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Adhesion Behavior in Sliding Test of Austenitic Stainless Steel on VC Coated by TRD Process

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Abstract

Austenitic stainless steel is prone to adhere to tool steels which are used as forming tools. This causes difficulties in the formation of stainless steels.(1) Hard coating on forming tools is a method to diminish adhesion problems. In this work, adhesive behavior of stainless steel was tested against VC coated by thermo-reactive deposition and diffusion (TRD) process. Sliding wear test was conducted under unlubricated condition at room temperature by a ring-on-disc tester. AISI 304 was used as a ring for sliding couple with VC coating layer. DC 53 steel was used as a disc on which VC with a thickness of 7 microns was coated in molten borax salt bath under ambient atmosphere. Normal load and sliding velocity in sliding test were varied in the range of 120 – 320N and 0.716 – 2.148 m/s, respectively. The wear track was investigated by optical microscope and scanning electron microscope (SEM). The chemical composition of the ring surface was identified by X-ray energy dispersive spectroscopy (EDS).

It was found that weight loss of the ring increased gradually with increasing normal load from 120N to 220N; it then increased abruptly until the load reached 320N. The EDS analysis of the ring surface for a load of 320N showed that the ring surface contained higher oxygen content than that without wear testing. This implies that oxide of Cr and Fe on the ring surface contributed to adhesion, resulting in higher weight loss for a load of 320N. In the case of sliding velocity, the weight loss of SS ring increased from a velocity of 0.716 m/s to 1.432 m/s; it then seemed to remain constant with increasing sliding velocity. The thick Cr-oxide layer which formed on the stainless steel surface during sliding test might have prevented adhesion.

Key words: Adhesion, Stainless steel, Vanadium carbide, TRD Process

Introduction

Austenitic stainless steel is used widely in the forming industry since severe wear is often found in forming austenitic stainless steel which involves adhesion or transfer of metal to the contact surface. Dry sliding condition in particular is prone to adhere extremely to tool steel, such as mold, cutting tools, and cold-rolling tool steel.(1) The effectiveness of working tool steel is deteriorated with pick-up materials on the tool. Hard coating is one method to modify the tool surface in order to improve wear resistance and reduce damage from adhesion of stainless steel. Several papers endeavored to solve this problem.(2-5) The surface roughness of the substrate and polishing of PVD coating material on the tool are found to be crucial to prevent pick-up of stainless steel, especially in the case of hard coating, which generates a high friction coefficient.(4) In PVD-TiN coated tool steel sliding against austenitic stainless steel, adhesion is believed to accumulate on the same area. Surface oxide of stainless steel which shows adhesion to TiN consists of a mixture of Fe-oxide and Cr-oxide in which Fe-oxide is predominant.(5)

In this work, the ring-on-disc type of sliding test was performed by using VC coated by TRD process against austenitic stainless steel. The adhesion behavior of VC and stainless steel is discussed.

Materials and Experimental Procedures

DC 53 steel was used as a disc with a diameter of 46 mm. VC was coated on the disc by TRD Process in salt bath at a temperature of 1,000°C for

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6 hours 15 minutes.[6] AISI 304 steel was used as a ring for sliding couple with VC coating layer. The sliding test was conducted by Friction and Wear Tester EFM III-1010 with ring-on-disc type. The normal load and sliding velocity were varied in the range of 120 – 320N and 0.716 – 2.148 m/s, respectively. The sliding distance was varied in the range of 1,000-2,200 m. The disc roughness was measured by surface roughness tester, Mitutoyo SV 3000. VC coated disc was polished to provide a surface roughness (R_a) of about 0.10-0.15 micron. The ring weights were measured before and after sliding test. Sliding contact was investigated by optical microscope and scanning electron microscope. The chemical composition of the ring surface was identified by SEM-EDS. The cross-section of the ring was analyzed by EPMA.

Results and Discussion

In sliding test, the weight loss of stainless steel ring was measurable while that of the disc was not significant. Considering wear track of ring and disc, the ring exhibited a delaminated surface, as shown in Figure 1, while the disc showed stainless steel stuck on VC surface, as demonstrated in Figure 2. After sliding test, it was difficult to distinguish the weight of worn-out part of VC layer and stainless steel sticking on the disc. For that reason, weight loss of disc is not considered in the present paper.

Figure 3 presents the relation of sliding distance and weight loss of ring at a sliding velocity of 1.432 m/s and normal load of 220N. At a sliding distance of 1,000 m and 1,500 m, the average weight loss of ring possessed nearly the same value, about 21 mg. Subsequently, weight loss of ring increased with further sliding distance up to 2,200 m, at which point weight loss was 34 mg. It can thus be affirmed that weight loss of ring was increased with increasing sliding distance.[2]

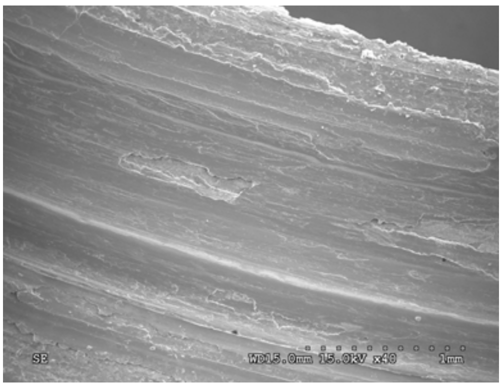

Figure 1. Sliding contact of ring

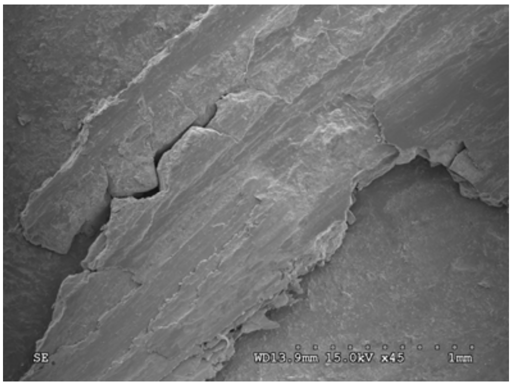

Figure 2. Stainless steel sticking on VC

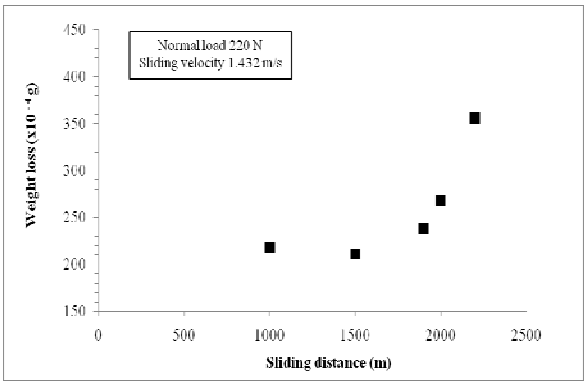

Figure 3. The relationship between weight loss of stainless steel ring and sliding distance

Figure 4 shows the relationship between weight loss of ring and sliding velocity. At a normal load of 220N and a sliding distance of 2,000 m, weight loss of ring increased with increasing sliding velocity from 0.716 m/s to 2.148 m/s. Weight loss at 0.716 m/s was 13 mg, and at 2.148 m/s it was 35 mg. It is thought that increasing sliding velocity resulted in a high shearing force; consequently, a higher weight loss of stainless steel ring was obtained.

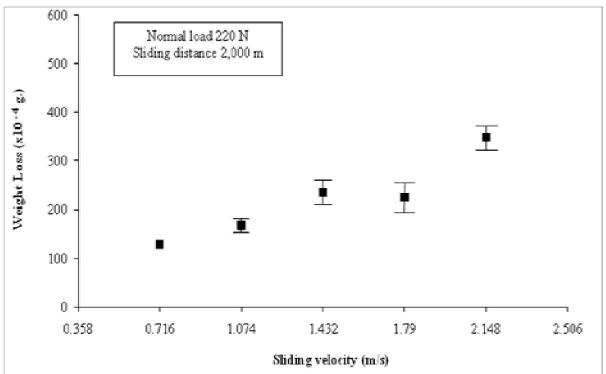

Figure 4. The relationship between weight loss of ring and sliding velocity

Figure 5(a) illustrates the relationship between weight loss of ring and normal load. At a sliding velocity of 1.432 m/s, weight loss of ring increased gradually with increasing normal load from 120N to 220N; it then increased abruptly up to the maximum at a normal load of 320N. Weight loss at 120N was 22 mg while at 320N it reached nearly 100 mg. With respect to the friction coefficient in Figure 5(b) it is intriguing that the maximum weight loss at a normal load of 320 N displayed the minimum friction coefficient of about 0.25 at a certain period of sliding. It is thought that the stainless steel ring delaminated significantly over the first 300 m in which the friction coefficient was high. Subsequently, the ring surface seemed to be protected when the friction coefficient was as low as 0.25. When the friction coefficient increased again at a sliding distance of about 1,100 m, the ring surface finally delaminated once more. Further, the sliding test was interrupted at a distance of 576 m, and the ring weight was measured. The weight loss at a distance of 576 m was 55 mg; this figure amounts to about 55% of total weight loss at a distance of 2,000 m. The test interruption confirmed the above findings.

The EDS analysis of the ring surface for a normal load of 320N showed that the ring test surface contained more oxygen than that without wear testing. This implies that oxide on stainless steel was thicker after test or contained more Fe than that without wear testing, in which case the oxide layer was thin and contained only Cr-oxide. The Cr-oxide and Fe-oxide which formed on the ring surface might have contributed to adhesion[3] resulting in higher weight loss in a normal load of 320N. However, the EPMA result of the ring cross-section was tested up to a sliding distance of 576 m in Figure 6, which illustrates that the surface of the stainless steel ring was covered by a layer as thick as 20 microns. This layer contained Cr without Fe and Ni and is thought to be Cr-oxide. Between sliding distances of 400-1,100 m, in which the friction coefficient was as low as 0.25, stainless steel surface seemed to be protected and thick Cr-oxide might have contributed to this protection against transfer of stainless steel. Finally, when Cr-oxide was destroyed at a sliding distance of about 1,100 m, weight loss occurred again, which corresponds to the friction coefficient increasing from 0.25 to about 0.4 until completion of sliding test.

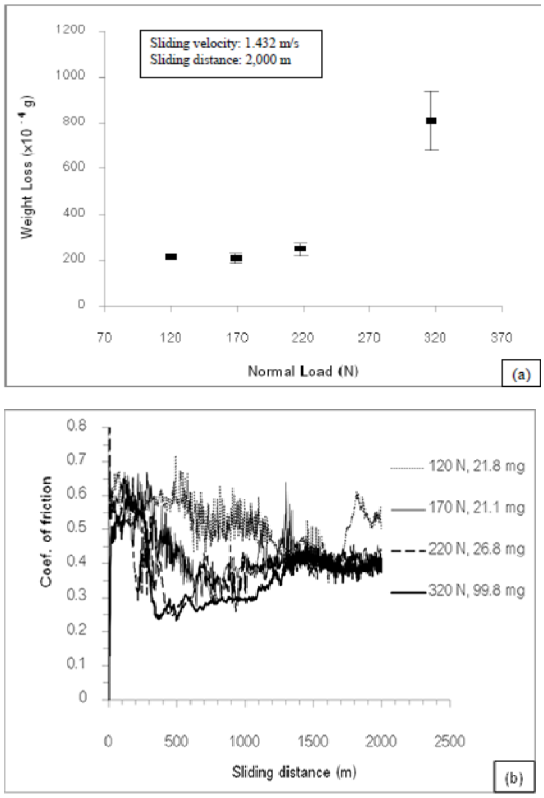

Figure 5. (a) The relationship between weight loss of ring and normal load,
(b) friction coefficient during sliding test at various normal loads

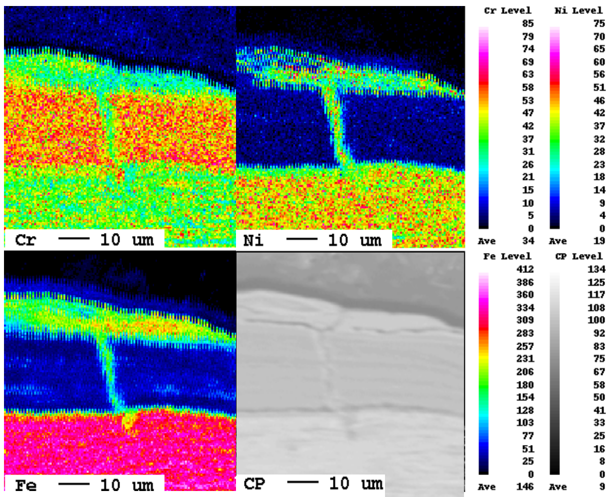

Figure 6. EPMA of cross-section of ring tested up to a distance of 576 m

Conclusions

Sliding test was conducted by ring-on-disc type using stainless steel as a ring and VC coated tool steel as a disc. Results were concluded as follows:

1. At normal load of 220 N, weight loss of stainless steel ring increased with increasing sliding velocity from 0.716 m/s to 2.148 m/s.
2. At sliding velocity of 1.432m/s, weight loss of stainless steel ring increased gradually with increasing normal load from 120N to 220N; it then increased abruptly until normal load was 320N.
3. Surface oxide of stainless steel was very sticky oxide, resulting in adhesion to VC coating layer. Thick Cr-oxide which formed on stainless steel surface during sliding might have prevented adhesion.

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