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TRIBOLOGICAL PERFORMANCE OF HIGHLY FINE NICKEL-MOLYBDENUM DISULFIDE POWDERS ADDITIVE TO LUBRICANT OIL

Dr. Haidar Akram Hussien
Lecturer
Technical College - Baghdad
Foundation of Technical Education
E-mail: drhaidar3@yahoo.com

ABSTRACT

Wear is a phenomenon which is 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. Molybdenum is one of the major refractory metals (metals with very high resistance to heat and wear). As already noted, for lubricant compositions as fillers can be used soft powder (anti-friction) of metals – nickel.

This work focuses on studying an urgency and favorable prospects of practical use of firm powder additives on the basis of MoS_2 which particles are coated with one layer of soft metal (Ni), and their effect on tribological characteristics of lubricant oil (SAE 50) at a range of concentration (2 – 8) wt%. Optimum lubricating effect concluded on the level of concentration of the composite additive powder in the range of (3.5 – 4.5) wt %, by the formation of protective boundary layer between sliding tribosurfaces that prevents wear.

Tribological characteristics significantly improved i.e.friction coefficient may drop about (1.5-2) times, and the wear rate about (3-3.5) times compared with the case of usig the lubricant oil without additives.

KEYWORDS: Tribological Properties, Additives, Coating, Lubricating Effect, Solid Lubricant.

دراسة تاثير اضافة مسحوق نيكل – ثنائي كبريتيد المليبدنيوم عالي النعومة على الخواص التريبولوجية لزيوت المحركات

د. حيدر اكرم حسين
مدرس
هيئة التعليم التقني/ الكلية التقنية – بغداد

الموجز

يعتبر الاستهلاك من الظواهر المهمه الجديره بالدراسه لاسيما بين اسطح الاجزاء المتلامسه، ولتقليل الضياعات الحاصلة في الطاقه والانهيارات الحاصله بسبب التشغيل الميكانيكي والاحتكاك الحاصل بين الاجزاء المنزلقه بدا العلماء بالعمل لايجاد بعض البدائل والحلول لتحسين الخواص التريبولوجيه لمواد

التزييت خصوصا في بعض الظروف الخاصه (درجة حراره وضغط عاليين) ويعتبر عنصر المليبدنيوم من العناصرالرئيسيه في هدا المجال بسبب تركيبه البلوري ومقاومته العاليه للحراره والاستهلاك. يتناول هدا البحث دراسة تاثيراضافة مسحوق(نيكل - ثنائي كبريتيد المليبدنيوم) عالي النعومه (مسحوق مركب معامل كيميائيا بحيث تكون دقائق مسحوق ثنائي كبريتيد المليبدنيوم مغلفه بطبقه رقيقه من المعدن الناعم – النيكل)، الى زيت المحركات نوع (SAE 50)، على الخواص التريبولوجيه للزيت وبتراكيز مختلفه تتراوح بين(2 – 8)% غم/لتر من خلال حساب معامل الاحتكاك بين السطوح المنزلقه ومعدل الاستهلاك. لقد اظهرت النتائج امكانيه عاليه في تحقيق هدف البحث المتمثل بتحسين الخصائص التريبولوجيه للزيت المستخدم بسبب الطبقه الواقيه المتكونه عند الاسطح المتلامسه التي تعمل على زيادة المساحه السطحيه للسطوح المتلامسه وبالتالي نقليل الاحتكاك والاستهلاك، فقد انخفضت قيمة معامل الاحتكاك بحدود (1.5 - 2) مره ومعدل الاستهلاك بحدود(3- 3.5) مره على التوالي ودلك باضافة (3.5- 4.5)% غم/لتر من مسحوق (نيكل - ثنائي كبريتيد المليبدنيوم) الى الزيت بالمقارنه مع الحاله عند استخدام الزيت بدون اضافات.

INTRODUCTION

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, where as the morphological element refers to the effects due to the mechanical, chemical, and tribological surface phenomena characteristic of the mating materials [**Zhang, 2010**]. 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, 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) [**Godloviski, 2008 and Taylor, 2000**].

Wear is a phenomenon which is 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 [**Washida, 2003 and Hoshi, 1994**]. Molybdenum is one of the five major refractory metals (metals with very high resistance to heat and wear). The other refractory metals are tungsten, tantalum, rhenium and niobium. Molybdenum's strength and resistance to expanding or softening at high temperatures is particularly sought after in critical areas where high temperatures are common, such as in nuclear power plants and aircraft engines [**Holinski, 2003 and Taylor, 1997**]. Nickel-based sintered composites produced by powder metallurgy processes are now widely used in tribological engineering parts, e.g. bearings and bushes. Also composites based on nickel molybdenum disulfide alloys containing a solid lubricant have been developed as self-lubricating materials under extreme conditions of load, atmosphere and temperature. It is well known that the addition of molybdenum disulfide serves to reduce friction and wear in nickel–molybdenum disulfide alloys. However it should be noted that the addition of molybdenum disulfide (MoS_2) has an adverse effect on the composites’ mechanical properties [**Godloviski, 2008 and Popczyk, 2006**]. The lubricant MoS_2 powder was coated with Ni to reinforce their bonding to the Ni particles in the composites during sintering. The hardness, microstructure and bending strength of the sintered specimens were changed. The friction and wear properties of the materials were clearly decreased. Although mechanical properties of the composites decreased with increasing amount of added MoS_2, the use of Ni-coated lubricant powders improved the bending strength. Molybdenum disulfide was very effective in reducing the wear and friction of the composites [**Rafal, 2011 and Budniok, 2007**].

This work focuses on studying urgency and favorable prospects of practical use of firm powder additives on the basis of molybdenum disulfide which particles are coated with one layer of soft metal (Ni), and their effect on tribological characteristics of lubricant oil.

EXPERIMENT PROCEDURE

The tribological characteristics of investigated metal-molybdenum disulfide additives to lubricant oil with single-layered coating were received during wide range of experiments.

Study of tribological characteristics of the developed lubricant compositions was performed on a friction machine model CMT-2. A simplified diagram is shown in **Figure 1** [**Godloviski, 2008**].

Friction moment on the shaft (rotating disk) was measured using an inductive sensor. Electrical signals werefed into the electrical circuit and then compared to the potentiometer readings, mounted in anelectrical controlcabinet.

Testing samples were made of steel 45, hardness 40-42, dimensions l x b x h = (10 x 10 x10 mm). All samples had a same surface roughness. The roller was d = 40 mm diameter, 15 mm thick, made of steel 45, hardness 35─ 40.

Friction conditions [**Godloviski, 2008**]: the rate of slip-(2m / s) was not changed during the tests, the load on the sample increased stepwise from 0.2 kN to a sharp increase in friction moment. Contact area of friction pairs - about 1 cm². Lubricating compositions were administered in the friction zone on the metal surface for 2km sliding path. During the study recorded the friction coefficient and wear rate.

MATERIALS USED

In this study, the basic lubricant oil used was SAE 50. Investigated lubricant composition additives powders consist of : molybdenum disulfide powder (particle size 4 - 53µm) at a range of concentration (2 – 8) wt%, soft metal powder, nickel powder,(particle size 4 - 53µm) at a range of concentration(2 – 8) wt% and nickel-molybdenum disulfide powder with single-layered coating 4wt% [**Godloviski, 2008 and Rafal, 2011**].

MEASUREMENTS

COEFFICIENT OF FRICTION:

Coefficient of friction was measured by using the formula [**Godloviski, 2008**]:

$$\mu = 2T/ P.\ D \qquad (1)$$

where µ =coefficient of friction

T =moment of friction(N.m).

P =load (N).

D =roller diameter(m).

WEAR RATE:

Measurement of linear wear was carried out by the "artificial bases" method by the establishment of an impression on the contacting friction surfaces using the hardness device TCS - 1M. The diameters were determined from the impression using a microscope MBS - 10.

The wear rate was determined by the formula [**Godloviski, 2008**]:

$$W = 0.004(d2 - d1) / S \qquad (2)$$

Where W = wear rate (μm / km)
d1 =diameter of impression before wearing (mm)
d2 =diameter of impression after wearing (mm)
S = sliding path (km)

RESULTS and DISCUSSION

The tribological properties of lubricating compositions based on the lubricant oil SAE 50, filled with powders of various grades of MoS_2 as well as soft metal(Ni) were studied.

EFFECT of MoS_2 POWDER:

Effect of MoS_2 powder addition on the tribolorgical characteristics of lubricant oil based on SAE 50 was studied at a range of concentration (2 – 8) wt% [**Holinski, 2003**] as shown in **Figure 2**. The lubricating properties of MoS_2 have been explained by the strong polarization of the sulfur atoms 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 (2 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 (6 wt%) results in a thick loose film, deleted in wear action with an increase in friction moment. Results also revealed that minimum friction coefficient was obtained at (4 wt%) of MoS_2 addition . In **Figure 3** results had revealed that, an addition of (4 wt%) of MoS_2 powder to lubricant oil based on SAE 50 would help to reduce friction losses, i.e. reduce the coefficient of friction to reach 0.095 at the load of 0.4 kN, this related to the formation of a solid protective lubricating film of MoS_2 on the sliding metals surfaces which increased the contact surface area between the sliding bodies, MoS_2 powder has the characteristics which are crystal structure, fine particle and large specific surface area. In **Figure 4** results revealed little influence of MoS_2 powder adding to the lubricant oil based on SAE 50, on the wear rate at these operating conditions [**Godloviski, 2008 and Holinski, 2003**]. This is because of little changing in wear rate values.

EFFECT of SOFT METAL(Ni) POWDER:

As already noted, for lubricant compositions as fillers can be used soft powder (anti-friction) of metals - nickel, tin, lead, etc.[**Aurelian, 1989**]. Effect of Ni powder addition on the tribolorgical characteristics of lubricant oil based on SAE 50 was studied at a range of concentration (2 – 8) wt% [**Godloviski, 2008**] as shown in **Figure 5**. It was noted that an addition of Ni powder to the lubricant oil at a range of 4wt% would help to reduce friction losses, i.e. reduce the coefficient of friction to reach its minimum value under experiment conditions. This related to the formation of thin plastic film of nickel on steel surfaces, that increased the contact surface area. In **Figure 6** results had revealed that an addition of (4wt%) soft powder (anti-friction) of metals – nickel to the lubricant oil based on SAE 50 would help to reduce friction losses, i.e. coefficient of friction reduced from 0.122 for lubricant oil SAE 50 without additives at a load of 0.4 kN to 0.116 for the lubricant oil SAE 50 with 4wt% addition of Ni powder at the same load. In **Figure 7** results had revealed that an addition of (4wt%) soft powder (anti-friction) of metals – nickel to the lubricant oil based on SAE 50 would help to reduce the wear rate under these experiments conditions, i.e. wear rate reduced from 6.5μm/km for lubricant oil SAE 50 without additives at a load of 0.4 kN to 3.8 μm/km for the lubricant oil SAE 50 with 4wt% addition of Ni powder at the same load. This may related to the formation of thin plastic film of nickel 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 – nickel, so wear and friction at the same time significantly reduced.

EFFECT of NICKEL MOLYBDENUM DISULFIDE COMPOSITE POWDER:

Significantly improve the lubricating effect of the fillers can be pre-modification of their surface, i.e. modifying the layered filler powders by reduction of the particles of powder metal films by chemical method [**Washida, 2003 and Popczyk, 2006**]. Effect of addition of nickel molybdenum disulfide composite powder, i.e. use of firm powder additives on the basis of molybdenum disulfide which particles are coated with one layer of soft metal(Ni), on the tribolorgical characteristics of lubricant oil based on SAE 50, was studied as shown in **Figure 8** and **Figure 9**. It was noted that an addition of (4wt%) nickel molybdenum disulfide composite powder to the lubricant oil would help to reduce friction losses, i.e. the friction coefficient was reduced in (1.5 – 2) times under a load of 0.4 kN(Fig.8), the wear rate was lowered to (3 – 3.5) times (**Figure 9**) and load capacity of the friction pair was increased by 1.5 times, by compairing with the case of lubricant oil without additives at the same conditions. Since MoS_2 powder as a filler, reducing the coefficient of friction, and nickel powder - the wear rate under the same regimes of friction and lubrication , which should lead to reduce friction and wear. Then the formation on the contacting friction surfaces of nickel films abled to express anti-friction and wear effects [**Godloviski, 2008 and Holinski, 2003**]. In **Figure 10** friction surfaces was carried out before and after 20 (km) path of friction in the lubricant oil SAE 50 with newly developed nickel molybdenum disulfide composite powder at a load of the working surface of 0.4 (kN). Photographing the surfaces was carried out using an electron microscope with an increase of 2,000 times, obtained profilograms and photos were presented in **Figures 10 – a and b and 11**. It was noted the sharply difference between profilograms surface friction for lubricant oil SAE 50 without additives (fig.10 - a) and with 4wt% nickel molybdenum disulfide composite powder (**Figure10 - b**). This may related to the formation of solid lubricant and metallic film on the contacting friction surface, abled to improve tribological properties of the lubricant oil composition.

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 SAE 50, i.e. addition of molybdenum disulfide powder-coated metal (Ni) in comparison with the case of separate administration of the same amounts of molybdenum disulfide powder and soft metal, entered separately.

2. Put forward a theoretical concept that the introduction of a lubricating base medium of molybdenum disulfide powder and metal as thin layer coating of molybdenum disulfide powder particles should lead to an increase in anti-friction efficiency and anti-wear performance in comparison with the case of separate administration of the same amounts of molybdenum disulfide powder and soft metal, entered separately.

3. Obtained tribological characteristics of composite molybdenum disulfide -metal additives in the lubricant oil with a single layer coating. It was shown that in monolayer nickel coating the friction coefficient may drop about (1.5-2) times, and the wear rate about (3-3.5) times compared with the case of usig the lubricant oil without additives.

4. Established for the friction pair steel-steel that the introduction of molybdenum disulfide, nickel and composite additives powders observed optimum lubricating effect on the level of concentration of the additive in the range of 3.5 – 4.5 wt. %.

5. Metallization of powders - filling lubricant compositions help to solve important issues such as:

a - reducing the amount of powder fillers.

b - alignment specific gravity (density) of the powders.

6. Use as a filler nickel coated molybdenum disulfide powder leads to the formation of nickel films on the contacting friction surfaces able to express anti-friction and wear effects.

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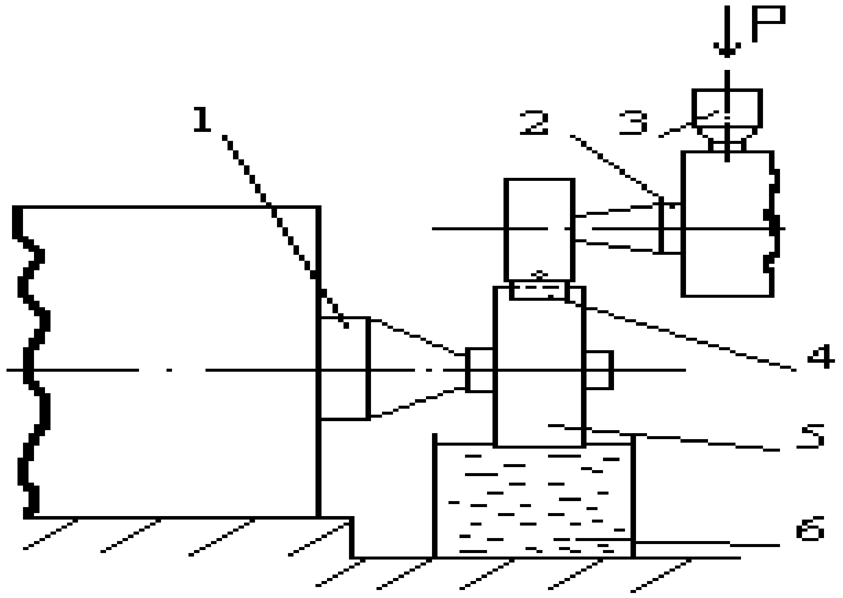


Figure 1 Simplified diagram of the friction machine CMT - 2
1 - bottom (rotating) shaft, 2 - upper (stationary) shaft; 3- loading device, 4- sample,
5 – Rider (roller); 6 - bath for lubrication [**Godloviski, 2008**] .

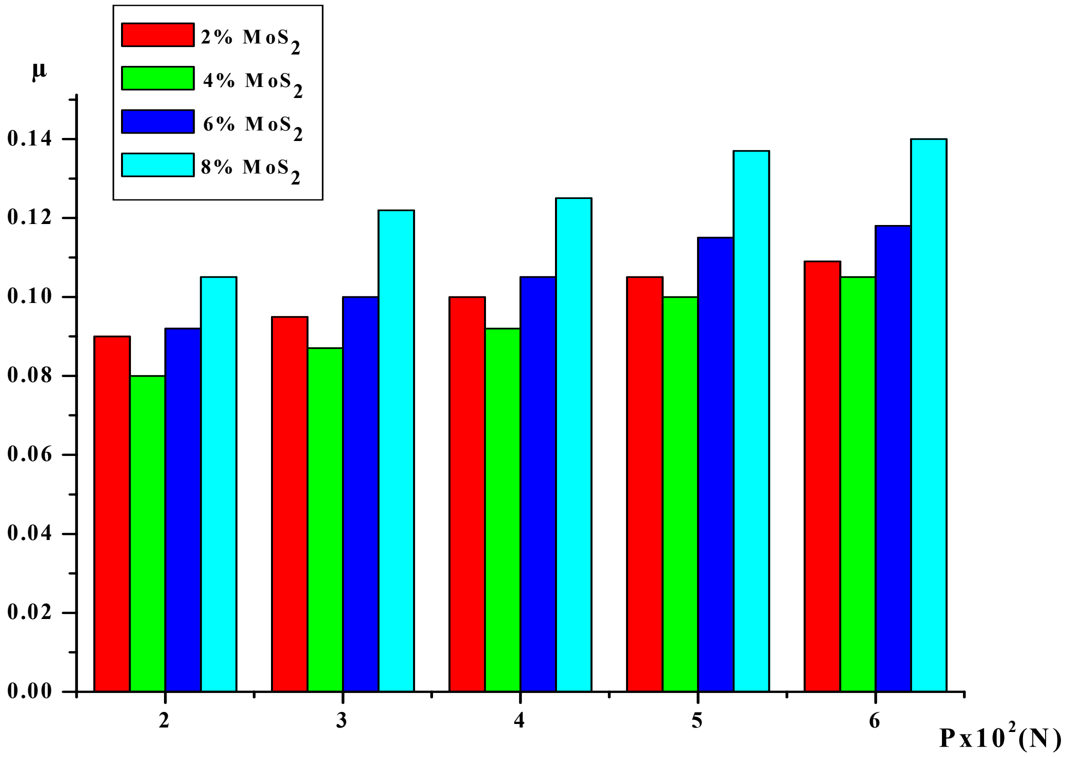


Figure 2 Effect of MoS_2 powder concentration at various loads on friction coefficient(μ) for lubricant oil composite based on SAE 50

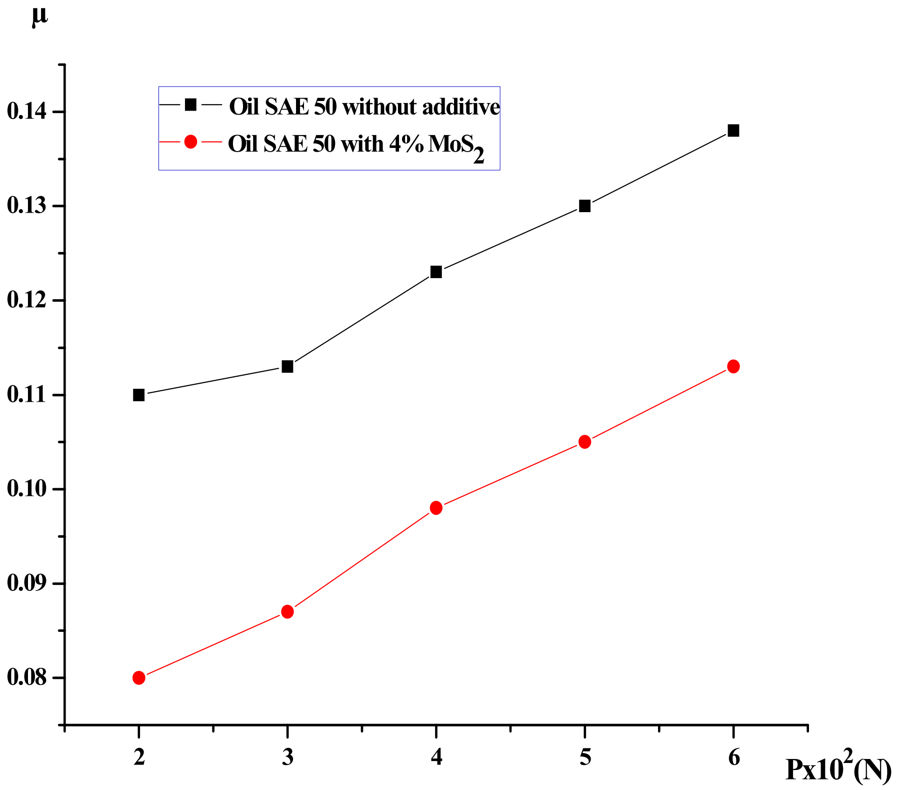


Figure 3 Effect of load (P) on friction coefficient (μ) for lubricant oil composite based on SAE 50

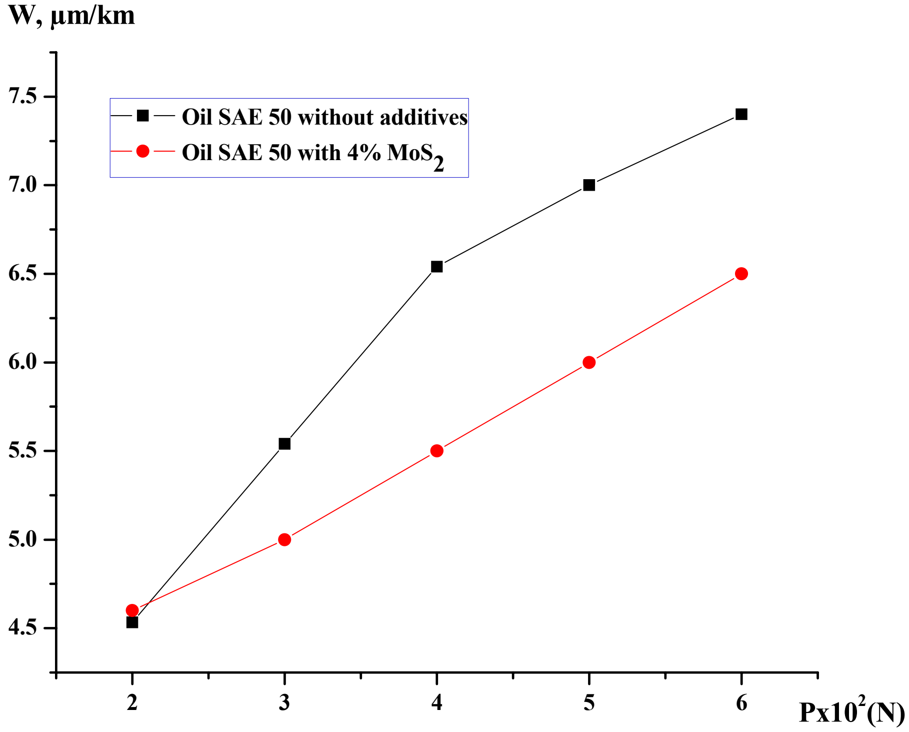


Figure 4 Effect of load (P) on wear rate (W) for lubricant oil composite based on SAE 50

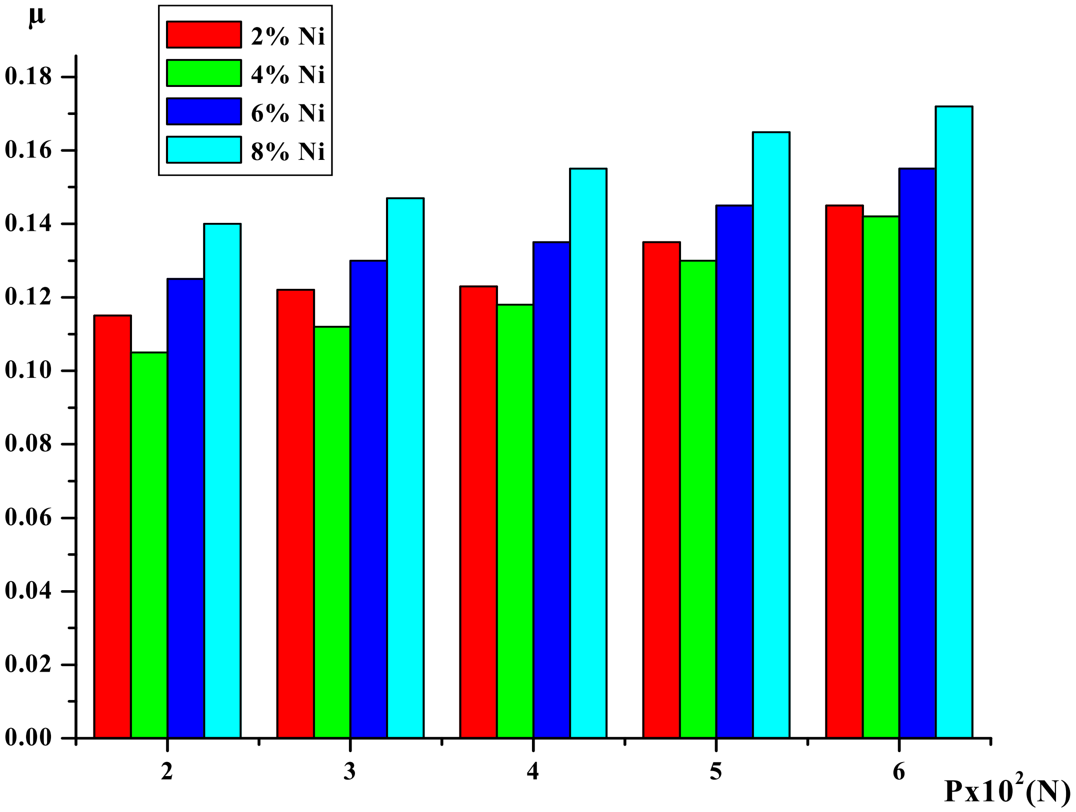


Figure 5 Effect of Ni powder concentration at various loads on friction coefficient(μ) for lubricant oil composite based on SAE 50

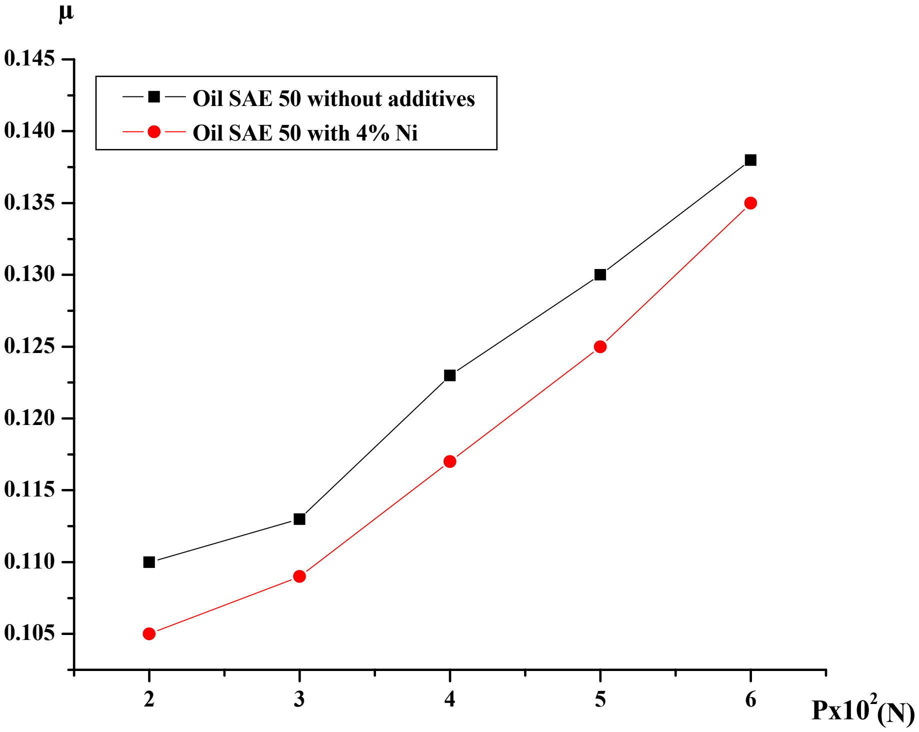


Figure 6 Effect of load (P) on friction coefficient (μ) for lubricant oil composite based on SAE 50

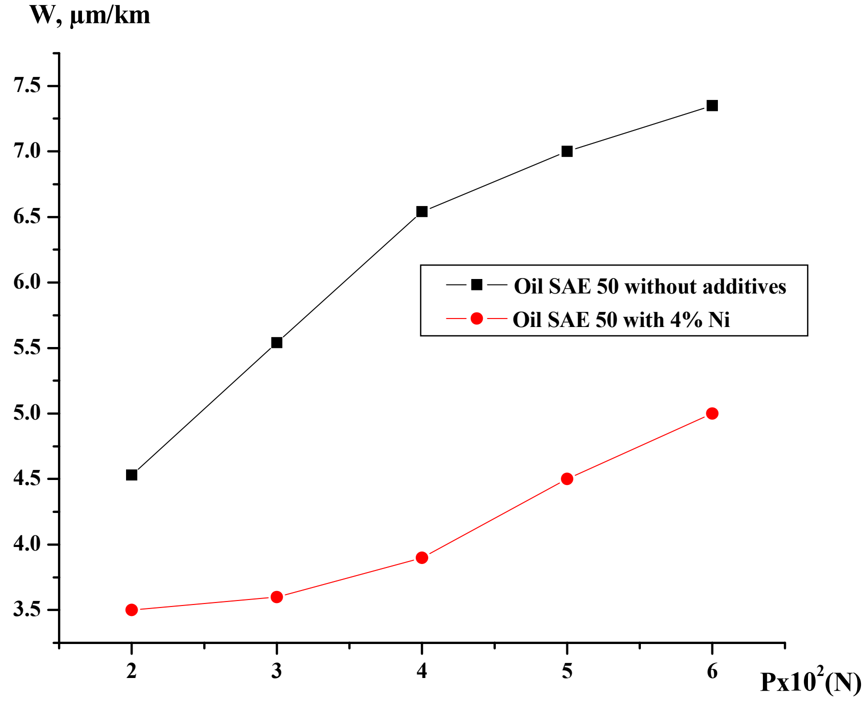


Figure 7 Effect of load(P) on wear rate(W) for lubricant oil composite based on SAE 50

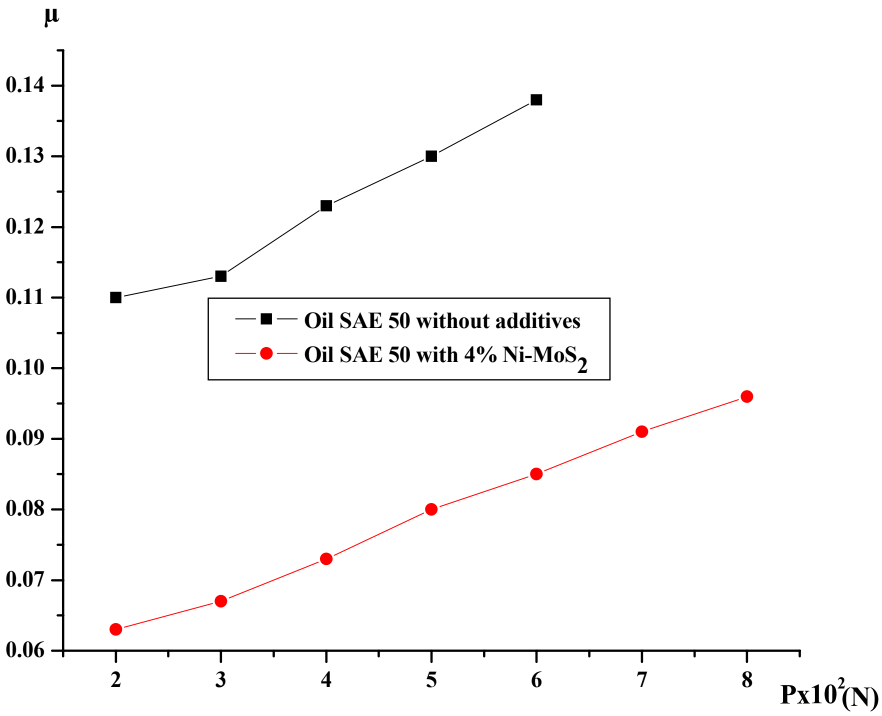


Figure 8 Effect of load (P) on friction coefficient (µ) for lubricant oil composite based on SAE 50

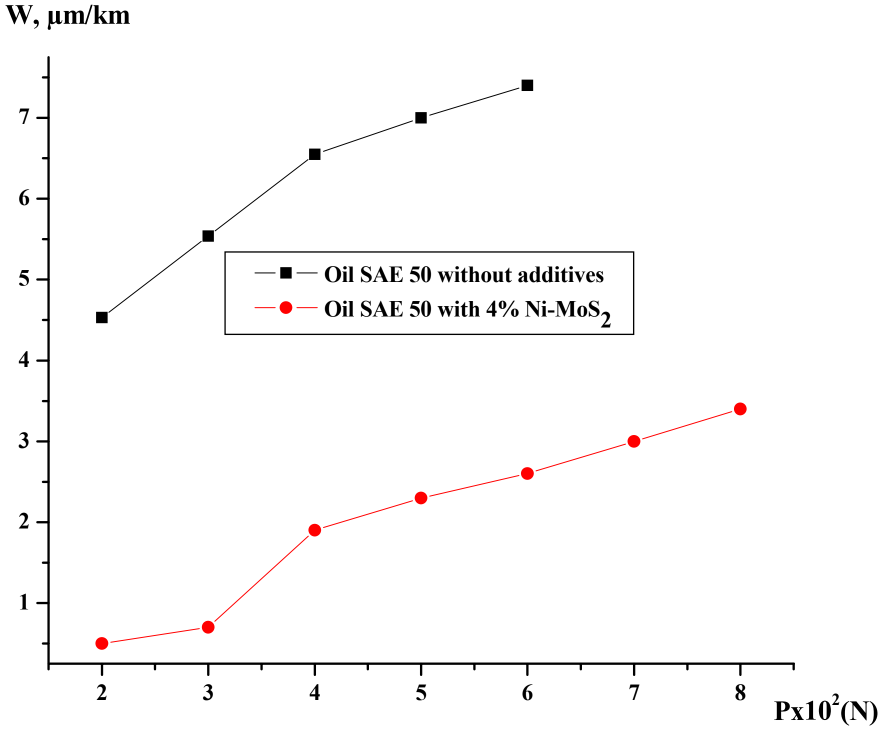
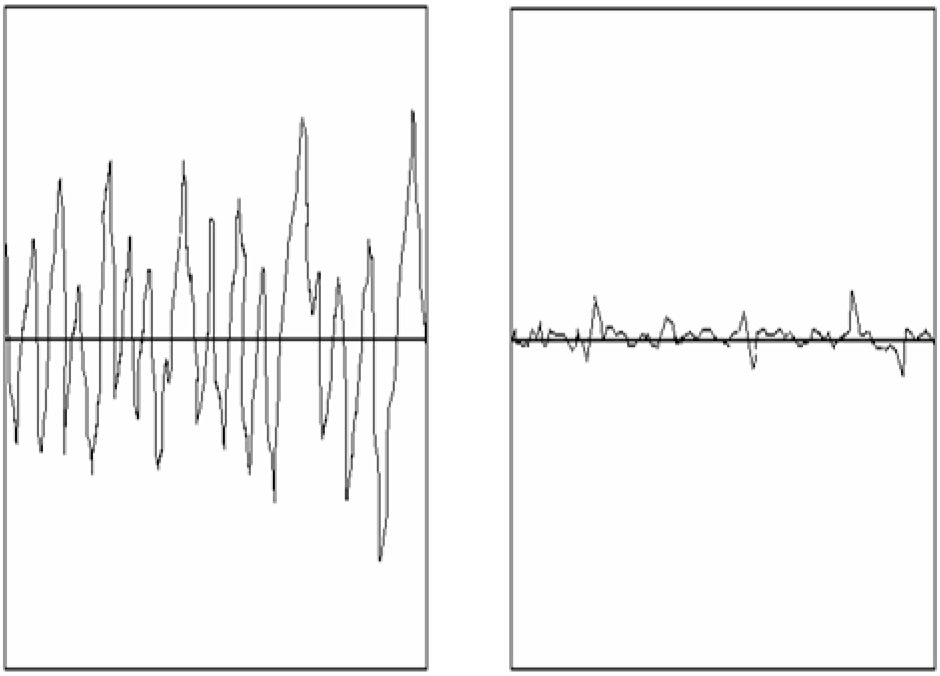


Figure 9 Effect of load(P) on wear rate(W) for lubricant oil composite based on SAE 50



(a) (b)

Figure 10 Profilograms surface friction for lubricant oil SAE 50 without additives (a) and with 4wt% nickel molybdenum disulfide composite powder (b).

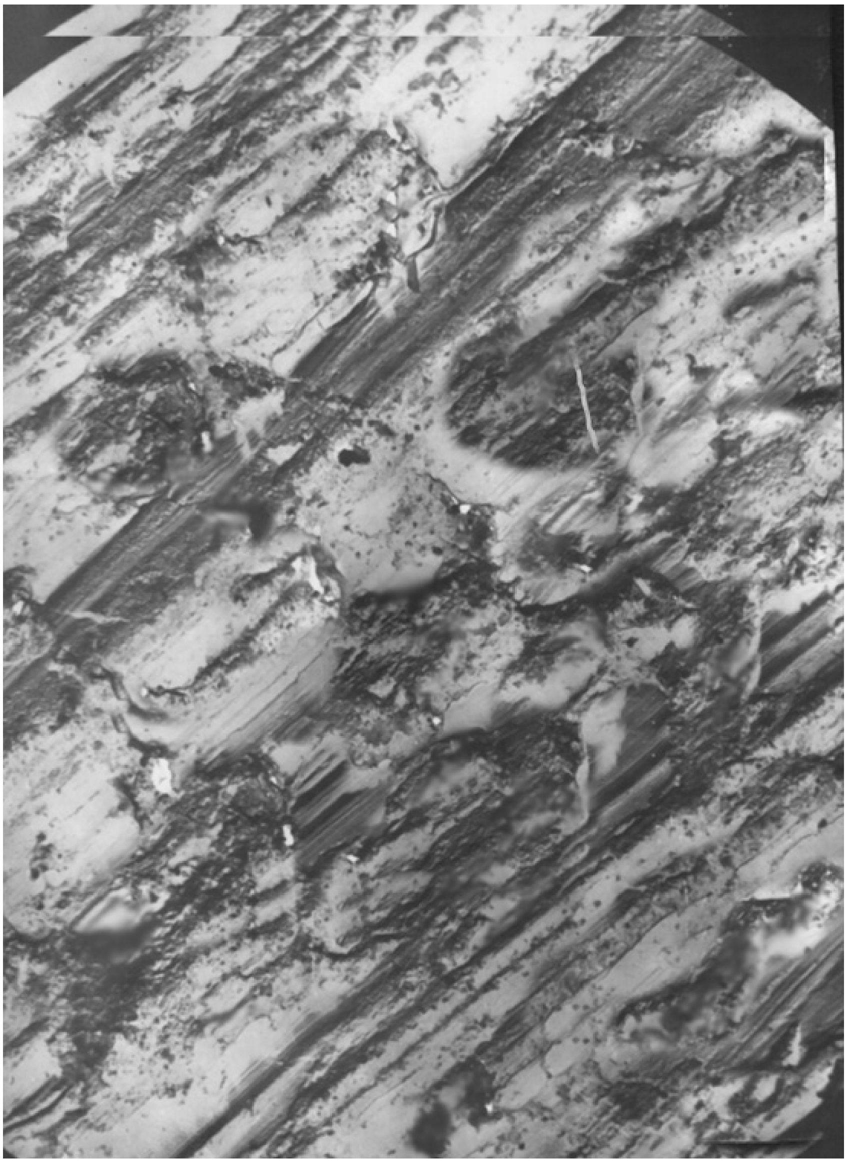


Figure 11 Surface friction photo for lubricant oil SAE 50 with 4wt% nickel molybdenum disulfide composite powder (increasing x 2000).