuffing, [10]. It was concluded that with a thin oil film small and medium size particles can cause surface denting, while large particles can lead to agglomeration, fluid starvation and scuffing, [11]. The influence of debris particles on the mechanism of surface dent formation in bearings was investigated, [12, 13]. If the particle size is larger than the film thickness of the lubricant, the particle causes a high local Hertzian pressure when it travels through the contact zone. A grease lubricated rolling bearing typically operates in a starved lubrication regime with a film thickness of 35 - 70% of the corresponding film thickness obtained with an oil of the same type as the base oil of the grease. When analyzing the influence of solid contaminants in a thin lubricating film on the operation of a grease lubricated bearing, the differences in the rheological properties of lubricating greases and oils, respectively, must be seriously taken into consideration.

The greases can be contaminated from some contaminants which may be built into the system because of inadequate cleaning of the component parts or because of faulty assembly. Contaminants may be picked up when adding fresh grease to the sliding surfaces, and during the installation of spare parts, where traces of casting sand and machining swarf are usually present in new machine elements in spite of the care devoted by manufacturers to excluding them, [14]. Contaminants may be generated at sliding surfaces of bearings, where metallic wear debris is constantly being added to the abrasive content of the grease. Greases in storage containers may have become contaminated during processing and filling. The major part of abrasive material in the grease is the sand.

Little attention was considered for the effect of sand particles on lubricating greases, [15 – 18]. The usual method of increasing the load carrying capacity of a journal bearing operating under boundary or mixed lubricating condition is to use a lubricant containing extreme pressure (EP) additives, [19, 20]. Tests have been carried out to study the wear of journal bearing lubricated by grease containing powdered polytetrafluoroethylene (PTFE) additive, [21]. The results show that the wear of the bearing lubricated by such a grease is initially greater than that of the bearing lubricated by grease with PTFE. Moreover, greases with and without load carrying capacity additives have been prepared using paraffin as base oil. Penetration and four ball load carrying tests were carried out on the lubricants and the extent of adsorption of the additives onto the thickeners was determined. The results show that the lubricant efficiency increases in the presence of the used additives. It was concluded that the improvement of the lubricating properties of the tested greases is dependent upon the type of thickener and independent of the amount used.

It is clear that grease can be considered as an efficient contamination carrier because of its higher ability of holding the foreign particles. Hence, the effect of abrasive contaminants on the behaviour of the machine elements which are grease lubricated, has been studied. Here, solid additives were used to improve the performance under condition of boundary lubrication, [22].

In the present work, the antiwear effect of lubricating lithium based grease dispersed by different polymeric thickeners was studied. PA6, HDPE, LDPE, PS, PVC and PMMA are added in powder form to grease at different concentrations. The experiments were carried out using clean and sand contaminated greases.

EXPERIMENTAL

Experiments were carried out using a cross pin wear tester, Fig. 1. It consists, mainly, of rotating and stationary pins of 18 mm diameter and 100 mm long. The material of the pins is carbon steel (St. 60), (0.6 % C, 0.25 % Si, 0.65 % Mn, 0.045 % P and 0.045 % S) of 1800 MPa hardness. The rotating pin was attached to a chuck mounted on the main shaft of the test rig. The stationary pin was fixed to the loading block where the load is applied. The main shaft of the test machine is driven by DC motor (300 watt, 250 volt) through a V-belt drive unit. Moreover, the motor speed is adjustable and can be controlled by varying the input voltage using an autotransformer. The test rig is fitted by a load cell to measure the frictional torque generated in the contact zone between the rotating and stationary pins. Normal load was applied by means of weights attached to a loading lever. A counter weight is used to balance the weights of the loading lever, the loading block and the stationary specimen. The tests were carried out at 300 rev/mm (0.30 m/sec), load of 40 N and for a test duration of 10 minutes. The wear scar diameter was measured for the upper stationary pin using an optical microscope within an accuracy of ±1 µm. Different polymeric powders are used as additional thickeners which were PA6, HDPE, LDPE, PMMA, PS and PVC of (0 – 50), (0 – 90), (90 – 150) and (150 – 300) µm particle sizes. The grease consists of mineral based oil thickened with lithium soap. Abrasive particles used in the present work was Air Cleaner Fine Test Dust (ACFTD Arizona sand) of particle size ranging from 0 to 80 µm. ACFTD were used to contaminate the lubricating grease at concentration of 10 wt. %. The wear tests were repeated three times and the mean value of the wear scar diameter was considered.

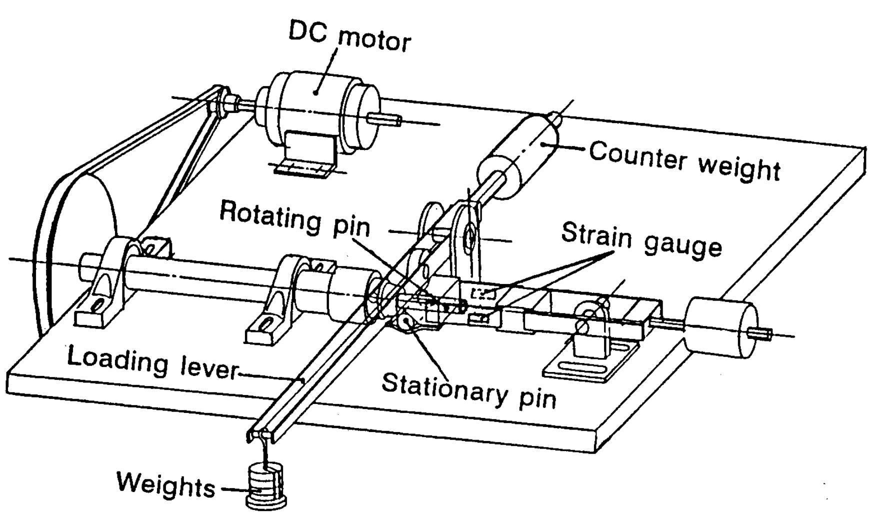

Fig. 1 Arrangement of wear tester.

RESULTS AND DISCUSSIONS

Polymeric powders such as PA6, HDPE, LDPE, PVC, PMMA and PS with particle size (0 - 50 µm) were used as thickener for lithium-based grease at concentration of 10 wt.%. Figure 2 shows the wear resistance of the specimens lubricated by clean and contaminated greases dispersed by polymeric thickeners. Also, the results of the tested grease with and without contaminated particles were described. It can be noticed that, a general improvement of the wear resistance of the rubbing surfaces displayed by both clean and contaminated greases was achieved due to the dispersion of the polymeric powder. This can be attributed to the formation of a polymeric layer on the sliding surfaces. However, the lowest wear scar diameter was obtained from the test specimens lubricated by grease containing the powder of HDPE, LDPE and PVC. This improvement was noticed for both the clean and contaminated greases. It seems that wear decreased as the adherence of the polymeric film increased. HDPE, LDPE and PVC have negative charges as a result of their friction with steel. Some of those particles would strongly adhere to the steel surface and protecting it from excessive wear. The friction of sand, PMMA and PA particles generate positive electric charge when they rub steel surface, while particles of PS, HDPE, LDPE and PVC particles gain negative charge. The tendency of the adherence of PS, HDPE, LDPE and PVC particles into the surface of sand is relatively higher. It is expected that those polymeric particles are more effective in reducing the abrasion action of the sand. In addition to that, it was observed that sand contaminated grease produced lower wear that that observed for clean grease. This behaviour might be attributed to the rolling action of sand particles trapped in the contact area where they reduced both friction and wear.

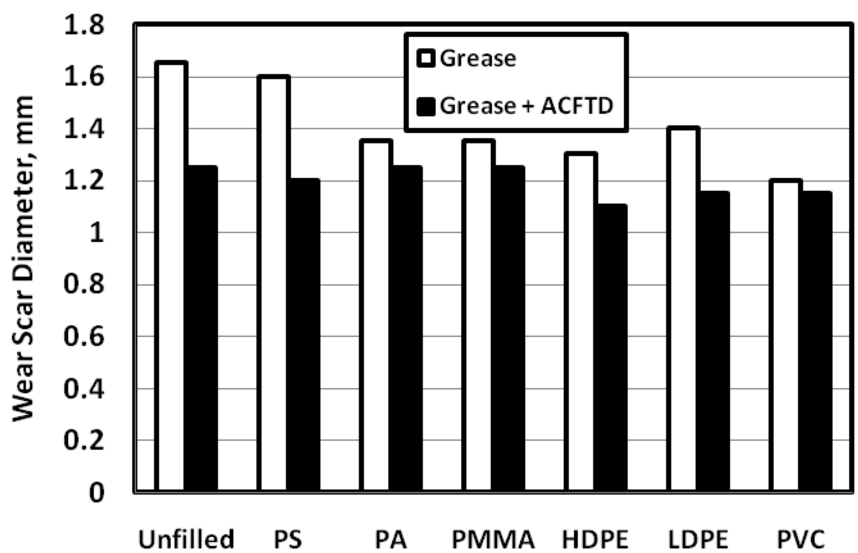

Fig. 2 The effect of dispersing grease by polymeric powder and contaminating by sand particles on wear of test specimens.

Further comparative wear experiments were performed using the powder of (PA6), (HDPE) and (PVC) as grease thickeners at different contents ranging from 5 to 50 wt. %. However, the common ratio of the lubricating base oil to both of the additives and thickener in the grease has been kept constant (i.e. about 66 wt.% lubricating base oil and 34 wt.% additives and thickener) by the addition of base oil (SAE 30) to the grease. The tests were carried out at normal load of 80 N, linear velocity of 0.30 m/s and at ACFTD content of 10 wt. %. The wear scar diameter versus the content of the polymeric thickeners is shown in Fig. 3.

It can be observed that, the lubricating grease with HDPE provides the best wear resistance. Also, no significant improvement of the wear resistance has been achieved by increasing the concentration of the polymeric powders from 5 wt. % to 50 wt. %. This can be attributed to the fact that the presence of the polymeric powder of 5 wt. % content at the rubbing zone provided the friction mechanism with a certain suitable number of polymeric particles adhered to the surfaces of sand particles and steel. Hence, the loaded particles of the polymer react as an elastic third body between the sliding surfaces and decrease the efficiency of the abrasive cutting process occurring between the sliding surfaces and sand particles. From the previous tests, it can be recommended that the antiwear action of lubricating greases can be improved by the addition of polymeric particles.

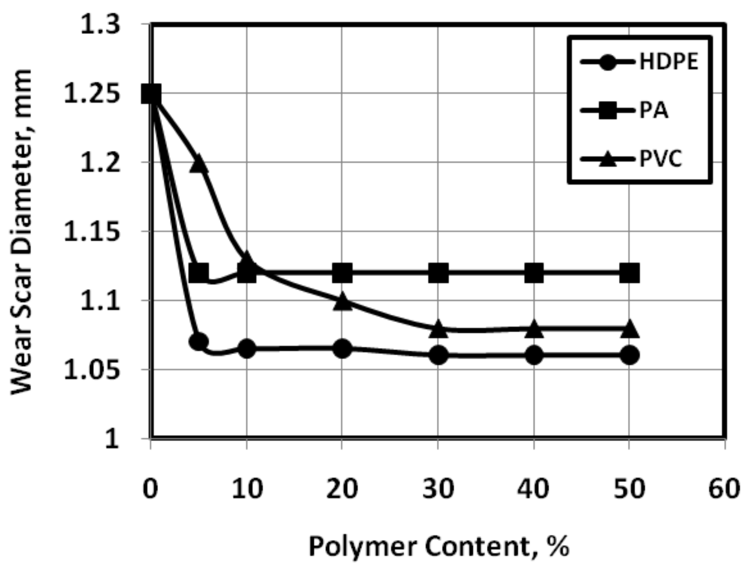

Fig. 3 The effect of dispersing grease by polymeric powder on wear of test specimens.

Further experiments were carried out to investigate the effect of the particle size of the polymer on friction coefficient and wear. Figures 4 and 5 show the friction coefficient and wear scar diameter of the test specimens lubricated with clean grease containing HDPE particle of sizes of 90 µm, 150 µm and 300 µm. It can be seen that, a general decaying trend for the friction coefficient was obtained by increasing the content of the polymer up to 35 wt. %, Fig. 4. Moreover, the coefficient of friction decreased by the increase of the particle size at constant content of HDPE, where minimum friction values were observed for 300 µm particle size. The friction decrease might attributed to the adherence of PE particles in the steel surface and preventing metal to metal contact.

Wear scar diameter drastically decreased as the PE content increased for particle sizes (0 – 90 µm) and (90 – 150 µm), Fig. 5. However, the optimal improvement of the wear resistance was achieved by PE particle size of 150 µm at content of 50 wt. %. PE of (150 – 300 µm) particle size showed wear reduction. It seems that that size was difficult to strongly adhere to the contact area. The mechanism of action of the PE particles was the adherence in the contact area forming a film that protected the surface from excessive wear.

Further experiments were carried out to explain the dependence of the friction coefficient and wear resistance of the rubbing surfaces on both of the particle size of the sand particles in the lubricating grease and that of the polymeric particles. Friction coefficient and wear scar diameter versus polymeric powder content at sand contaminated running condition were illustrated in figures 6 and 7 respectively. When the tested grease was dispersed by PE of (0 – 90 µm) particle size, friction coefficient drastically decreased down to minimum then increased with increasing PE content, Fig. 6. Minimum friction coefficient was observed at 10 wt. % PE content. The same trend was observed for PE of (150 – 300 µm) particle size accompanied by higher values of friction coefficient. PE of (90 - 150 µm) particle size showed an increased trend of friction with increasing PE content. The friction increase might be from the ability of PE particles to adhere in the surfaces of the sand particles as well as steel in a manner that the friction became between steel and PE particles.

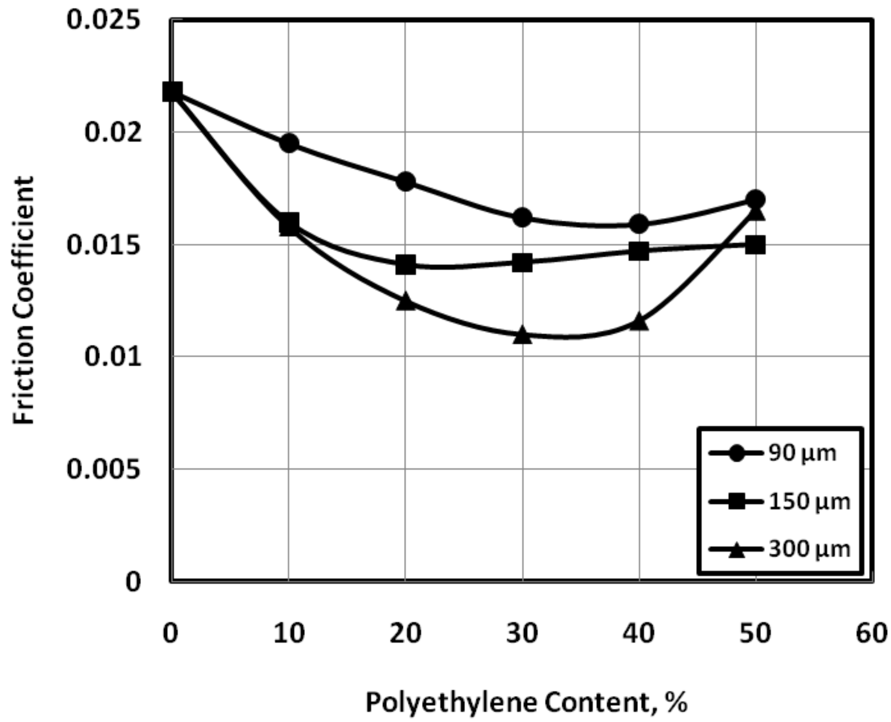

Fig. 4 The effect of particle size of polyethylene dispersing grease on friction coefficient displayed by the test specimens.

The effect of particle size of polyethylene dispersing abrasive contaminated grease on wear of the test specimens is shown in Fig. 7. Wear slightly decreased down to minimum then increased with increasing PE content. Minimum wear was observed at PE content ranging between 30 to 40 %. The best PE particle size was (90 - 150 µm) that gave the minimum wear due to the good adherence of their particles into the sand particles. This behavior was confirmed by the friction values shown in Fig. 6, where the improvement in wear was accompanied by slight increase of friction coefficient. The relation between the particle sizes of the polymer and the contaminants can explain wear reduction for the PE particle size of (90 - 150 µm). This phenomena can be attributed to the fact that the particle size of the contaminants is smaller than that of the deformed and non-deformed PE particles. In this condition PE particles would be able to coat at least the sharp corners of sand particles and retard the action of the three body abrasion into the steel surface.

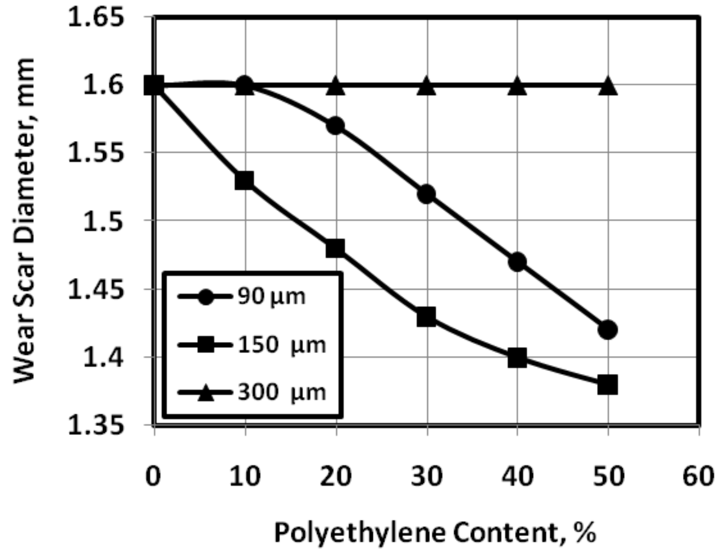

Fig. 5 The effect of particle size of polyethylene dispersing grease on wear of the test specimens.

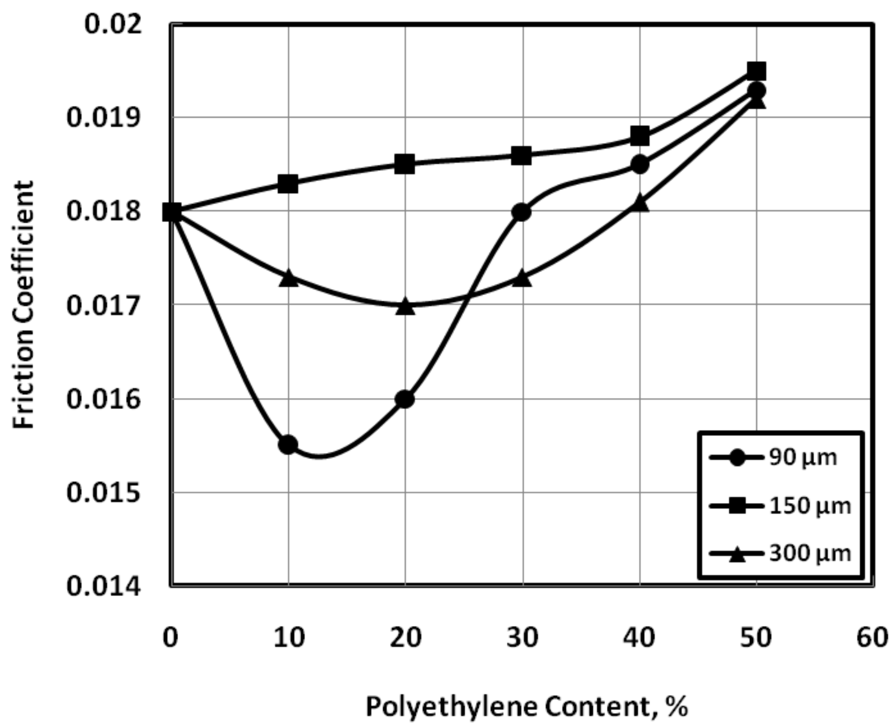

Fig. 6 The effect of particle size of polyethylene dispersing abrasive contaminated grease on friction coefficient displayed by the test specimens.

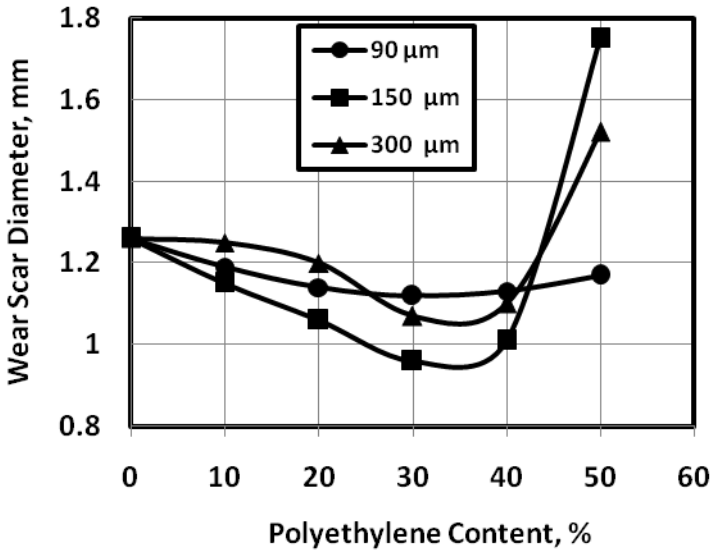

Fig. 7 The effect of particle size of polyethylene dispersing abrasive contaminated grease on wear of the test specimens.

Increasing particle size of the polymer to reach 300 µm decreased the number of the particles which prevent or eliminate the action of the three body abrasion mechanism. Also, this reduction of the number of active polymeric particles increased the stress generated from the applied load on them resulting in severe plastic deformation with a change of the spherical shape of the polymeric particles into flattened one. Hence, the use of extreme large polymeric particles in the lubricating grease has the similar effect as the small polymeric particles. Lubricating grease dispersed by polymeric particles with concentration of 50 wt.% displayed higher values of coefficient of friction and wear scar diameter due to the relative reduction of the apparent viscosity of the grease. It is important to notice that, the decrease of the apparent viscosity affects strongly both of the performance and flowability of the lubricating grease in the sliding zone.

CONCLUSIONS

From the results and discussion of the present work, the following conclusions can be drawn:

1. Dispersing lubricating greases by polymeric particles decreases both friction coefficient and wear.
2. Addition of polymeric particles of sizes greater than that of the sand contaminants to lubricating grease can be considered as a useful method of eliminating the cutting process introduced from the presence of the hard contaminated particles.
3. Among the tested polymers, HDPE showed the best performance in decreasing both friction and wear. The best content observed to minimize friction coefficient and wear.

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