Study of MoS_2 Nanoparticles Effect on Friction and Wear Reduction by Using Pin on Disc Machine

Salar Karim Fatah

Department of Physics - College of Education - University of Garmian – Kalar -Iraq

salarkarim@garmian.edu.krd

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Abstract

The solid-state lubricant, especially molybdenum disulfide (MoS_2), nanoparticles have been used for several decades, due to their significant characteristics in the lubrication process, as a means to protect surfaces and increase the load capacity of the rubbing arrangements in sliding motion systems. In this study, 0.5 g of MoS_2 nanoparticles (average particle size 90 nm), with a purity of approximately 99% have been used. Then 1 ml mixture of MoS_2 nanoparticles with 20 ml of isopropanol-liquid was used to lubricate the substrate which was a steel disc surface in a pin on disc machine. Then by using this machine, friction coefficient behavior of the MoS_2 distribution particles and the position depth of the steel pin on the steel disc surface were studied, the study was processed under the humidity and room temperature. After the running tests, Scanning Electron Microscopy (SEM) was used to characterize the morphology and microstructure of the distributed MoS_2 nanoparticles. As a result, MoS_2 showed less friction coefficient. Also, it resulted less pin position on the disc surface, and it protected the surface from severe wear.

Keywords: MoS_2 nanoparticles, Friction, wear, lubrication, pin on disc machine.

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Salar Karim Fatah

دراسة تأثير مسحوق MoS_2 النانوي على الاحتكاك والحد من التأكل باستخدام دبوس على آلة القرص

سالار كريم فتاح

قسم الفيزياء - كلية التربية – جامعة گرميان - كلار - العراق

الخلاصة

ان مادة التشحيم الصلبة، وخاصة مسحوق ثاني كبريتيد الموليبدينوم النانوي (MoS_2)، تم استخدامه للعديد من العقود، نظراً لخصائصه الهامة في عملية التشحيم كوسيلة لحماية السطوح والزيادة من سعة تحمل عمليات الاحتكاك (تلامس سطوح الاجسام) في انظمة الحركة. في هذه الدراسة، تم استخدام كمية من مسحوق MoS_2 النانوي حوالي 0.5 غرام (حجم الجسيمات النانوية 90 nm) بنقاوة ما يقارب 99٪، ثم مزج 1 مل من مسحوق MoS_2 النانوي مع 20 مل من الأيزوبروبانول السائل المستخدمة لتشحيم الركيزة التي هي عبارة عن آلة تتكون من سطح قرص ذو حركة دورانية و يوجد فوقه دبوس. باستخدام هذا الجهاز تم دراسة سلوك معامل الاحتكاك لتوزيع جسيمات MoS_2 وعمق موضع الدبوس على سطح القرص الصلب، الدراسة تمت معالجتها تحت رطوبة ودرجة حرارة الغرفة. بعد تنفيذ الاختبارات، تم استخدام المجهر الإلكتروني الماسح (SEM) لتوصيف المورفولوجية والتركيب الدقيق لتوزيع مسحوق MoS_2 النانوي. النتائج بينت ان MoS_2، قلل الاحتكاك و الاختراق لرأس الدبوس على سطح القرص الصلب و مقاومة السطح الشديد للتآكل.

الكلمات المفتاحية: مسحوق MoS_2 النانوي، احتكاك، تآكل، تشحيم، دبوس على آلة القرص.

Introduction

Solid-state lubricant such as MoS_2 has been used for decades, particularly for applications where other kinds of lubrication such as grease or liquid would not be practical, even though in the case of using it either alone or mixed with other materials [1]. Currently, due to environmental conditions, solid-state lubricants have been developed as a means of providing a perfect lubricant in high temperature in which liquid and grease cannot survive, and in the case of low temperature in which oils and grease freeze to form brittle solids [2]. Also, solid-state lubrication would be the only feasible lubrication mechanism in the case of contamination-sensitive fabrication, for instance in food processing and textile manufacturing [1]. Generally, common types of solid-state lubricants are molybdenum disulfide (MoS_2), tungsten disulfide (WS_2) and graphite. However, recently the most common kind is MoS_2 [3]. In addition, MoS_2 can reduce friction and the wear damage inside equipment during the running process; as a result, many researchers have focused on the tribological behaviour of MoS_2 under various working conditions [4].

MoS_2 has a very low coefficient of friction, and it has been acknowledged for long period. Due to these characteristics, it has been the subject of much research and speculation [5,6]. The low coefficient of friction of MoS_2 corresponds to three significant points, which in short is, 1) the easy split that is the intrinsic behavior of the crystal construction of the substance, 2) the low friction that is also relative to the adsorbed molecule's interface crystallites, and 3) the frictional properties would be controlled by the forces acting between single crystallites and split participate alongside grain margins which are resisted to the split interface sheets in a single crystal [5]. However, the coefficient of friction of MoS_2 is not continually low value, and with running time it will increase. MoS_2 sticks easily to the most of the substrates. Due to, when the sliding wear participates interface MoS_2 and the solid surface materials, the event of the adhesion with junction development will be taking part, and then the high friction coefficient would be produced in the system [7]. Moreover, the friction coefficient also depends on various parameters, such as contact pressure, the integrity of the film, film thickness, humidity, a presence of contaminants and temperature [8], [9].

When MoS_2 has a pure, dense properties at the high contact pressure under the conditions of a clean, dry environment, the friction coefficients will be as low as 0.02. This test has been conducted under unidirectional sliding. On the other hand, when MoS_2 has impurities and experiences humidity, low pressure, and non-aligned orientation, the friction coefficient has a high value of approximately 0.05 to 0.1 in a vacuum environment and is around 0.1 to 0.2 in air and water with a normal load of 0.5 N [9]. Furthermore, the coefficient of friction of the MoS_2 in special environments, such as an ultra-high vacuum at a pressure of 50×10^{-9} Pa, would be different, and very low compared with other environments, where it is approximately 0.001 [9].

The aim of this study is to determine the behavior of MoS_2 Nano powders in the case of solid lubrication, study the friction and wear behavior of them by using the pin on disc machine. Additionally, compared the surface of steel disc with MoS_2 distribution and without distribution. Then, SEM was used to study the morphology and structure of nanoparticles of MoS_2 after the running tests.

Materials and Methods

MoS_2 powder with average scale size of 90 nm and purity 99.8% has been used. Two samples were prepared, the samples substrate was steel disc with diameter 70 mm and 6.8 mm thickness, also the pins were steel with 6 mm diameter and 12 mm length. Sample one is steel disc without distribution of MoS_2 particles and sample two is with distribution of it. After preparing a solution of 20 ml of isopropanol-liquid with 0.5 g of MoS_2, 1 ml mixture of them was distributed on the surface of the steel disc manually. The distributed particles can be seen in figure 1. In general, the number of distributed particles would be around 3.39×10^{15} per m^2, and the distribution for a small amount as 10 μm^2 on the surfaces would be about 3.39×10^{5} per m^2.

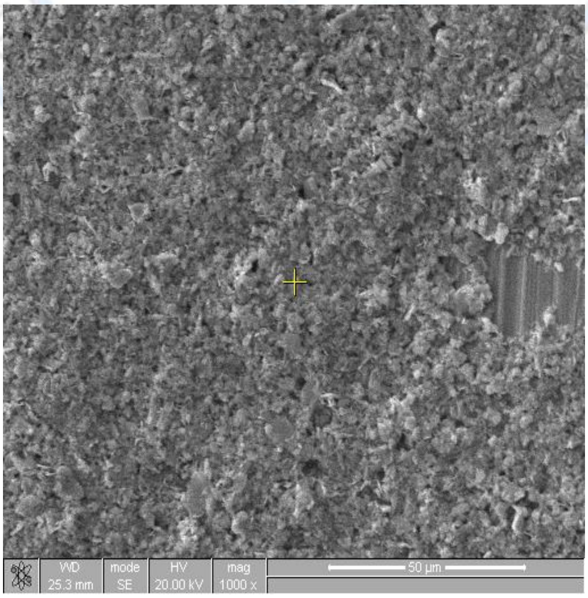

Figure 1: The distributed particles on the steel surface.

Pin on disc machine was used, the work of this device is that it has a steel pin rotating perpendicularly on the surface of a steel disc. It can find the friction and pin position on the disc surface of steel with and without distribution of MoS_2. It's directly connected to the computer, so the software program shows the friction curves vs. time and pin position (how much pin press inside the disc surface) during the running process. The photographed picture of the machine can be seen in figure 2, this machine model name was (CETR UMT-2).

Figure 2: The device of the pin on disc machine

Results and Discussion

Friction Coefficient

The results of the coefficient of friction for the study with different test conditions have been shown for two tests in table 1. In the first test when pin A used with the conditions shown in the table 1, the coefficient of friction was determined to be approximately 0.75, as shown in figure 3. It is observed that at the time of the start of the test, the coefficient of friction of the steel surface has a low value, which is estimated at approximately 0.22, but with the run time, this value gradually increased until it stabilized at roughly 0.75. According to Suh and Sin's new theory on friction, they showed that the friction between steel on steel surfaces will rise gradually towards the steady state of the friction coefficient, and then it drops to a constant value [10]. These values of friction coefficient for steel on steel materials compared with the results work of Grigoriev, who explained that steel on steel static friction is equal to 0.74 [11].

In the second test, when the test conditions were the same as test 1, the coefficient of friction generally measured approximately 0.22. As determined from figure 4, the value at the start of the test was low, while with run time this gradually increased. Owing to the fact that the surface had a layer of MoS_2 particles which protected the surface from real contact. Consequently, the difference of the coefficient of frictions of the samples with and without of MoS_2 powders can be noticed.

Table 1: Results of Pin on disc with and without distribution of MoS2 powders

Sample test name	Pin used	Test no.	Test condition		End point of the coefficient of friction	End point of the height position of the pin (µm)
Steel pin on steel disc without distribution of particle interface between them	A	Test 1	Time Load Revolution Radius of wear track	10 min 0.5 kg 20 rpm 25 mm	0.75	-18 µm
Pin on disc with interface distribution particles of approximately 3.38 x 10^{17} per m^2	B	Test 2	Time Load Revolution Radius of wear track	10 min 0.5 kg 20 rpm 25 mm	0.22	-3 µm

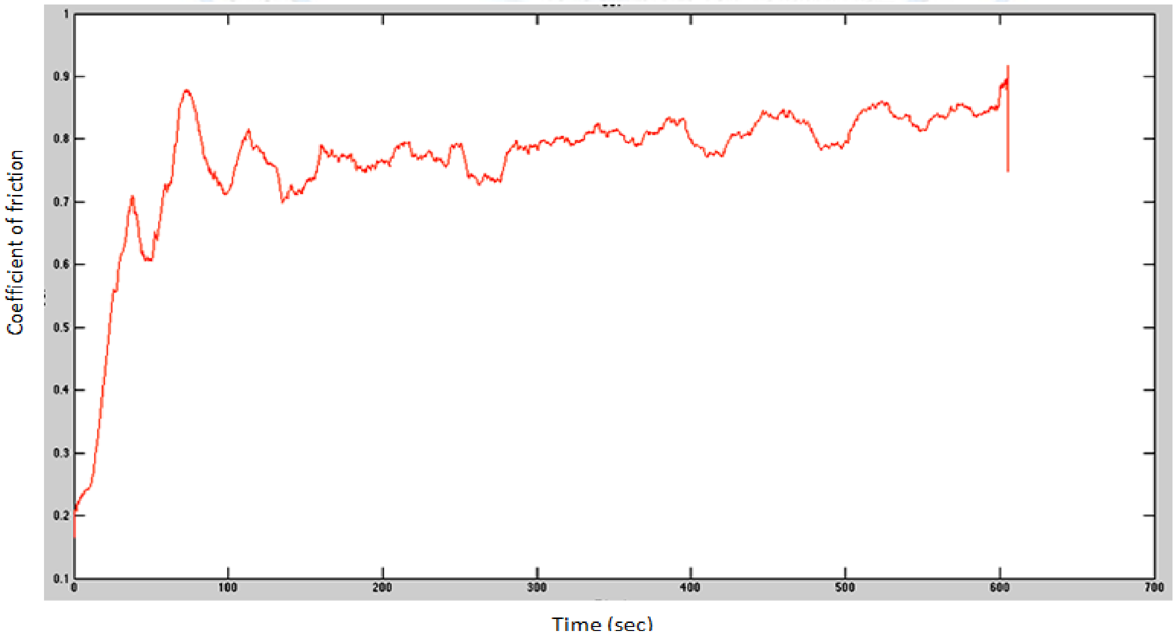

Figure 3: Coefficient of friction with time for (steel pin on steel disc without MoS_2 distribution, with parameters of load (0.5 kg), time (10 min), revolution (20 rpm) and radius of wear track (25 mm)

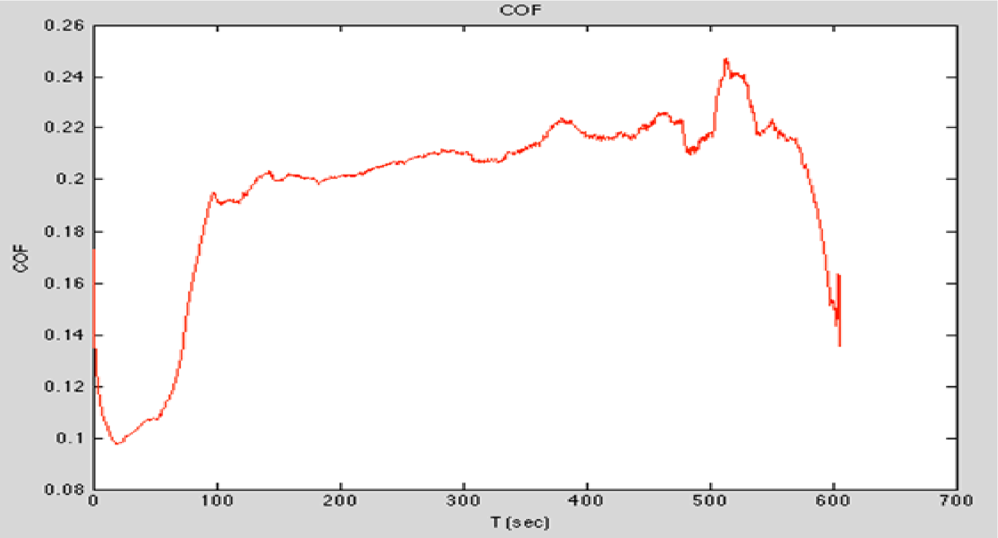

Figure 4: Coefficient of friction of (steel pin on steel disc with the distribution of particles on the surface (3.38 x 10^{17} per m^2), with time (10 min), normal load (0.5 kg), the revolution of disc (20 rpm) and radius of wear track (25 mm).

Pin Positional Measurement (Depth of Pin on The Disc Surface)

The various end points of pin height data resulting from the different test conditions are tabulated in table 1. The height of the steel pin on the steel disc surface has been calculated for the first test as approximately -18 µm, this is shown in figure 5. According to the figure, it can be noted that the position of the pin on the surface at the start time of the test was slightly raised on the disc surface, while with run time it was gradually reduced down on the steel surface of the disc. Generally, there are reasons behind this phenomenon, for instance, surface oxidation, contamination on the surfaces and the environment. Another reason is that when the friction starts to participate interface surfaces, wear particles would be generated between them and then these wear particles remain constant entrapped between the sliding surfaces, within it would be equal to the wear particle interface left between them [9]. In this case, the position of the pin would be above the disc surface. Due to, the surface has several valleys and peaks, and at the start of the surfaces meeting the peaks are removed by sliding contact between them, after which the real contact would occur between them.

The results of the height of the steel pin for the particle distribution, of approximately 3.38 x 10^{17} per m^2, has shown a different form of the depth on the surface of the steel disc and steel pin. The depth that the pin generated on the surface of steel disc has been measured as shown in figure 6. From this figure, the height of the pin on the original disc surface has been calculated as approximately -3 µm. As a result, this value compared with the other test has the lowest value; owing to the amount of MoS_2 powder being increased for the distribution process. The surface has been protected from true contact between both the pin and disc surfaces. Furthermore, the MoS_2 nanoparticles can reduce friction and wear depth between two bodies in motion. When the two surfaces are contacting asperities with each other, particularly at the highest point of the surfaces, the tops of each surface would be removed, and this phenomenon can be called mild wear [12]. Besides the removal of the surface on the system during mild wear, oxidation and substrate distortion would participate in the process [12]. On the other hand, severe wear would participate by following the mild wear in the lubrication system that damaging surface would be greater than normal mild wear, and the wear depth increases by double the amount in the mild wear case [12]. In addition, the debris wear particles in the case of severe wear are of a larger size than those of mild wear.

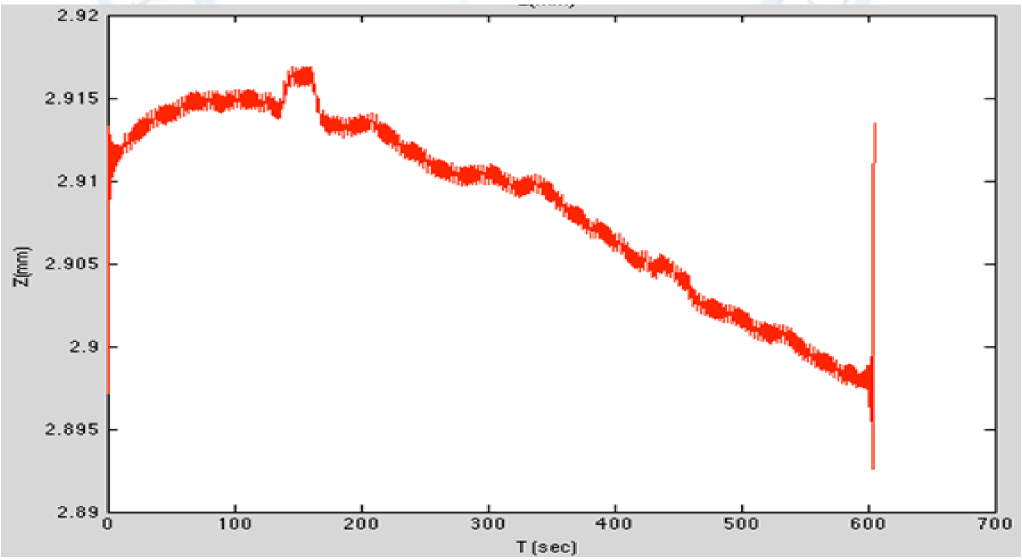

Figure 5: Height position of pin on disc (Z mm) with time (sec), under conditions of time (10 min), revolution (20 rpm), load (0.5 kg), and wear track radius (25 mm)

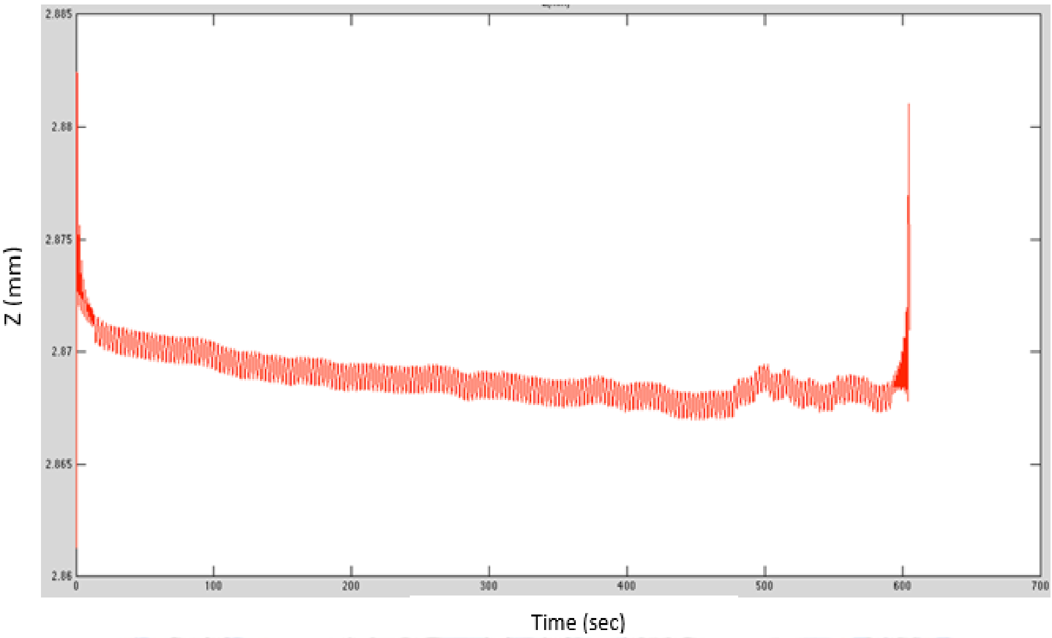

Figure 6: Height location of pin on steel disc with a distribution of particles on the surface (3.38 x 10^{17} per m^2). With time (10 min), normal load (0.5 kg), revolution of the disc (20 rpm), and wear track on the surface (25mm)

Morphology and microstructure

The overview SEM images of the steel pin on steel disc without distribution of MoS_2 powders and with the distribution of approximately 3.38 x 10^{17} per m^2 have been shown in figure (7- a and 7- b) respectively. The overview figures (7- a and 7- b) show the scratched disc surface by the steel pin and the wear track can be clearly observed on the surfaces as being approximately 1 mm, and on the surface of the steel disc, two lines are observed on both sides of the center of the wear track, this is due to the pin shape, which is hemispheric. Then, only the peak of the pin is in contact with the disc surface. In the enlargement figure 7- (a-1), the particles can be seen that have been thrown away from the contact surfaces by pressure of the pin on the disc, and they agglomerate in the form of group particles approximately 28 µm with some tiny separate particles on the surface, with fewer scratches, due to space between the pinned curve and flat disc. While, in the enlargement figure 7 (b-1), at the edge of the wear track the different sizes of particles can be noticed, and they are either debris wear or

MoS_2 particles thrown away from the center of the wear track, and the size of single wear particles is around 12 µm and for cluster wear particles it is around 18 µm.

The center of the wear track of the steel disc with and without MoS_2 distribution can be seen in enlargement figures (7 (a-2), 7 (b-2)) respectively. In figure a-2, the wear particles and scratch surface can be seen, the size and the shape of the worn particles are different; in some places they are agglomerated as a matrix group of particles with a size of approximately 42 µm, besides which single small steel particles are evident on the surface of around 10 µm. Even though, small worn particles can be seen on the surface. However, in figure b-2, near the center of the wear track the surface can be observed as being smooth and without any particles, this is due to the distribution of MoS_2 particles on the surface made a smooth layer to protect the surface from real contact.

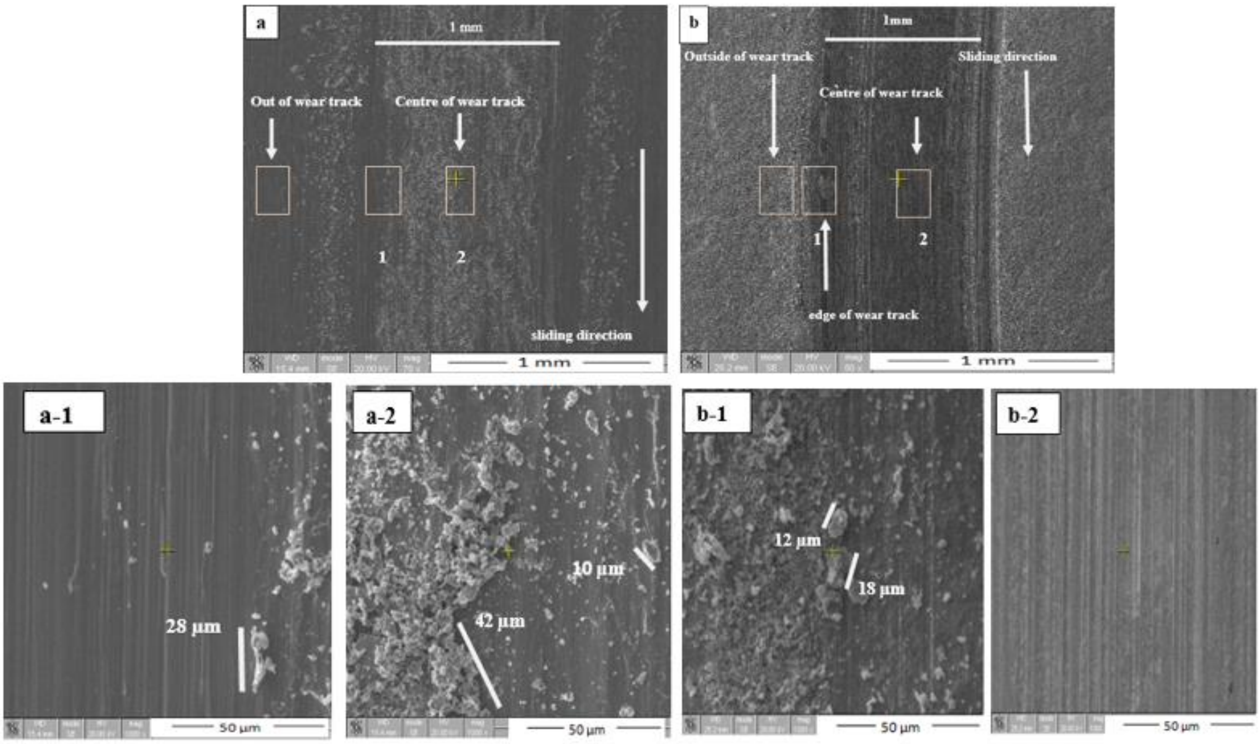

Figure 7: a) SEM image of an overview of steel disc surface without distribution of MoS_2, a-1) and a-2) enlargements of the worn surface at 1000 X, b) SEM of steel disc surface with the distribution of powders, b-1) and b-2) enlargements of the worn surface at 1000 X.

Conclusion

The effect of MoS_2 nanoparticles on friction and wear reduction have been studied by using the pin on disc tribometer. The friction coefficient for both samples has been determined, which for sample 1 is approximately 0.75. However, for sample 2 the value was around 0.22 These results showed that:

1. the friction coefficient changed from a high value to low value, due to using MoS_2 as a lubricant between the surfaces. Then, the position of the pin on the steel surface disc has been determined for both samples which are -18 µm for sample 1, and for sample 2 is approximate -3 µm. According to the data, the effect of using MoS_2 nanoparticles as a lubricant can be seen clearly. In addition, the microstructure of the steel surface and the MoS_2 distribution particles has been shown using SEM.
2. The results showed that for sample 1 the shape of the microstructure wear on the surface varied from small to large size particles of around 10 µm (single wear) and 42 µm (group wear particles). In the case of sample 2, particles had sizes around 12 µm (single wear particles) and 18 µm (cluster particles).

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