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Fretting Wear Behavior of Ti(CN)-Based Advanced Cermets

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Abstract. Advanced ceramics and cermets, due to their excellent mechanical properties (elastic modulus, hardness), are increasingly appreciated in the tribological applications such as wear parts, cutting tools etc. Particularly for machining applications, Ti(CN)-based cermets represent common and important cutting tool inserts and now second to that of the conventional hardmetal (WC-Co). This research concentrates on the fretting wear behavior of Ti(CN)-Ni cermets reinforced with WC as secondary carbides. The wear tests were carried out on $Ti(C_{0.7}N_{0.3})$-x WC-Ni (x the varying carbide content) against bearing steel in the ambient conditions of temperature and humidity (50-55 % RH). Friction results indicate that significantly lower Coefficient of Friction (COF) can be achieved with Ti(CN)-based cermets as compared to conventional WC-Co materials. Detailed analysis of the tribological data was carried out to unravel the influence of secondary carbide on the wear performance of Ti(CN)-Ni cermets. Additionally, the morphology of the worn surfaces was investigated using SEM and Raman spectroscopy to understand the wear mechanism.

Introduction

In the field of machining, Ti(CN)-based cermets are used as cutting tool inserts. A comparison of the cutting performance of WC-Co conventional tool materials with that of Ti(CN)-based cermets reveals that the TiCN-cermets provide improved surface finishing and excellent chip and tolerance control and after geometrical accuracy in the workpieces. All of these characteristics are attributable to the mechanical properties of the hard phases, which are retained in the cermets. A typical cermet microstructure has a characteristic core/rim structure [1]. The rim phases, around the Ti(CN) cores are formed via dissolution-reprecipitation [2,3] process in the liquid melt. The rim phase is composed of a mixture of Ti(CN) and transitional metal carbides such as WC, NbC etc. Undissolved Ti(CN) cores are responsible for the excellent wear resistance, while crack interactions with the solid solution such as (Ti, W)(C,N) rim structure and the Ni binder phase determine its toughness and integrity [4].

Experimental Procedure

The fretting experiments were performed on a computer controlled ball-on-plate fretting (DUCOM, Bangalore, India) tribometer under ambient conditions of temperature (23-25^{0}C) and 50-55% RH.The composition of the flat materials is listed in Table 1. All the cermets were sintered to full density at 1510^{0}C for 1h in vacuum. A typical polished microstructure of sintered BS 1-1 cermet showing the characteristic core/rim structure is illustrated in Fig.1. Cermets were used as stationary flat samples in the fretting test, whereas the oscillating balls (∅ = 6 mm) were made of steel (Bearing grade, SAE 52100). The flat samples (as-received cermet discs) were ground and polished until a surface roughness of 0.05μm. Prior to the fretting experiment, the materials were ultrasonically cleaned in acetone. The experimental parameters include a normal load of 8 N, a linear displacement of 150 μm, a frequency of 8 Hz and test duration of 10,000 cycles. The COF was calculated from the on-line measured tangential force [5]. Detailed microstructural characterization of the as-worn and cleaned surfaces was performed with a Zeiss optical microscope, Scanning electron microscope and Raman microprobe.

Table1. *Sample Specification and composition of Cermets used in the present work.*

Sample Code	Composition	WC wt%
BS 1-0	Ti $(C_{0.7}N_{0.3})$ - 20Ni	0
BS 1-1	Ti $(C_{0.7}N_{0.3})$ - 5WC -20Ni	5
BS 1-2	Ti $(C_{0.7}N_{0.3})$ - 10WC -20Ni	10
BS 1-3	Ti $(C_{0.7}N_{0.3})$ - 15WC -20Ni	15
BS 1-4	Ti $(C_{0.7}N_{0.3})$ - 20WC -20Ni	20
BS 1-5	Ti $(C_{0.7}N_{0.3})$ - 25WC -20Ni	25

The wear volume was calculated from the measured wear scar diameters (both in the sliding and in the transverse directions) according to the equation proposed by Klaffke [6]. The use of this equation was reported [ ] to be justified for the present fretting conditions, providing errors less than 5% when the wear scar diameter is larger than twice the Hertzian contact diameter, as was the case in our experiments.

Results

The frictional behavior of the investigated cermet (stationary)-steel (oscillating) is illustrated in Figs. 2 and 3. The plotted results in Fig. 2 were reproduced in at least three tests and the error bars in Fig. 3 are the standard deviation of steady state COF obtained with three tests.

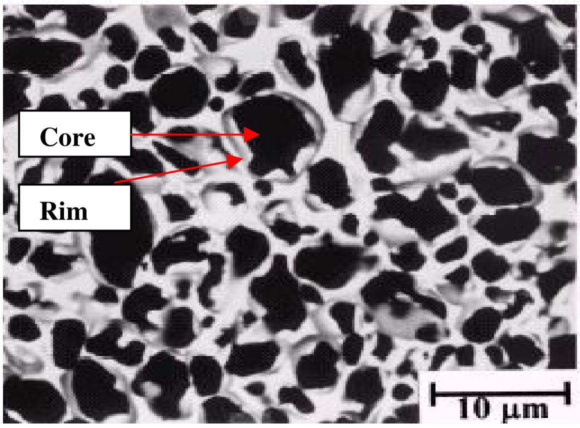


Figure 1. *BSE-SEM image of the polished surface revealing the core-rim structure of Ti(C0.7N0.3)-5WC-20Ni cermet.*

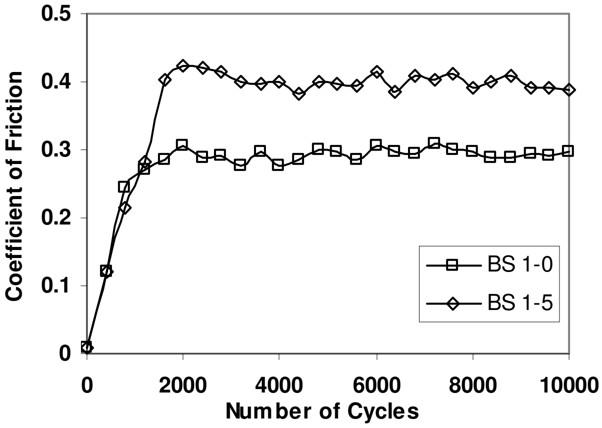


Figure 2. *The evolution of the coefficient of friction was achieved when fretting steel against cermet under load 8N for 10,000 cycles with a frequency of 8 Hz and 150 µm displacement*

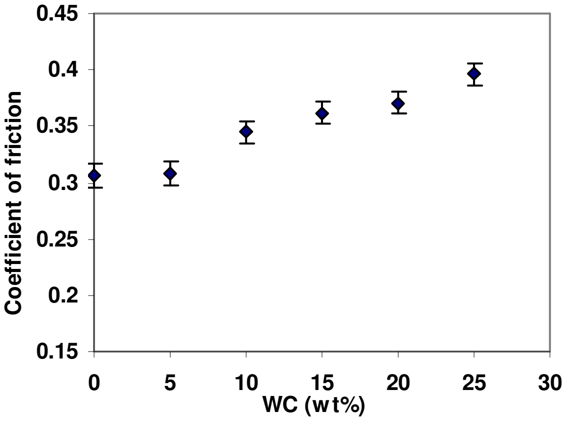


Figure 3. *The change in the coefficient of friction with the addition of WC in $Ti(C_{0.7}N_{0.3})$-20Ni system*

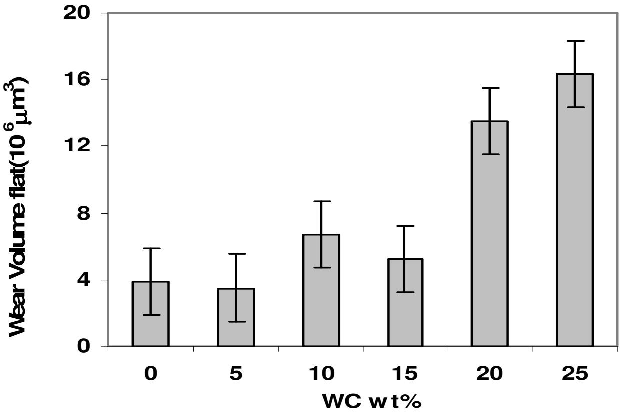
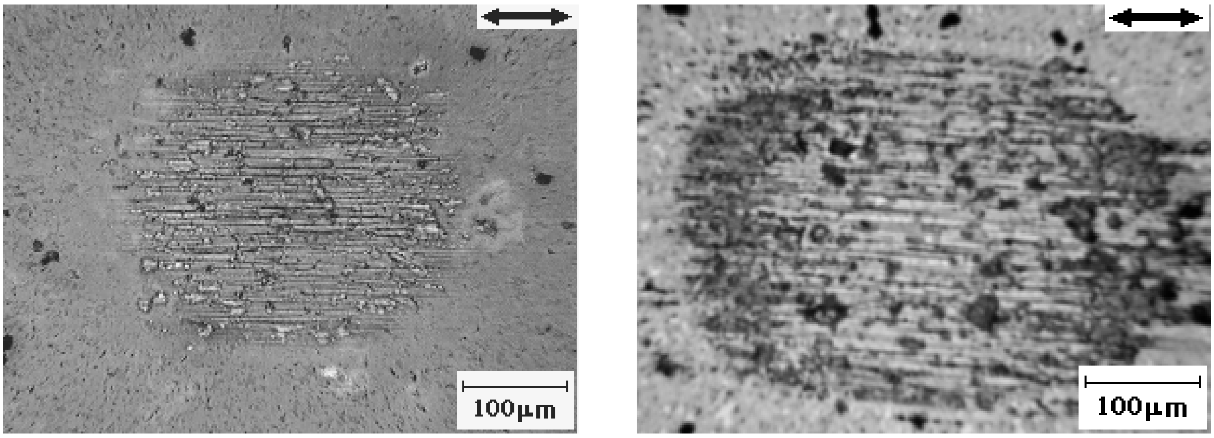


Figure 4. *Wear volumes of cermet after fretting against steel ball under a load 8N for 10,000 cycles with a frequency of 8 Hz & 150 µm displacement*

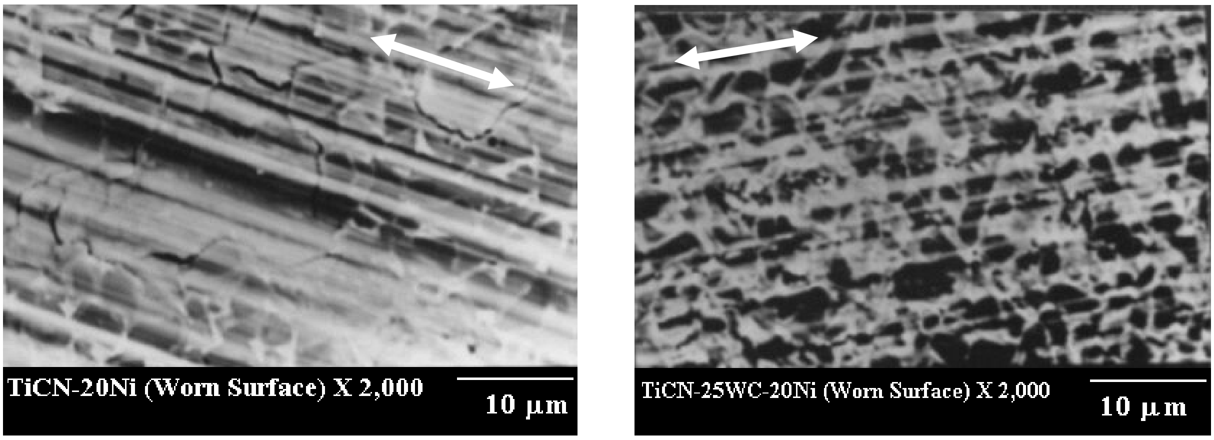
The coefficient of friction, 0.39, of the BS 1-5 with steel was highest, whereas a significantly lower COF of 0.31 was measured for the BS 1-0/steel material combination. Fig. 3 also reveals that COF remains same up to addition of 5 wt% WC in Ti($C_{0.7}N_{0.3}$)-20Ni cermets. It should be noted that the steady state COF (0.3-0.4) measured with Ti(CN) based cermets is much lower than that obtained with conventional WC-Co cermets (0.5) [7].

The volumetric wear data obtained with cermet flats as a function of WC content is plotted in Fig. 4. The error bars indicate the scatter in the wear data of at least three fretting tests. Clearly, the wear of cermets significantly increases when the addition of WC content is beyond 15 wt%. The wear loss of the cermet flats in the Ti($C_{0.7}N_{0.3}$)-(0-15)WC-20Ni test were approximately half of magnitude and lower than the wear volume of Ti($C_{0.7}N_{0.3}$)-(20-25)WC-20Ni flats in fretting conditions. The highest Ti($C_{0.7}N_{0.3}$)-(25)WC-20Ni wear was measured when fretting against steel.



(a) **(b)**

Figure 5. *Optical micrograph of worn surface a) BS 1-1 b) BS 1-5, after fretting against bearing steel at 8N for 10,000 cycles. The double pointed arrows indicate the fretting direction.*



(a) **(b)**

Figure 6. *SEM micrographs of the worn flat surfaces of a) BS 1-0 & b) BS1-1, after fretting against bearing steel at 8N for 10,000 cycles. The double pointed arrows indicate the fretting direction*

The morphology of the as-worn surfaces in the cermet/steel fretting couple is presented in Fig5. The worn cermet flat was found to be covered by a thin tribolayer with wear debris spread at and around the edge of the wear scar. The observation of the wear scar also reveals the greater extent of wear experienced by Ti(CN) cermet with higher WC content. The detailed morphology of the fretting pits on the cermet after 10,000 fretting cycles in ambient condition investigated by SEM is shown in Fig. 6. The morphology of the cleaned worn surface on the (Fig. 6a) BS 1-0 flat (without WC) indicates the presence of microcracks along with deep abrasive scratches in the wear pit, whereas mild abrasive wear scratches are found in (Fig. 6b) BS 1-1 (with 5wt% WC) after fretting test. The microcracks will eventually cause of spalling during the course of fretting. The Raman Spectra, shown in Fig. 7, is obtained from the worn surface on Ti ($C_{0.7}N_{0.3}$)-20WC-

20Ni. The characteristic Raman peaks related to the WO_3 (located at 643 and 714cm^{-1}) are indicated in Fig. 7. Raman Spectra taken from the worn surface reveals that a considerable amount of tungsten oxide forms during the fretting process. XRD could not detect any tungsten oxide phase on polished unworn cermet flat specimen. The above observation is a clear proof of the formation of tungsten oxide phase during the fretting wear process. This also indicates extensive tribo-oxidation of cermet and steel and mutual transfer (WO_3) between the mating counterbodies during fretting. In addition, Raman results did not show any evidence of the formation of TiO_2.

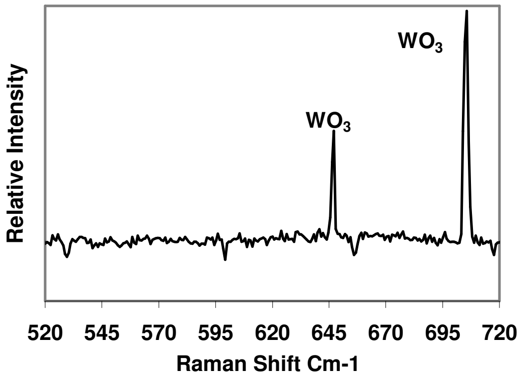


Figure 7. *Raman Spectra of as worn surface (BS1-4)*

Discussion

Looking at the tribological data and morphological investigations of the worn surfaces, the wear mechanism for the cermet/steel tribocouple can be summarized. For the BS 1-5/steel fretting couple, tribochemical oxidation along mutual material transfer and mild abrasion was observed. The oxidized layer on the cermet surface experienced delamination and abrasion by the countermaterial. On the basis of representative COF data (Fig.3) and wear volume (Fig- 4), it is clear that under identical contact conditions, cermet without carbide experiences microcracks induced spalling and abrasive wear whereas cermets with high WC content showed strong adhesive wear and tribochemical wear.and tribochemical wear. Indeed, a distinct oxidized layer is observed to adhere in the tribocontact of the cermet/steel combination. The adhesion of the tribolayers is considered to be the major reason for the high COF (Fig.3) and volumetric wear loss (Fig. 4).

Conclusions

1) The steady state coefficient of friction in a Ti($C_{0.7}N_{0.3}$)-20Ni/steel fretting couple was measured to be around 0.31 and is significantly lower than that of Ti($C_{0.7}N_{0.3}$)-25WC-20Ni /steel, which in turn was found to be also higher than that of any secondary carbide containing cermet-steel fretting couple.
2) The Ti($C_{0.7}N_{0.3}$)-5WC-20Ni /steel combination showed the best volumetric fretting wear resistance, whereas the Ti($C_{0.7}N_{0.3}$)-25WC-20Ni /steel shows the highest volumetric wear loss under the selected experimental fretting conditions. The wear of cermets significantly increases as the addition of WC content is increased beyond 15 wt%.
3) Microcracking induced spalling and abrasive wear mechanism were found to be the predominant wear mechanism for cermets without secondary carbide whereas strong adhesive wear and tribochemical wear are responsible in cermets containing higher amount of WC.
4) Raman investigation unambiguously revealed that the fretting wear was accompanied by the formation of tungsten oxide phase. The oxidation of tungsten in rim phase was the major reason for the low fretting wear resistance of Ti(CN) cermets with high WC content under selected experimental conditions.

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