The Improved Friction Properties of Bonded MoS_2 Films By MAO Treating of Al Substrates

Hu Hanjun, Zhou Hui, Zheng Yugang, Sang Ruipeng，Zhang Kaifeng,Wan Zhihua

Lanzhou Institute of Physics, China Academy of Space Technology, Lanzhou 730000, PR China

Abstract

The bonded MoS_2 films is widely used as solid lubricants in aerospace mechanisms due to their excellent tribological properties. Traditionally, the MoS_2 was directly bonded on the Al substrate that was only treated by the technique named of sandblast. For improving the tribological properties of MoS_2 films, micro arc oxidation(MAO) instead of sandblast was introduced as a new technique for treatment of Al substrate. In this article, the tribological properties of MoS_2 films bonded on different surface of Al substrate as mentioned above was discussed, respectively. It is concluded from the test results that the MoS_2 films bonded on substrate treated by MAO have better tribological properties than the ones treated by sandblast, and the endurance life against abrasion of the former is as high as twenty times than the latter by the stand test method of ball on disk using the UMT Multi-Specimen Test System. This test results can be illustrated by the following reasons. One point is the porous microstructures of MAO ceramic coatings on the Al substrate. The coatings have numerous pits to be good at increasing the binding force with the MoS_2 films, and the pits can also provide a MoS_2 lubricants reservoir during processes of friction. Both of them improved the MoS_2 film's ability of wear-protective. Otherwise, naturally the MAO coatings' hardness is higher than the Al, and this ensures well wearing resistance, especially in practical application to big load-supporting moving parts, such as bearing, gear, etc…

Keywords: MoS2; Micro arc oxidation; Tribology; Wear; Endurance life

1. Introduction

The bonded MoS_2 films were widely used as excellent lubricants at aerospace moving parts in flight hardware for many years, and its tribological properties in vacuum are unique [1]. Some research departments in the worlds included NASA, ESA, etc.., were interested in the study of bonded MoS_2 films and paid lots of attention to extend its endurance life [2, 3]. According to the research results of the former, it was generally conceived that the substrate surface with a proper roughness was good for increasing the bonding strength between the substrate and the MoS2 films. For example, the Lyndon B considered that the MoS2 films were mechanically bonded to metal surfaces, and this surface must be roughened to promote lubricant adhesion by increasing the contact area [4]. Traditionarily, the usual method for roughening the substrate surface was abrasive blasting or glass bead blasting. Novelly, in this article a smart technology named MAO (micro arc oxidation) was introduced as a method instead of the abrasive blasting for roughening the metal substrates. MAO was a distinguished technique to fabricate a ceramic coating with lots of pores on light alloys such as Al, Mg, Ti and their alloys, by arc discharge at high voltage on the anodic surface under the cooperating effects of thermochemistry, plasma chemistry and electrochemistry reaction[5,6,7]. The pores with different sizes promoted the bonding force between the MoS_2 films and the ceramic substrates. Additionaly, the pores can act as 'reservior' of lubricants for further improving the endurance life of bonded MoS_2 films[8]. The following paragraph of this article would discuss the properties of bonded MoS_2 films which substrates surface was treated by MAO technology.

2. Experimental

2.1 Aluminum substrate surface treated by MAO

Aluminum alloy substrate was selected for preparing bonded MoS_2 films, and was treated by MAO skill under different processing parameters. As the power pulse frequency increased, the ceramics thickness and roughness synthesized on the substrates surface were also increased. In order to show the effects of MAO methods better or not, one of the substrate was treated by abrasive blasting for contrast. The information of the substrate surface treated by different processing parameters or methods was listed in Table 1.

Table 1 The different substrate surface

Sample No.	Processing parameter	thickness	roughness	method
1#	50v,6%,1000Hz,120s	3.27um	0.29um	MAO
2#	550v,6%,800Hz,120s	10.95um	1.06um	MAO
3#	550v,6%,500Hz,120s	20.59um	2.76um	MAO
4#	550v,6%,100Hz,120s	29.74um	4.18um	MAO
5#	—	—	2um	abrasive blasting

2.2 MoS_2 films bonded on the aluminum substrates

Firstly, using ethanol solvent cleaned the substrates surface through any technique capable of removing particulate and organic surface contamination. Secondly, the expoxy-bonded MoS2 films were prepared on the substrate surface via a metallic muzzle (this is the key step for deciding the thickness and roughness of lubricant films. Because the substrates listed in Table1 were processed in the same batch at this step, all of the samples in this article have the same lubricant films but different substrate surfaces.).

2.3 Testing and characterizing

Testing: The tribological behaviors of the samples were evaluated using a ball-on-disc tester (CETR UMT-2 Friction-Wear Tester) under dry sliding conditions. GCr15 ball with a diameter of 8 mm and a surface roughness smaller than 0.05μm was used as the counter face material. The measurement of the friction coefficient was performed at the load of 5 N and the sliding speed of 300 rpm. The endurance life of the lubricant films was evaluated by the total testing times before the friction coefficient sharply changed and got to the point of 0.3. All the tests were conducted at ambient lab conditions (25 °C and relative humidity of 50%).

Characterizing: Lots of charactering technologies were used for analyzing samples. The MAO thickness was measured by using MINITEST-4100 eddy current thickness tester. The MAO roughness was measured by Nano-scratch tester (NST, CSM) at constant load 5mN, scanning length 3mm. The MAO surface morphology was observed by using Light Microscope/CCD Camera (PEC3010, CSM). The microstructure of MAO was observed by SEM.

3. Results And Discussion

3.1 Surface morphology

Fig.1 and Fig.2 show the surface morphology of different samples as listed in table 1, which Fig.1 and Fig.2 belonged to the samples with the processing of abrasive blasting and with MAO coatings, respectively. As showed in Fig.1, it could be observed clearly that the surface of Al substrate was properly modified. Some of the metal sheets and pits existed on the

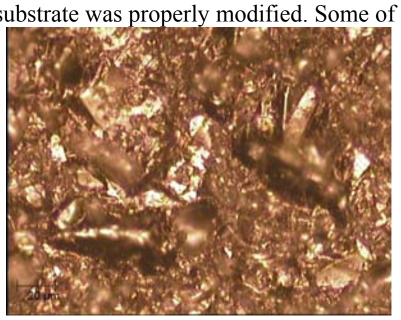

Fig. 1 Surface morphology of 5#

surface were formed to be good at extending the interface and improving the binding strength.

As is shown in Fig.2, it could be observed that the sizes of surface micro-pores were increased gradually from 1# to 4#. Contrarily, the amounts of micro-pores were reduced. The reason for the different surface morphology may be attributed to the MAO processing parameter with different pulse frequency. With decrease of impulse frequency, the total thermal energy for synthesizing MAO coatings was increased at the same processing time, the relationship between the thermal energy and frequency can be inferred from formula 1(the thermal energy is direct proportioned with impulse width.). With increase of thermal energy, more fusing objects of oxide were sintered or deposited in the surrounds of the micro-pores, and the lots of pores with small sizes were fused for forming big pores, and the thickness and roughness of the MAO coatings were also increased as showed in table 1.

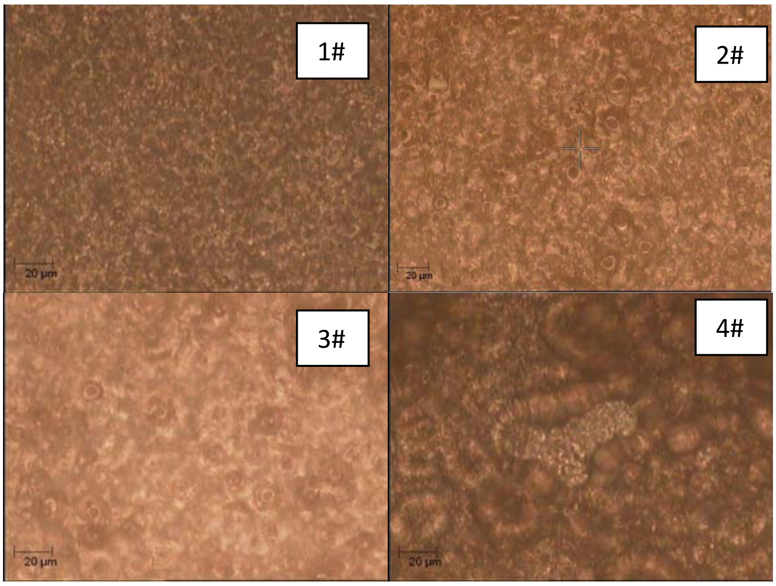

Fig. 2 Surface morphology of 1#, 2#, 3#, and 4#

$$T \times \phi = \frac{1}{f} \times \phi = T_{on} \qquad (1)$$

T: cycle F: frequency,

Φ: duty cycle T_{on}: impulse width

Otherwise, making contrast among the pictures, the MAO coatings could also help to reach the purpose like the abrasive blasting processing as showed in Fig.1, furthermore, the MAO coating may more adapt to improving the friction property of bonded MoS2 films, for its powerful binding strength with Al substrates and lots of pores with different sizes on the surface. For more clearly observed the micro-pores of MAO coatings, Fig.3 shows the microstructure of MAO coating surface. As Fig.3a showed, lots of micro-pores and protuberance were uniformly dispersed on the surface of coating, and no micro cracks existed .Fig.3b was one of the open micro-pores existed on the surface. These open micro-pores may effect as a ‘reservoir’ and be filled with some lubricants.

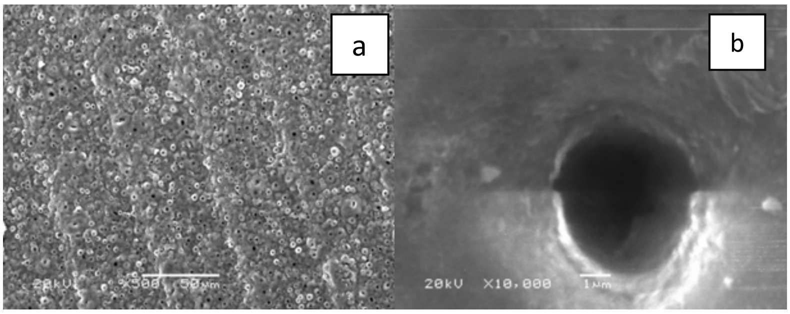

Fig.3 The microstructure of MAO coating with micro-pores

3.2 Microstructure of section

Fig.4 shows the sectional microstructure of MAO coating, and it included MAO coating and Al substrate. It was obvious that there was more than 10um thickness MAO coating naturally growing on the Al substrate, and there wasn't clear interface between the coating and the substrate, which mean the MAO coating tightly combined with Al substrate. Otherwise, it was also observed that the structural density of MAO coating was big even more than Al substrate, which ensured the excellent load-supporting ability of the coating.

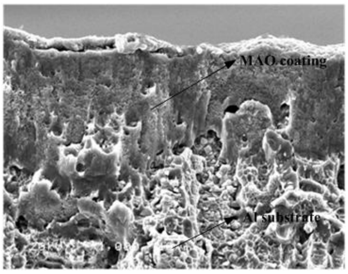

Fig.4 The sectional micro-morphology of MAO coating

Fig.5 showed the sectional microstructure of MAO coating with bonded MoS_2 film after friction test. Fig.5a showed the entire sectional micro-morphology of samples, which included substrate, MAO coating and MoS_2 film. The MoS_2 film was wore out, and transited to small pieces of MoS_2 arranged along the direction of friction test. Fig.5b was the high

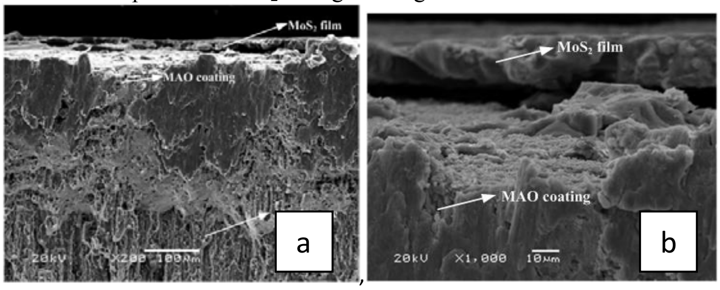

Fig.5 The sectional sectionmicro-morphology of MAO coating with bonded MoS2 films

magnifying section of MoS_2 film and MAO coating. As display of the Fig.5b, the small pieces of MoS_2 was gathered and coated on the tribological orbital local of MAO coating, and the edge of MoS_2 film didn't flaked away in the manner of great pieces, which all of this illustrated the good bonding force of the interface.

3.3 Friction properties

Fig.6 shows the frictions coefficient (COF) of different samples. It was observed from the curves that the COF was about 0.2 at the start stage, and it would increased step by step along with the prolongation of friction test time. For friction test, it was defined that the endurance life of the samples were the time when the friction coefficient arrived at 0.3. Fig.7 shows the endurance life of different samples. As shows in Fig.7, the 3# sample with roughness of 2.76um has the longest endurance life up to 30h, and the 5# sample treated by abrasive blasting has the shortest endurance life less than 1.5h. The former is as longer as twenty times of the latter. All of the samples treated by MAO have the longer endurance life than the 5#. These results expressed that the endurance life of bonded MoS_2 film can be improved by MAO treating of substrate, even more than 20 times than before, and this may attribute to the porous microstructures of MAO ceramic coatings on the Al substrate as showed in Fig.3. The coatings have numerous pores and pits to be good at increasing the binding force with the MoS_2 coatings, and the pores can also act as a MoS_2 lubricants reservoir during processes of friction. Both of them improve the MoS_2 film's ability of wear-protective. Otherwise, naturally the MAO coatings' hardness is higher than the Al, and this ensure well wearing resistance.

Fig.7 also shows that the proper roughness of MAO coating is very important for the tribological properties of bonded MoS_2 film. With the increase of roughness of MAO coating, the binding force between MAO coating and MoS_2 film is also enhanced. Nevertheless, when the roughness came high to certain point and the pores changed, the surface roughness and inner stress of bonded MoS_2 film would also get higher, which would finally deteriorate the tribological properties the films, therefore, by adjusting the processing parameter of preparing MAO coating could get the proper roughness for preparing the bonded MoS_2 film with excellent tribological properties and longer endurance life.

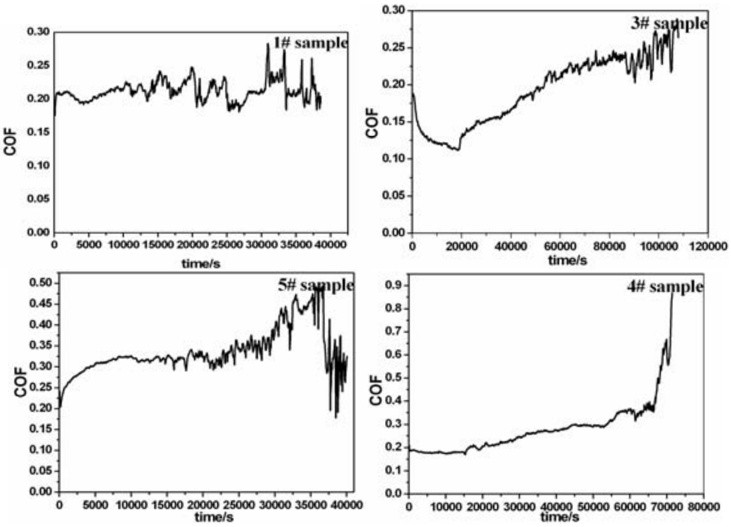

Fig.6 The friction coefficient of different samples

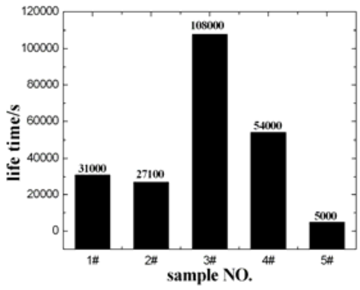

Fig.7 endurance life of different samples

4. Conclusion

The surface of MAO coating existed a lot of pores with different sizes, and this surface morphology was good for enhancement of binding force between the bonded MoS2 films and substrate. The MAO coating naturally grown on the Al substrate, and there wasn't clear interface between the coating and the substrate. The MoS_2 films bonded on substrate treated by MAO have better tribological properties than the ones treated by sandblast, and the endurance life against abrasion of the former is as high as twenty times of the latter by the stand test method of ball on disk using the UMT Multi-Specimen Test System. The main reason for above results of endurance life was the special structural characteristics of MAO coating, in especial of rough and porous structure. By adjusting the processing parameter of preparing MAO coating could get the proper roughness and pores for preparing the bonded MoS2 film with excellent friction properties and longer endurance life.

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