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EFFECT OF LUBRICATING ADDITIVES ON THE PERFORMANCE OF ROLLING BEARINGS

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ABSTRACT

The present work discusses the effect of solid lubricant additives such as graphite, aluminum powders, molybdenum disulphide (MoS_2), polytetrafluoroethylene (PTFE), polyethylene (PE), polymethylmethacrylate (PMMA), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC) on the friction of rolling bearings. The tested solid lubricants are dispersed in lubricating greases. Performance tests were carried out using tribometer testing machine. A comparison performance was conducted using cement particles as contaminant in the tested grease at 10 wt. % content.

Based on the experimental observations, it was found that grease dispersed by solid lubricants and free of cement showed a decreasing trend of friction coefficient, where the lowest values were displayed by MoS_2 followed by aluminum particles then PTFE, PE, PP, PVC, graphite, PMMA and PS. While the lowest friction values of grease contaminated by cement were displayed by PMMA followed by MoS_2, PP, PVC, PE, PS, aluminum particles, graphite and PTFE.

The behavior of solid lubricants used in the present work can be explained on the ability of polymeric particles to adhere into the sliding surfaces by the help of the electric static charge generated on their surfaces as a result of the friction with the steel surface. Adhesion force depends on the deformed surface area of the polymeric particles which increases for soft polymers such as PE, PP, PTFE and PVC. As for hard polymers such as PMMA and PS, their particles roll on the sliding surfaces protecting them from extra friction. In addition, the ranking of polymeric materials in reducing wear caused by cement particles predicted that their ability depends on their adherence to the surfaces of solid contaminants and contact area. Knowing that the force of adhesion depends on the amount of electric charge generated during friction adherence, it can be recommended to select the polymeric materials according to their triboelectrification properties.

KEYWORDS
Lubricating additives, grease, friction coefficient, rolling bearings.

INTRODUCTION

Lubrication is critical for minimizing friction in mechanical systems that operate for extended time periods. Developing lubricants that can be used in engineering systems is very important for increasing the functional lifetime of mechanical components. Laboratory friction tests on cement mortar specimens, prepared with various fractions of limestone and emery sand, were carried out using the accelerated polishing machine and the British pendulum tester, [1]. It was found that the finer fractions are more effective in influencing the skid resistance value of mortars. The total surface area of hard particles determines the friction characteristics of the mortars.

Solid lubricant films, [2], have received considerable research attention in the last decades owing to their remarkable improved tribological characteristics. The abrasive wear behaviour of five types of solid lubricant films (magnetron-sputtered diamond-like carbon, magnetron-sputtered molybdenum disulfide, bonded molybdenum disulfide, bonded PTFE and bonded graphite) in sand-dust environment has been investigated. Experimental results showed the formed composite transfer layer plays a vital role in reducing friction and wear due to its anti-friction and protecting action of the film surface from the hard metal asperities.

Solid lubricant composite material was made by compression molding PTFE and ultra-fine kaolin particulates, [3]. Composites from 0 to 15 wt. % were prepared. These composites were tested against a 45 carbon steel counterface on a reciprocating tribometer. The friction coefficient of the composites increased over unfilled PTFE from roughly 0.12 to 0.22, at filler concentrations of 10 wt. %. The tribological performance of polymer materials (PP and PTFE) as solid lubricant filling lithium grease is discussed. The polymers addition is aimed to reduce the effect of main components of white cement such as sand, kaolin and limestone contaminating lithium grease on friction coefficient and wear of steel test specimens. Experimental results showed that a 15 wt. % PTFE added to lithium grease films gave excellent anti-friction and wear resistance performance, [4]. It was found that lithium grease should be dispersed by 20 wt. % oil to balance the contaminants and get the lowest friction and wear values. As the oil content, added to the grease, increased friction coefficient and wear slightly decreased.

Graphite and PMMA were used as solid lubricants dispersed in lithium grease, [5]. Their effect on friction and wear of moving surfaces contaminated by solid contaminants in the cement plant is discussed. It was found that, graphite caused slight increase in friction and significant reduction of wear, while PMMA in most case causes decrease in friction and wear. Besides, wear and friction decreased with increasing oil content in grease, Wear and friction decreased with increasing PMMA. Graphite displayed low wear and the friction coefficient increases gradually when graphite content increased.

The friction coefficient displayed by rolling bearing greased by lithium grease dispersed by solid lubricants such as graphite, molybdenum disulphide, talc and polymeric particles was investigated, [6]. It was shown that addition of talc showed significant increase in friction coefficient. Molybdenum disulphide displayed relatively lower friction coefficient than graphite and talc. Copper particles dispersed in grease displayed the lowest friction values. Grease dispersed by high density polyethylene showed friction decrease. The lowest friction reduction was observed for PMMA. The strong adhesion of PTFE particles into the sliding surfaces significantly increased

friction coefficient. It seems that PTFE particles were adhered to surfaces of inner and outer races as well as the balls.

Performance of robots mainly depends on frictionless rotation and linear movement. Sand particles as solid contaminants inside the bearings cause significant friction increase and shorten their life time. Wear particles, collected from the bearings of an industrial robot, were examined by optical microscope to reveal details of size, shape and quantity, [7, 8]. Generation of large severe wear particles that signal the imminent failure of wearing surface was detected. Particles in the form of loops, spirals, and bent wires were generated, where increase in the number and size of these particles showed that an abrasive wear mechanism was progressing rapidly. Sand particles of different size in relatively high concentration were detected. Friction increase caused by sand particles can cause positioning errors and inconsistent motions of robots and manipulators running in dusty environment. The effect of concentration and particle size of sand contaminating the moving surfaces on the friction coefficient was discussed, [9]. Based on the present observations, it was found that, friction coefficient displayed by base oil free of sand particles showed low fluctuations in friction coefficient which approached 12. 5 %, while in the presence of sand particles of 0.2 wt. % content friction coefficient showed percentage fluctuations of 26.6 %. As the sand particles content increased up to 0.5 wt. %, the fluctuations of friction reached 200 % of the mean value which reflected unstable performance. In the presence of sand of (3 – 5 µm) size, friction showed relatively high fluctuations. Friction coefficient showed wavy performance with the time when the particle size of sand particles increased up to 20 µm. The fluctuations as well as the wavy behaviour of friction coefficient can influence the response of the robot motion and disturb positioning error. It is recommended to compensate the friction caused by sand particles contaminating the lubricating oil.

The present work discusses the effect of the tested solid lubricant additives on the friction of rolling bearing. The tested solid lubricants are dispersed in lubricating grease.

EXPERIMENTAL

Experiments were carried out using a test rig, Fig. 1, to measure the friction torque of the tested rolling bearing mounted on a rotating shaft. A locking nut is being mounted towards the bearing inner race on the threaded end of the shaft. The other end of the shaft was installed in a chuck Fig. 2. The chuck was mounted on the main rotating shaft, driven by a motor and gearbox, where the velocity was controlled by an electrical inverter. The outer race of the bearing is loaded by a weight of 100 N over a loading block which is connected by an arm with a load cell connected to a monitor.

The load cell is used to measure the frictional torque generated between the bearing rolling elements and its races. Normal load is applied by the mean of weight attached to the load lever. Friction coefficient is determined by the ratio between the friction force and normal load. Test specimens consist of the tested rolling bearings mounted on a shaft of 180 mm length and diameter of 20 mm, while at one end of the shaft diameter had been reduced to 15 mm fitted to the bearing inner race diameter with the same width of bearing. A thread had been created matching a locking nut of M10 diameter. Bearings designation is 6002, (single raw deep groove ball bearing), with 15 mm internal diameter, 9 mm width and 32 mm outer diameter.

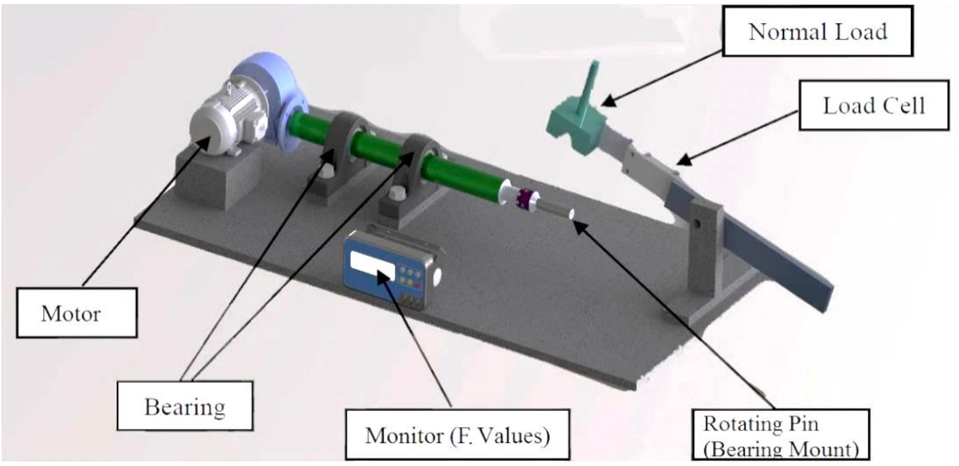

Fig.1 Arrangement of the test rig.

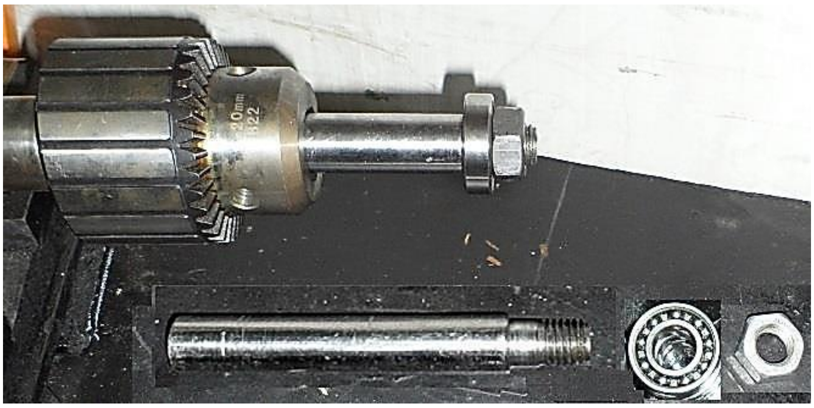

Fig. 2 Installation of the tested bearing.

Experiments were carried out at 500 rpm rotating speed and 100 N load. Bearing was greased before the start of the experiment by filling about 25% of the empty spaces between the inner and outer races. Experiments time was 60 minutes. Bearings were greased by lithium thickener type grease, NLGI class 2, (an extreme pressure (EP) grease) contaminated by cement of 10 wt. % of the total grease as well as10 wt. % additive content. Experiments time was 60 minutes for both clean and contaminated grease. Additives were prepared by adding the additive powder to the double volume of paraffin oil, and the mixture was added to grease according to the required content percentage. A digital monitor was connected to the load cell in order to detect the friction force. The coefficient of friction was determined by the ratio between the friction force and normal load. Measurements were recorded every two minutes, average was considered.

RESULTS AND DISCUSSION

Grease dispersed by graphite showed a decreasing trend of friction coefficient down to minimum then slightly increased with increasing graphite content, Fig. 3. The minimum friction value (0.04) was displayed at 10 wt. % graphite content. The mechanism of action of solid lubricant dispersion can be explained on the basis that the particles fill the pits and valleys in the roughness of the sliding surface, thereby increasing the contact area and providing a reservoir of lubricant. This performance will be enhanced if the particles are strongly adhered to the contact area and the shear strength of the solid lubricant is less than the adhesion to the substrate. In addition, a film of solid lubricant is built up of sufficient thickness to cover the contact area completely, and sliding takes place between two smooth oriented layers of lamellar solid lubricant. In the presence of cement particles contaminating the grease, friction coefficient showed an increasing trend up to maximum then decreased with increasing graphite content. The maximum friction value (0.07) was displayed at 10 wt. % graphite content. The friction of the contacting surfaces produced electric static charge on both the two sliding surfaces. The sign and amount of the charge depended on the location of the surface materials and grease in the triboelectric series. In the presence of graphite as conducting medium the sliding surfaces could not keep the electric charge and consequently the adherence of graphite into the steel surfaces was interrupted.

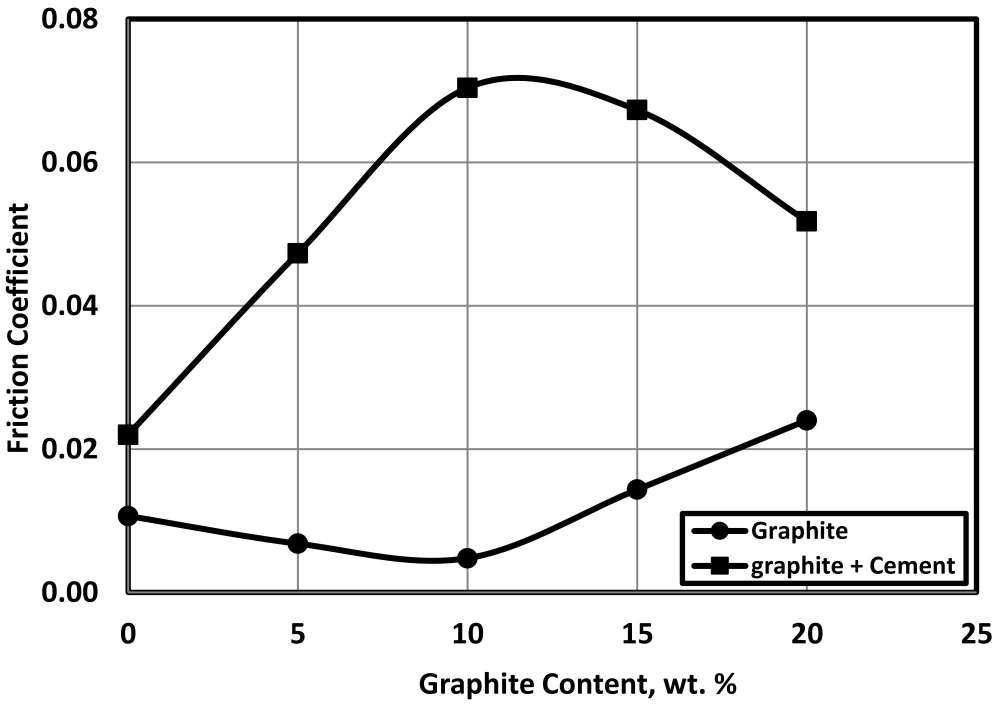

Fig.3 Effect of graphite content on friction coefficient displayed by rolling bearing.

Friction coefficient displayed by rolling bearing containing aluminium particles dispersed in the grease, Fig. 4, slightly increased with increasing aluminium content. Based on the triboelectric series, it is well known that aluminium particles have positive charge as a result of their friction with steel, so that they were adhered to the steel surface forming an aluminium layer. In that condition, the contact was steel/aluminium. In the presence of cement contamination, friction coefficient significantly increased up to maximum then decreased with increasing aluminium content. The highest friction values were observed at 10 wt. % aluminium content. It seems that aluminium particles adhered into the steel had separated the two sliding steel surfaces. The friction decrease clearly was observed at 20 wt. % aluminium content.

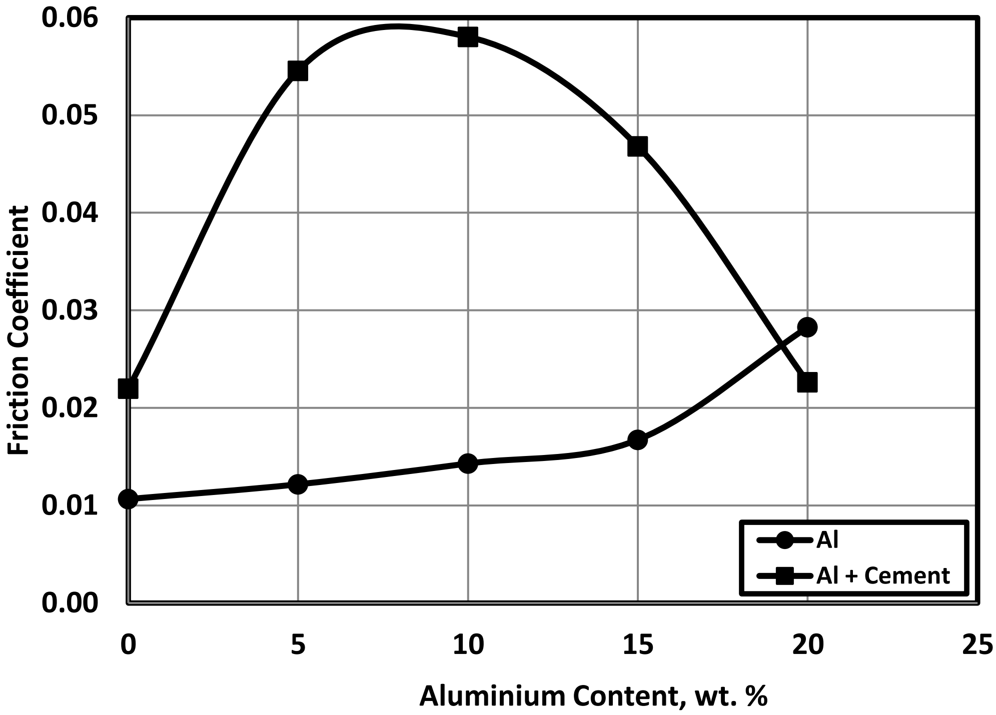

Fig. 4 Effect of aluminium content on friction coefficient displayed by rolling bearing.

Addition of MoS_2 into the grease caused slight friction increase, Fig. 5. Although MoS_2 has quite good surface adherence attributed to strong metal-sulfur bonds and shears easily to give low friction due to the weakness of the sulfur-to-sulfur bond, this behaviour was not observed for grease free of cement. The highest and lowest friction values were observed at 15 and 20 wt. % MoS_2 respectively. The mechanism of action of the grease was to keep the two contacting surfaces away from each other by forming a protecting layer on the sliding surfaces. Drastic friction decrease was observed in the presence of cement particles with increasing MoS_2 content. The friction decrease might be attributed to the ability of $MoS_2$to be adhered to the surface of cement particles and rubbing surfaces, forming relatively thick layer making the cement less abrasive and protecting the rubbing surfaces from excessive friction.

Friction coefficient displayed by rolling bearing dispersed by PE particles showed relatively lower values, Fig. 6. Based on the triboelectric series, it is well known PE has negative electric static charges resulted from their friction with steel. Therefore, some of those particles strongly were adhered to the steel surface protecting it from excessive friction. The tendency of the adherence of PE particles into the surface of steel depends on their location in the triboelectric series. The relatively low yield strength of PE enabled its particles trapped between the two sliding surfaces to be completely deformed, where they consequently covered efficiently the contact area more than the other tested polymers. The lowest friction coefficient (0.03) was displayed at 15 - 20 wt. % PE content. Friction coefficient displayed by rolling bearing contaminated by cement showed drastic decrease with increasing PE content. The decrease in friction values

observed for PE was due to the relatively strong negative charge generated on its particles and consequently cement particles were strongly adhered by PE particles.

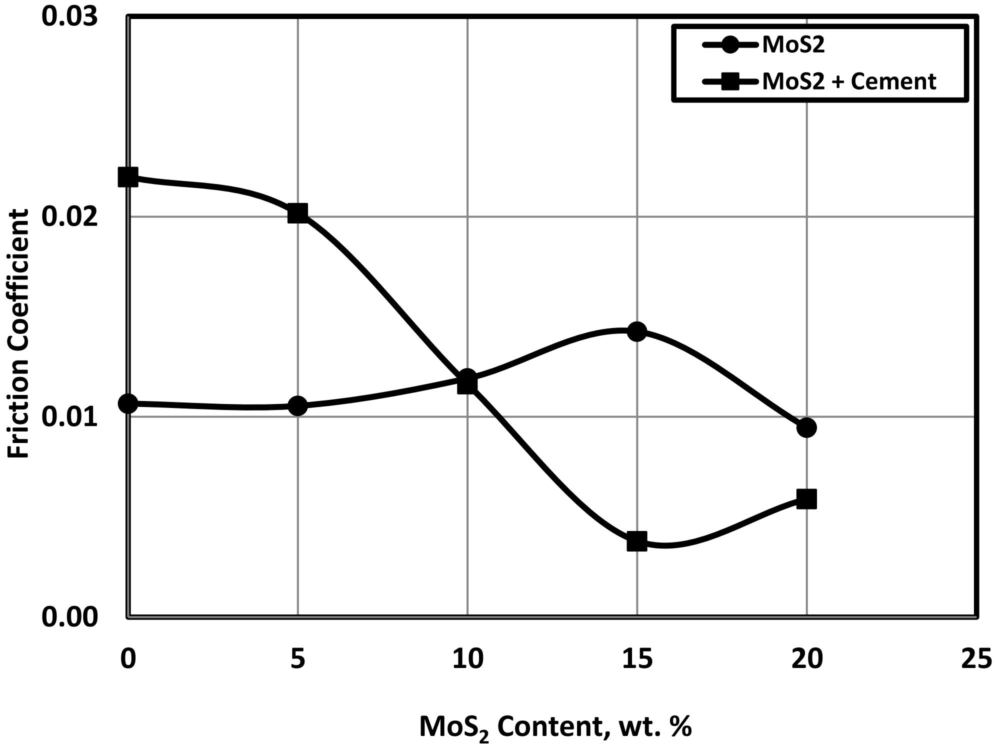

Fig. 5 Effect of MoS_2 content on friction coefficient displayed by rolling bearing.

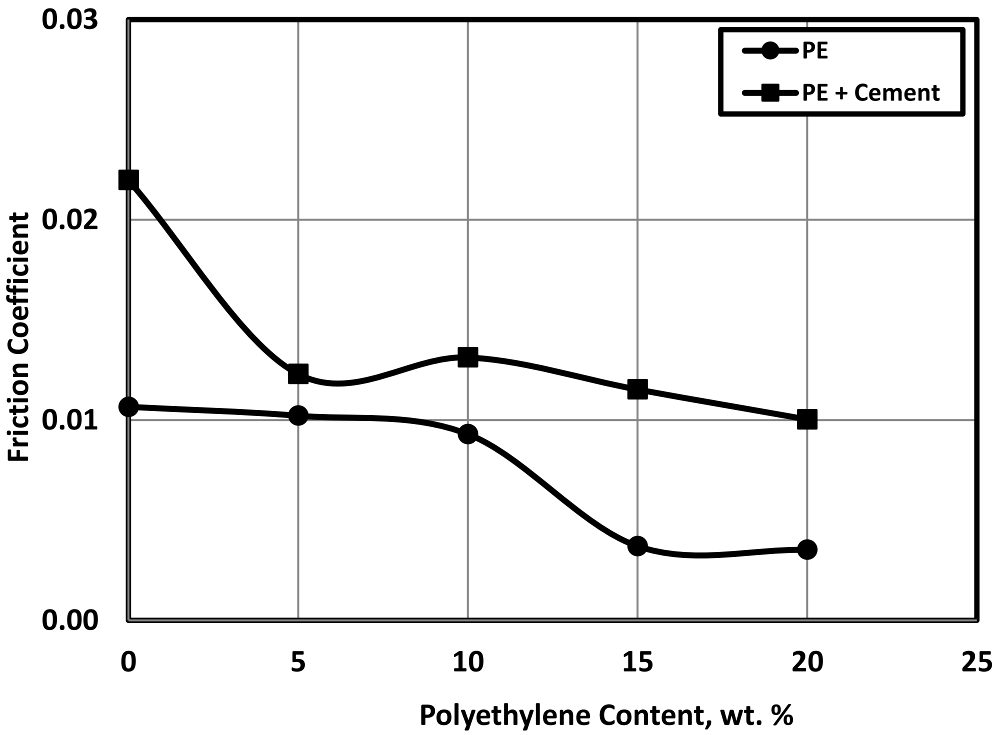

Fig. 6 Effect of PE content on friction coefficient displayed by rolling bearing.

Effect of PMMA content on friction coefficient displayed by rolling bearing is illustrated in Fig. 7, where the lowest friction value (0.0495) was observed at 10 wt. % PMMA. Based on the triboelectric series it is well known that, PMMA has positive charge when sliding against steel. PMMA is considered as hard polymer, where their particles tend to roll than to be deformed on the contact surface. Therefore, rolling of PMMA particles on the sliding surfaces was responsible for friction reduction through protecting the contact area from abrading action of steel counterface. Further increase of PMMA content caused significant friction increase due to the increased friction of PMMA particles themselves. PMMA content of 10 wt. % showed the lowest friction value displayed by rolling bearing contaminated by cement. Most polymer films are more plastic than metals, and many of them have sufficient ductility to deform together with the topography of the contact surface. Thus they form a film on the contact surface. The presence of cement contaminants in the grease contained by rolling elements can have a harmful effect on bearing service life as well as lead to a significant failure of component surface, [10, 11]. Cement contaminants are undesirable in grease lubricated machine elements, because grease is an effective carrier and tends to hold the foreign particles in the contact area where they do the most damage.

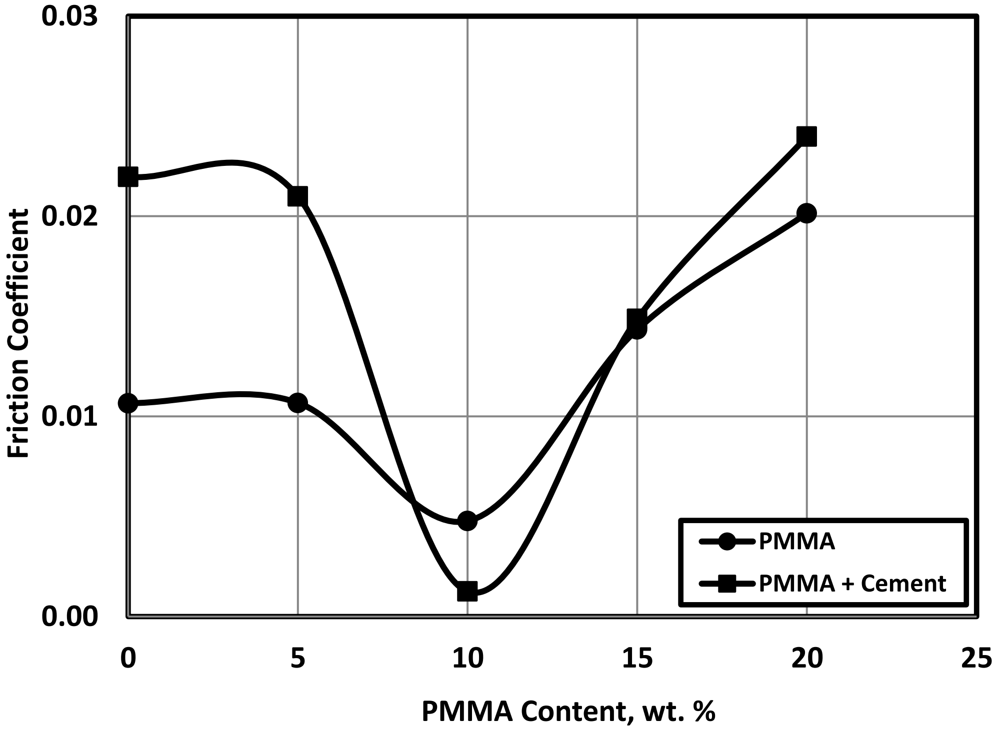

Fig. 7 Effect of PMMA content on friction coefficient displayed by rolling bearing.

It was shown that an 80 to 90 percent reduction in bearing life compared to that as measured in clean lubricant resulted when ceramics, silica and iron particles were continuously fed into the bearing lubrication system, [12]. Furthermore, the presence of wear debris in the lubricant can lead to gross wear damage and failure, [13 - 19]. Friction increase will continue as long as contaminant particle size exceeds the thickness of the lubricant film separating the bearing surfaces. Addition of PP in content of 20 wt. % into the grease showed very low friction value (0.035), Fig. 8. When two different

materials are pressed or rubbed together, the surface of one material will generally gain some electrons from the surface of the other material. The material that gains electrons has the stronger affinity for negative charge of the two materials, and that surface will be negatively charged after the materials are separated. The other material will have an equal amount of positive charge. The amount and polarity of the charge on each surface can be measured for insulating materials. The triboelectric series predict which will become positive or negative and how strong the electric charge will be. The influence of cement contaminants on the mechanism of surface damage was investigated can be discussed on the fact that 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. Cement particles which enter the bearing together with the lubricant damage the contact surfaces by indentations. The material edged up around the indentation penetrates the lubricant film and causes local mixed friction. PP content caused significant decrease in friction coefficient displayed by rolling bearing contaminated by cement. The lowest friction coefficient (0.065) was observed at 20 wt. % PP.

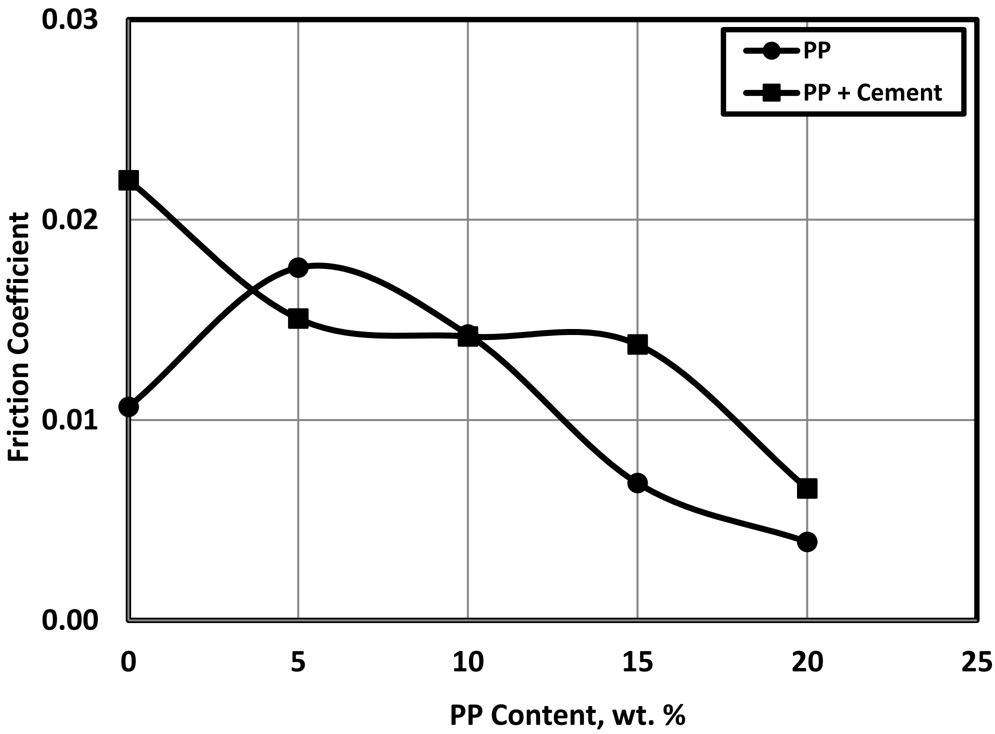

Fig. 8 Effect of PP content on friction coefficient displayed by rolling bearing.

Dispersing the grease by PS caused significant increase in friction coefficient up to maximum then decreased with increasing PS content, Fig. 9. This behaviour might be attributed to the ability of polymeric particles to roll or adhere on the sliding surfaces by the help of the electric static charge on their surfaces as a result of the friction with the steel surface. PS particles as relatively hard polymer tended to roll than to adhere into the steel surface. As the PS content increased to 20 wt. % friction coefficient decreased. PS content of 15 wt. % showed significant decrease in friction coefficient displayed by rolling bearing contaminated by cement. It seems that the rolling of PS particles on the sliding surfaces was responsible for friction decrease through protecting the contact area from extra friction of steel counterface.

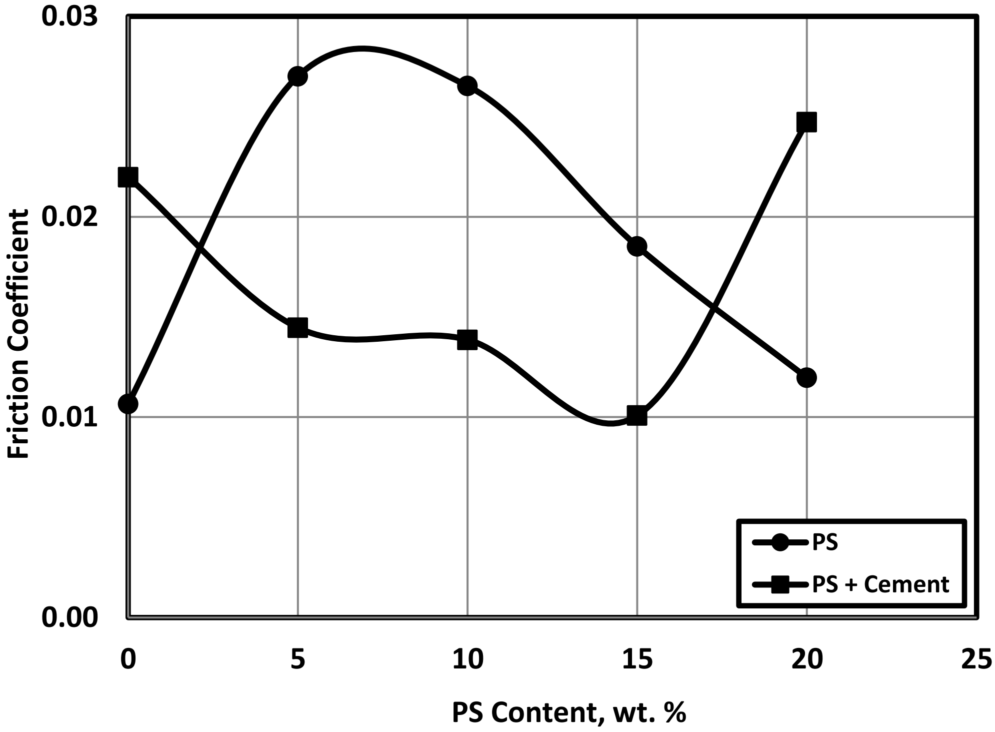

Fig. 9 Effect of PS content on friction coefficient displayed by rolling bearing.

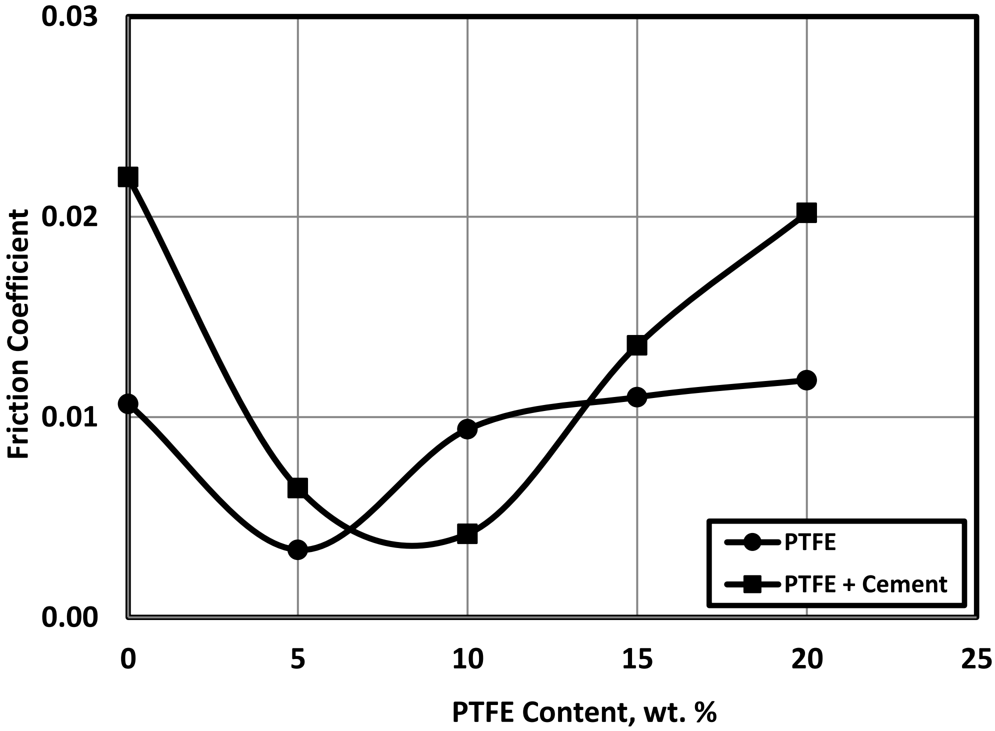

Fig. 10 Effect of PTFE content on friction coefficient displayed by rolling bearing.

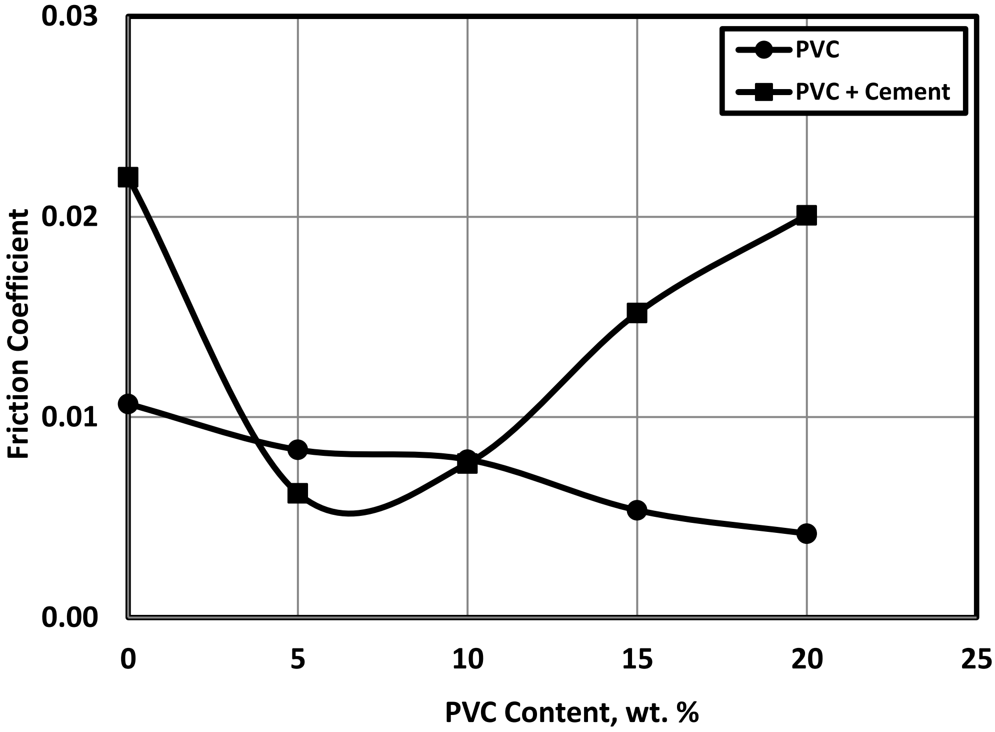

Fig. 11 Effect of PVC content on friction coefficient displayed by rolling bearing.

PTFE as thickener in lubricating greases was thought to be promising for applications requiring higher loads or very low torques. PTFE in thin film form, can exhibit lower friction than any other known polymer and lack of chemical reactivity. The low friction of PTFE is attributed to the smooth molecular profile of the polymer chain which, after orientation in early stages of sliding, can then slip easily over each other. It was found that the effect of abrasive contaminants can be reduced by dispersing the grease by polymeric powders.

It was expected that relatively soft polymeric particles are more effective in reducing the abrasion action of cement particles than PMMA and PS. The electric static charge generated from the friction of PTFE with steel is much higher than that generated from the PE and PMMA. The adherence of PTFE in the surface of cement particles decreased the ability of cement to abrade the sliding surfaces and consequently decreased friction. Friction coefficient displayed by the sliding surfaces greased by cement free grease dispersed by PTFE is shown in Fig. 10. PTFE of 5 wt. % content displayed the lowest friction coefficient. Friction decrease might be attributed to the effect of PTFE adhesion into the sliding surfaces. When the grease was contaminated by cement, a relative improvement of the friction coefficient of the rubbing surfaces was displayed at 10 wt. % PTFE content. It is clear that ranking of polymeric materials in reducing friction caused by solid contaminants depends on their adherence to the surfaces of sand particles and contact area.

PVC displayed a decreasing trend of friction coefficient as the content increased, Fig. 11. Friction decrease observed for PVC might be attributed to its adhesion into the sliding surfaces. The lowest friction coefficient (0.04) was observed at 20 wt. % PVC. It is known that the ability of polymeric particles to be adhered into the sliding surfaces by the help of the electricstatic charge generated on their surfaces as a result of the friction with each other and the steel surfaces is the major factor of controlling friction. Adhesion force depended on the deformed surface area of the polymeric particles which increases with soft polymers. PVC as soft polymer displayed low friction value at 5 wt. % content for cement contaminated grease. That observation confirmed the good ability of PVC to defeat the action of cement contaminants in the grease.

CONCLUSIONS

1. Grease dispersed by graphite showed a decreasing trend of friction coefficient down to minimum then increased with increasing graphite content. The minimum friction value (0.04) was displayed at 10 wt. % graphite content. In the presence of cement particles contaminating the grease, the maximum friction value (0.07) was displayed at 10 wt. % graphite content.

2. Friction coefficient significantly increased with increasing aluminium content. In the presence of cement contaminants, the highest friction values were observed at 10 wt. % aluminium content.

3. Addition of MoS_2 into the grease caused slight friction increase. As for cement contaminated grease, drastic friction decrease was observed with increasing MoS_2 content.

4. Friction coefficient displayed by PE particles showed relatively lower values. Temperature rise showed relatively higher values than MoS_2. When cement was contaminating the grease, friction coefficient showed drastic decrease with increasing PE content.

5. Addition of PMMA into grease displayed relatively higher friction value (0.0495) at 10 wt. % PMMA. In the presence of cement, PMMA content of 10 wt. % showed the lowest friction value.

6. Addition of PP in content of 20 wt. % into the grease showed very low friction value (0.035). PP content caused significant decrease in friction coefficient displayed by rolling bearing contaminated by cement. The lowest friction coefficient (0.065) was observed at 20 wt. % PP.

7. Dispersing the grease by PS caused significant increase in friction coefficient up to maximum then decreased with increasing PS content. PS content of 15 wt. % showed significant decrease in friction coefficient in the presence of cement.

8. Friction coefficient of grease dispersed by PTFE of 5 wt. % content, displayed the lowest friction coefficient. Relative improvement of the friction coefficient of the rubbing surfaces was displayed at 10 wt. % PTFE content in presence of cement.

9. PVC displayed a decreasing trend in friction coefficient with increasing its content. The lowest friction coefficient (0.04) was observed at 20 wt. % PVC for 5 wt. % cement contaminated grease.

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