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LUBRICATING PROPERTIES OF MOLYBDENUM DISULFIDE AND TUNGSTEN DISULFIDE UNDER HEAVY FRICTION CONDITIONS

by

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The frictional properties of the title compds. were detd. on an MT-6 four-ball machine against steel at 50 and 100 kg. loading over the range 20 to 400 degrees. Similar expts. were at 20 degrees and 50 kg. In vacuo and in argon and oxygen formation of sulfide films was noted; they were also prepd. by heating the powd. sulfides on clean steel plates for 10 hr. at 400 degrees. In air, nitrogen, or argon, or at a given vacuum. The films were analyzed. In vacuo, the Fe surface is converted to FeS, and in nitrogen or argon to given iron sulfides. Given compounds and given iron sulfides are also formed by air oxidn. [AT1019520]

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П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

LUBRICATING PROPERTIES OF MOLYBDENUM DISULFIDE AND TUNGSTEN DISULFIDE UNDER HEAVY FRICTION CONDITIONS

L. A. Mayorova

Molybdenum disulfide MoS_2 and tungsten disulfide WS_2 are used as solid lubricants, however, their lubricating properties under heavy friction conditions (high temperature, heavy load or velocity), when it is possible to expect the development of a chemical interaction between the lubricant and the friction surfaces and the surrounding medium, are still insufficiently illuminated. Investigations conducted by the author made it possible to obtain new data on the lubricating properties of MoS_2 and WS_2 during work under extremely severe friction conditions.

The table contains the basic physical properties of the investigated substances.

The determination of the lubricating capacity of solid lubricants was conducted on an MT-6 four-ball machine equipped with a vacuum chamber.[1] The balls made from EI347 steel had a diameter of

[1]T. V. Vinogradov and others. Four-ball friction machines for the investigation of antiwear and antifriction properties of lubricants at high temperatures. — In the Coll.: Devices for investigating physico-mechanical properties and the structure of metals and materials, Issue 6. M., TSITEI, 1960, p. 3.

Table. The physical properties of solid lubricants.

(1) Вещество	(2) Температура плавления, °C	(3) Молекулярный вес	(4) Объемный вес, г/см³	(5) Плотность, г/см³
MoS_2	1185	160,08	0,546	4,8*
WS_2	1250	247,98	0,68—0,76	7,5**

(6)* При 14°C. (6) ** При 10°C.

KEY: (1) Substance; (2) Melting point, °C; (3) Molecular weight; (4) Volumetric weight, g/cm^3; (5) Density, g/cm^3; (6) at.

12.7 mm, hardness HRC 62-63, and a finish which corresponds to the 11th class. The argon fed into the vacuum chamber was purified from CO_2 and O_2 and dried by a cleansing system (alkali, pyrogallol, refined copper incandescent to 800°, and calcium chloride). The gas pressure in the chamber was maintained at 780 mm Hg and was measured by a mercury manometer. The friction point was heated by a ring electric furnace and temperature was maintained at the assigned level with the help of the automatic electron potentiometer of the type EPD-12. The force of friction was measured by an extensometric dynamometer and was recorded by a device of the type EPP-15. Tests were conducted in the one-minute method with the replacement of the balls after every test. Solid lubricant in the form of MoS_2 or WS_2 powder was placed into a cup with the steel balls.

Figure 1 shows the curves of dependence of the friction coefficient on the duration of a test in an atmosphere of air at various temperatures and loads, which show that the use of these lubricants significantly improves the process of friction in comparison with dry friction. In the tests without lubrication at 20° an abrupt change was observed in the friction coefficient, especially at a load of 100 kg. When MoS_2 and WS_2 were used in the beginning of the tests a sharp increase was observed in the friction coefficient, but then it dropped rapidly to a constant value. This phenomenon is apparently conditioned by the lowering of contact pressure from $45.5 \cdot 10^3$ to $21.8 \cdot 10^3$ kg/cm^2 due to an increase in wear and intensification of the

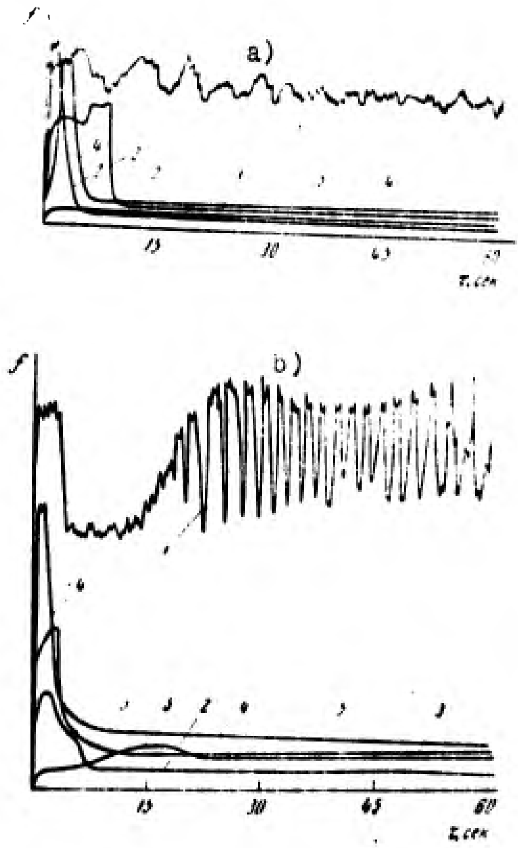

Fig. 1. The dependence of the friction coefficient on the duration of testing in the case of dry friction of steel EI347 based on the same steel and lubrication by MoS_2 and WS_2 powders at a load of 50 kg (a) and 100 kg (b). Temperature 20°C: 1 – dry friction, 2 – MoS_2, 3 – WS_2. Temperature 400°C: 4 – MoS_2, 5 – WS_2. Designation: [сек = s].

process of chemical interaction of the metal with the surrounding gas and lubricating media (because of the significant increase in temperature in the zone of friction during seizing), as a result of which the formation of a chemically modified layer occurred on the friction surfaces. In tests with WS_2 at 400° the degeneration of seizing occurred (curve 5), and in tests on MoS_2 it was preserved (curve 4).

Figure 2 shows the dependence of the friction coefficient on temperature at loads of 50 and 100 kg for the same lubricants.

In the tests with MoS_2 the increase in temperature from 20 to 200° was accompanied by a lowering in the friction coefficient, and from 200 to 400° – by its increase. This can be explained by the fact that the increase in temperature at the point of contact of the friction surfaces facilitates the chemical interaction of the medium and the metal, as a result of which a chemically modified layer is formed, which improves the process of friction and diminishes wear. Furthermore there is an increase in the rate of oxidation of MoS_2 by atmospheric oxygen with the formation of the abrasive product MoO_3. At temperatures up to 200° a significant influence is exerted on the process of friction by the modified layer, and above 200° – the products of oxidation of the solid lubricant MoS_2. In tests with WS_2 the increase in temperature from 20 to 400° was accompanied by the gradual decrease in the friction coefficient because of the formation of the modified layer at loads of 50 and 100 kg. Such a difference in the dependence of the friction coefficient on temperature for MoS_2 and WS_2 is explained by the fact that MoS_2 is less stable than WS_2 under the same conditions, furthermore, MoO_3 and WO_3 possess various structures, and therefore lubricating properties.

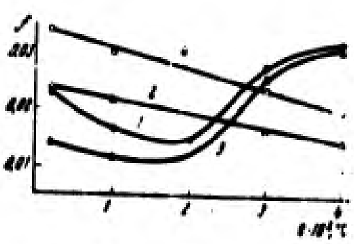

Fig. 2. The dependence of the friction coefficient on temperature. Load 50 kg: 1 – MoS_2; 2 – WS_2; load 100 kg: 3 – MoS_2; 4 – WS_2.

X-ray structural analysis of MoS_2 powder, maintained at 400° for 10 hours in the air, showed that it was completely converted into MoO_3 while WS_2, maintained under the same conditions, was only partially oxidized to WO_3. In X-ray photographs the interferential lines of the initial structure of WS_2 and the lines which belong to the oxides of tungsten WO_3 are clearly visible.

Figure 3 shows the dependence of the diameter of a spot of wear on temperature for MoS_2 and WS_2. During the testing of MoS_2 the increase of temperature from 20 to 400° was accompanied by an increase of wear of the balls, especially at a load of 50 kg, and with WS_2 wear was practically unchanged.

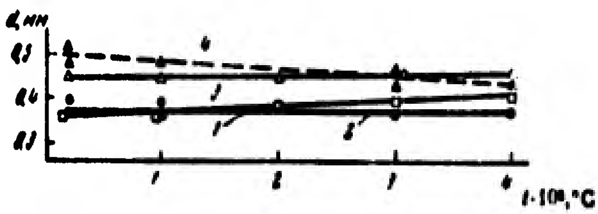

Fig. 3. The dependence of the diameter of the spot of wear on temperature. Load 50 kg: 1 – MoS_2; 2 – WS_2; load 100 kg: 3 – MoS_2; 4 – WS_2.

After the testing of MoS_2 and WS_2 lubricants the formation of a strong sulfur film – the products of the chemical interaction of solid lubricants with the metal of the friction bodies – was observed on the balls around the spot of wear. The intensity of film formation increased with the increase in temperature and load.

For clarification of the nature of the sulfur film tests were conducted for determining the chemical activity of solid sulfur-containing lubricants for EI347 steel and an X-ray structural analysis was made of the analogous film which is formed on the surface of metallic plates made from the indicated steel under static conditions. The metallic samples were plates made from EI347 steel polished to 10 fineness, thoroughly washed by gasoline and benzene, and dried in the air. After immersion in a quartz container with the powder-like lubricant they were placed into a special chamber where they were maintained at a temperature of 400° for 10 hours. The tests were conducted in an atmosphere of inert gas (nitrogen or argon), air, or in a vacuum of 10^{-6} mm Hg.

The primary (initial) and secondary structures of metallic samples were subjected to X-ray structural analysis. The secondary structure was formed as a result of the chemical interaction of the surface layer of metal with the surrounding gas and lubricating media.

The tests showed that under the specified conditions on the surface of steel in the presence of the sulfur-containing lubricants FeS,

FeS_2, and Fe_3O_4 are formed, but on the surface of the sample maintained without lubrication under the same conditions, new compounds were not revealed. Apparently under heavy friction conditions on the surface of the balls a chemical interaction occurs between the metal and the solid lubricant or the products of its decomposition which is similar to liquid oils containing surface-active additives. Therefore the lubricating capacity of MoS_2 and WS_2 under severe conditions depends on the properties of newly formed compounds FeS, FeS_2, Fe_3O_4, MoO_3, or WO_3 in the zone of friction.

Figure 4 shows the dependence of the friction coefficient on the duration of the test of steel samples with lubricants MoS_2 and WS_2 in a vacuum and in various gaseous media at a load of 50 kg. In the tests in air and in an atmosphere of argon the duration and intensity of seizing were approximately identical, but the friction coefficient in the established regimen was somewhat lower in argon. During the test of MoS_2 in oxygen the duration of seizing was increased by more than two times as compared with the tests in argon and in the air. The friction coefficient in the established regimen was also increased. The process of friction with MoS_2 in a vacuum was considerably worsened. This can be explained by the influence of the surrounding gaseous medium on the processes of chemical interaction which flow on the surface of metal in the zone of friction, as a result of which compounds are formed which are different in chemical composition, physicochemical, and structural properties.

For clarification of the nature of the compounds being formed tests were conducted in argon and in a vacuum of $1.4 \cdot 10^{-6}$ mm Hg for determining the chemical activity of MoS_2 and WS_2 toward EI347 steel, and an X-ray structural analysis was made of the surface layer of the samples. The X-ray structural analysis of samples, which were maintained at a temperature of 400° in the air in the presence of solid sulfur-containing lubricants, showed that the sulfur film formed consists basically of FeS_2 and Fe_3O_4 and insignificant quantity of FeS. After the test in a vacuum of $1.4 \cdot 10^{-6}$ mm Hg at a temperature of 400°, along with the lines which belong to the structure FeS, a considerable number of lines of the initial structure of the metal were revealed.

This gives grounds to propose that the processes of chemical interaction under the indicated conditions were made difficult by the phenomena of dissociation and evaporation of the FeS compounds formed.

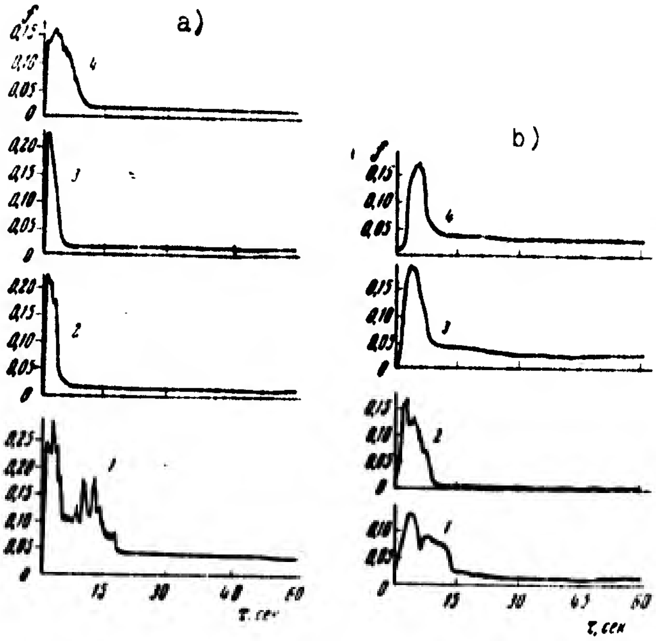

Fig. 4. The dependence of the friction coefficient on the duration of the test of steel samples at a load of 50 kg, temperature 20°, and lubrication with MoS_2 (a) and WS_2 (b) powder. 1 -- vacuum; 2 - argon; 3 - air; 4 - oxygen.

The investigation of the influence of the gaseous medium on the processes of friction and wear in the presence of solid lubricants MoS_2 and WS_2 leads to the conclusion that the oxidation of solid lubricants and the depth of the chemical reactions with the metal of the friction bodies are connected with the presence of oxygen in the gaseous medium and with the activity of the lubricants themselves.

In the air and especially in an atmosphere of oxygen during severe friction conditions when MoS_2 and WS_2 are used apparently intensive oxidation processes of solid lubricants take place along with the formation of the iron sulfides FeS and FeS_2, iron oxide Fe_3O_4 and the oxidation products of the lubricants themselves MoO_3

and WO_3. In an atmosphere of the inert gas of nitrogen or argon the iron sulfides FeS_2 and FeS are formed, and in a vacuum only FeS. The deterioration of the process of friction and the raising of the friction coefficient depend basically on the structure and the properties of the MoO_3, WO_3, and FeS compounds being formed.

Thus the investigation of the lubricating capacity of solid lubricants MoS_2 and WS_2 makes it possible to draw the following conclusions.

In the mechanism of the lubricating action of solid lubricants under heavy friction conditions there is vital importance in the processes of the chemical interaction of MoS_2 and WS_2 with the metal, and also with the surrounding gaseous medium. As a result of these processes on the friction surfaces a chemically modified boundary layer is formed which consists basically of the iron sulfides and partially iron oxides. The presence of a chemically modified layer on the friction surfaces facilitates the averting of gripping, conditions the degeneration of seizing, and lowers the friction coefficient and wear.