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ENHANCING THE TRIBOLOGICAL PROPERTIES OF BEARINGS IN MANIPULATORS

Ali A. S.[1], Ali W. Y.[2] and Ibrahem R. A.[3]

[1]Mechanical Power Engineering Dept., Faculty of Engineering, Suez Canal University, EGYPT.
[2]Department of Production engineering and Mechanical Design, Faculty of Engineering, Minia University, El-Minia, EGYPT.
[3]Mechanical Engineering Dept., Faculty of Engineering, Beni-Suef University, Beni-Suef, EGYPT.

ABSTRACT

The present work aims to enhance the friction and wear resistance of the bearings and joints in manipulator. The effect of dispersing lubricating oil by silica nanoparticles as well as graphene oxide nanoplatelets as antiwear and friction modifiers was discussed. The performance of the proposed additives was compared to that observed by the conventional ones such as zinc dialkyldithiophosphate (ZDDP), molybdenum disulphide (MoS_2), graphite (C) and detergent additive (calcium sulphonate).

The bearings of the manipulators are suffering from high friction coefficient due to the high load and the low surface velocity. In that condition, the contact between asperities is dominating so that friction and wear increase. It is necessary to separate the two surfaces and changes the lubrication regime into full-film lubrication.

The effect of dispersing lubricating oil by the tested additives to decrease friction coefficient and wear is experimentally investigated. It was found that oil free of additives displayed the lowest friction values followed by detergent additives due to the high polarity of their molecules. ZDDP, MoS_2 and C displayed higher friction values. Graphene oxide nanoplatelets and silica nanoparticles were able to separate the sliding surface and consequently they decreased both friction coefficient and wear. It is recommended to disperse lubricating oil of bearing in manipulators by graphene oxide nanoplatelets and silica nanoparticles to reduce friction and wear.

KEYWORDS

Lubrication, bearings, manipulators, silica nanoparticles, graphene oxide.

INTRODUCTION

The motion of the majority bearings and joints in robots is reciprocating, where the velocity of the shaft is not enough to build up the pressure and film thickness required to reach the hydrodynamic lubrication regime. Several attempts were tried to produce Stribeck curves for the reciprocating motion to follow the lubricant regime that prevails

inside the bearing, [1]. In a Stribeck curve the Hersey number is plotted against friction coefficient. The Hersey number can be calculated from the velocity (U in m/s) times the dynamic viscosity (η in N.s/m^2), divided by the load per unit length of bearing (F in N/m).

In boundary lubrication the asperities of the two mating surfaces are close together, where the contact between them is possible. It is expected that friction and wear displayed increased values. At high load or low velocity, the lubricant film thickness is small causing the two surfaces to be in contact [2], where the lubrication regime is boundary lubrication, where the asperities completely carrying the load and causing significant friction increase [3 - 9]. That regime displays the highest friction coefficient of all three lubrication regimes Fig. 1. The relative velocity varies between zero and maximum, and consequently lubrication regime varies from boundary to hydrodynamic if the value of velocity is enough high to form thick film thickness. To reduce the effect of asperity contact on friction and wear, it is necessary to use antiwear and friction modifier additives by forming tribochemical layer that prevents and separates asperities from friction.

Friction coefficient can be decreased in the boundary lubrication regime by dispersing the oil by additives. It was proven the effective of silica nanoparticles as lubricant additives. Besides, they are environmentally friend and economic. Silica nanoparticles were dispersing oil, where the tribological behavior of silica nanoparticles was tested. Silica nanoparticles (SiO_2) act as ball bearings separating the two contact surfaces, where fluid film forms. Crushing of the SiO_2 nanoparticles was accompanied by deformation induced loss of the rolling effect, when the load was increased. Without nanoparticles, a transfer layer formed at high velocity and low load. The addition, of SiO_2 nanoparticles to lubricants, was tested, [10 - 23]. It was found that SiO_2 nanoparticles have more dispersivity and stability than nanodiamond in oil.

Graphene oxide (GO) provides interlaminar sliding and low shear force, thus giving them super lubricity properties. The platelets of GO can cover the contact asperities forming a low shear film, reduce surface roughness and compensate material removed from the surface. Nanoparticles help to transfer sliding friction into rolling one and decrease the friction coefficient. The lubrication mechanism of graphene and graphene oxide is to form a protective film on the sliding surfaces, where the nanoscale thickness and provides lower shear strength, causing lower friction. Addition of proper dispersant can disable the agglomeration of graphene in the lubricating oil. It was found that the friction reduction and anti-wear ability of pure lubricant was improved by the addition of graphene. Oil dispersed with 0.05 wt. % graphene reduced friction and wear. Multi-layered graphene has higher load carrying capacity and efficiently prevent direct contact of the mating surface asperities. Higher concentration decreases the improvement of friction and wear due to the agglomeration of graphene, [24 - 31]. Oxide graphene nanosheets showed relatively higher performance.

In the present work, the use of silica nanoparticles and graphene oxide as antiwear and friction modifiers to reduce friction and wear of bearing of manipulators is discussed.

EXPERIMENTAL

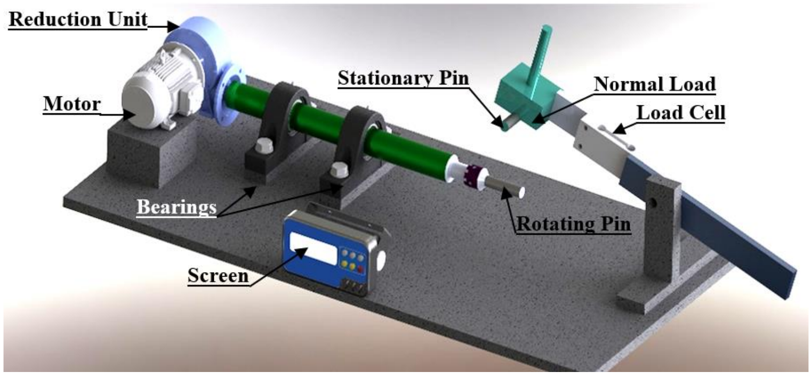


Fig. 1 Arrangement of the test rig.

Cross pin tester was used to carry out the experiments, Fig. 1. It consists of rotating and stationary pins of 18 mm diameter and 150 mm long. The material of the rotating pin was alloyed steel, (H_v = 2900 N/mm^2). It was attached to a chuck assembled to the shaft driven by gear reduction unit through DC motor (500 watts, 230 volts). The carbon steel stationary pin (H_v = 1300 N/mm^2) was attached to the loading block where the load was applied by weights. The friction force was measured by load cell as shown in Fig. 1. Wear was measured by the wear scar diameter observed in the contact surface of the stationary pin at 96 N load and 0.8 m/s sliding velocity. Experiments to determine friction coefficient were carried out at varying sliding velocity ranging between 0.50 – 2.5 m/s and 16, 32, 48, 64, 80 and 96 N load. The running time of each experiment was 300 seconds. The lubricant used in the experiment was paraffin oil, (S. A. E. 30), while the lubricant additives were zinc dialkyldithiophosphate additive (ZDDP), molybdenum disulphide (MoS_2), graphite (C) and detergent additive (calcium sulphonate), silica nanoparticles of particle size ranging between 20 – 30 ηm and graphene oxide nanoplatelets.

RESULTS AND DISCUSSION

The bearings of the manipulators are subjected to rotational, oscillating and linear motion. In the majority of applications, the load is high and the surface velocity of the bearing is relatively low, then the lubricant film thickness is small causing the two surfaces to be in contact. The lubrication regime is then defined as boundary lubrication, where the surface asperities are in contact and friction coefficient is relatively high. The characteristics of boundary lubrication regime are liquid-solid interactions and contact between asperities that increased friction and wear. The applied load is shared by asperity-asperity contacts as well as lubricant pressures generated by the lubricant films. When the load decreases or sliding velocity increases the bearing surfaces move out of the boundary lubrication regime into the mixed lubrication as the lubricant film thickness increases. Further increase in the lubricant film carries the load, separates the two surfaces and changes the lubrication regime into full-film lubrication, where friction coefficient is low.

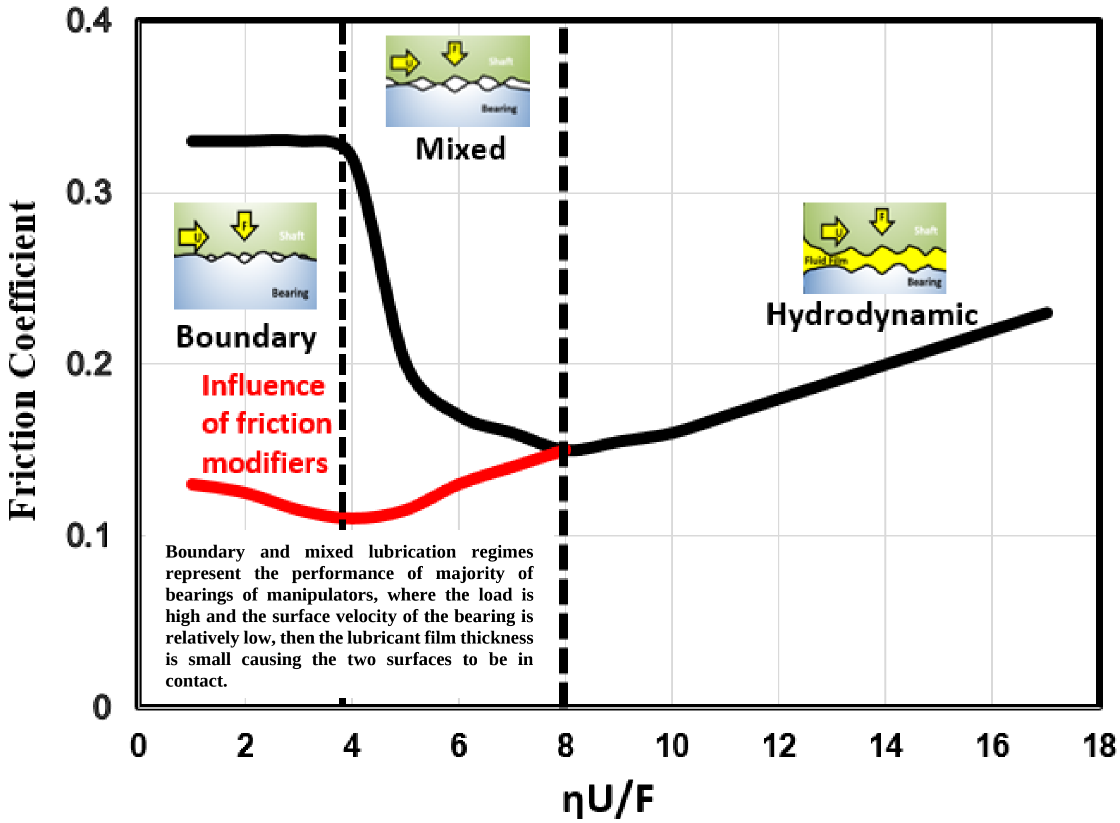
The relationship between friction coefficient and Stribeck number (viscosity of the lubricating fluid [η], load [F], and velocity [U]) is illustrated in Fig. 2. The curve illustrates the characteristics of various lubrication regimes, including boundary lubrication, Fig. 3,

and mixed lubrication, Fig. 4. In hydrodynamic lubrication, Fig. 5, the fluid completely isolates the friction surfaces, where the fluid friction alone determines tribological characteristics. In elastohydrodynamic (mixed) lubrication, fluid viscosity and the elastic coefficient of the solid surface are the most dominant factors. In contrast, the boundary lubrication regime is mainly characterized by the facts that friction surfaces are in contact at microasperities, where hydrodynamic effects of lubricating fluid insignificantly influence tribological characteristics and the interactions in the contact between friction surfaces and between friction surfaces and the lubricant dominate tribological characteristics.

Friction coefficient displayed by the sliding surfaces lubricated by oil and oil dispersed by the tested additives is shown in Fig. 6. The relationship shows increased friction at low Stribeck number, a well developed minimum at intermediate Stribeck number and an increased friction at high Stribeck number. The minimum friction value (0.042) was observed for oil free of additives. The conventional lubrication mechanisms are based on physical and chemical adsorption, where the polar molecules play key role in interactions with the sliding surfaces. The best tribological performance is expected for polar oils. Efficiency of the lubricant depends on the strength of the fluid film and consequently on the adsorption on the sliding surfaces. Increasing the polar functionality in oil structure has a positive impact on friction reduction resulting from stronger adsorption potential on metal surface.

Surfaces lubricated by oil dispersed by detergent additive (calcium sulphonate) showed slight friction increase, where the minimum values was 0.055. This behaviour might be attributed to high polarity of detergent molecules. The decrease of friction coefficient might be attributed to the ability of the polar molecules to form multilayer on the steel surface. The mixed lubrication provided by the tested oil is primarily governed by the formation of a stable oil film on the sliding surfaces. Polar molecules of the tested oil and additive can significantly improve the friction resulting from their adsorption on the sliding surfaces.

Oil free of additives displayed the lowest friction values, Fig. 6. Detergent additives showed lower friction than the other tested additives followed by ZDDP additive. The mechanism of action of detergent additive depends on its strong adherence on the sliding surfaces and consequently decreases friction coefficient. While, the friction decrease observed from ZDDP might be from the formation of soluble organic sulphides, organo thiophosphates and organo phosphate that form oil insoluble components such as zinc polyphosphates on surfaces as tribochemical films. MoS_2 additive showed relatively higher friction than that observed for oil free additives and oil dispersed by detergent and ZDDP. It seems that the surface adherence of MoS_2 attributed to metal-sulfur bonds was not enough to withstand friction. Surfaces lubricated by oil dispersed by graphite displayed the highest values compared to those lubricated by the other tested additives.



Boundary and mixed lubrication regimes represent the performance of majority of bearings of manipulators, where the load is high and the surface velocity of the bearing is relatively low, then the lubricant film thickness is small causing the two surfaces to be in contact.

Fig. 2 Relationship between Stribeck number and friction coefficient.

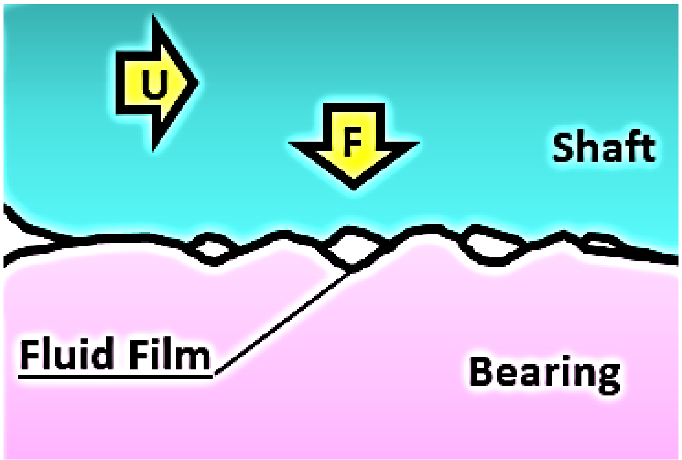


Fig. 3 Surface interaction at boundary lubrication regime.

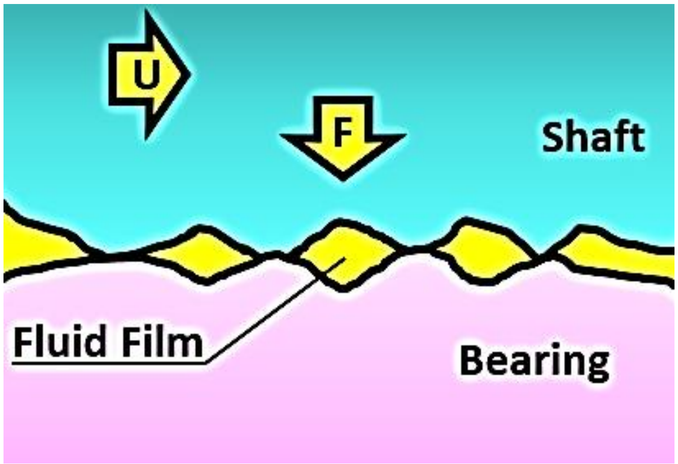


Fig. 4 Surface interaction at mixed lubrication regime.

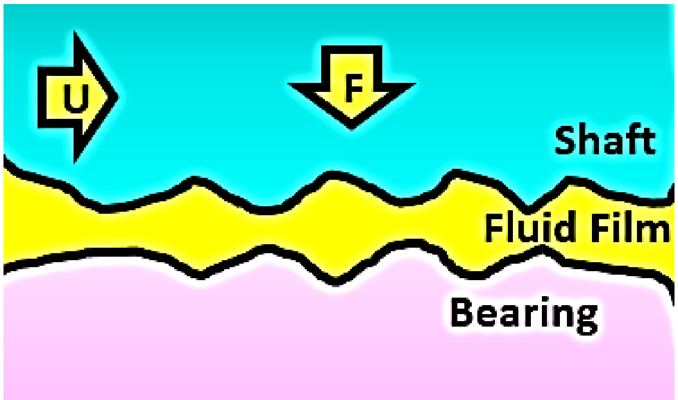


Fig. 5 Surface interaction at hudrodynamic lubrication regime.

Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by silica nanoparticles and graphene oxide nanoplatelets is shown in Fig. 7. It is clearly shown that graphene nanoplatelets caused significant decrease in friction coefficient compared to oil free of additives and oil dispersed with silica nanoparticles. This behavior might be attributed to the fact that graphene oxide is two-dimensional material and ultrathin even with multilayers. It seems that the ability of graphene oxide nanoplatelets to separate the two contact surfaces is higher than offered by silica nanoparticles. It is recommended to apply graphene oxide nanoplatelets in oscillating, rotating, and sliding contacts to reduce friction and wear.

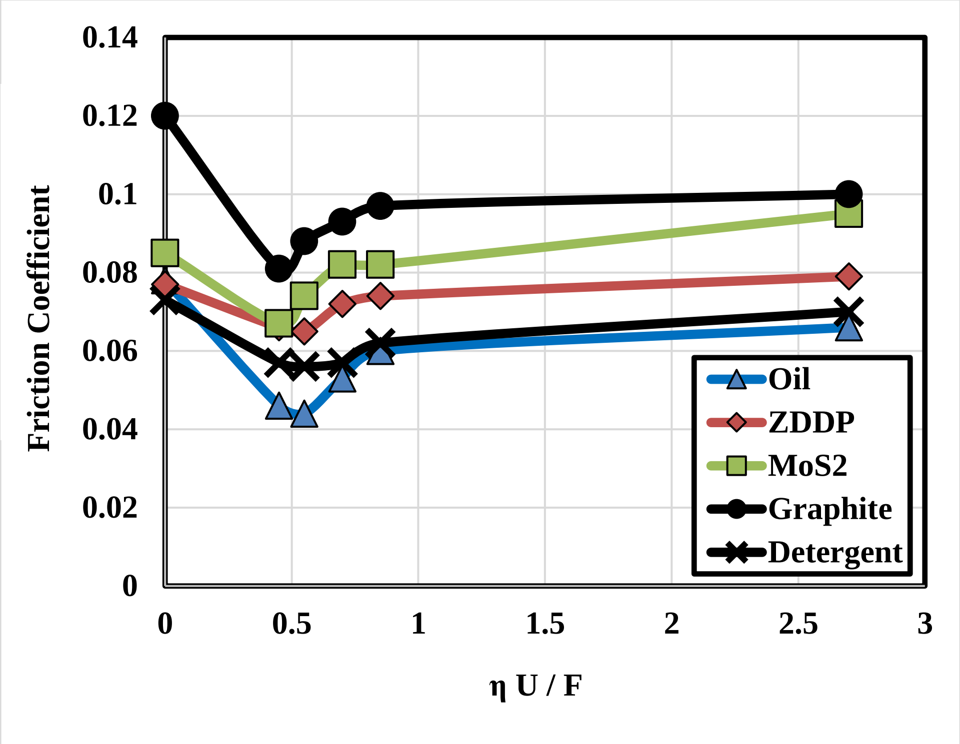


Fig. 6 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by the tested additive.

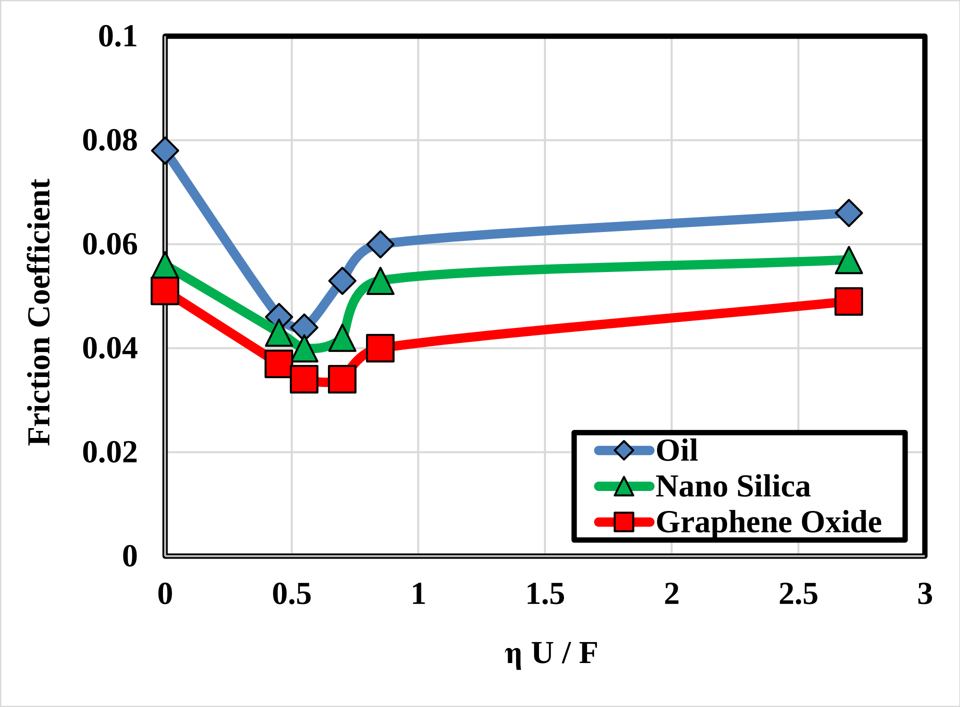


Fig. 7 Friction coefficient displayed by the sliding surfaces lubricated by oil dispersed by silica nanoparticles and graphene oxide nanoplatelets.

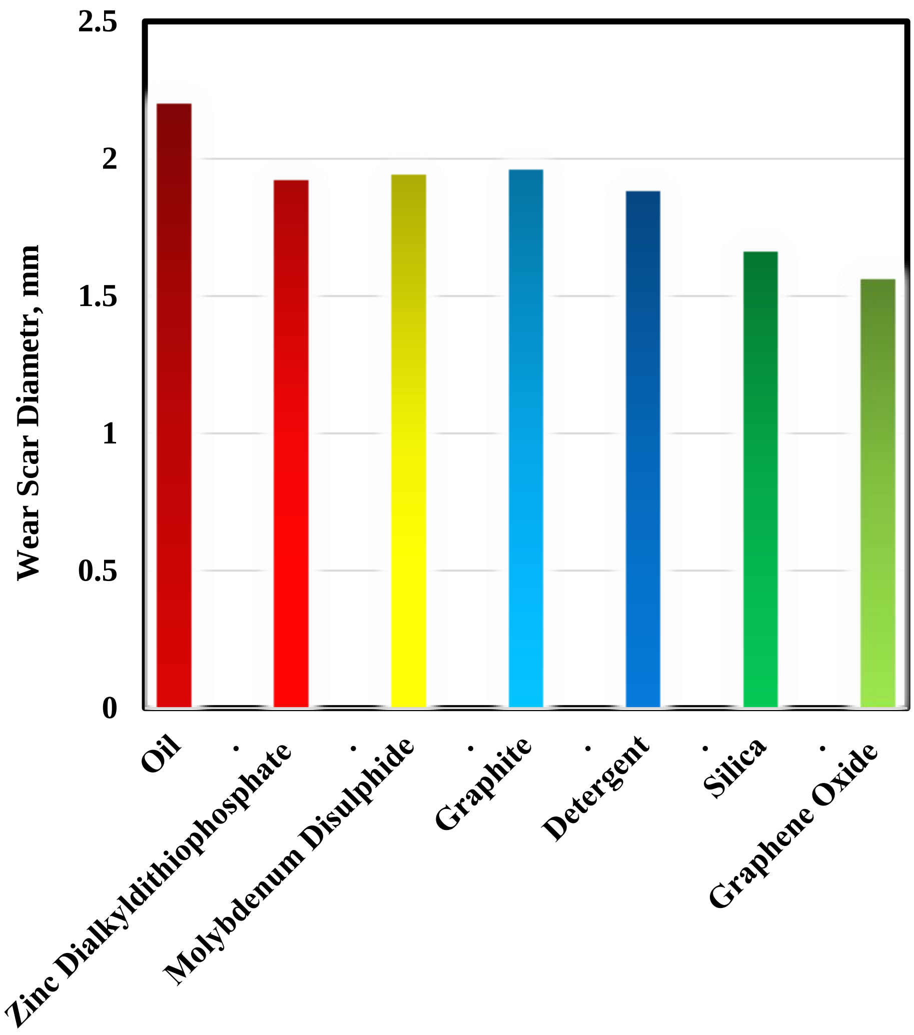


Fig. 8 Effect of the tested additives on wear.

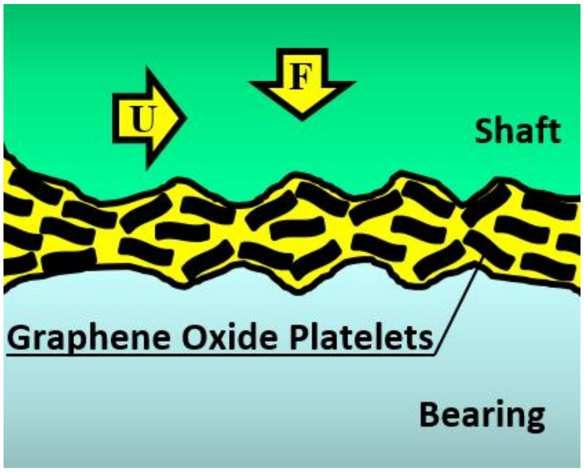


Fig. 9 Mechanism of action of graphene oxide nanoplatelets.

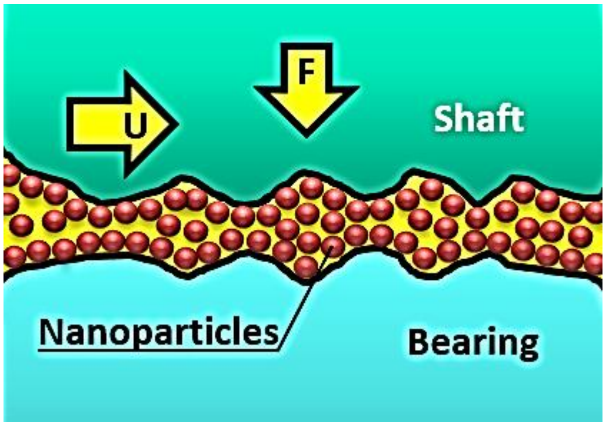


Fig. 10 Mechanism of action of silica nanoparticles.

Effect of the tested additives on wear scar diameter is shown in Fig. 8. The lowest wear was observed for the test specimens lubricated by oil dispersed by of graphene oxide nanoplatelets followed by silica nanoparticles, while oil free of additives displayed the highest wear. The enhancement in friction coefficient and wear can be explained on the action of the additives. The lubrication mechanism of graphene oxide depends on its nature as platelets. They are entering into the rubbing surfaces and adsorbing on the sliding surfaces and form physically deposited film, Fig. 9. Number of layers and thickness are influencing friction behavior, where friction decreases as the number of layers decreases. It was proven that the easy deformation of the layers causes significant reduction in friction, [33 – 35], where a film is formed on the contact and protect the surfaces from further friction and wear. This performance is done by decreasing the surface roughness and offering low shear strength between layers. Besides, silica nanoparticles showed lower friction than oil free of additives. They worked as ball bearings and changed the friction between contact asperities into rolling and sliding, Fig. 10. At higher load, crushing of SiO_2 nanoparticles loses the rolling effect. The rolling action prevents the formation of transfer layer on the sliding surfaces.

CONCLUSIONS

1. Oil free of additives displayed the lowest friction values followed by detergent additives and ZDDP additive that showed lower friction than the other tested additives. MoS_2 additive showed relatively higher friction due to the weak surface adherence to the sliding surfaces. Besides, surfaces lubricated by oil dispersed by graphite displayed the highest values compared to those lubricated by the other tested additives.
2. Friction coefficient displayed by graphene oxide nanoplatelets represented lower values than that observed for conventional additives followed by silica nanoparticles. This behaviour can be attributed to their ability to separate the two contact surfaces.
3. Graphene oxide nanoplatelets and silica nanoparticles showed the lowest wear, while oil free of additives displayed the highest one.
4. It is recommended to apply graphene oxide nanoplatelets in oscillating, rotating, and sliding contacts to reduce friction and wear.

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