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Comparative Investigation of the Tribological Properties of Solid lubricant Powders Additive to Lubricant Oil

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Abstract— **(Wear is a phenomenon in which surface materials damage or loss between two contact solids surfaces in sliding, rolling, or impact movement. In most cases, wear is caused by the interaction of surface asperities. To reduce the energy loss and equipment damage generated due to the mechanical parts friction in the operation, around the world is stepping up developing appropriate lubricants and lubrication technology.**

The antifriction ability of powder lubrication and the state of powder layer are strongly related to the service conditions. Therefore, the effects of sliding velocity and normal load under powder lubrication were studied using a pin on disc contact apparatus. In our work, some solid lubricants, ie. Molybdenum disulfide and serpentine powders were separately introduced into the frictional interface in the state of solid lubricants.

The wear rate optimized content of these powders was obtained in the lubricant oil SAE90, mineral gear oil (Iraqi petroleum products), and it were examined that the loads and friction pairs move velocity's changes had effect to tribological performance in friction course. This work focuses on studying urgency and favorable prospects of practical use of firm powder additives on the basis of serpentine, and molybdenum disulfide powders and their effect on tribological characteristics of lubricant oil (SAE90). Optimum lubricating effect concluded on the level of concentration of the serpentine and MoS2 additive powders in the range of (1.25 – 1.5) wt % and (2 – 3) wt% respectively, by the formation of protective boundary layer between the sliding tribosur faces that prevents wear. Tribological characteristics significantly improved i.e. the wear rate dropped about (3-3.5) times with serpentine powder and about (2-2.5) times with MoS2 powder compared with the case of using the lubricant oil without additives)

Keywords— (Solid lubri cant powder, tribological characteristics, wear rate, lubricant oil.

I. INTRODUCTION

The study of friction, wear, and lubrication has long been of enormous practical importance, since the functioning of many mechanical, electromechanical and biological systems depends on the appropriate friction and wear values. In recent decades, this field, termed "tribology," has received increasing attention as it has become evident that the wastage of resources resulting from high friction and wear is greater than 6% of the Gross National Product [1].

Wear is a phenomenon in which surface materials damage or loss between two contact solids surfaces in sliding, rolling, or impact movement. In most cases, wear is caused by the interaction of surface asperities, fig.(1,2). To reduce the energy loss and equipment damage generated due to the mechanical parts friction in the operation, around the world is stepping up developing appropriate lubricants and lubrication technology [2].

Powder lubrication has been employed as a suitable dry lubricant in a variety of sliding contacts as an alternative to conventional liquid lubricants. The essential postulate of this alternative approach is that there are two operative elements, hydrodynamic and morphological. The hydrodynamic element refers to the layered shearing of particles between sliding tribosurfaces, whereas the morphological element refers to the effects due to the mechanical, chemical, and tribological surface phenomena characteristic of the mating materials [3]. The term "powder lubricants" is usually given to those lamellar solids that have low interlayer friction. Some of the interesting attributes of powder lubricants that are worth noting are that they have been known to adhere to surfaces forming a protective boundary layer that prevents wear, act like a lubricant in sliding contacts by accommodating relative surface velocities, and are capable of lubricating at high-temperatures. Several of these powder lubricants— molybdenum disulfide, calcium difluoride, serpentine, tungsten disulfide, titanium oxide, boron nitride, and boric acid— were evaluated for their lubrication behavior in extreme-environments (i.e., high speeds ~ 45m/s, high temperature ~ 400°C) [4,16]. Dry particulate lubrication, different from solid film lubrication or self-lubrication material, is employed to reduce friction with nonrestrictive solid particles [5] in the extreme environment. Over the course of past 20 years, dry particulate lubrication has been attempted in many industrial fields, such as the bearing [6,7], engine, milling, casting [8,9], and so on, which was proven to be an effective and promising lubrication method. Particulate lubrication has mainly been categorized into granular lubrication and powder lubrication. Dry, cohesionless, hard particles have usually been used in granular lubrication that adequately maintains their geometry under load and accommodates surface velocity differences through sliding and rolling at low shear rates, and through collisions at high shear rates [1,18]. Elkholy [10] investigated the effect of the enduring contact and the true temperature in the system of metal granular lubricant sheared between two parallel plates. The results revealed the occurrence of stick–slip at low velocity and provided further evidence for the formation of granular lift between two disks undergoing sliding motion with consideration of side flow. Yu [11] measured the normal and shear stress by the shearing glass beads in similar equipment. According to Yu's experimental results, Higgs [12] proposed a granular kinetic lubrication (GKL) model, which is a continuum approach that applies proper rheological constitutive equations for stress, conduction, and dissipation to thin shearing flows of granular particles. Powder lubrication uses dry, cohesive, and soft particles that radically deformed under load and accommodated surface velocity differences mostly by adhering to surfaces and shearing in the bulk medium[1,2]. Higgs [12] conducted a series of tests on a tribometer that consisted of simultaneous pellet-on-disk and pad-on-disk sliding contacts. The work showed that the MoS2 pellet actually acted as a self-repairing, self-replenishing, and oil-free lubrication mechanism. The experiments, performed by Heshmat [13,19] on the three-pad journal bearing with MoS2, graphite or WS2 powders, showed the friction coefficient and friction torque retained a stable value with the increasing load and rotational speed. The experimental results are not sensitive to the variations of temperature from 70 to 1200 K. Wang [14] compared the powder lubrication characteristics using four kinds of powders under plane contact and found that properties of powder significantly affected the lubrication performance.

The role of solid lubricant assisted machining with serpentine and MoS2 lubricants on surface quality, cutting forces and specific energy while machining AISI 1045 steel using the cutting tools with different geometry was investigated [3,15,17]. The results indicated there is a considerable improvement in the processing performance with solid lubricant-assisted machining compared with that of machining with cutting fluids. The work demonstrated that solid lubricant-assisted machining is an environmental friendly clean technology. The insulating and lubricating ability influenced by the components and the composition of powder lubricants was investigated by Kimura, Zarubin and Godloviski [3,4,15]. The results showed powder lubricants-(serpentine, MoS2) are effective to prevent forming the scattered chill because the insulating ability of powder lubricant is higher than that of the conventional oil-soluble or water-soluble lubricants. As already noted, for lubricant compositions as fillers can be used soft powder (anti-friction) of metals - nickel, tin, lead, etc.[2]. In powder lubrication, the key problem is the formation of powder layer between the counter faces. The role of the powder layer is to avoid the direct contact of the counter faces and to reduce friction.[1,2]. In fact, the antifriction ability of powder lubrication and the formation of powder layer greatly depend on service conditions. Although many studies on powder lubrication have been reported, it is necessary to further study the effects of sliding velocity and load on power lubrication. In this paper, the effects of the sliding velocity and normal load on the friction coefficient and sample temperature rise were researched in the case of powder lubrication. Besides, the formation and damage of the powder layer were discussed in detail to reveal dynamic behaviors of the powder in a rubbing interface.

This work focuses on studying an urgency and favorable prospects of practical use of firm powder additives as solid lubricants on the basis of SAE90 lubricant oil and their effect on tribological characteristics.

II. EXPERIMENTAL SETUP

Materials used

In this study, the basic lubricant oil used was SAE90, mineral gear oil (Iraqi petroleum products). Investigated lubricant additive powders consist of : serpentine powder (particle size, 4 - 10μm) at a range of concentration (0.5 – 2.5) wt% and molybdenum disulfide powder(particle size, 4 - 10μm) at a range of concentration (1 – 5) wt% .

Wear test

A pin on disc apparatus [fig.3] was used at room temperature to investigate the wet sliding wear characteristics of tool steel of hardness 61HRC. The tests were made with applied loads of 2.5, 5, 10,15 and 17.5 N. Wear specimens (pins) [fig.4] were a cylinder of 10 mm diameter and 20 mm length. Surface of each pin was ground with ASTM grits of 220, 400, 600, 800,1200 emery papers, and then the samples were polished with 0.3μm alumina. The initial weight of the specimen was determined using digital balance with an accuracy of 0.0001gm. The pin was kept pressed against a rotating steel disc [fig.5] of hardness 68HRC in suitable position under loaded condition. The revolution counter was stopped at each 10 minutes of testing time in order to allow intermediate measurements of pin lost weight. These measurements were always preceded by a complete cleaning of specimens by ethanol with a flux of compressed air before weighing. The pin and disc were fixed in the same position and orientation by an initial sign (fig.6).

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Measurements

Sliding speed

Tow rotational speed were used, 150 and 250 r.p.m, that mean two linear velocities of 71 m/min, and 118 m/min were calculated respectively using the formula:

$$V = 2\pi \times r \times n$$

where
V: linear sliding velocity (m/min).
r: distance from the center of sample to the center of disc in meter (0.075 m).
n: disc rotational speed in (r.p.m).

Total sliding distance was calculated as follows:

$$\mathbf{S} = V \times t \times 100$$

where:

S: total sliding distance (cm).
t: time of running in minute (10 min).

V: linear sliding (m/min).

Wear rate:
Wear rates were computed by the weight loss measurement. The formulas used to convert the weight loss into wear rate are :

$$Wr = \Delta W/S$$

Where

Wr: wear rate in (gm/cm).
ΔW: weight difference of the sample before and after each test in (gm)

$$(\Delta W = W1 - W2)$$

III. RESULTS AND DISCUSSION

EFFECT OF SLIDING VELOCITY

Effect of sliding velocity between the two contacting surfaces under powder lubrication was studiedwith lubricant oil based on SAE90 without additive. In(fig.7), two rotational speed were used, 150 and 250 (r.p.m). Results showed little influence in the wear rate values according to 250 rpm as a sliding velocity, comparing with the case of using 150 rpm at the same condition of the experiments, i.e. wear rate dropped from (5.7×10^{-9})gm/cm at the load (15N) and (250rpm) to(5.5×10^{-9})gm/cm at (150rpm) and the same load.

IV. EFFECT OF MoS_2 POWDER

Effect of MoS_2 powder addition on the tribolorgical characteristics of lubricant oil based on SAE 90 was studied at a range of concentration (1 – 5)wt% [6,7,17] as shown in fig.(8). The lubricating properties of MoS_2 have been explained by the strong polarization of the sulfur atomsfig.(9), which produce a layer structure, good adhesion to metal surfaces, adhesion between MoS_2 basal planes, easy sliding of MoS_2 and the formation of a homogeneous continuous film. The load carrying part of the MoS_2 film lies only on the asperities of the metal surface.The results can be explained by the fact that MoS_2, as a solid lubricant helped to form, through the process, a solid lubricant layer helps to reduce friction losses in the relative sliding of solid bodies. It was evident that (1 wt%) MoS_2 in the lubricant composition is not enough to form a solid lubricating film on the metal surfaces that separates from the rubbing surfaces. However, increasing the amount of MoS_2 over (4 wt%) results in a thick loose film, deleted in wear action with an increase infriction moment. Results also revealed that minimum wear rate was obtained at (2.5 wt%) of MoS_2 addition as shown in fig.(8). It was noted that an addition of (2.5wt%) MoS2 powder to the lubricant oil would help to reduce friction losses, i.e. the wear rate at load (10N) was lowered (2 – 2.5) times by comparing with the case of lubricant oil without additives, at the same conditions of the experiment as shown in (fig.10). MoS_2 powder has the characteristics which are crystal structure, fine particle and large specific surface area.

- In fig.(11), variation in hardness with varying MoS2 content was also studied at a range of concentration (1-5) wt%. It was noted that an addition of (2.5wt%) MoS2 powder to the lubricant oil would decrease the pin hardness, i.e.the hardness dropped from (61 HRC) to (57 HRC).
- This may related to the formation of thin plastic film of MoS2 on steel surfaces, that increased the contact surface area, then the pair of friction steel – steel gradually in some areas on the sliding surfaces, was replaced by a pair of energetically favorable friction steel – MoS2, so the hardness decreased.

V. EFFECT OF SERPENTINE POWDER

Significantly improve the lubricating effect of the lubricant oil can be by adding serpentine powder. Serpentine is a kind of phyllosilicates whose crystal structure leads to monoclinic. It has the characteristics which are fine particle and large specific surface area. It has great quantities of Si-O-Si, O-Si-O, hydrogen bonds and magnesium bonds on its top, which enable serpentine to have the feature of absorption, ion exchanging and expansion. Because of its unique crystal structure, serpentine powders in liquid lubricants can show a good tribological performance. At present, besides in construction, fire resistant, heat insulation materials research applications, a large number of scholars have begun to study the serpentine powders as a lubricant additive to achieve the efficacy of friction reduction, anti-wear and self-repairing effects. Serpentine powder composition, added to the lubricant oils, does not has a chemical reaction with the oil.

Effect of addition of serpentine powderon the tribolorgical characteristics with lubricant oil based on SAE 90, was studied at a range of concentration (0.5 – 2,5)wt% [3,4] as shown in fig.(12). It was noted that an addition of (1.5wt%) serpentine powder to the lubricant oil would help to reduce friction losses, i.e. the wear rate was lowered (3 – 4) times (fig.10) and load capacity of the friction pair was increased by 1.5 times, by comparing with the case of lubricant oil without additives, at the same conditions.This may related to the formation of thin plastic film of serpentine on steel surfaces, that increased the contact surface area, then the pair of friction steel – steel gradually in some areas on the sliding surfaces, was replaced by a pair of energetically favorable friction steel – serpentine, so wear and friction at the same time significantly reduced.

In fig.(13), variation in hardness with varying serpentine content was also studied at a range of concentration (0.5-2.5) wt%. It was noted that an addition of (1.5wt%) serpentine powder to the lubricant oil would increase the hardness i.e.the pin hardness changed from (61 HRC) to (66 HRC).

This may related to the formation of thin plastic film of serpentine on steel surfaces, that increased the contact surface area, then the pair of friction steel – steel gradually in some areas on the sliding surfaces, was replaced by a pair of energetically favorable friction steel – serpentine, so the hardness increased.

VI. INFLUENCE OF SURFACE ROUGHNESS

Surface roughness influences the contact and subsurface stresses in a loaded contact. This influence depends very much on whether the asperities are deformed elastically or plastically. The mode of asperity deformation also influences the real contact area and thus the friction and wear. When the asperities are deformed plastically the load is linearly related to the real area of contact for any distribution of asperity heights.

When the asperities deform elastically, linearity between load and real area of contact will occur only when the asperity distribution is exponential, which is common for practical surfaces. The influence of surface roughness on surface and subsurface stresses and other contact parameters is small if the asperities are deformed plastically, as is often the case for soft coatings[1,2].

Fig (14)friction surfaces was carried outbeforeand after about 10(km)path offrictionin the lubricant oil SAE 90with newly developed MoS2 and serpentine powder sat a load of the working surface of 17.5N. Photographing the surfaces was carried outusingan electron microscope with an increase of 2,000 times, obtained profile grams these surfaces as shown in figure (14). It was noted the sharply difference between profile grams surface friction for lubricant oil SAE 90 without additives (fig.14 - a) and with 1.5wt% serpentine additive powder (fig.14 - b) and also with 2.5wt% MoS2 powder (fig.14 - c). This may related to the formation of solid lubricant and plastic film on the contacting friction surfaces, abled to improve tribological properties of the lubricant oil composition.

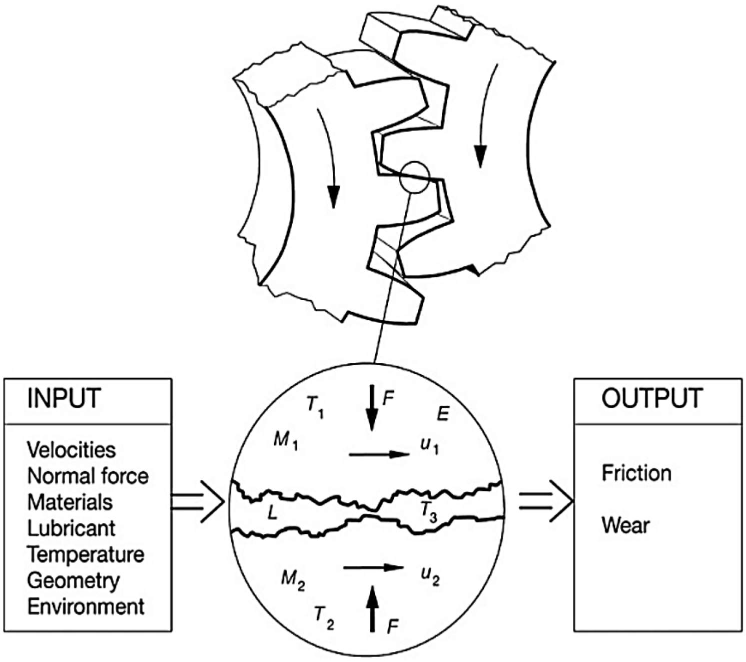

Fig. 1. Several material, contact condition and environmental input parameters influence the dynamic tribophysical and tribochemical contact processes which control friction and wear[2].

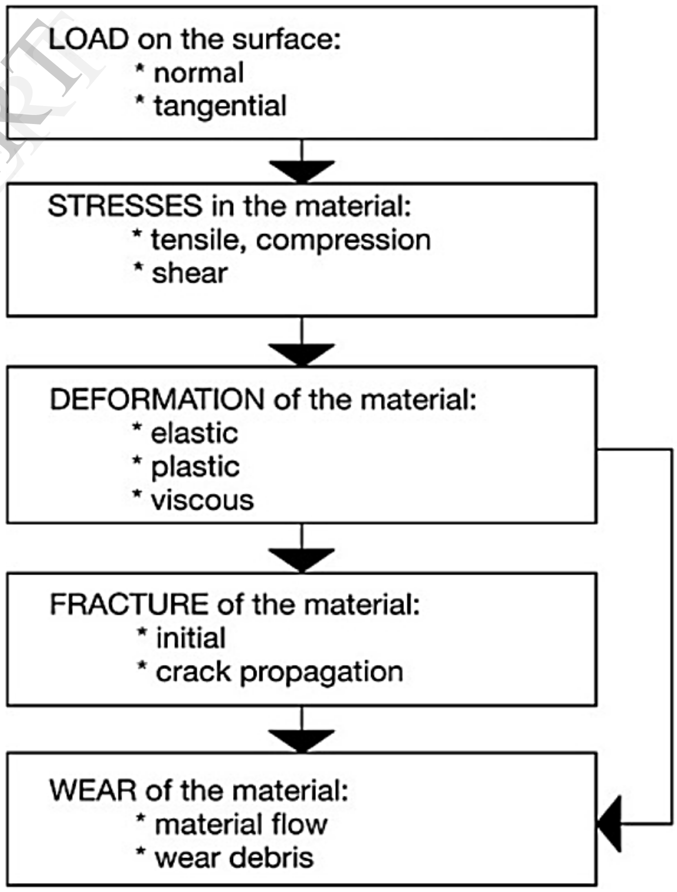

Fig. 2. Schematic diagram of the process from loading of the surface to wear [1].

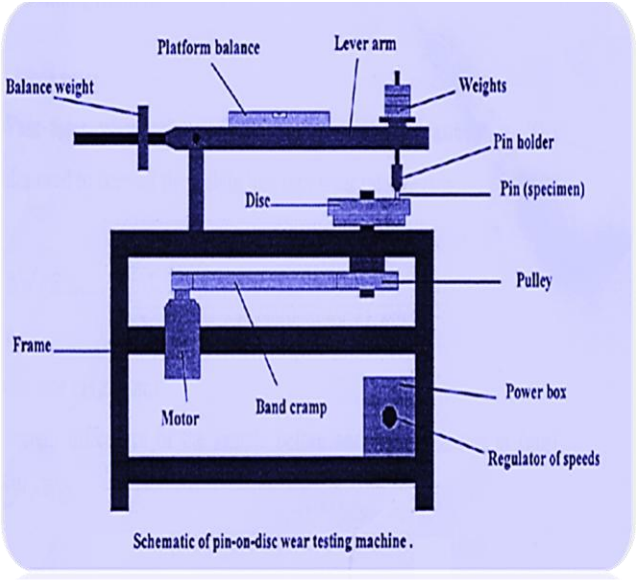

Fig.3 Schematic of the used pin-on-disc testing machine

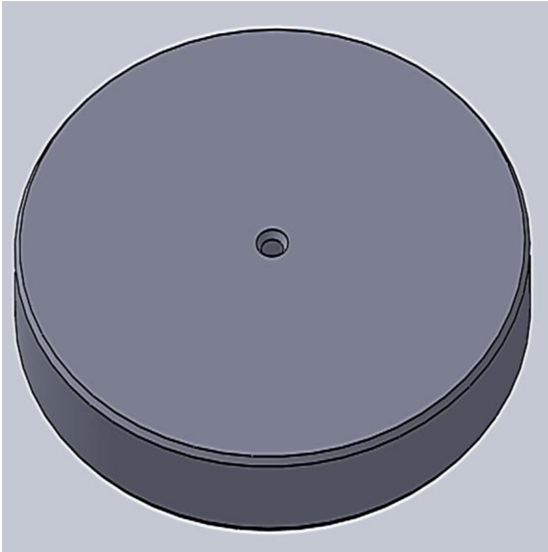

Fig.5 The rotating steel disc, a disc of 200 mm diameter and 25mm thickness

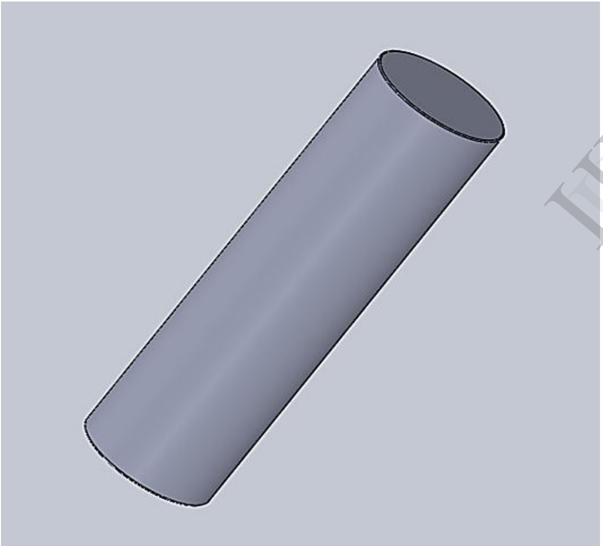

Fig.4Wear specimen (pin), a cylinder of 10 mm diameter and 20 mm length.

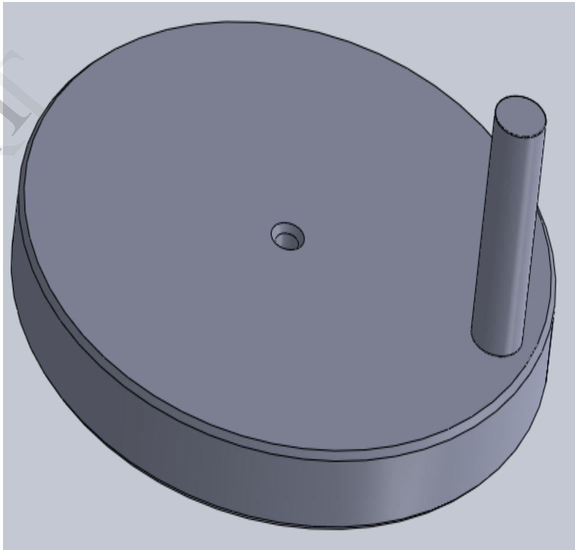

Fig.6 The pin and disc assembly

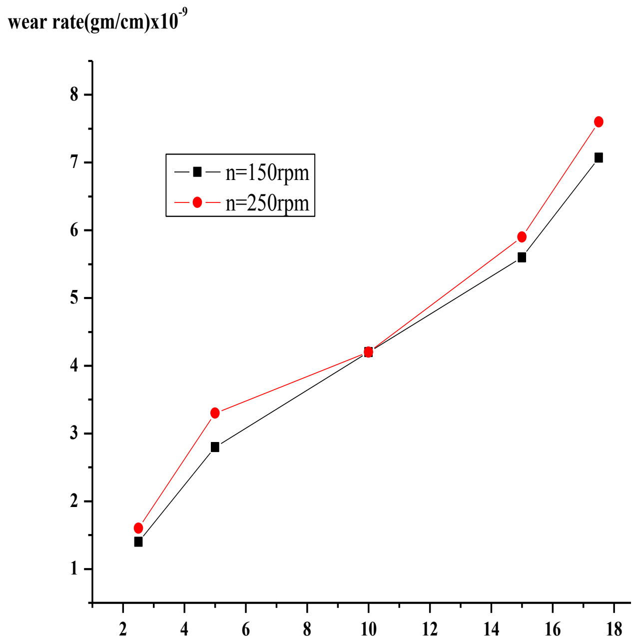

Fig.7. Effect of sliding velocity with varying loads on the wear rate for lubricant oil based on SAE90

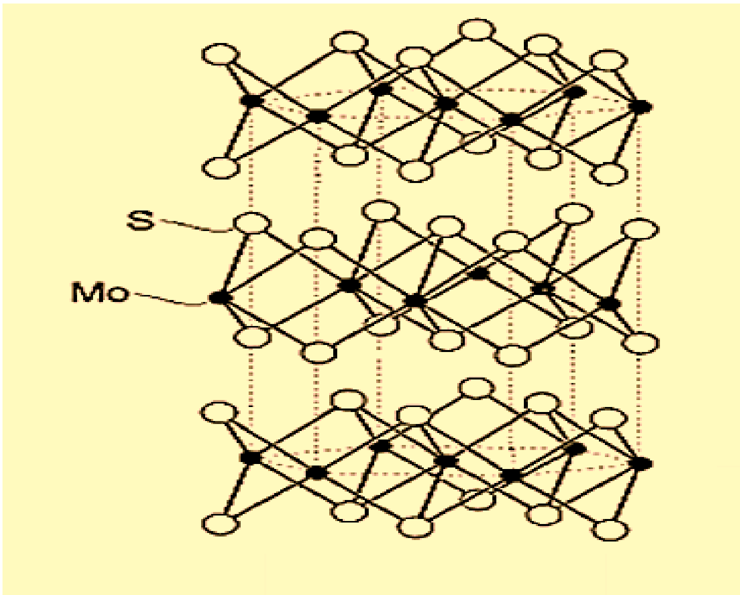

Fig.9. Structure of molybdenum disulphide [2].

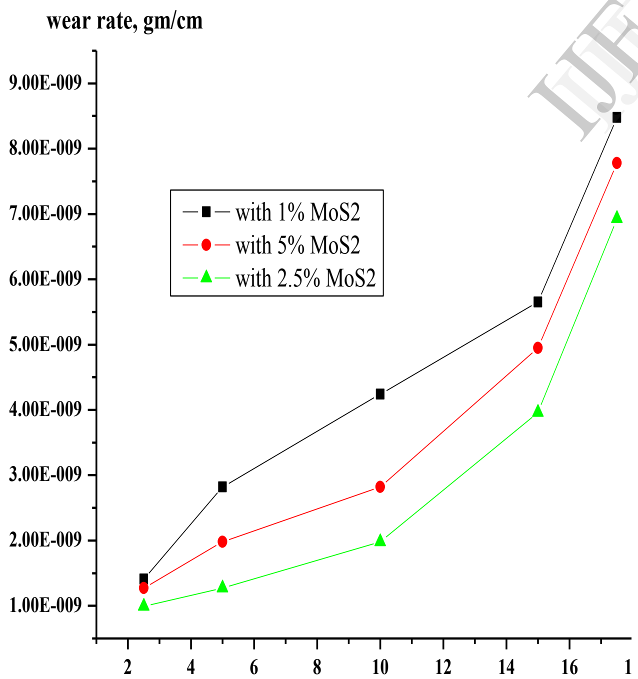

Fig.8. Effect of MoS2 concentration with varying loads on the wear rate for lubricant oil based on SAE 90

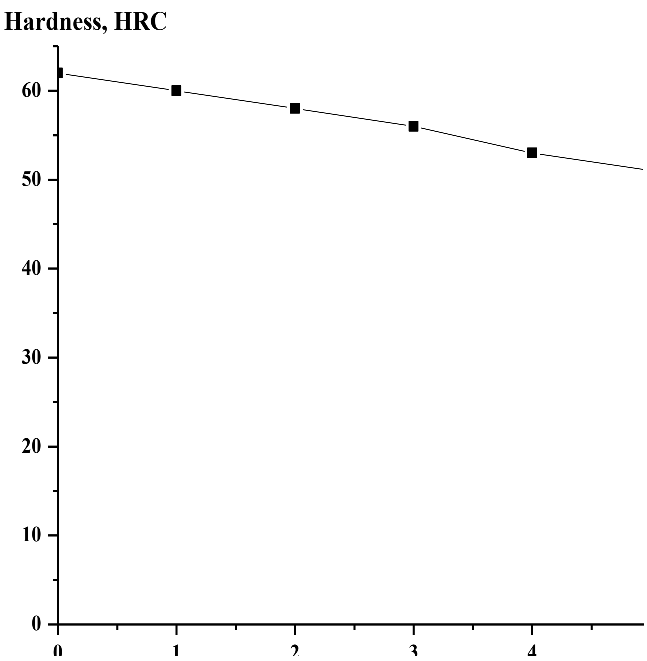

Fig.10. Variation in hardness with varying MoS2 content for lubricant oil based on SAE 90

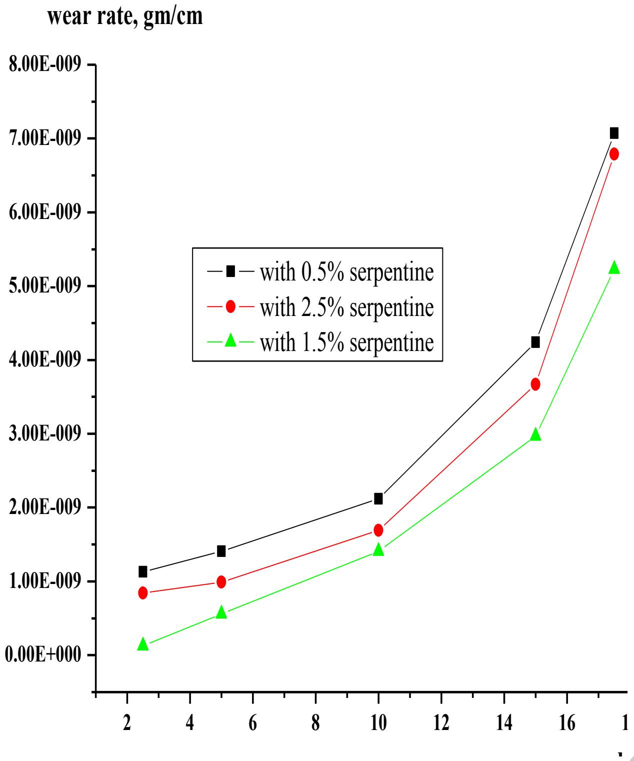

Fig.11. Effect of serpentine concentration with varying loads on the wear rate for lubricant oil based on SAE 90

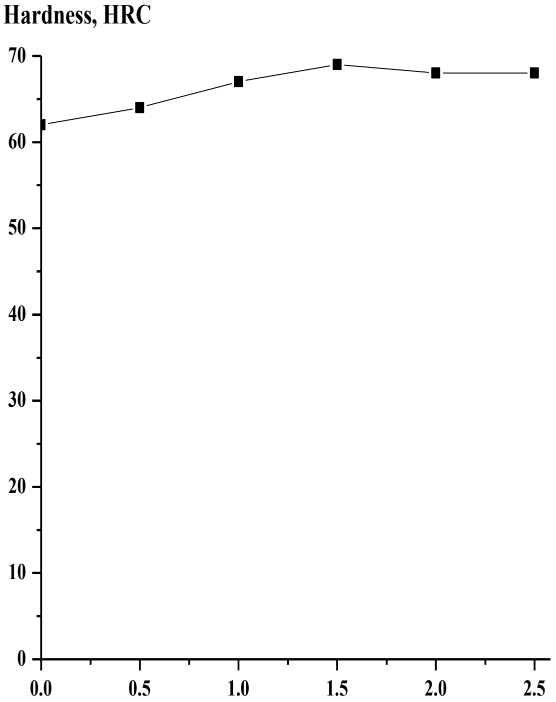

Fig.13. Variation in hardness with varying serpentine content for lubricant oil based on SAE 90.

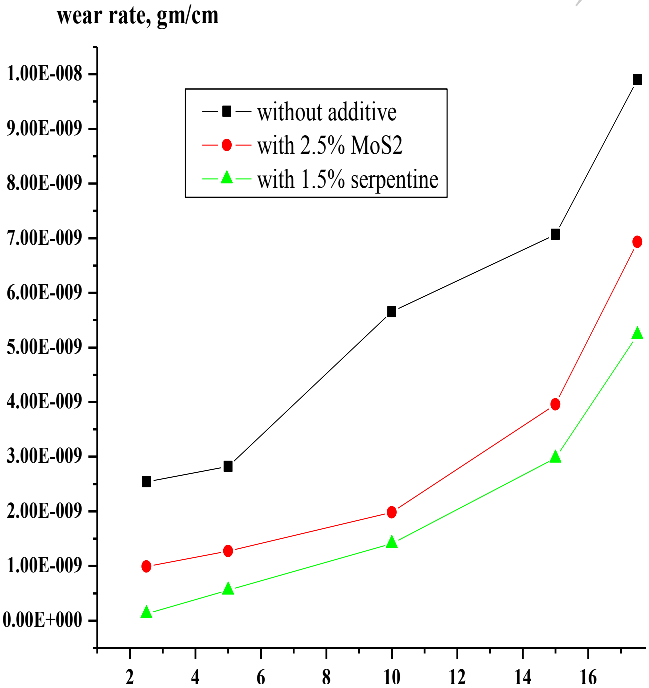

Fig.12. Variation in wear rate with varying load for lubricant oil based on SAE 90

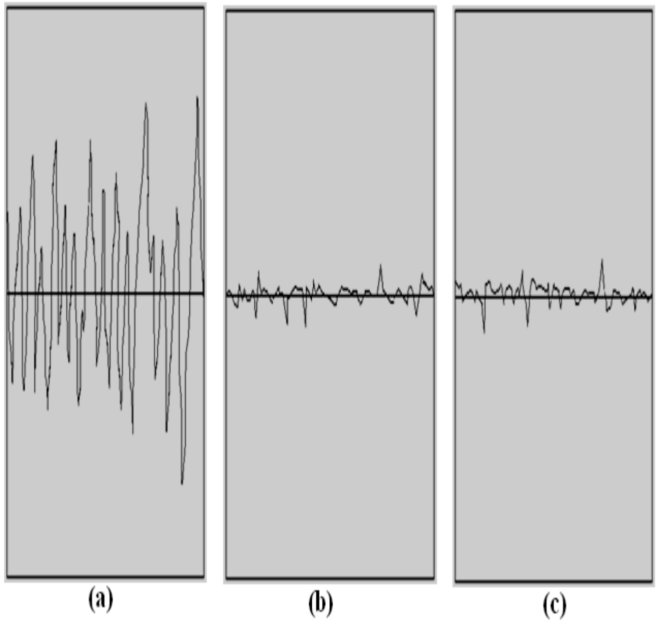

Fig. 14 Profilograms surface friction for lubricant oil SAE 90 without additives (a), with 1.5wt% serpentine powder(b) and with 2.5wt%MoS2 powder(c).

CONCLUSION

[1] The experiments observed an increase in the efficiency of the lubricating medium in sliding steel-steel pair, with the addition of additives to the lubricant oil SAE90, i.e. addition of molybdenum disulfide and serpentine powders.

[2] Put forward a theoretical concept that the introduction of serpentine and molybdenum disulfide powders should lead to an increase in anti-friction efficiency and anti-wear performance in comparison with the case of using the lubricant oil without these additives.

[3] Obtained tribological characteristics of molybdenum disulfide and serpentine additives in the lubricant oil SAE90. It was shown that the wear rate may drop about (2-2.5) times with MoS2 powder and about (3-3.5) times with serpentine powder compared with the case of using the lubricant oil without additives.

[4] Established for the friction pair steel-steel that the introduction of serpentine and molybdenum disulfide powders observed optimum lubricating effect on the level of concentration of these additive in the range of (1.25-1.5) wt. % and (2 – 3) wt. % respectively.

[5] The experiments observed little influence of sliding velocity on the wear rate values under same conditions of the experiments.

[6] Used the serpentine and molybdenum disulfide powders lead to the formation of a homogeneous protective film on the contacting friction surfaces abled to express anti-friction and wear effects.

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