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Wear Behavior of Al_2O_3-TiCN Composite Ceramic Sliding on Stainless Steel

X.Z. Zhao, J.J. Liu, B.L. Zhu, Z.B. Luo, H.Z. Miao

It is well known that austenitic stainless steel AISI 302 is relatively difficult to cut. In order to investigate the wear behavior of Al_2O_3-TiCN composite ceramic when machining austenitic stainless steels, a block-on-ring tribometer was used to simulate a real machining process. The test results showed that the wear of both the ceramic and the stainless steel increased rapidly with increasing load and speed. The boundary lubrication actions of water and oil used in this test could not reduce the wear of the rubbing materials. Scanning electron microscopy and energy-dispersive x-ray spectroscopy analyses identified material transferred between the ceramic and the stainless steel surfaces in rubbing process. On the one hand, stainless steel transferred on the ceramic surface because of adhesion; on the other, some ceramic fragments caused by microfracture of the ceramic were found to be embedded in the worn stainless steel surface. The wear of Al_2O_3-TiCN ceramic sliding against stainless steel was caused primarily by adhesion between the rubbing surfaces and the microfracture of the ceramic.

Keywords

adhesive wear, boundary lubrication, ceramic, microfracture, TiCN composite, 302 stainless steel

1. Introduction

CERAMICS possess a number of excellent properties, including high melting point, high hardness, and good wear and corrosion resistance, and thus are increasingly used in various systems (Ref 1-3). One of their most important uses is for cutting tools, particularly those to be used at very high cutting speeds. Some difficult-to-cut materials and ultrahard materials can be machined easily when suitable ceramic cutting tools are used. In addition, machining efficiency can be raised and energy loss reduced (Ref 4).

In this study, a block-on-ring tribometer was used to investigate the wear mechanism of the Al_2O_3-TiCN ceramic when sliding against stainless steel. Useful information about the selection and wear control of ceramic cutting tools was obtained.

2. Experimental Procedure

2.1 *Test Apparatus and Specimens*

The wear tests were carried out on a block-on-ring tribometer. The selected load range was from 98 to 292.4 N; the speed range was 0.3 to 0.78 m/s. The block specimen was made from hot-pressed Al_2O_3-TiCN composite ceramic, 5 by 5 by 25 mm. The ring specimen, 40 mm in diameter and 10 mm in width, was machined from stainless steel AISI 301. The frictional surface roughness of the block and the ring was $R_a = 0.32$ and 0.20 μm, respectively. The contact model of the block and ring is shown in Fig. 1. Several properties of the ceramic are given in Table 1.

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2.2 *Test Method*

The wear tests were carried out under both dry and lubricated conditions. Distilled water and a pure mineral oil (kinematic viscosity at 25 °C is 30 mm^2/s) each were used for lubrication. The water or oil was fed into the contact point between the block and ring at an average flow rate of 5 drops per minute (about 0.1 mL/min). Each pair of specimens had 10 min of running time after a 2 min running-in process. At least two tests were performed for a selected speed and load condition. The results differed by less than 6%. Before and after testing,

Table 1 Various properties of the tested Al_2O_3-TiCN ceramic

Hardness, HV	1500
Bending strength, MPa	720
Fracture toughness, MPa$\sqrt{m}$	4.1
Density, g/cm^3	5.1

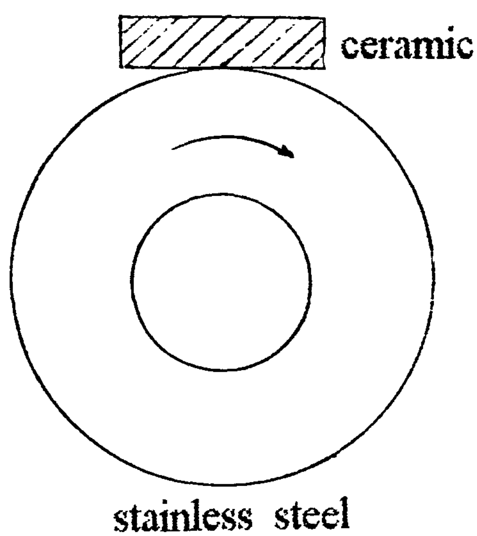

Fig. 1 Contact model of the block and ring

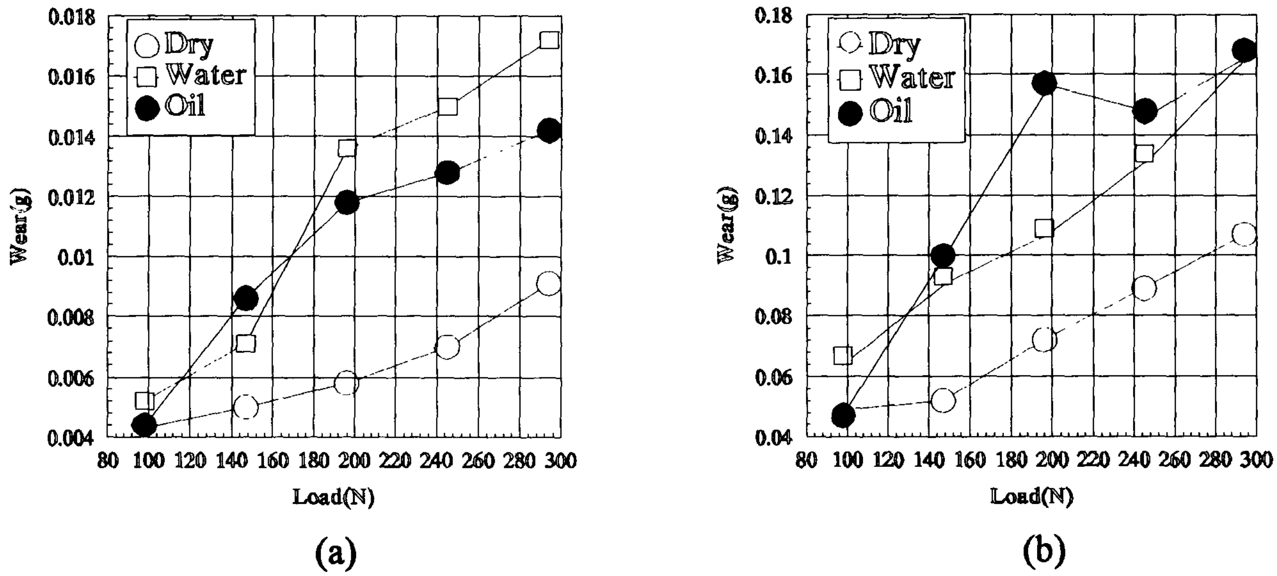

Fig. 2 Variation of wear with load speed 0.48 m/s. (a) Ceramic. (b) Stainless steel

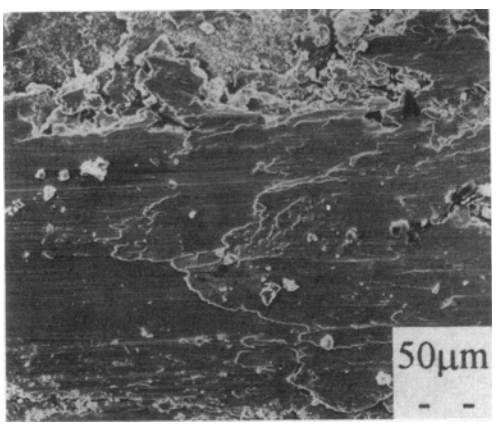

Fig. 3 SEM morphology of worn ceramic surface. Dry condition, 196 N, 0.48 m/s

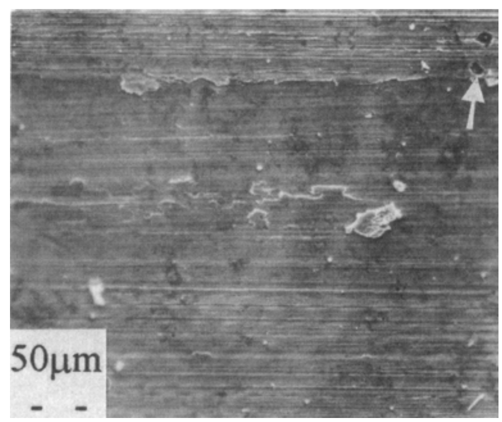

Fig. 4 SEM morphology of worn stainless steel surface. Dry condition, 196 N, 0.48 m/s

the specimens were ultrasonically cleaned in an acetone bath for 15 min and then in a hexane bath for 2 min.

The wear of the ceramic was calculated from the wear scar width, which was measured under an optical microscope. The wear of the metal was evaluated by using a precision balance. Scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy (EDXS) were used to examine the worn surfaces. The wear mechanism of the ceramic in sliding contact with stainless steel was proposed.

3. Results and Discussion

3.1 *Effect of Load on Wear*

The relationship between wear and load at a constant sliding speed of 0.48 m/s is shown in Fig. 2. It can be seen that the wear of both the ceramic and the metal increased gradually with load from 98 to 196 N, and rose rapidly after 196 N. The steep increase in wear of both rubbing materials could be related to the transition of wear mechanism. In the lower load range from 98 to 196 N, the main wear model could be abrasive wear of the stainless steel; slight adhesive wear might also occur for both the stainless steel and the ceramic. In the high load range, however, severe adhesive wear occurs for both materials because high temperatures exist in the contact zone caused by high load. In addition, microfracture of the ceramic would occur frequently in the high load range due to the brittleness of the ceramic. Subsequently, the microfracture fragments of the ceramic would bring about heavy three-body abrasive wear for the rubbing surfaces. Comparison of the curves in Fig. 2(a) or (b) shows that the existence of water or oil did not decrease the wear of the metal and the ceramic; in fact, wear increased. The lowest wear values of the stainless steel and the ceramic oc-

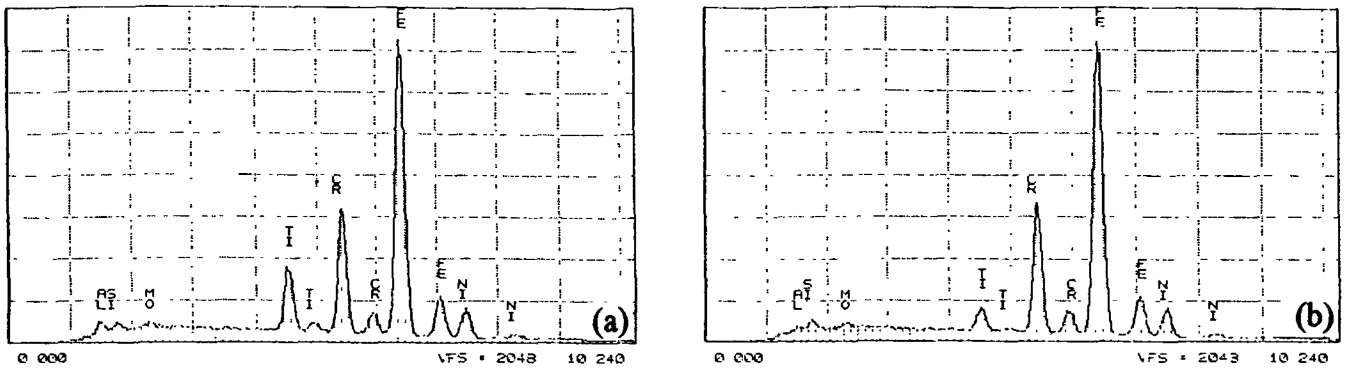

Fig. 5 EDXS spectra of the worn surfaces. (a) Ceramic. (b) Stainless steel

curred under unlubricated conditions. This result seems abnormal, perhaps the result of the selected test conditions, and will be discussed in detail in Section 3.3.

Figures 3 and 4 are SEM images of the worn ceramic and stainless steel surfaces, respectively, under unlubricated conditions. It can be seen that metal transfer occurred on the ceramic surface, because iron, nickel, and chromium in the relative amounts found in stainless steel were found on the ceramic. Serious adhesion and scratching occurred on the stainless steel surface, and some ceramic fragments also were found embedded in the surface. The EDXS spectra corresponding to the worn surfaces in Fig. 3 and 4 are shown in Fig. 5(a) and (b), respectively, and the spectrum of the embedded fragments is shown in Fig. 6. The SEM morphologies of the worn ceramic surfaces when lubricated with water or oil are presented in Fig. 7(a) and (b), respectively. Compared with Fig. 4, the amount of transferred metal on the worn ceramic surfaces was reduced. The lubricants prevented the metal from transferring to the ceramic surfaces to different extents.

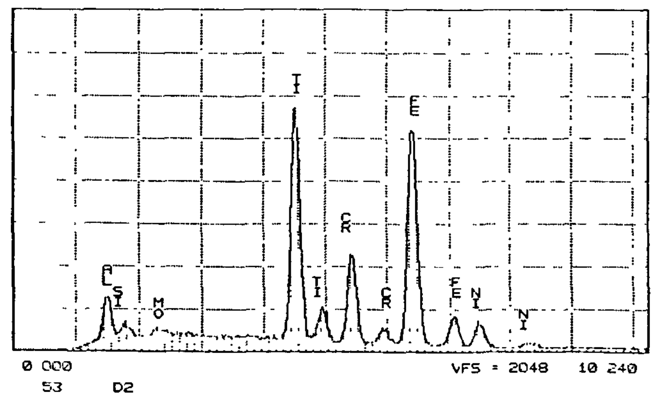

Fig. 6 EDXS spectrum of the embedded ceramic fragments

3.2 *Effect of Speed on Wear*

Figure 8 shows the relationship between wear and speed at a load of 196 N. The wear of the ceramic or the metal increased with speed. Higher speed caused higher temperatures of the rubbing surfaces, resulting in intense adhesion between the surfaces.

3.3 *Wear Characteristics under Lubricated Conditions*

For the ceramic/stainless steel sliding pairs, the wear of the ceramic was mainly caused by adhesion between the rubbing surfaces and microfracture of the ceramic. The wear of the stainless steel was dominated by adhesion wear and abrasive wear. Compared with the test results of dry friction conditions, the severe boundary lubrication provided by little water or oil did not play an antiwear role in the rubbing process; conversely, it results in increasing wear of the ceramic and the metal, which could be explained as follows.

Sasada et al. (Ref 5, 6) postulated that in the rubbing process the newly produced material particles torn from the rubbing surfaces would not depart the rubbing surfaces immediately as wear debris. Instead, they would perhaps meet and combine easily with other particles to form larger particles. Because of their high surface energy, these integrated particles would grow larger and larger, then quit the rubbing surfaces, or the newly produced particles would again adhere to the original surface, or to the counter rubbing surface. This process was called "element transmission." In this test, minimal lubrication acted to contaminate the rubbing surfaces and the newly formed particle surfaces, preventing the particles from readhering to the original rubbing surface or to the counter rubbing surface. In conditions of dry friction, the newly formed metallic particles either readhered easily to their mother metallic surface (because of high surface energy), which reduced the number of particles leaving the rubbing surface as wear debris, and thus reducing wear, or they adhered to the counter ceramic surface, forming a metallic transfer film. In this case, the metallic transfer film protected the ceramic surface from wear. Thus, minimal use of lubricants on the rubbing surfaces caused the materials to wear more quickly compared with dry friction conditions.

In fact, the final material wear was a combined result of the positive and negative effects of boundary lubrication on the wear of the ceramic/stainless steel sliding pairs. However, wear of the tested materials increased under boundary lubrication conditions compared with dry friction conditions, so the negative effect of the boundary lubrication in this test was dominant in the wear of the ceramic/stainless steel sliding pairs.

This explanation of the wear mechanism is based on the operating conditions of this test: relatively low sliding speed, high load, severe boundary lubrication, and so on. Certainly, the

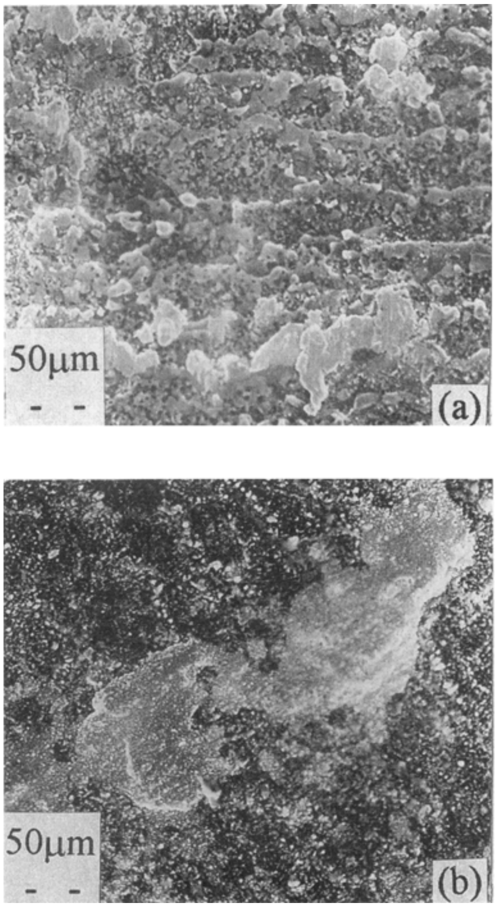

Fig. 7 SEM morphologies of the worn ceramic surfaces. (a) Water lubrication. (b) Oil lubrication

wear mechanism will change with the test conditions. The lubricating methods and lubricant types may significantly affect the wear of ceramic/stainless steel sliding contacts. Additional research in this area is currently under way.

4. Conclusions

In this test, ceramic wear was caused primarily by adhesion between the rubbing surfaces and microfracture of the ceramic. The dominant wear mechanisms of the stainless steel were adhesive wear and abrasive wear.

In the rubbing process, material transfer occurred between the rubbing surfaces. Stainless steel transferred to the ceramic surface, and microfracture fragments of the ceramic became embedded in the stainless steel surface.

Compared with dry friction conditions, the severe boundary lubrication condition provided by minimal water or oil in this test increased wear of the ceramic and the stainless steel. This should be attributed to the complicated adhesive wear mechanism of the sliding pair, which was explained in detail in this paper.

Under the severe boundary lubrication conditions of this test, the lubricants have both positive and negative effects on

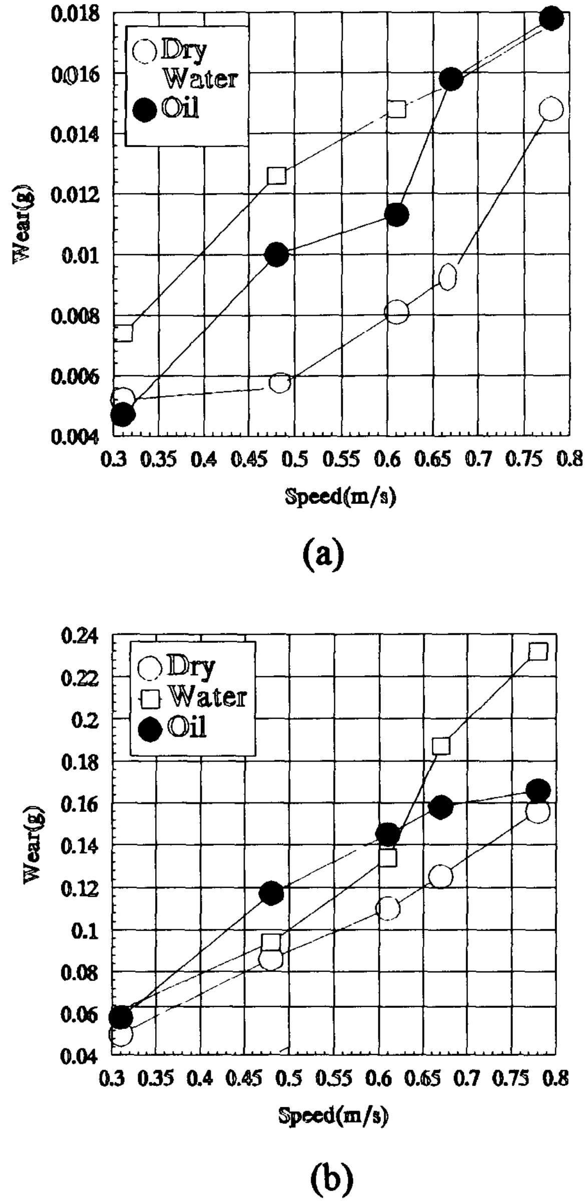

Fig. 8 Variation of wear with speed under a load of 196 N. (a) Ceramic. (b) Stainless steel

the wear of the rubbing materials. There is a balance between the two contrary effects, which accounts for the variable wear of the materials.

Acknowledgment

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