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Friction and Wear of Pressureless Sintered Ti(C,N)-WC Ceramics

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Friction and wear of pressureless sintered Ti(C,N)-WC ceramics were studied using a ball-on-reciprocating flat apparatus in open air. The silicon nitride ball and the cemented carbide (WC-Co) ball were used against the Ti(C,N)-WC plate samples. The friction coefficients of the Ti(C,N)-WC samples against the silicon nitride ball and the cemented carbide ball were about 0.57 and 0.3, respectively. The wear coefficient of the sample without WC addition was 5 times as large as that of the sample with 10 mole % WC addition when tested against the silicon nitride ball under 98 N. The higher wear coefficient of Ti(C,N)-0WC was explained in part by larger grain size. Wear occurred mainly by grain dislodgment after intergranular cracking mainly caused by the accumulated stress within the grains.

Keywords : Ti(C,N)-WC, Friction, Wear, WC-Co Silicon Nitride

1. INTRODUCTION

Titanium carbonitride (Ti(C,N)) is widely used in cutting tool manufacturing industry. It is used as a thin coating or as a major constituent of cermet cutting tools due to the high hardness and good chemical stability.[1-5] Recently, we reported the properties of Ti(C,N) based ceramics that had been sintered to a full density in a flowing nitrogen atmosphere.[6] Vickers hardness, the fracture toughness, and the three point flexural strength of the Ti(C,N) based ceramics were 16-18 GPa, 3.5-5.5 MPam$^{1/2}$, and 0.7-1.1 GPa, respectively. Since most of the current applications of Ti(C,N) are related to wear resistance and the previously reported Ti(C,N) based ceramics exhibited good mechanical properties,[6] it is interesting to study their wear behavior.

Wear of ceramics has been studied by many researchers.[5, 7-9] In this study, friction and wear of Ti(C,N)-WC ceramics were measured using a ball-on-reciprocating flat apparatus. Commercially available bearing-grade silicon nitride ball and WC-Co cemented carbide ball were used as the mating specimens.

2. Experimental Procedure

Preparation of Ti(C,N)-WC ceramics was described in a previous report.[6] Friction and wear experiments were carried out using a ball-on-reciprocating flat apparatus at room temperature in an ambient environment. The ball of 6.35 mm in diameter was either the bearing grade silicon nitride ball (Cerbec, Norton Advanced Ceramics, East Granby, CT) or the bearing grade WC-Co cemented carbide ball (Jinheung Enterprise, Inchon, Korea). Prior to the wear test, the ball and the flat sample were cleaned with acetone and ethanol. The normal load was either 98 N or 196 N, and the sliding speed, the stroke and total number of strokes for each test were 20 mm/s, 9.84 mm and 5,000, respectively. The friction force was measured using a load cell connected to an amplifier and then to a data acquisition system. The friction coefficient was defined as the friction force divided by the normal load. The wear test was interrupted after every 500 strokes for measuring wear of the flat sample, and each test was repeated three times. Wear was measured by a profilometer. Some tests were interrupted for examining the wear track in order to study the contact damage evolution. Since wear of Ti(C,N)-WC samples against WC-Co ball under 98 N was too small to measure, the normal load was increased to 196 N for wear large enough to measure.

The wear tracks of the plate samples were examined using a tranmission electron microscope (TEM) and a scanning electron microscope (SEM) equipped with EDS. For preparing the TEM sample, thinning was performed only on the surface opposite to the wear surface. The wear track was analyzed using SIMS (Secondary Ion Mass Spectroscopy, IMS 4F, Cameca, Paris, France). The areas inside and outside the wear track were analyzed for each sample. For SIMS, the bombarding ion (the primary ion) used was Cs$^+$. The accelerating voltage and the ionic current were 14.5 kV and 10nA, respectively. The secondary ions with 0.5 – 240 amu (atomic mass unit) were detected.

3. Results

While friction coefficients of Ti(C,N)-WC samples against silicon nitride ball were nearly constant, between 0.55 and 0.57, those against the cemented carbide ball were increased from 0.28 to 0.34 as the WC content was increased. The wear volume of the Ti(C,N)-WC samples tested against the silicon nitride ball according to the number of strokes. Wear of Ti(C,N)-0WC sample was increased rapidly before 500 strokes and then increased slowly for further number of strokes. Wear of Ti(C,N)-10WC sample showed a steady increase up to 5,000 strokes. The wear coefficients of Ti(C,N)-WC samples that is defined as wear volume divided by normal load and by sliding distance. Among Ti(C,N)-WC samples, the wear coefficient was decreased as the WC content was increased. The wear coefficient of Ti(C,N)-0WC sample was 5 times as big as that of Ti(C,N)-10WC sample when tested against the silicon nitride ball under 98 N. The wear coeffient of the former sample was 15 times as large as theat of the latter sample when tested against the cemented carbide ball under 196 N. SEM micrographs and EDS results of wear tracks of Ti(C,N)-WC samples tested against the silicon nitride ball revealed that more silicon and oxygen were detected as the WC content was decreased. Quantitative analysis of the elements confirms that the amount of Si on the wear track was decreased as the sample contains more WC. Co was detected from both the wear track and unworn area of Ti(C,N)-WC sample, and its content was too low for a further discussion (lower than 0.6 wt%). Contact damage evolution at the early stage of wear of Ti(C,N)-0WC sample against the silicon nitride ball under 98 N load showed that only plastic deformation without any visible crack on the wear track after 10 strokes. Intergranular cracks were developed rapidly between 10 strokes and 20 strokes. Extensive intergranular cracks and some grain dislodgment were observed on the wear track after 30 strokes. Meanwhile, there are cone cracks formed by 20 passes of the ball in one direction on the wear track of Ti(C,N)-10WC sample. While extensive plastic deformation and localized intergranular cracks followed by grain dislodgment were observed on the wear track of Ti(C,N)-0WC sample, brittle cone cracks were observed on otherwise smooth wear track of Ti(C,N)-10WC sample. SIMS results obtained from outside and inside wear tracks shows that peak corresponding to TiO_2^- was detected from the wear tracks formed by the silicon nitride ball and the cemented carbide ball, but not from outside the wear track. Meanwhile, peaks corresponding to W-oxides were observed only from the wear track against the cemented carbide ball. Since some compounds, e.g. TiC and SiO_2, have similar amu, the SIMS data need to be used with other data like EDS for a better identification of the peaks.

4. SUMMARY

The friction coefficients between Ti(C,N)-WC ceramics and the silicon nitride ball were about 0.56, almost independent of the WC content, and they were explained mainly by interlocking of asperities of the opposing surfaces. Meanwhile, worn surfaces of the Ti(C,N)-WC samples were much smoother and the friction coefficients were much lower, 0.28 to 0.34, when the cemented carbide ball was used instead of the silicon nitride ball. In this case, chemical composition on the contact surface becomes important. Ti-oxide was contributed to the low friction coefficients, and the friction coefficient was increased as the WC content in the sample was increased.

Wear of the current samples occurred mainly by grain dislodgment after intergranular cracking mainly caused by accumulated stress within the grains. Brittle Hertzian cone cracks were formed on Ti(C,N)-3WC and Ti(C,N)-10WC samples that showed lower fracture toughness than Ti(C,N)-0WC sample. However, their contribution to wear were not as significant as the stress accumulation followed by intergranular cracking and grain dislodgement.

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