금속표면처리
Journal of the Metal Finishing Society of Korea
Vol. 21, No. 1, March 1988

〈총 설〉

Influence of Load and Speed on the Coefficient of Friction of a Solid Film Lubricant.

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초 록

MoS_2의 상용 고체 윤활제 코-팅의 마찰 계수를 하중 100-1000g, Sliding 속도 분당 91-608m의 범위에서 측정하여 고체 윤활제(Sandstrom 9A)의 하중과 Sliding 속도에 따른 마찰특성을 조사한 결과, 하중이 증가함에 따라 또한 Sliding 속도가 증가함에 따라 마찰 계수가 감소함이 나타났다.

또한 고체윤활제 코-팅의 전처리인 인산염 피막처리의 열적특성을 망간계와 아연계 인산염 피막에 대하여 TGA와 DTA 방법으로 비교 분석하여 망간계 피막이 아연계 피막에 비하여 열적으로 안정하여 적합함을 밝혔다.

1. Introduction

The use of molybdenum disulfide as a solid film lubricant has been emphasized since the late 1920's with the possible application on the metallic surface under the rotating and reciprocating motion (1). The physical and chemical properties of the MoS_2 were widely studied and reviewed by the several investigators (2), and it has been found that MoS_2 is superior to other solid lubricants such as graphite and PTFE from the view point of anti-friction and anti-corrosion (3). Furthermore, MoS_2 has gained rapid acceptance in the environments of high temperature, vacuum, radiation and so on as a dry lubricant due to its intrinsic thermal and chemical stability which has been widely reported in the literature (4). But the insufficiency of basic lubrication data, essential to design and manufacture of high speed rotating machines is one of the difficulties in estimating the endurance life and the efficiency of machines.

The performance of the MoS_2 as a coating layer on steel was investigated and evaluated for the purpose of obtaining data for machine design by measuring the friction coefficient of coatings in a certain range of speeds and loads. Also the feasible condition of phosphate film prior to providing a solid film lubricant is considered by studying the thermal characteristics of the phosphate film.

This study may be expected to contribute to the understanding of the lubricating mechanism in resin bonded MoS_2 under motion and to the development of effective design technology by use of solid film lubricant.

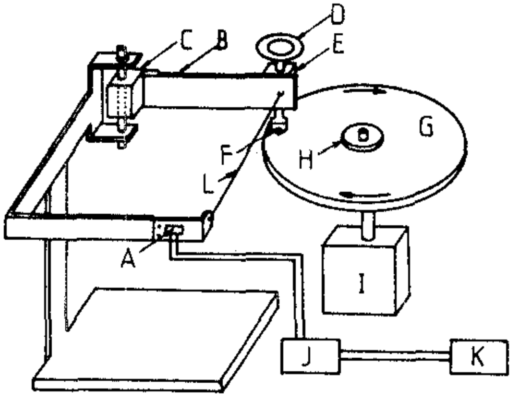
2. Experimental Procedure

Specimen Preparation

The specimen to be coated in this study was prepared from cold rolled steel sheet with 2mm thickness. The normal composition was, by weight, 0.059 C, 0.058 Si, 0.43 Mn, 0.011 P, 0.010 S and bal. Fe. The circular plates of 100mm diameter were cut from the sheet. All the samples were degreased in trichloroethylene solution, and rinsed in deionized water. The surface was blasted with 220 mesh steel grit and then coated with the phosphate film as an interlayer. The phosphate film of 3-4μm thickness was obtained from a 12.5% Mn phosphate solution with 0.2% iron content by weight. In order to investigate the thermal stability of interlayers, Zn phosphate film was also prepared and compared with Mn phosphate film. Four kinds of commercial solid film lubricants (Sandstrom 9A*, Sandstrom 26A*, Molydry 1611**, Molydry 1621**) were coated on phosphate films with thickness of between 12 15 μm and used as the specimens for the friction test.

Friction Testing

The measurement of friction coefficients was made by means of a sliding friction apparatus, as shown in Fig. 1, which consisted basically of an elastically restrained spherical rider sliding on a rotating disk. The rider with ϕ6.35mm commercial steel ball was loaded by weights applied along the vertical axis of the rider holder. Friction force between the rider and the disk was measured using strain gauges.



A : Strain-Gage Assembly
B : Rider Arm
C : Rider Arm Holder
D : Applied Load
E : Cylinder Holder
F : Rider ($\frac{1}{4}$″ Steel Ball)
G : Rotating Disk
H : Sample Holder
I : Rider-Assembly Motor
J : Wheatstone Bridge
K : Strip Chart Recorder
L : String

Fig. 1. Schematic Diagram of Sliding-Friction Apparatus.

Thermal Testing of Interlayer

To investigate the thermal characteristics of Mn and Zn phosphate films, the thermogravimetric analysis at the temperature range of 150–300°C and the differential thermal analysis at the constant heating rate of 15°C/min were carried out.

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* Sandstrom Products Co. (U.S.A.)

** Sumico Co. (Japan)

3. Results and Discussion

The Effect of Sliding Speed and Load

Coefficients of friction using four kinds of solid film lubricant were shown in Table 1. Each friction value was determined at a sliding speed of 334mpm. Fig. 2 indicates that the friction coefficients were in the range of 0.06 to 0.01 as the sliding speed varied from 100 to 600mpm.

Fig. 2 shows that the greatest change in friction coefficient occurs in the sliding speed region of 100-200mpm. The effect of load on the friction coefficient was also plotted and is shown in Fig. 3. As the load increased a slight decrease in the friction coefficient is observed 0.01 at each sliding speed. Fig. 2 and Fig. 3 indicate that at the higher sliding speed and increased load, the friction coefficient decreases. It has been generally known that the static friction coefficient was always higher than the kinetic one. Thus the decreasing tendency in the friction coefficient with sliding speed was understood to be with respect to the intrinsic cleavage mechanism of MoS_2 crystal structure (5). The crystal structure consists of sulfur atoms on each layer separated by a layer of molybdenum atoms. The distance between the sulfur atoms of each lamina and those of the next ones are actually greater than the thickness of lamina itself. Therefore, the basal cleavage of hexagonal structure can not easily occur in low sliding speed because of unoriented MoS_2 particles. Thus the coefficient of friction decreased with increasing sliding speed. On the other hand, it is also known by several authors (6), (7) that changes in friction coefficient with sliding speed and load were

Table. 1 Friction Coefficients of Each solid Film Lubricant.

(Sliding speed: 334mpm)

Kinds	The Friction Coefficient (Uk)	
	(300g Load)	(1000g Load)
Sandstrom 9A	2.37×10^{-2}	1.85×10^{-2}
Sandstrom 26A	1.65×10^{-2}	1.48×10^{-2}
Molydry 1611	2.75×10^{-2}	2.07×10^{-2}
Molydry 1621	1.70×10^{-2}	1.39×10^{-2}

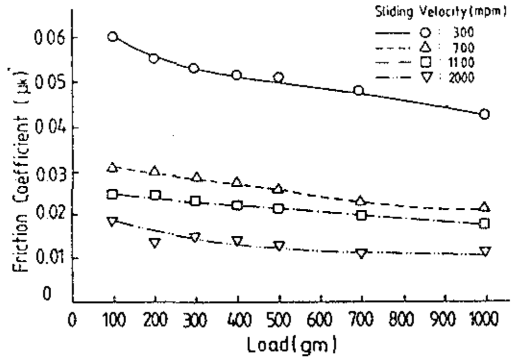

Fig. 2 Effect of Sliding Speed on Friction for Surfaces each with Solid Film Lubricant.

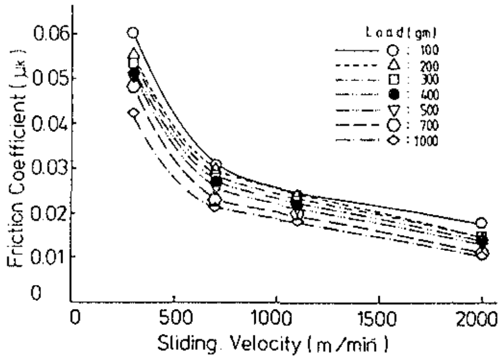

Fig. 3 Effect of Load on Friction for Surface with Solid Film Lubricant.

actually the result of a changing moisture content in the film. When the sliding speed and load were increased, the lamina structure was realigned in the direction of easy shear and the moisture content of the film was decreased due to high contact heat generated between the steel ball of rider and the surface of lubricant film. In the case of graphite with lamina structure, its lubrication mechanism was known to be not intrinsic in its lamina crystal structure alone, but also depends upon adsorption film on the lamina surfaces (8). The coefficient of friction in the graphite increased with increasing sliding speed because the moisture content decreased with increasing surface temperature. On the contrary, the lubricating property of MoS_2 was independent of adsorption film (9), which disturbed the lubricating property. Others (10) reported that the coefficient of friction generally decreased with increasing sliding speed in the 30-300mpm, and it then remained substantially constant with further increases up to 2,400mpm. From these experimental results, the friction coefficient of MoS_2 lubricant decreased with increasing sliding speed. The relation between the coefficient of friction and load was shown in Fig. 3. Increasing the normal load lowered the friction coefficient as others have reported (11), (12). It was due to the compressive alignment of MoS_2 particles with lamina structure. That is to say, that applied load was transferred to coated film and to lamina layer of hexagonal structure in each MoS_2 particle, and thus each lamina layer was realigned in the direction to low shearing force (13). Therefore, the friction coefficient decreased with increasing load. It was thought that the moisture in the MoS_2 film decreased with the higher surface temperature, because the high loads generated high contact heat during sliding. But Johnson et. al (10) reported that the coefficient of friction slightly increased with load at low loads and then remained at a constant value with increasing load. With an hemispherical slider on a flat plate, it would bring about the extension of the shearing area under an incremental load. This widening of shear area in turn caused the increase in friction (14) in contrast to this result.

Observation of Interlayer

In order to investigate a suitable pretreatment for a solid film lubricant coating, Mn and Zn phosphate films were investigated by TGA (thermogravimetric analysis) and DTA (differential thermal analysis) shown in Fig. 4. From these TGA and DTA curves in the temperature range of 0-600°C, it was recognized that the crystals with Mn and Zn phosphate tetrahydrate film lost their moisture of hydration in three steps, respectively. It is evident from the Fig. 4(a) that one molecule of water was lost at 210°C, two at 330°C and the other one at 410°C in the Mn phosphate film $[(Mn, Fe)_5 \cdot H_2(PO_4)_4 \cdot 4H_2O]$. These dehydration stages were accompanied by phase changes. Similarly, two molecules of water were released at 225°C, one at 330°C and the last one at 371°C in the Zn phosphate film $[Zn_3(PO_4) \cdot 4H_2O]$ as shown in Fig.4(b). This result was different from the observations of E.A. Rodzewich(15) who reported that two molecules of water were lost at 180°C and the remaining two at 320°C. Weight losses of Mn and Zn phosphate film were plotted with variable heating time at constant temperature by TGA as in Fig. 5. The amount of weight loss was assumed to increase with the heating

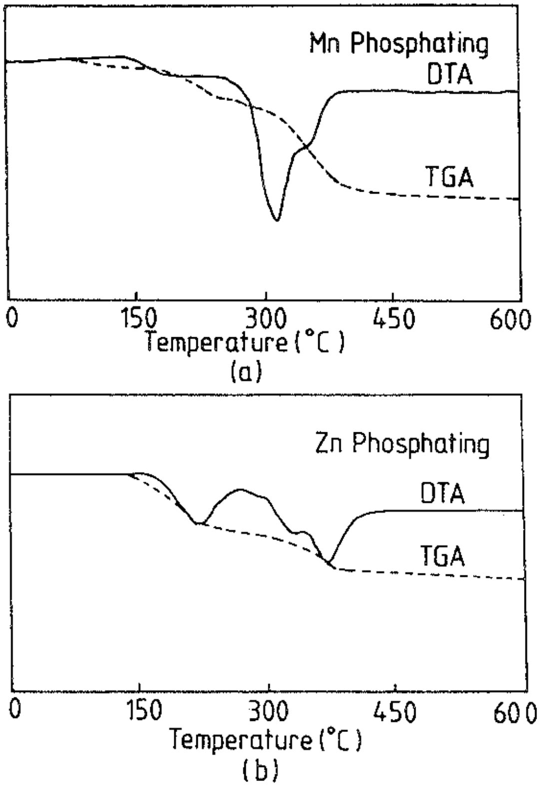

Fig. 4 A Thermogravimetric Analysis (TGA) and a Differential Thermal Analysis (DTA) Study (Heating Rate 15℃/min).
(A) Mn phosphate Coating.
(B) Zn phosphate Coating.

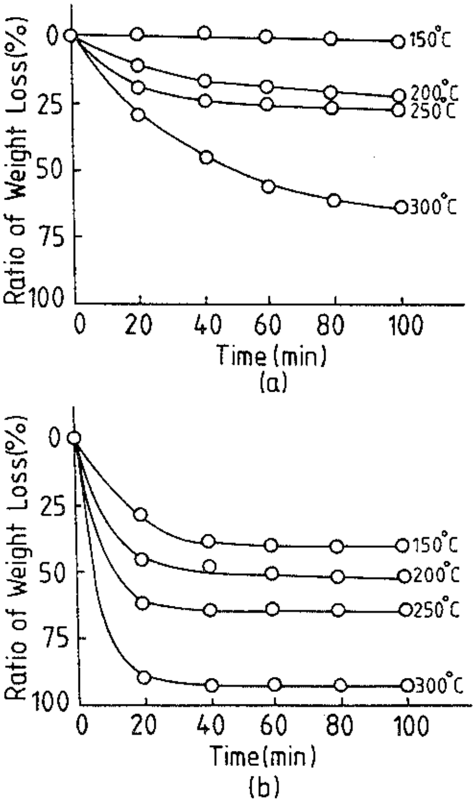

Fig. 5 Dehydration of Coating during continuous Heating at each Temperatures.
(A) Mn Phosphate Coating.
(B) Zn phosphate Coatung.

temperature due to activate favourable environmental condition for dehydration. At the curing temperature of about 200°C in the resin bonded solid film lubricant, dehydration occurred with losing one molecule of water in Mn phosphate film and two in the Zn phosphate film. It was known that heating of Zn phosphate surface to the temperature in the range of 180-200°C prior to painting improved the corrosion resistance of finished product because the smaller dehydrated Zn phosphate crystal apparently increased more galvanic insulation effect of the coating than that of tetrahydrated one. But it was assumed that Mn phosphate film with small weight loss would be more suitable than Zn phosphate film showing large weight loss in the resin bonded lubricant. Therefore, the MoS_2 coating with Mn phosphate film would lead to less porosity than the one with Zn phosphate film during curing stage of solid film lubricant.

4. Conclusion

Four kinds of commercial solid film lubricants of molybdenum disulfide were tested and friction coefficients were measured under sliding friction condition. The friction coefficient was shown to decline with the sliding speed and applied load as the contact heat caused the evolution of moisture in the coating layer. The decrease in the moisture of lamina layer contributes to easier sliding motion between lamina layers of hexagonal crystal structure and a lower friction coefficient is obtained. In addition, the heavier load also helped to realign the lamina layers of hexagonal structure to reduce the shearing force and thus resulted in the reduction of the friction coefficient. Mn phosphate film of interlayer prior to coating a solid film lubricant was demonstrated to be more suitable than Zn one in terms of thermal stability.

References

(1)Koehler, W., U.S. patent, 1,714,564, Aug. 1. (1927).

(2)H. Peter Jost, et. al., Sheet Metal Industries, Oct., (1956) 679.

(3)Peter M. Magie, Electrochemical Design, Apr., (1960) 50.

(4)M.E. Campbell, Solid Lubricants, NASA SP-5059 (01).

(5)R.G. Dickinson, L. Pauling, J. Am. Chem. Soc., 45, (1923) 146.

(6)D.G. Flom, A.J. Haltner, C.A. Gaulin, ASLE Trans., 8 (2), (1965) 133.

(7)A.J. Haltner, Wear, 7, (1964) 102.

(8)R.H. Savage, J. App. Phys., 19, (1948), 1.

(9)R.H. Savage, Fundamentals of Friction and Lubrication in Engineering, American Society of Lubrication Engineers, Chicago, 1954, pp161.

(10)R.L. Johnson, D. Godfrey, E.E. Bission, NACA Tech., Note NACA TN, 1578 (1948).

(11)J. Boyd, B.P. Robertson, ASME Trans, 67, (1945) 51.

(12)E.B. Palmer, Materials in Design Engineering, Aug., (1961) 1.

(13)I-Ming Feng, Lubrication Engineering, Dec., (1952) 285.

(14)J.W. Midgley, J. Inst. Petrol., 42, (1956) 316.

(15)E.A. Rodzewich, AES, Inc., Copyright 1974.