Effect of Graphene Nano Particles Dispersing Lithium Grease on the Tribological Behaviour of Steel Surfaces

Gomaa, A. A.
Production Engineering and Mechanical Design.
El-Minya High Institute of Engineering and Technology, El-Minya, EGYPT.
Eng_mizzoo1@yahoo.com.

Khashaba, M. I.
Production Engineering and Mechanical Design.
Faculty of Engineering, Minia University.
El-Minya, EGYPT.

***Abstract*—Friction and wear between bearing surfaces are important reasons for failure of mechanical components. The search for new additives with excellent tribological properties has attracted considerable interest. In this paper, the friction and wear of steel surfaces are discussed. Graphene nano particles dispersing lithium grease were used as lubricant. Graphene addition is aimed to reduce the effect of sand particles, which is considered as the most abrasive component of white cement contaminating lithium grease, on friction coefficient and wear of steel test specimens. Experimental results show that a 0.4 wt. % graphene nano filler added to lithium grease gave good anti-friction and wear resistance performance, but the best tribological results of nano graphene appeared clearly after adding 10 wt. % PMMA to the grease, which facilitated rolling of sand particles on the steel surfaces. Besides, the results indicates that lithium grease should be dispersed by 20 wt. % oil to balance the effect of contaminant. As the oil content, added to the grease, increased friction coefficient and wear decreased.**

Keywords—Graphene, Nano Technology, Friction, Wear, Grease, Solid contaminants, Sand, Cement plant, Lithium Grease, PMMA.

Introduction

Friction, wear and fatigue are three most commonly encountered industrial problems leading to the replacement of components and assemblies in engineering [1]. The abrasive wear, [2], behaviour of many materials is closely related to their hardness. However, classical wear models do not take into consideration the contact scale dependence of hardness, an effect commonly known as indentation size effect (ISE). Scores of abrasive wear problems particularly those in the harsh environments involve remarkable breakage of the abrasive [3]. 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, [4, 5]. 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, [6]. Wear by hard particles occurs in many different situations such as with earth-moving equipment, slurry pumps or pipelines, rock drilling, rock or ore crushers, pneumatic transport of powders, dies in power metallurgy, extruders, or chutes. More particularly in the moon probe project, the sand dust environment contains small, angular and irregularly shaped particles that have demonstrated high wear and abrasion on mechanical and sealing systems. In abrasive wear, the material is displaced or detached from the solid surface by hard particles or hard particles between or embedded in one or both of the two solid surfaces in relative motion, or by the presence of hard protuberances on the counterface sliding with the velocity relatively along the surface. Therefore, one of the best alternatives to resolving the tribological problems of mechanical systems in sand-dust environments is to apply effective protective films with good wear resistance and friction-reducing capacity on the moving parts. The intention of this work was to elucidate the role of sand dust in determining the tribological performance of selected solid lubricant films. The friction and wear behaviour of these films were compared and the influence of amount of contaminant examined. The effect of solid contaminants on the wear process for a cement factory was experimentally quantified. White Portland cement or white ordinary Portland cement (WOPC) is similar to ordinary, gray Portland cement in all respects except for its high degree of whiteness, [7]. Due to the large surface to volume ratios, nano/micro-structured functional materials have been predicted and demonstrated to be excellent functional material, [8]. Approximately, [9], 10 nm Fe_3O_4 magnetic nano-particles (MNPs), modified by oleic acid, were used as lubricant additives and dispersed into base oil. The tribological properties of 0.45% carbon steel were investigated in sliding contact against 440 C stainless steel lubricated with various concentrations of Fe_3O_4 MNPs. The results show that the coefficient of friction and wear – loss – volume can be reduced efficiently with addition of Fe_3O_4 MNPs. Nowadays, [10], different materials with various nanostructures are used as additives for improving properties of lubricants. The effect of multi-walled carbon nanotubes (MWCNTs) in different concentrations on some of the properties of engine oils was studied. Viscosity, pour point, flash point and thermal conductivity as four quality parameters, which are effective in functionality of engine oil, were also studied. Among the different methods, which have been applied for dispersing nanotubes inside the base oil, the functionalization method for carbon nanotubes and using planetary ball mill have been determined as the best methods for stabilization of nanotubes inside the SAE 20 W50 engine oil. According to the obtained results, thermal conductivity and flash point of nano-lubricants with 0.1 wt. % improved by 13.2% and 6.7%, respectively, with respect to the base oil. Graphene is a kind of very promising filler, [11]. Graphene, [12], is a two dimensional one atom thick allotrope of carbon that displays unusual crystal structure, electronic characteristics, charge transport behavior, optical clarity, physical & mechanical properties, thermal conductivity and much more that is yet to be discovered. Consequently, it has generated unprecedented excitement in the scientific community; and is of great interest to wide ranging industries including semiconductor, optoelectronics and printed electronics. Graphene is considered to be a next-generation conducting material with a remarkable band-gap structure, and has the potential to replace traditional electrode materials in optoelectronic devices. It has also been identified as one of the most promising materials for post-silicon electronics. For many such applications, modulation of the electrical and optical properties, together with tuning the band gap and the resulting work function of zero band gap graphene are critical in achieving the desired properties and outcome. In understanding the importance, a number of strategies including various functionalization, doping and hybridization have recently been identified and explored to successfully alter the work function of graphene. In this review we primarily highlight the different ways of surface modification, which have been used to specifically modify the band gap of graphene and its work function. This article focuses on the most recent perspectives, current trends and gives some indication of future challenges and possibilities.

Due to its atomic thickness (thinness), the wear of graphene in nanoscale devices or as a protective coating is a serious concern. It is highly desirable to develop effective methods to reduce the wear of graphene. In the current paper, the effect of a nano-lubricant, perfluoropolyether, on the wear of graphene on different substrates is investigated. The nano-lubricant is applied on the graphene by dip-coating. The friction and wear of graphene samples are characterized by nanotribometer. The results showed that lubricating silicon/graphene with nano-lubricant reduces the friction but increases the wear. However, lubricating nickel/graphene with nano-lubricant has little effect on the friction but reduce the wear significantly. The underlying mechanism has been discussed on the basis of the graphene–substrate adhesion and the roughness. The current study provides guidance to the future design of graphene-containing devices, [13].

EXPERIMENTAL

Experiments were carried out using a cross pin tester, Fig. 1. It consists, mainly, of rotating and stationary pins of 18 mm diameter and 180 mm long. 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 test machine is driven by AC motor (560 watts, 1280 r.p.m.) through reduction unit (1:7.5). Moreover, 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. Rotational speed was 170 r.p.m. and 10N Normal load was applied by means of weights attached to a loading lever. The rotating specimens were greased before the test and further greasing was carried out every 30 sec during the test. The test time was 5 min. A digital screen was attached to the load cell to detect the friction force. Coefficient of friction is determined by the ratio between the friction force and normal load and wear is determined by measuring the scar diameter on the optical microscope and calculating depth of the dome, then, calculating the wear volume, Fig. 2. The test specimens are prepared from carbon steel (St. 60), (0.6 wt. % C, 0.25 wt. % Si, 0.65 wt. % Mn, 0.045 wt. % P and 0.045 wt. % S). Experiments were carried out at 25 °C using lithium based grease dispersed by the solid additives of Graphene nano particles, PMMA particles have grain size up to 150 µm, and the grain size of sand which contaminated lithium grease is up to 150 µm.

In geometry, [15], a spherical cap or spherical dome is a portion of a sphere cut off by a plane due to wear. If the plane passes through the center of the sphere, so that the height of the cap is equal to the radius of the sphere, the spherical cap is called a hemisphere could be seen on figure 2.

If the radius of the base of the cap is a, and the height of the cap is h, then the volume of the spherical cap is

$$V = \frac{\pi h}{6}(3a^2 + h^2) \quad (1)$$

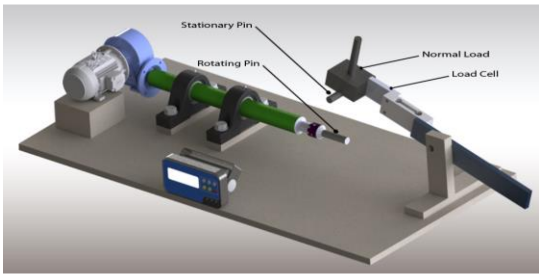

Figure 1 Layout of cross pin wear tester.

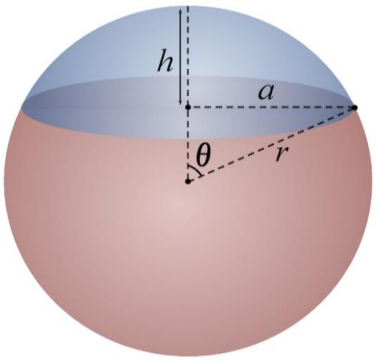

Figure 2 Wear volume dimensions, [15].

RESULTS AND DISCUSSION

The most abrasive element in white Portland cement or white ordinary Portland cement (WOPC) is sand particles, where it's percent is 11 wt. %, [14]. Friction increased with increasing sand content in lithium grease because they have irregular shapes. Friction slightly increased with increasing oil content, adding oil content makes good distribution to lithium grease at the contact area and balance the effect of contaminants. This can be attributed to the improvement of the oil dispersion over the running surface, illustrated in figure 4.

Wear volume increased after adding sand particles to lithium grease due to the sharpness and hardness of their irregular particles, adding 20 wt. % synthetic oil to lithium grease decreased the wear values caused by sand particles, because oil content facilitates the movement of sand particles, shown in figure 5.

Increasing sand content in lithium grease leads to increase friction coefficient. Due to its atomic thickness (thinness), the friction of graphene in nanoscale devices or as a protective coating is a serious concern. It is highly desirable to develop effective methods to reduce the friction. It can be seen that, the values of friction decreased with increasing nano graphene content up to 0.4 wt. %, which made a protective thin layer between the contact surfaces illustrated in figure 6.

Figure 3 Sharp and irregular sand particles.

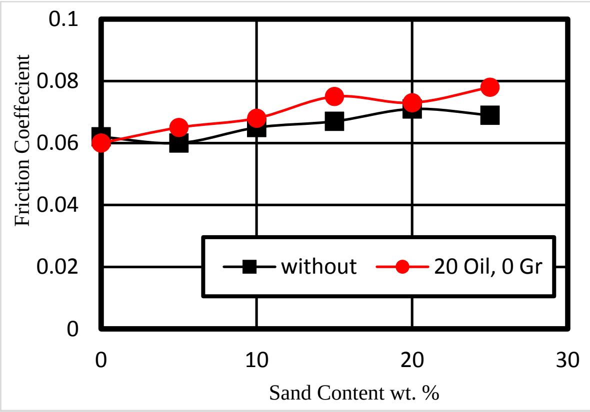

Figure 4 Effect of sand content on friction coefficient.

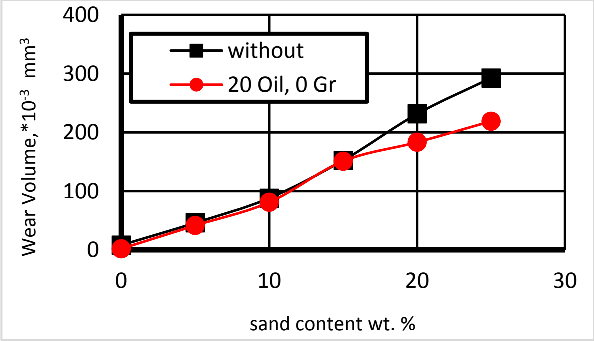

Figure 5 Wear volume of specimens Caused by abrasive sand particles.

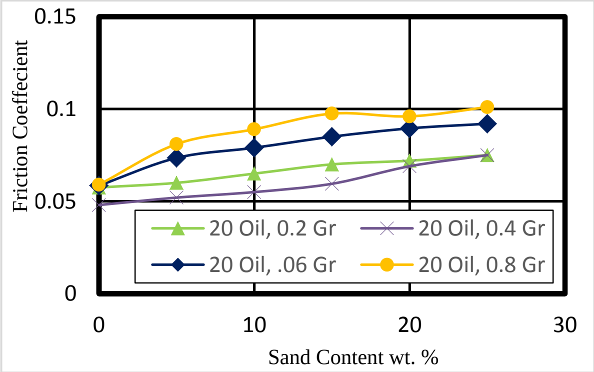

Figure 6 Friction coefficient of specimens with grease different contents of nano graphene and sand.

Figure 7 shows that, the tribological properties of grease can be improved significantly by addition of graphene nano particles. There exists an optimum graphene nano particles concentration, where the grease can exhibit simultaneously optimal anti-wear and friction-reducing properties. Meanwhile, the final tribological performances of the grease not only depend on the mechanical properties of tribofilm formed with graphene nano particles, but also lie on the selectivity of the best concentration of nano particles (0.4 wt.%).

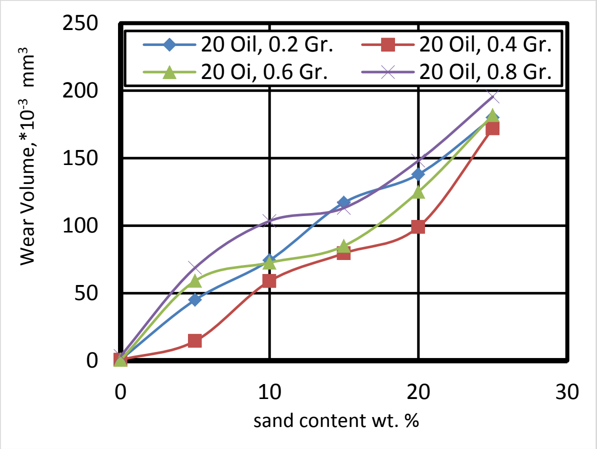

Figure 7 Effect of nano graphene content on wear volume of specimens.

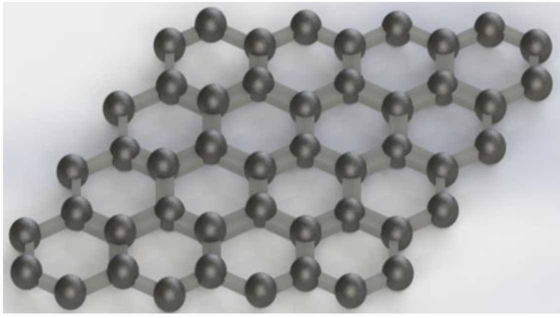

Figure 8 Graphene layer.

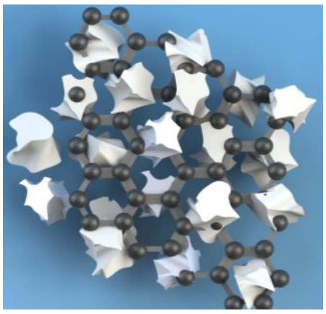

Figure 9 Nano particles coated the contact area.

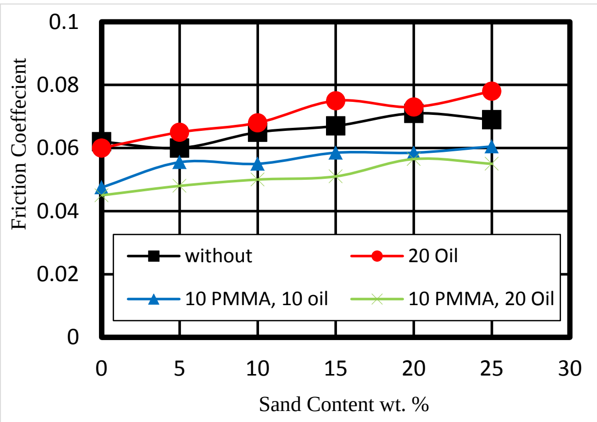

Figure 10 Effect of sand and PMMA contents on the coefficient of friction.

The analysis in figure 10 indicates that, friction slightly increased with increasing oil content, where oil content made good distribution to lithium grease between the steel specimens. After adding particles of PMMA to lithium grease the friction values decreased, adding PMMA to lithium grease facilitates the rolling between the contact surface and reduced friction values

Figure 11 shows that, wear volume decreased after adding 20 wt. % oil to lithium grease, when PMMA were added to the grease, wear values decreased. Because of PMMA particles featuring good tribological properties that resulted in the formation of improved boundary lubrication films.

Friction coefficient increased with increasing sand content because of the sharpness and irregularity of its particles. PMMA particles facilitate rolling between the specimen surfaces and reduced friction. Due to the large surface to volume ratios, nano-structured functional graphene have been predicted and demonstrated to be excellent tribological material, shown in figure 12.

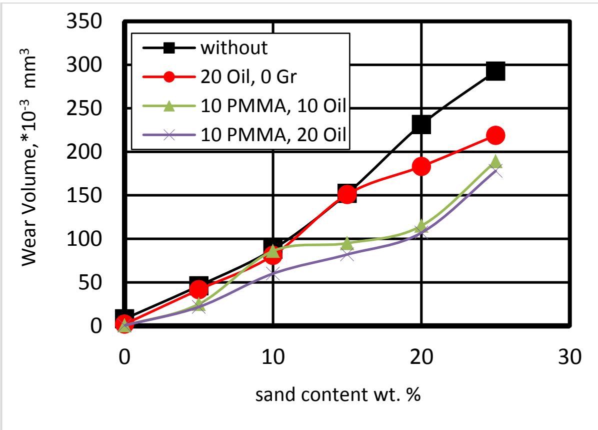

Figure 11 Relation between sand content and wear with different contents of PMMA and oil.

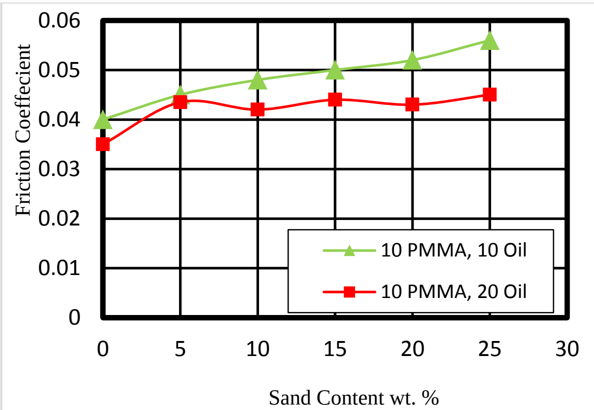

Figure 12 Friction coefficient of specimens after adding 0.4 wt. % graphene and different contents of sand content.

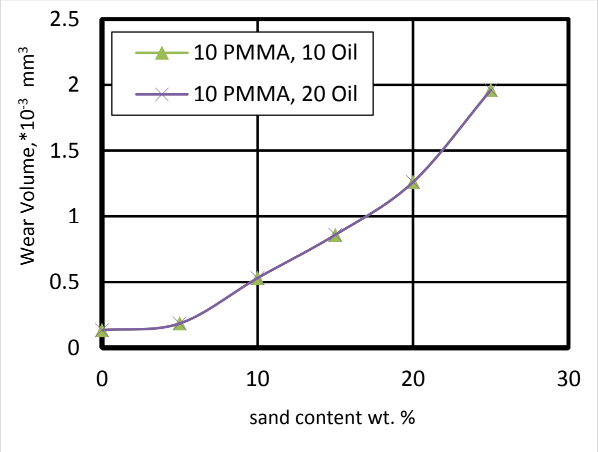

Figure 13 *Effect of few layer (0.4 wt. %) from nano graphene on wear of sliding surfaces.*

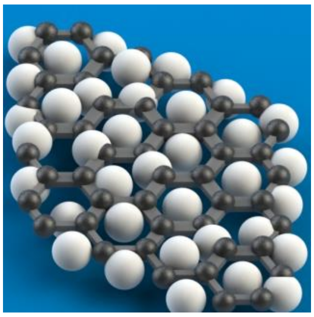

Figure 14 *PMMA particles with graphene nano particles.*

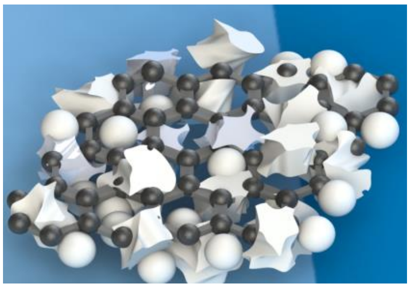

Figure 15 *Nano graphene and PMMA particles with sand particles.*

Relation between wear volume and sand content added to lithium grease shown in figure 13. Increasing sand particles leads to increase the wear volume, because the abrasive sand particles penetrates surface of steel specimen, adding 10wt.% PMMA to lithium grease prevented the particles of the sand from this penetration. 0.4 wt. % Graphene nano particles are excellent nano fillers for enhancing the tribological performance of lithium grease. GNPs are able to reduce friction and, especially, to increase the wear resistance due to the exfoliation of the nano particles that creates an adhered protective tribofilm.

Conclusion

The present experimental study confirms that, Friction and wear values decrease with increasing graphene nano particles up to 0.4 wt. %. Graphene layers act as a two-dimensional nanomaterial and form a conformal protective coating on the sliding contact interfaces. This reason facilitates shear and slow down scratching sand particles to steel surfaces, thus drastically reduce wear. It's recommended that adding 10 PMMA and 0.4 graphene nano particles together to lithium grease give excellent tribological performance. Abrasive sand particles as a contaminant in lithium grease are responsible for increasing friction and wear values related to their hardness and their irregular shapes. Wear values decreased after adding 20 wt. % oil content to lithium grease and friction coefficient slightly increased. Wear reduced after adding PMMA particles which have a spherical shapes and facilitate rolling between steel surfaces.

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