Proceedings of WTC2005
World Tribology Congress III
September 12 –16, 2005, Washington, D.C., USA

WTC2005-63696

FRICTION AND WEAR BEHAVIOR OF BORONIZED CHROMIUM FOR BIOLOGICAL APPLICATIONS

R. Ribeiro, S. Ingole, O. Juan, H. Liang
Mechanical Engineering, Texas A&M University, College Station, Texas, 77843-3123, USA.

M. Usta
Gebze Institute of Technology
Materials Science & Engineering
41400, Gebze, Turkey.

C. Bindal
Sakarya University
Metallurgical & Materials Engineering
54187, Sakarya, Turkey.

A. H. Ucisik
Bogazici University
Institute of Biomedical Engineering
80815, Bebek/Istanbul, Turkey.

ABSTRACT

Enhanced corrosion and wear resistance are crucially important to prolong the service life of biomaterials. Boronizing has been reported to enhance the wear resistance of pure chromium. In this research, we investigate friction and wear behavior of boronized chromium. Pin-on-disc tribometer was used to conduct the wear and friction tests. Experiments were conducted in dry conditions as well as in simulated body fluid (SBF). Fundamental aspects of wear mode and lubrication behavior were studied using surface characterization techniques such as TEM, and X-ray diffraction. Results showed evidence of tribo-chemical interactions between SBF and work piece materials.

INTRODUCTION

Boride coatings have been applied to metal surfaces in order to improve their corrosion resistance, electrochemical properties, tribological performance, and to prolong service life [1, 2, 3 and 4]. Boronizing is one way to form this uniform coating on the substrate material. It is a thermo-chemical diffusion surface treatment in which boron atoms diffuse into the surface of the work piece to form hard borides with the base materials [5]. Efforts have been made in studying material properties of boronized steels. Anthymidis et al. did a comparative study of boride coatings on a steel substrate obtained by the pack-cementation method and by fluidized bed technology [6]. Wear mechanisms of boronized steels have been reported. In a previous study, formation and self-lubricating mechanisms of thin boron oxide and boric acid films on surfaces of boronized steel were reported. The ultra-low friction behavior of boronized steel surfaces was due to layer-lattice structures of these films [7, 8, 9, 10, and 11]. Martini [12] found that there was difference in values of surface height in different regions of the coatings in a study of wear mechanism of boronized steel. The difference was due to various crystallographic orders of iron borides.

The motivation of present research is to understand the most fundamental tribological issues of boronized chromium. Our previous work reported the wear behavior of boronized tungsten and niobium [13, 14, and 15].

MATERIALS AND METHODS

Boronized chromium for 4 hours at 940^{o}C in a solid medium using Ekabor powders was studied. The dimensions of the specimen were approximately 1.1 cm x 0.7 cm x 0.5 cm.

A pin on disk tribometer (CSM instruments) was used for the friction and wear tests with boronized chromium as the disk materials and steel bearing ball (E52100) as the pin. Two different test conditions were used i.e. dry and using simulated body fluid (SBF). The chemical composition of SBF is given in Table 1. The normal load applied was 5N. The half amplitude of the linear reciprocating sliding motion was 1 mm with a maximum linear speed of 2.5 cm/s which formed the wear track of 2 mm.

The debris characterization was done using the transmission electron microscopes JEOL 1200, and JEOL 2010.

Table 1: Ionic concentration of Simulated body fluid [16].

Ion	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	HCO_3^-	HPO_4^-	SO_4^{2-}
Conc. (mM)	142.0	5.0	1.5	2.5	147.8	4.2	1.0	0.5

RESULTS AND DISCUSSION

Figures 1, and 2 show variation of coefficient of friction with time for boronized chromium against a steel bearing ball in dry and wet conditions respectively. In the case of dry conditions, the friction coefficient fluctuated initially but had an overall increase and stabilized at approximately 0.42. There was no well defined break-in period. In wet condition, initially coefficient of friction was achieved a local maxima and then lowered. After that there was continuous increase in it. This might indicates that the reaction between sliding materials and the SBF fluid deteriorated the friction. The results indicate a difference in the surface friction characteristics of the two materials. On close examination of the wear particles (formed during dry sliding of CrB) using transmission electron microscopy shown in Figure 3, it was found that the particles were amorphous. Similar observation is necessary for the wear particles formed during wet test as well. These results provide us with important information on the surface properties of boronized chromium for future biomaterials development.

CONCLUSIONS

Friction and wear behavior of CrB in biofluid were studied. The biofluid reduced the friction but was not stabilized. In dry test the amorphous debris was formed.

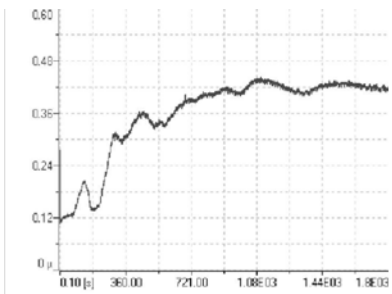

Fig. 1: Friction coefficient Vs time for dry CrB.

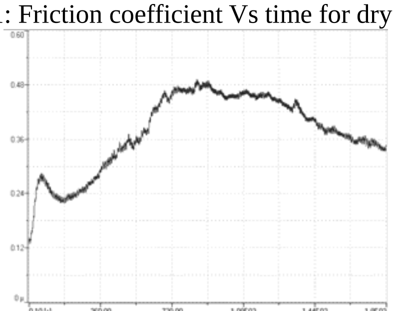

Fig. 2: Friction coefficient Vs time for wet CrB.

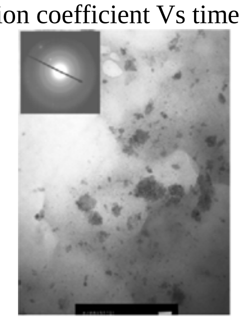

Fig. 3: TEM micrograph of CrB debris in dry condition. Inset: Selected area diffraction.

ACKNOWLEDGMENTS

This work was sponsored by NSF CAREER award CMS-0239136 (including REU) and the UAF Graduate School Fellowship. Support from the Texas Engineering Experiment Station and the Texas A & M University are greatly appreciated.

REFERENCES

[1] K.G. Anthymidis, N. Maragoudakis, G. Stergioudis, O. Haidar, and D.N. Tsipas, 2003, “A comparative study of boride coatings obtained by pack cementation method and by fluidized bed technology,” Materials Letters, **57,** 16-17, pp. 2399-2403.

[2] C. H Xu, W. Gao, and Y.-L Yang, 2001, “Superplastic boronizing of a low alloy steel - microstructural aspects,” Journal of Materials Processing Technology, **108(**3), pp. 349.

[3] G. Palombarini, G. Sambogna, and M. Carbucicchio, 1993, “Role of oxygen in iron boriding using boron carbide, Journal of Materials Science Letters, **12(**10), pp. 741-742.

[4] G Palombarini, and M. Carbucicchio, 1987, “Growth of boride coatings on iron,” Journal of Materials Science Letters, **6**(4), pp. 415-416.

[5] I. Ozebek, H. Akbkulut, S. Zeytin, C. Bindal, and A. Hikmet Ucisik, 2000, “The characterization of borided 99.5% purity nickel” Surface and Coating technology, **126** 166-170.

[6] K.G. Anthymidis, N. Maragoudakis, G. Stergioudis, O. Haidar, D.N. Tsipas, 2003, “A comparative study of boride coatings obtained by pack cementation method and by fluidized bed technology,” Materials Letters, **57,** 16-17, pp. 2399-2403.

[7] A. Erdemir and C. Bindal, 1995, “Formation and Self-lubricating Mechanisms of Boric Acid on Borided Steel Surfaces,” Surface and Coatings Technology, **76-77**, pp. 443-449.

[8] C. Bindal, A. Erdemir, 1996, “Ultralow friction behavior of borided steel surface after falsh annealing,” Applied Physics Letter, **68** (7), pp. 923.

[9] S. Mirmiran, Vladimir Tsukruk, A. Erdemir, 1999, “Nano-Tribilogical and wear behavior of boric acid solid lubricant,” Tribology Transactions, **42**(1), pp. 180-185.

[10] A. Erdemir, C. Bindal, C. Zuiker, E. Savrun,1996, “Tribology of naturally occurring boric acid films on boron carbide,” Surface Coating and Technology, **86-87,** pp. 507.

[11] A. Erdemir, C. Bindal, G.R. Fenske, 1996, “Formation of ultralow friction surface films on boron carbide,” Applied Physics Letters, **68**(12), pp. 1637-1639.

[12] C. Martini, G. Palombarini, G. Poli, D. Prandstraller, 2004, “Sliding and abrasive wear behavior of boride coatings,” Wear, **256**(6), pp. 608-613.

[13] S. Ingole, H. Liang, M. Usta, C. Bindal and A.H. Ucisik, 2005, “Multi-scale wear of a boride coating on tungsten,” Wear, **259** (7-12), pp. 849-860.

[14] S. Ingole, 2005, “Nanotribological Characterization of Dynamic Surfaces,” Ph.D. Dissertation, University of Alaska, Fairbanks, AK.

[15] S. Ingole, H. Liang, M. Usta, C. Bindal and A.H. Ucisik, 2005, “Wear study of boride coating on niobium” Journal of ASTM International, **2** (6).

[16] Shi, Xinfeng, 2002, “Apatite Coating over Zirconium Metal by a Biomimetic Method,” Master’s thesis, Rose-Hulman Institute of Technology Terre Haute, IN.