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Tribological Performance of Lithium Grease Dispersed by Polymers and Graphene Nano Particles

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***Abstract*—The search for promising additives with excellent tribological properties has attracted considerable interest. In this paper, graphene nano particles dispersing lithium grease are used as lubricant filler. Graphene addition is aimed to reduce the effect of sand particles on friction coefficient and wear of steel test specimens, where sand particles considered as the most abrasive component of white cement contaminating lithium grease. Experimental results show that, adding 0.4 wt. % graphene nano filler to lithium grease gives good anti-friction and wear resistance performance. After adding micro particles of polymers to the graphene film, two different results endorsed. Friction and wear decreased after adding 10 wt. % of Polyamide (PA) which earns positive charges when rubbing steel surface according to triboelectric series. This phenomena helped to scatter the sand particles which have the same positive charges. As for Polyethylene (PE) earns negative charges when rubbing steel surface, made adverse results, where sand particles are attracted to steel surface. Besides, the results indicate that lithium grease should be dispersed by 20 wt. % oil to balance the effect of contaminant. As the oil content, added to the grease, increases friction coefficient and wear decreases.**

Keywords—Graphene, Nano Particles, Friction, Wear, Solid contaminants, Sand, Cement plant, Lithium Grease, Polyamide, Polyethylene, Triboelectrification.

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 powder 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]. Graphite (C) and polymethyl methacrylate (PMMA) were used as solid lubricants dispersed in lithium grease. Based on the experimental results .It was found that, graphite causes increase in friction but causes low wear while PMMA in most case causes decrease in friction and wear. Based on the experimental results, it was found that, wear and friction decreased with increasing oil content in grease [8].

Due to the large surface to volume ratios, nano/micro-structured functional materials have been predicted and demonstrated to be excellent functional material, [9]. Approximately, [10], 10 nm Fe3O4 magnetic nano-particles (MNPs), modified by oleic acid, were used as lubricant additives and dispersed into base oil. Graphene is a kind of very promising filler, [12]. Graphene, [13], 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, [14].

Triboelectric Phenomena is a list that ranks various materials according to their tendency to gain or lose electrons. It usually lists materials in order of decreasing tendency to charge positively (lose electrons), and increasing tendency to charge negatively (gain electrons). Creating electrostatic charge by contact and separation of materials is known as "triboelectric charging." The word “triboelectric” comes from the Greek words, tribo meaning “to rub” and electros meaning “amber” (fossilized resin from prehistoric trees). It involves the transfer of electrons between materials. The atoms of a material with no static charge have an equal number of positive (+) protons in their nucleus and negative (-) electrons orbiting the nucleus, [51]. When the two materials are placed in contact and then separated, negatively charged electrons are transferred from the surface of one material to the surface of the other material. Which material loses electrons and which gains electrons will depend on the nature of the two materials. The material that loses electrons becomes positively charged, while the material that gains electrons is negatively charged, [15, 16].

This process of material contact, electron transfer and separation is a much more complex mechanism than described here. The amount of charge created by triboelectric generation is affected by the area of contact, the speed of separation, relative humidity, and chemistry of the materials, surface work function and other factors. Once the charge is created on a material, it becomes an electrostatic charge (if it remains on the material). This charge may be transferred from the material, creating an electrostatic discharge or ESD event. Additional factors, such as the resistance of the actual discharge circuit and the contact resistance at the interface between contacting surfaces also affect the actual charge that is released, [16]. When two materials contact and separate, the polarity and magnitude of the charge are indicated by the materials’ positions in a triboelectric series. The triboelectric series tables show how charges are generated on various materials. When two materials contact and separate, the one nearer the top of the series takes on a positive charge, the other a negative charge. Materials further apart on the table typically generate a higher charge than ones closer together. These tables, however, should only be used as a general guide because there are many variables involved that cannot be controlled well enough to ensure repeatability.

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, PA and PE particles have grain size up to 150 µm, and the grain size of sand which contaminated lithium grease was 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

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

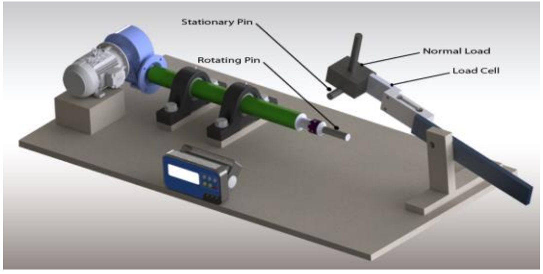

Figure 1 Layout of cross pin wear tester.

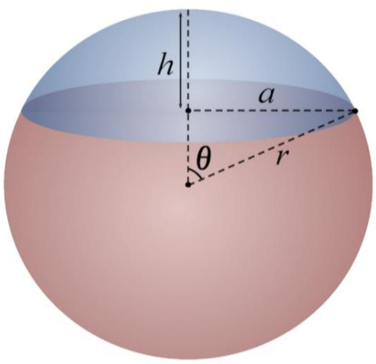

Figure 2 Wear volume dimensions, [15].

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. %, [18]. Figure 3 shows that, when the abrasive sand particles rubbing steel surface, according to triboelectric series, steel surface gains negative charge and particles of sand gain positive charge. This causes attraction between them and leads to increase friction and wear values.

The increase of sand content increases the friction and wear between the contact surfaces, these phenomena may be related to the higher abrasive action of sand due to its hardness. Here, penetration of the sharp edges of sand particles can be considered as a reason for the occurrence of three-body abrasion mechanism, adding 20 wt. % oil to lithium grease 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 as shown in figures 4 and 5.

Increasing sand content in lithium grease leads to increase friction coefficient, this results might be attributed to the hard and irregular particles of the sand. The low friction coefficient of graphene in nanoscale played a role as a protective coating is a serious concern, due to its atomic thickness (thinness). It is highly desirable to develop effective methods to reduce the friction. It can be seen, in figure 6. 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. On the other hand, after increasing graphene content more than 0.4 wt. %, friction coefficient increased, this result could be due to the hardness of graphene nano particles themselves, illustrated in figure 6.

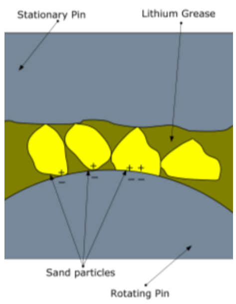

Figure 3 Sand particles rubbing steel surface.

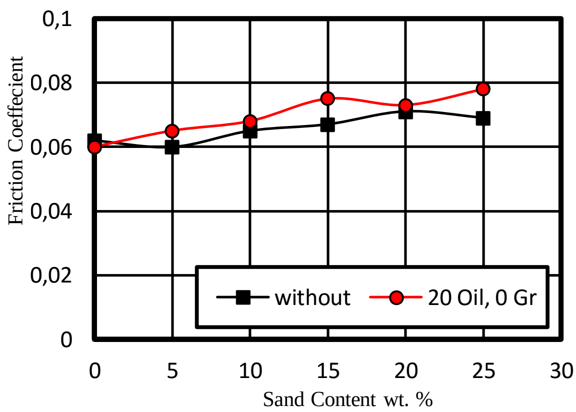

Figure 4 Effect of sand content on friction coefficient.

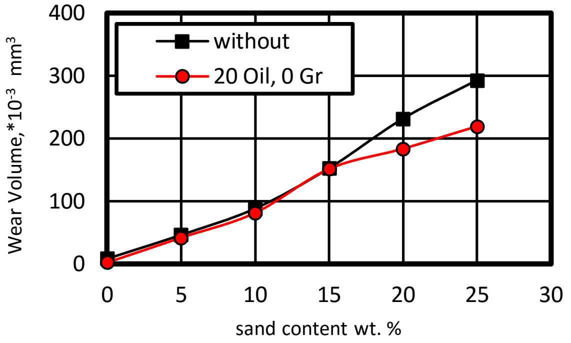

Figure 5 Wear volume of specimens Caused by abrasive sand particles.

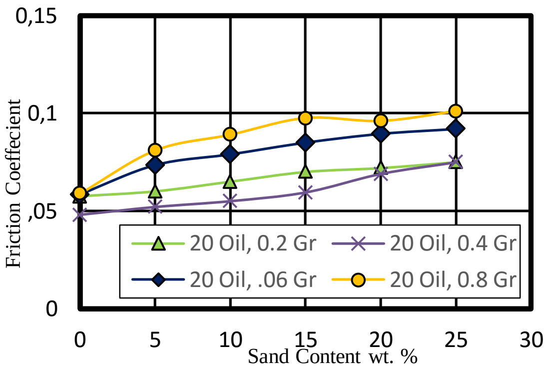

Figure 6 Friction coefficient of specimens with grease different contents of nano graphene and sand.

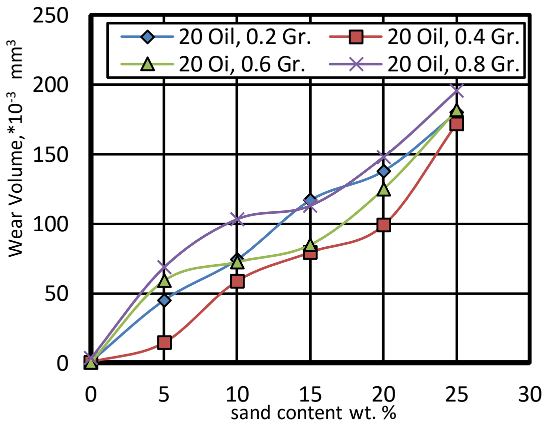

Figure 7 Effect of nano graphene content on wear volume of specimens.

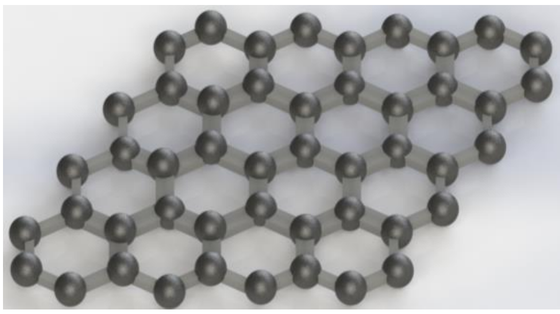

Figure 8 Graphene layer.

Figure 7 shows that, the wear resistance of lithium grease can be improved significantly by adding graphene nano particles, this outgrowth might be due to the good tribological properties of graphene and the nano scale of particles. 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 lay on the selectivity of the best concentration of nano particles (0.4 wt.%).

Sketch in figure 8 indicates layer of graphene. Graphene is a two-dimensional zero-band gap semiconductor with a unique energy diagram, dimensions of nanomaterial forms a conformal protective coating on the sliding contact interfaces.

Mixing nanoparticles of graphene may be indicated in figure 9, where the particles of sand could be dissipated with the aid of nano graphene particles, besides the good lubricating properties of graphene as solid additive to lithium grease.

Friction coefficient increases with increasing sand content, friction values decreases after adding polyamide particles, this results could be attributed to the triboelectric phenomena. PA particles helps in dissipating sand particles between the specimen surfaces and reduces friction. Friction values decreases after adding 0.4 wt. % nano graphene. 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 10.

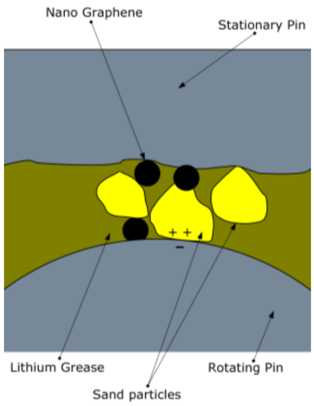

Figure 9 Graphene Nano particles with sand particles.

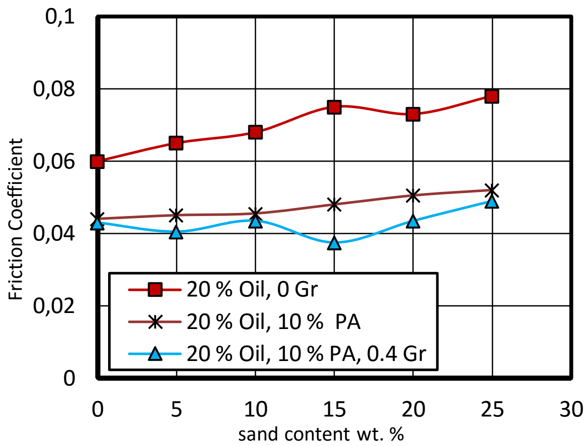

Figure 10 Effect of graphene nano particles and PA on friction coefficient.

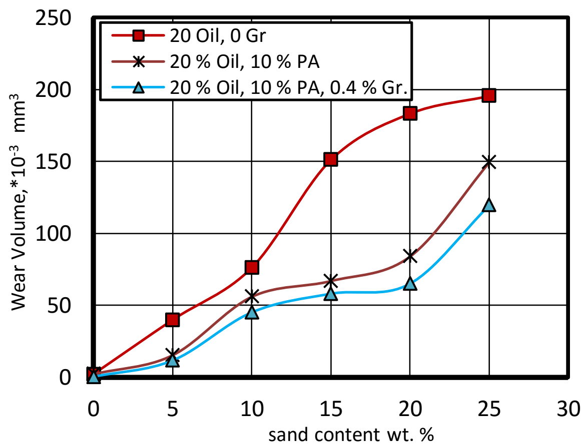

Figure 11 Effect of adding polyamide to graphene nanoparticles on wear of steel specimen.

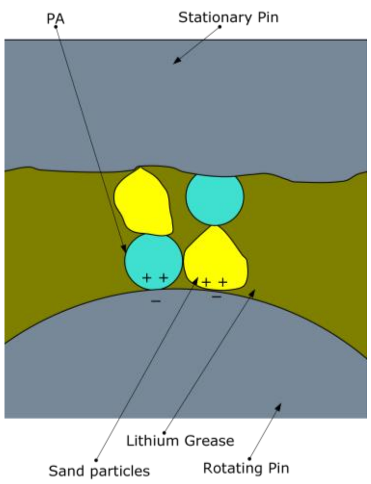

Figure 12 polyamide rubbing steel surface.

Relation between wear values and abrasive sand content added to lithium grease could be indicated in figure 11, where wear increases with increase sand content, this result may be related to the higher abrasive action of sand due to its hardness. Adding polyamide particles enhances the lubricating properties of lithium grease by scattering sand particles from the contact area. Besides adding graphene nanoparticles act as a two-dimensional nanomaterial and form a conformal protective coating on the sliding contact interfaces.

Figure 12 shows that, when the abrasive sand particles rubbing steel surface, according to triboelectric series, steel surface gains negative charge and particles of sand and PA gains positive charge. This creates a repulsive force and dissipated sand particles, then friction and wear values decreases.

When the abrasive sand particles rubbing steel surface, according to triboelectric series, steel surface gains negative charge and particles of sand and PA gain positive charge. This creates a repulsive force and dissipated sand particles. After adding graphene nanoparticles, homogeneous distribution of electric static charge leading clear disharmonize between polymers and sand particles, then wear decreased, as shown in figure 13.

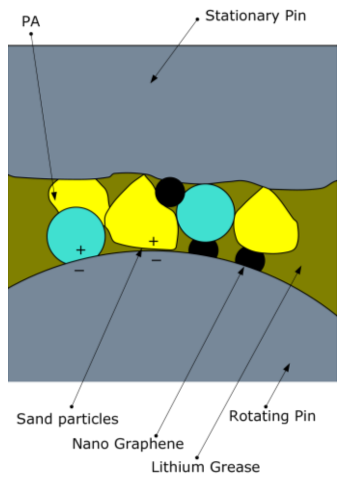

Figure 13 Nano graphene and PA with sand particles.

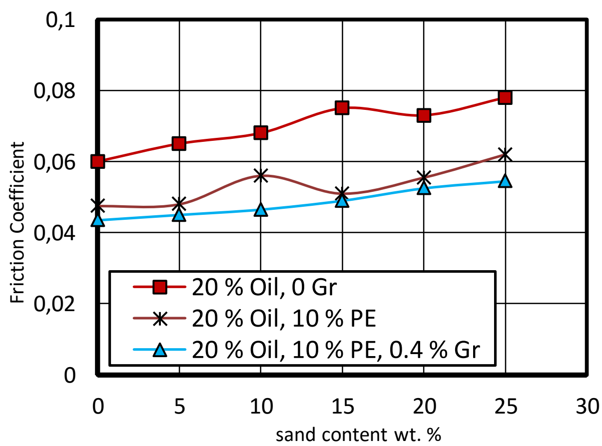

Figure 14 Effect of adding polyethylene and graphene nanoparticles on friction coefficient.

The behavior means that, the increase of the sand content increases the friction, these phenomena may be related to the higher abrasive action of sand due to its hardness. Here, penetration of the sharp edges of sand particles can be considered as a reason for the occurrence of three-body abrasion mechanism. Furthermore, adding polyethylene (PE) content decreases the friction coefficient, it could be seen also that adding graphene nanoparticles decreases friction values due to the good lubricating properties of graphene as shown in figure 14.

Figure 15 indicates that, the increase of sand content tends to increase the wear of the steel specimens because sand is classified as an abrasive material due to the hardness and sharpness of its particles as compared to steel specimens. However polyethylene is classified as a lubricant additive material, but in this condition wear between the steel specimens increased with adding polyethylene content, this result may be because the particles of sand gain positive charge and polyethylene particles gain negative charge when rubbing steel surface due to triboelectric phenomena this case causes concentrating sand particles between the rubbing steel surfaces and wear values increase.

when the abrasive sand particles rubbing steel surface, according to triboelectric series, PE gains negative charge and particles of sand gain positive charge. This creates attraction force and concentrated sand particles between the two contact surfaces, as shown in Figure 16.

Figure 17 shows that, the abrasive sand particles rubbing steel surface, according to triboelectric series, PE gains negative charge and particles of sand gain positive charge. This creates attractive force and concentrated sand particles between the contact surfaces. After adding graphene nanoparticles, homogeneous distribution of electric static charge leading good interaction between polymers and sand particles, then wear increased.

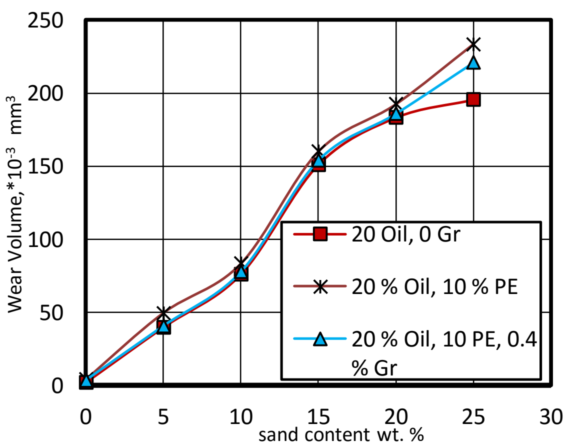

Figure 15 Effect of adding polyethylene to graphene nanoparticles on wear.

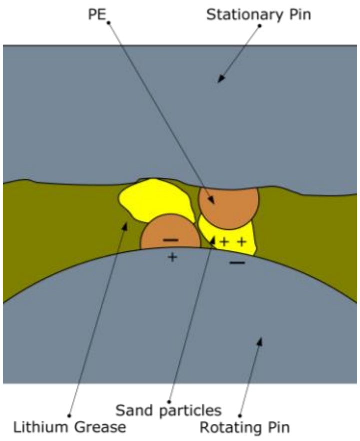

Figure 16 PE and sand particles when rubbing steel surface.

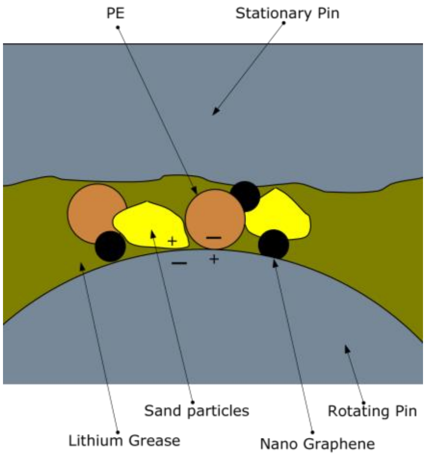

Figure 17 PE and sand particles when rubbing steel surface after adding graphene nanoparticles.

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 slows down abrasion action of sand particles to steel surface, thus drastically reduces wear. In polymers such as PA, which gains positive charge when sliding against steel surface according to tribo electric phenomena and makes use of the excellent conductivity of graphene which accelerates scattering of sand particles out of the contact area. While PE which gains negative charge and attracts sand particles into steel surface.

It is recommended that adding polymers which have positive charge such as PA with 0.4 wt. % graphene nano particles to lithium grease gives excellent tribological performance and reduces the abrasive effect of sand particles, and avoid using polymers with negative charge such as PE to decrease the effect of sand particles. Abrasive sand particles as 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.

REFERENCES

[1] Unal H., Mimaroglu A., "Friction and wear behaviour of unfilled engineering thermoplastics", Materials and Design 24 (2003) 183–187, (2003).

[2] S. Graça, R. Vilar, R. Colaço, "The role of indentation size effect on the abrasive wear behaviour of ductile metallic materials: A nanotribological study", Wear 268, pp. 931-938, (2010).

[3] Poorya Hosseini, Peter Radziszewski, "Combined study of wear and abrasive fragmentation using Steel Wheel Abrasion Test", Wear 271, pp. 689-696, (2011).

[4] Hu J., Li D.Y., Llewellyn R., "Computational investigation of microstructural effects on abrasive wear of composite materials", Wear 259, pp. 6-17, (2005).

[5] Yousif B. F., El-Tayeb N.S.M., "Wear characteristics of thermoset composite under high stress three-body abrasive", Tribology International 43, pp. 2356- 2371, (2010).

[6] Ali, W. Y and Mousa, M. O., "Experimental Study of Wear and Friction Caused By Abrasive Contaminants and Fuel Dilution in Lubricating Oil", 5th International Congress on Tribology EUROTRIB 89, Helsinki, Finland, pp. 437 - 431, June 13, (1988).

[7] Jianwei Qi, Liping Wang, Yunfeng Wang, Jibin Pu, Fengyuan Yan, Qunji Xue, "The tribological performance of selected solid lubricant films in sand-dust environments", Wear 271, pp. 899-910, (2011).

[8] Ezzat A. A. and Mousa M. O., "FRICTION AND WEAR OF MOVING SURFACES IN ABRASIVE CONTAMINATED ENVIRONMENT", MJET, Lubrication and Lubricants, Vol. 31, No. 2, PP. 234 – 45, Jan (2012).

[9] Jing Zheng, Xingfa Ma, Xiaochun He, Mingjun Gao, and Guang Li, "Preparation, characterizations, and its potential applications of PANi/ graphene oxide nanocomposite", Procedia Engineering 27, PP. 1478-1487, (2012).

[10] Guanghong Zhou, Yufu Zhu, Xiangming Wang, Mujian Xia, Yue Zhang, Hongyan Ding, "Sliding tribological properties of 0.45% carbon steel lubricated with Fe_3O_4 magnetic nano-particle additives in base oil", Wear 301, PP. 753–757, (2013).

[11] Ehsan-o-llah Ettefaghi, Hojjat Ahmadi, Alimorad Rashidi, Amideddin Nouralishahi, Seyed Saeid Mohtasebi, "Preparation and thermal properties of oil-based nano fluid from multi-walled carbon nanotubes and engine oil as nano-lubricant", International Communications in Heat and Mass Transfer 46, PP. 142–147, (2013).

[12] Saihua Jiang, Zhou Gui, Chenlu Bao, Kang Dai, Xin Wang, Keqing Zhou, Yongqian Shi, Siuming Lo, Yuan Hu, "Preparation of functionalized graphene by simultaneous reduction and surface modification and its polymethyl methacrylate composites through latex technology and melt blending", Chemical Engineering Journal 226, PP. 326–335, (2013).

[13] Rajni Garg, Naba K. Dutta and Namita Roy Choudhury, "Work Function Engineering of Graphene", Nanomaterials, 4, PP. 267-300, (2014).

[14] Andrew Kozbial, Zhiting Li, Steven Iasella, Alexander T. Taylor, Brittni Morganstein, Yongjin Wang, Jianing Sun, Bo Zhou, Nicholas X. Randall, Haitao Liu, Lei Li, "Lubricating graphene with a nanometer-thick perfluoropolyether", Thin Solid Films 549, PP. 299–305, (2013).

[15] ESD ASSOCIATION, ROME, NY. , "FUNDAMENTALS OF ELECTROSTATIC DISCHARGE", AN INTRODUCTION TO ESD, PART ONE, (2013).

[16] K. ROBINSON, "STATIC BEAT: STOP TRIBOCHARGING YOUR PRODUCTS," PAPER, FILM& FOIL CONVERTER, VOL. 83, NO. 5, P.12, MAY, (2009).

[17] Sayed A. A., Samy A. M., Khashaba M.I., "Tribological Performance of Lithium Grease Filled by Thermoplastic Polymers in Dusty Environments" , MJET, Lubrication and lubricants, Vol. 33, No. 2, PP. 234 – 45, July (2014).

[18] https://en.wikipedia.org/wiki/Spherical_cap, April 10, (2016).