Friction transition diagram considering the effects of oxide layer formed on contact parts of TiN coated steel ball

C. W. CHO [1], J. S. LIM [1] and Y. Z. LEE [2]

[1]*Graduate School of Mechanical Engineering, SungKyunKwan University*
300 ChunChun-Dong, JangAn-Ku, Suwon 440-746, KOREA
[2]*School of Mechanical Engineering, SungKyunKwan University*
300 ChunChun-Dong, JangAn-Ku, Suwon 440-746, KOREA

In this study, the friction transition diagram based on the effect of oxide layer formation on contact surface between TiN coated steel ball and uncoated steel disk was constructed. From the diagram, it can be seen that as the contact load increases, the contact number of cycle at the beginning of oxide layer formation decreases linearly and as the coating thickness increases and the surface roughness of steel disk increases under same contact load, that increases. For the coated ball specimen, a AISI 52100 steel ball was used and AISI 1045 steel was used for the disk counter part.

Keywords : Friction transition diagram, Oxide layer, Adhesive wear

1. INTRODUCTION

Ceramic coatings can increase the life of machine elements due to their outstanding low friction characteristics and good wear resistance [1]. A problem that arises when such coatings are applied to a part which is counter acting with other material, is that friction and wear characteristics of the coating change according to characteristics of the transfer layer, which forms generally due to contact with steel and oxide layer, which forms due to transfer layer [2]. Many research results have reported that oxide layer protects coating material from wear when in contact with a counter part [3-6]. When ceramic coating is in contact with steel, it shows outstanding characteristics of low friction and wear resistance initially but as sliding motion continues, transfer layer and oxide layer form on sliding surfaces of both coating and steel due to wear particles from steel. In this case, it is known that coating is protected from wear once the layers are formed [3,5-6] but the low friction characteristic of coating disappears and the friction force between two materials increases causing wear of steel to increase as contact condition changes from steel on coating to steel on oxide layer, oxide layer on coating or oxide layer on oxide layer.

In this study, the friction transition diagram based on the effect of oxide layer formation on contact surface between TiN coated steel ball and uncoated steel disk was constructed.

2. EXPERIMENTAL DETAILS

2.1 Materials

For the coated ball specimen, AISI 52100 steel ball was used and its diameter was 10mm. Two types of balls were prepared by depositing TiN coating with 1 and 4μm in coating thickness using arc ion plating method. AISI 1045 steel was used for the disk type counter part with 60mm in diameter and 7mm in thickness. The surface hardness was $HV_{IN}300$. Three types of disks were prepared based on the surface roughness: Ra 0.06, 0.1 and 0.2μm. Various TiN coating thickness and surface roughness of steel disk were used to investigate the characteristics of oxide layer according to the changes in real contact area between two materials due to the changes in coating thickness and surface roughness.

2.2 Test conditions

Slow sliding speed of 0.04m/s (30rpm) was applied in all tests and the applied sliding contact load was ranged from 0.3N to 0.6N since it was found out that oxide layer forms very rapidly at high sliding speed and contact load through out the pretests and related researches [2], the test condition was determined as stated earlier to allow gradual formation of oxide layer on the contact parts. Also, to study the effect of oxide layer on friction characteristic, tests were carried out both in air and nitrogen environments.

3. RESULTS AND DISCUSSION

3.1 Friction characteristic of TiN coated ball and steel disk under sliding test in air

To investigate the friction characteristic of TiN coating, the changes in coefficient of friction was measured by putting the coated steel ball in sliding motion against the steel disk. The friction signal showed a gradual transition behavior according to the contact number of cycle. Such friction signal can be divided into three regions; the low friction region where typical friction characteristic of ceramic coating belongs, the friction transition region and the high friction region where the ceramic coating characteristic does not exists in friction point of view.

3.2 Effect of oxide layer on friction characteristics

To investigate the effect of oxide layer, which forms on the sliding surfaces of TiN coated steel ball and steel disk, on friction characteristic between two materials, sliding tests were conducted both in air and nitrogen environments under the contact load of 0.5N using TiN coated ball with 1μm coating thickness and steel disks with 0.06, 0.1 and 0.2μm. The results from the tests in nitrogen can be verified that the low friction region in ceramic coating continues during the tests unlike in air. This proves that both the friction transition region and the high friction region, which appear in air, are generated due to the oxidation of sliding surfaces. Also the effect of surface roughness of steel disk on the friction characteristic of TiN coated ball, which is the decrease in coefficient of friction as the surface roughness increases, can be observed. This is because that the real contact area between two materials reduces as the surface of counter part gets rougher [7].

3.3 Characteristic of oxide layer formation according to friction signal

To investigate the characteristic of oxide layer formation according to the friction signal, sliding tests were conducted using the coated ball with 1μm coating thickness on steel disks with surface roughness of 0.06, 0.1 and 0.2μm under 0.3N of contact load for 50 cycles in contact. The wear tracks generated on steel disks were examined using SEM and analyzed by EDS.

Three different friction signals were obtained according to the surface roughness. First, it can be seen that the high friction region was obtained when the steel disk with Ra 0.06μm was used. After analyzing the wear track with EDS, massive amount of oxygen was detected. Second, it can be seen that the friction transition region was obtained when the steel disk with Ra 0.1μm was used and EDS analysis showed that the oxygen amount in wear track decreased compared to that of the first case. The third case, which the steel disk with Ra 0.2μm was used and the coefficient of friction stayed in the low friction region during the test. Unlike in the first and second case, oxygen was not detected, which indicates no existence of oxide layer.

From the above test results, it was found out that the oxide layer forms at a point where the friction signal transits from the low friction region to the high friction region. This indicates that, by observing the friction signal during sliding test, the initiation point of oxide layer formation can be predicted.

3.4 Initiation time of oxide layer formation according to the real contact area of sliding surfaces

TABLE 1 contains the list of contact number of cycle at the beginning of oxide layer formation according to the contact load, the coating thickness and the surface roughness of steel disks. By plotting these data in log-log scale, the friction transition diagram was generated as shown in Fig. 1. From the diagram, it can be seen that as the contact load increases, the contact number of cycle at the beginning of oxide layer formation decreases linearly. Also, it can be observed that the contact number of cycle at the beginning of oxide layer formation increases as the coating thickness increases and the surface roughness of steel disk increases under same contact load in the order of 1μm-Ra 0.1μm, 4μm-Ra 0.1μm, 1μm-Ra 0.2μm and 4μm-Ra 0.2μm. The decrease of real contact area is believed to be in the same order as well. In this study, the effect of surface roughness of steel disk on the real contact area size is found to be more significant than the effect of coating thickness.

TABLE 1 Contact number of cycle at oxide layer formation

	Surface roughness of the steel disks					
	Ra 0.2μm		Ra 0.1μm		Ra 0.06μm	
Coating thickness / Normal Load	1 μm	4 μm	1 μm	4 μm	1 μm	4 μm
0.3N	73	98	23	75	0	0
0.4N	40	60	12	29	0	0
0.5N	34	40	9	20	0	0
0.6N	26	36	5	12	0	0

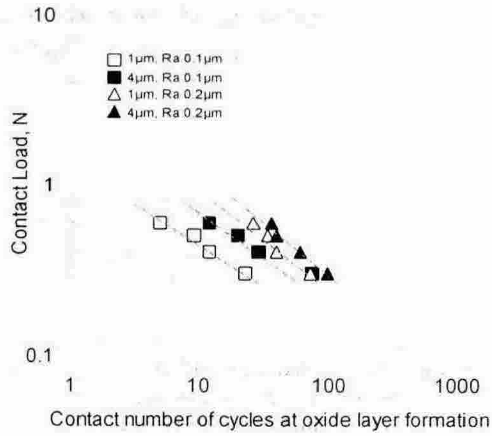

Fig. 1 Friction transition diagram: contact number of cycle at oxide layer formation as a function of contact load.

4. CONCLUSIONS

By varying the coating thickness and the surface roughness of counter part, the effect of real contact area on the oxide layer formation and the wear mechanism of TiN coated ball was investigated and as the results, the following conclusions were obtained.

(1) The iron oxide layer on steel disk dominates the friction characteristic between two materials and it induces friction transition and high friction.

(2) The oxide layer, on the sliding surfaces of two materials, begins to form at a point where friction signal transits from low friction to high friction. The formation on the counter part occurred early as the contact load increased, as the surface roughness of counter part decreased and as TiN coating thickness decreased. That is, it forms early as the real contact area increases.

5. REFERENCES

[1] Holmberg, K. and Matthews, A., "Coatings Tribology", Elsevier Amsterdam, pp. 172-189, 1994.

[2] Holmberg, K., Ronkainen, H. and Matthews, A., "Tribology of thin coatings", Ceramics International, Vol. 26, pp. 787-795, 2000.

[3] Wilson, S. and Alpas, A. T., "Effect of Temperature and Sliding Velocity on TiN Coating Wear", Surface & Coatings Technology, Vol. 94-95, pp. 53-59, 1997.

[4] Wilson, S. and Alpas, A.T., "Tribo-layer Formation during Sliding Wear of TiN Coatings", Wear, Vol. 245, pp. 223-229, 2000.

[5] Huang, Z. P., Sun, Y. and Bell, T., "Friction Behavior of TiN, CrN and (TiAl)N Coatings", Wear, Vol. 173, pp. 13-20, 1994.

[6] Erdemir, A., Bindal, C. Pagan, J. and Wilbur, P., "Characterization of Transfer Layers on Steel Surfaces Sliding against Diamond-like Hydrocarbon Films in Dry Nitrogen", Surface & Coatings Technology, Vol. 76-77, pp. 559-563, 1995.

[7] Lee, Y. Z. and Jeong, K. H., "Wear-life Diagram of TiN-Coated Steels", Wear, Vol. 217, pp. 175-181, 1998.

ACKNOWLEGEMENTS

The authors are grateful for the support provided by a grant from the Safety and Structural Integrity Research Center at SungKyunKwan University.