International Journal For Technological Research In Engineering (IJTRE)
Volume 2, Issue 7, March-2015
ISSN: 2347-4718

Fretting Wear Behaviours of Bonded Solid Lubricant Coatings: A Review

Natish Patyal[1], Varun Dutta[2*]
[1]M.Tech Student, School of Mechanical Engineering, SMVD University, Katra, J&K, INDIA
[2]Assistant Professor, School of Mechanical Engineering, SMVD University, Katra, J&K, INDIA

Abstract - **In this paper the solid lubricants have been studied along with their areas of applications in the industry. Further, the comparison of fretting wear behaviors and mechanisms of different bonded solid lubrication coatings, namely a bonded Molybdenum disulfide coating(MoS_2), a bonded graphite coating and a bonded polytetrafluroethylene coatings, on AISI E4142 steel have been reviewed and discussed thoroughly. The MoS_2 bonded solid lubricant coatings has been widely applied in sliding wear due to a cheap technical process and good thickness in comparison to MoS_2 coatings which is obtained by magnetron sputtering or ion beam assisted deposition. But, such coatings technology has been rarely reviewed and discussed in complex fretting conditions. In this paper, we have discussed the friction and wear performances of MoS_2 solid film lubricants in fretting conditions. And we have discussed about effect of wear and temperature on the various parameters of solid lubricants.**

Keywords **-** Fretting, MoS_2, Bonded Solid lubricant coating, wear

1. INTRODUCTION

Fretting is a low amplitude oscillatory movement that occurs between two contacting surfaces, which are usually at rest [6, 8]. The movement may be either because of external vibration fretting wear or the result of one of the contacting members being subjected to a cyclic stress fretting fatigue. Both fretting types may give rise to service failure due to the production of debris or the initiation and propagation of fatigue cracks [1]. There are many proposed remedies for fretting which include reduction in relative slip or vibration, raising the strength by changing the base material or by surface treatment and lowering the coefficient of friction.

1.1 Solid lubricants

They are materials which despite being in the solid phase are able to reduce friction between two surfaces sliding against each other without the need for a liquid medium [8]. The main dry lubricants are graphite (in powder form), Polytetrafluoroethylene and molybdenum disulphide (in powder or film form), these are effective lubricant additives due to their lamellar structure [2, 3].

Solid lubricants can be used as free-flowing powders, as additives in some oils and greases, and as key ingredients in high-performance anti-friction coatings and anti-seize pastes. The solid lubricants deliver efficient boundary lubrication, improving friction and minimizing wear under extreme operating environments. Boundary films created by solid lubricants are capable of maintaining a uniform thickness irrespective of speed, temperature and load in comparison to grease or oil fluid films.

1.1.1 Graphite

It has a layered lattice structure and superior lubricity is due to weak bonding between layers in the presence of moisture. The advantages of using graphite include superior lubrication in high humidity, protection against fretting corrosion, high-temperature stability and low coefficient of friction under high loads.

1.1.2 Polytetrafluoroethylene (PTFE)

It comprises carbon and fluorine atoms and is considered as one of the most slippery manmade materials due to its low surface tension. The advantages of using PTFE include good sliding-friction reduction, good chemical resistance, low load-carrying capacity, low coefficient of friction at low loads and colourless film lubricity.

1.1.3 Molybdenum disulfide (MoS_2)

It has a lamellar structure and it can be sheared easily in the direction of motion. The advantages of using MoS_2 include excellent adhesion, wide service-temperature range, protection against fretting corrosion, decreased friction with increasing loads, stick-slip prevention and high load-carrying capacity. But molybdenum disulfide solid lubricants cannot be utilized in wet conditions as friction increases with moisture.

In this paper, firstly we have discussed the experimental work done by J. Xu et al. (2003) (in section 2) for investigating fretting behaviour for bonded MoS_2 solid lubricant coating and after wards the results were discussed in details. In the second case (in section 3), we have discussed experimental work for the investigating fretting behaviour for various bonded solid lubricant coatings namely MoS_2, Graphite and PTFE and results were also discussed.

2 FRETTING BEHAVIOUR FOR BONDED MOS_2 SOLID LUBRICANT COATING

2.1 Experimental detail

All fretting tests were conducted on a fully computer controlled serve-hydraulic dynamic test system (Fig. 1) by Xu et al. (2003) [4]. The test specimen was mounted on a rod actuator, which serves as a heater and can give an imposed temperature. The 52100 steel ball specimen with a diameter of 40mm and a surface roughness, Ra of 0.02m, was fixed to the framework, which was connected to the piston and delivers the reciprocating movement of given amplitude. A second strain gauge dynamometer was lodged in the actuator to measure friction force; a high precision extensometer was situated to measure amplitude. The substrate materials were E4142 steel (heat treated at 860◦C for 20 min, oil quenched and then tempered 400◦C for 30min) and 1045 steel (heat treated at 860◦C for 20min, water quenched and then tempered at 600◦C for 30min) machined to the dimensions of 10mm × 10mm × 20mm.

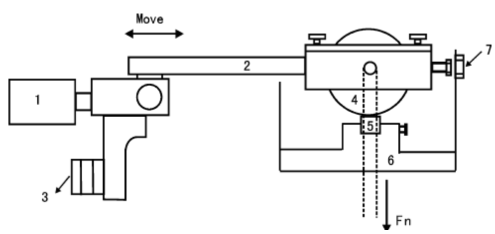


Fig 1: Fretting wear test rig: (1) second strain gauge dynamometer; (2) framework; (3) counterbalance; (4) ball specimen; (5) test specimen; (6) rod actuator; (7) high precision extensometer. [4]

Six coatings (denoted by A to F) with different characteristics, shown in Table 1 were studied and compared.

Table 1: Six types of MoS_2 bonded coatings [4]

Coatings	Substrate	Procedures	Thickness	Substrate surface R_a (μm)
A	E4142 steel	Sandblast + heat curing	10 ± 1	2.0 ± 0.2
B	E4142 steel	Sandblast + heat curing	16 ± 1	2.0 ± 0.2
C	E4142 steel	Sandblast + room curing	10 ± 1	2.0 ± 0.2
D	E4142 steel	Heat curing	10 ± 1	0.5 ± 0.15
E	E4142 steel	Room curing	10 ± 1	0.5 ± 0.15
F	1045	Sandblast + heat curing	10 ± 1	2.0 ± 0.2

2.2 Effect of various factors

A very important requirement for coating lubrication is the control of wear life in context to industrial applications. In order to better compare fretting wear life behaviour of various coatings, a criterion $N_{0.25}$ or fretting wear life (the number of fretting cycles needed for the coefficient of friction to reach 0.25) was defined.

Hardness effect

The hardness effect of substrate materials played an important role in the fretting wear life of bonded coating. Evolutions of the coefficient of friction for the coatings A and F at different displacement amplitudes is showed in Fig. 2. It is observed that the wear life of the coating A on the surface of harder E4142 steel was higher than that of the coating F on the surface of softer 1045 steel. The deformation of coating and substrate, and contact stress distribution of interface between coating and substrate depend mainly upon hardness of substrate.

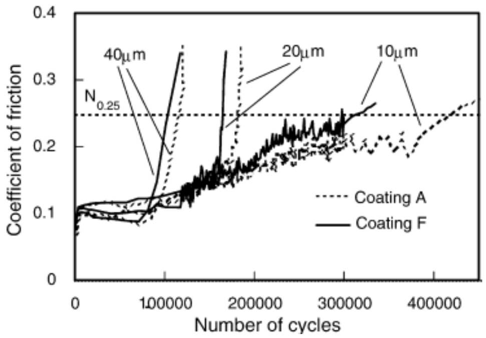


Fig 2: Effect of substrate materials hardness on the $N_{0.25}$, Fn=600 N. [4]

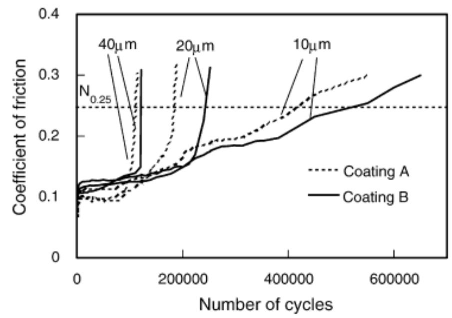


Fig 3: Effect of coating thickness on the $N_{0.25}$, Fn=600 N. [4]

Coating thickness

Effect of the coating thickness on wear life can be illustrated by fretting tests on the coatings A and B. The evolution of coefficient of friction at different displacement amplitude is shown in Fig. 3. For the same amplitude, the criterion $N_{0.25}$ was higher in the case of the thicker coating.

Substrate surface finish

Two types of substrate surface were prepared, one with roughness Ra of about 0.5m and the other about 2.0m. For rougher substrate surfaces, an increase in $N_{0.25}$ was observed in cases of both heating (coatings A and D) and room curing (coatings C and E), shown in Fig. 4. In fact, to enhance the bonded strength between the coating and the substrate, rougher surface was favourable. Also, rougher substrate surfaces had a beneficial effect against wear at later fretting stage.

Humidity

The Fig. 5 indicates that the life decreased at higher relative humidity (>80%) compared to that at 50%. The absolute value is decrease for the increased $N_{0.25}$ when the displacement amplitude was reduced. Actually water vapor may penetrate into the coating surface resulting in some disadvantages like: (1) vapor pressure may lead to rapid breakage of film in local contact zone; and (2) the performance of binder may weaken.

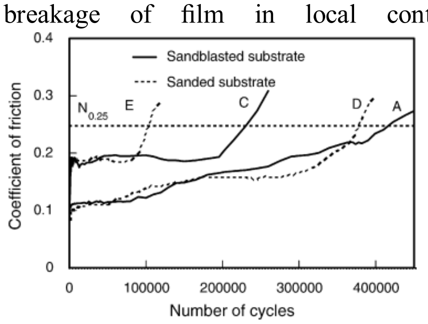


Fig 4: Effect of substrate surface finish on the $N_{0.25}$, Fn =600 N,D=10µm. [4]

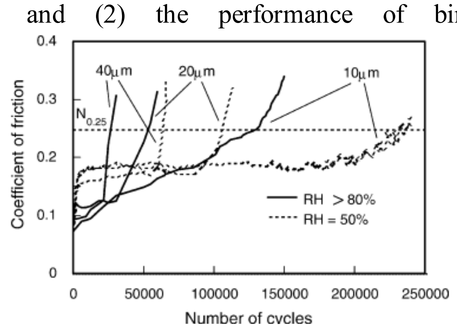


Fig 5: Effect of relative humidity on the $N_{0.25}$ for the coating C Fn=600 N. [4]

Temperature

Fretting tests have been carried out at a given temperature range from 23 to 300˚C. The rise in $N_{0.25}$ value at 100˚C is because of reduction in relative humidity due to heating from 23 to 100˚C, shown in Fig. 6. At higher temperatures from 100 to 300˚C, MoS_2 lubricating pigment tended to oxidize more rapidly resulting in decrease in $N_{0.25}$ value or fretting wear life and so the lubrication effect is decreased. Also, mechanical properties of the coatings may weaken.

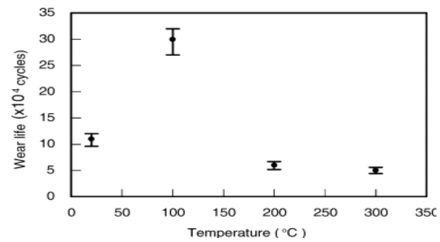


Fig 6: Effect of test temperature on the $N_{0.25}$ for the coating A, Fn=500 N, D=40µm. [4]

2.3 CONCLUSION

It is observed that enhancing substrate hardness increases coating thickness, sandblasting substrate surface, increasing temperature to solidify coating and also observed that reducing relative humidity were favourable to improve fretting behaviour for bonded MoS_2 solid lubricant coating.

3 Fretting behaviour for various bonded solid lubricant coatings namely MoS_2, Graphite and PTFE

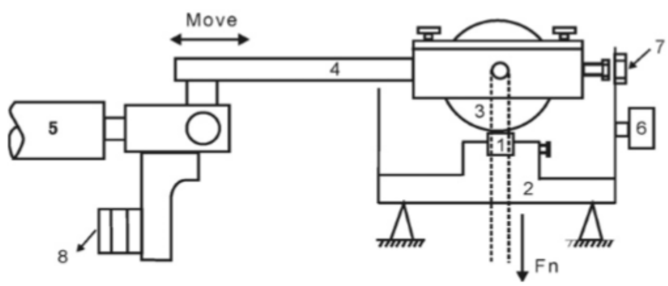


Fig 7: Fretting wear test rig. (1) The flat specimen; (2) the actuator; (3) the ball specimen; (4) the holder; (5) the piston of hydraulic; (6) the load cell; (7) the extensometer; (8) counterbalance. [5]

3.1 Experimental Detail

Fretting tests were carried out by Xu et al. (2007) on serve –hydraulic dynamic test system [5]. The apparatus shown in the Fig 7, uses an AISI 52100 steel ball of 40 mm diameter and surface roughness (R_a) of 0.02µm as the sphere specimen in which the substrate used for the surface coating was AISI E4142 steel, machined to the dimensions of 10mm * 10mm * 20mm. The final surface roughness (R_a) of the surface of the flat specimen was about 0.07 µm. The AISI E4142 was heat treated at 860^0 C for 20 min, the oil quenched and tempered at 400^0 C for 30 min.

The three coatings (MoS_2, graphite and PTFE) had the same process of preparation. The main processes were described in the literature as: - firstly, in order to improve bond strength between coatings and substrates, sandblasting was used to roughen the substrate surfaces to a surface roughness of (R_a) of 2.00± 0.20µm. Then, the fine solid lubricant particles were homogeneously dispersed in adhesive of a resin system, which contained the binder, solvent and modify agent. After that, specimen surfaces was sprayed by the mixture containing the lubricant particles and resin system using a spray gun and then cure was done by heating the coatings. The different characteristics of the three coatings are described in the Table no.2.

Table 2: Principal characteristics of three kinds of bonded coatings. [5]

Coatings	Structure	Thickness (µm)	R_a(µm)	Elastic modulus (GPa)	Hardness ($H_{v100)}$)
A	MoS_2 in novolac-epoxy resin	10 ± 1	1.10 ± 0.15	6	50 ± 10
B	Graphite in organic silicon resin	10 ± 1	1.10 ± 0.15	8	60 ± 10
C	PTFE in novolac – epoxy resin	26 ± 2	1.50 ± 0.20	2	30 ± 10

After all tests the steel balls were tested by scanning electron microscopy (SEM). The chemical structure of the original and worm surface of the coating were analyzed by X-ray diffraction (XRD).

3.2 RESULT AND DISCUSSION

Friction behavior

In this Xu et al have compared the running conditions obtained for contact between the coatings and an AISI 52100 steel ball, which showed that they are completely different from the behavior obtained by the steel on steel contact. To get the better results, the frictional behavior of coatings under fretting, more analysis on coefficient of friction was performed under load of 600 N when $N=10^5$ cycles for the variation of the co efficient of friction with displacement amplitude for coated materials, shown in fig.8.

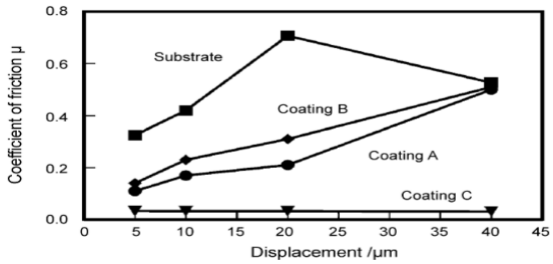
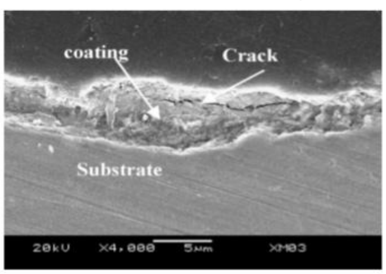


Fig 8: Variation of wear life with displacement amplitude,Fn= 600 N. [5]

It has been observed that these coatings can reduce the co efficient of friction under the fretting conditions.

Wear behavior

From the above results of the co efficient of friction with the displacement and number of cycles the fretting degradation can be divided into three stages. In the very first stage, the coatings were kept thick enough to enable plastic deformation, in this the peaks are being removed off so that the solid lubricant can form a continuous flow on the plastic layer. In the second stage, the changes in the component and structure can occur as a result of the mechanical and frictional heating and in the last stage when the coatings reaches the critical valve of 0.25 the MoS_2 for SEM observation (Fig. 9 and Fig. 10) for the damaged surface and through these roughness get contact in the specimen at contact center during this stage.



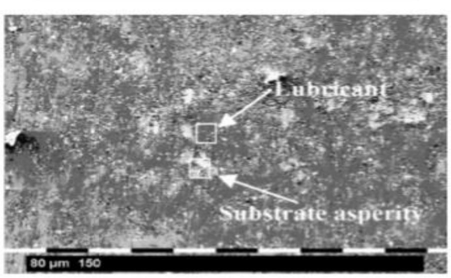


Fig 9: SEM observation for damage for coatings. [5] **Fig 10:** SEM observation of coatings. [5]

3.3 CONCLUSION

These three bonded solid lubricant coatings can increase the fretting wear –resistance performance of the AISI E 4142 steel in the test conditions the fretting test performed on the coatings reveals different wear life for each coatings. According to the test, coating (PTFE) of the thickness of 26 μm obtained as the best result. The degradation result of the coatings can be outlined as at three stages. 1) During the early stage, the transfer film and plastic flow layer form two contact pairs. XRD analysis shows that solid lubricant crystal grains tend to prefer the orientation in a direction approximately parallel to the surfaces. 2) Micro cracks initiate and propagate in the coatings and particles detach from the surfaces in flake like afterward 3) the severe detachment of particles occur at contact center [7].

REFERENCES

[1] D.E. Taylor, R.B. Waterhouse, Wear, fretting and fretting fatigue, in: R.B. Waterhouse, D. Kirk (Eds.), *Metal Behavior and Surface Engineering*, IITT-International, Gournay-sur-Marne (1989), pp. 13–35.
[2] J. Xu, M.H. Zhu, Z.R. Zhou, et al., *Wear 255 (2003)*, pp. 253–358.
[3] J. Xu, M.H. Zhu, Z.R. Zhou, *Thin solid film 457 (2004)*, pp. 320–325.
[4] J. Xu, M.H. Zhu, Z.R. Zhou, et al., *Wear 255 (2003)*, pp.253–358.
[5] J. Xu et al., *Journal of Materials Processing Technology 182 (2007)*, pp. 146–151.
[6] R.B. Waterhouse, Fretting Corrosion, Pergamon, Oxford, 1972.
[7] S.K. Biswas, V. Kalyani, *Wear 158 (1992)*, pp. 193–211.
[8] Z.R. Zhou, L. Vincentr, *Wear 225–229 (1999)*, pp. 962–967.