Wear micro-mechanisms during multi-pass abrasion of single asperity contact for advanced NbC cermets

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1. Introduction

Cermets are unique powder metallurgical composite of refractory carbides (WC, TiC, NbC, TaC, and Cr_3C_2) and metal matrices (Co, Ni, and Fe). WC-Co cemented carbide is the most commercially used cermets in cutting tools and wear parts, due to their good structural balance between hardness and toughness [1, 2]. Recent studies show that the NbC-Ni cermet composites have the potential to replace WC-Co in various wear-resistant applications [2]. However, micro-wear and associated surface damage mechanisms during abrasive wear of NbC-Ni composites are still unclear. Numerous studies have been standardized on a laboratory scale to analyze the quantitative wear during abrasion. However, most abrasion studies use multiple particles in contact, resulting in an inconsistent surface pattern on the surface, posing difficulties in identifying the micro-mechanisms of wear and the evolution of damage. Such interactions can be easily mapped by making multiple scratches on the surface using a single asperity abrasive contact, facilitated by a scratch tester [3]. The present study examines the micro-wear and associated damage mechanisms of different NbC cermet composites by imposing multiple scratches on the surface using a scratch test in a well-controlled environment.

2. Experimental

2.1. Materials

Detailed composition and mechanical properties of various WC and NbC cermets are specified in **Table 1**. The test specimen was a circular disc with a diameter of 40 mm and a thickness of 5 mm and the contact surface was mirror polished with an initial surface roughness (S_a) of 0.02 ± 0.01 µm. The microstructure morphology of different cermets as observed by Scanning Electron Microscopy (SEM) is shown in **Figure 1**. The grey and bright contrast phases are carbides of NbC and WC, while the dark interconnects are Ni and Co binders. The dark core rim structures represent the presence of the TiCN phase (**Figure 1f**).

Table 1. Properties

Cermet	Compositions (Vol %)	Hardness (kg/mm^2)*	Toughness ($MPa.m^{1/2}$)**
WC-1	WC-15.6Co	1383	10.90
WC-2	WC-12Ni	1153	23.35
NbC-1	NbC-6Ni-10Mo_2C	1499	7.11
NbC-2	NbC-12Ni-10Mo_2C	1348	8.30
NbC-3	NbC-18Ni-10Mo_2C	1064	8.79
NbC-4	NbC-14Ni-20TiC_7N_3-20WC-4Mo_2C	1461	8.01

*Tolerances = ±24; **Tolerances = ±0.6

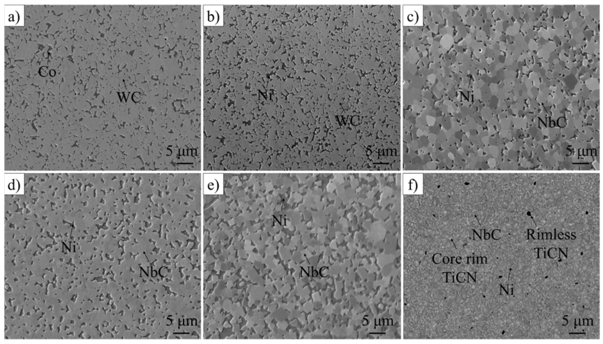

Figure 1. Microstructure morphology of cermets a) WC-Co, b) WC-12Ni c-e) NbC-Ni-Mo_2C (6 – 18 vol% of Ni), and f) NbC-TiCN-Ni-WC- Mo_2C

2.2. Methodology

A linear scratch test was performed by a universal mechanical tester (UMT tribolab, Bruker). The scratches were created by moving a polished sample under a vertically loaded diamond indenter. A diamond indenter with a conical angle of 120° (apex angle) and 100 µm tip radius was used in this study. Two different scratch modes such as single-pass and multi-pass scratches were applied on the sample. For a single pass, non-overlapping scratches generated on the sample surface at different locations. For multi-pass scratches mode, an array of scratches (2, 3, 4, 5, 10, 20, 30, 50, 100) were created by repeating the scratches on the same location several times. A constant normal force of 5 N and sliding (scratch) length of 5 mm was chosen in this test. The sliding speed was kept constant at 0.2 mm/s to avoid frictional heating during repeated passes. Two dimensional (2D) force sensor (2.5 mN resolution) is used to measure the sliding friction force as well as to measure and control the applied force. Each scratch was repeated three times for repeatability check. The indenter was also cleaned with ethanol before its use for the next test. A new indenter was used for each cermet and the adhesion of wear debris was analysed using scanning electron microscopy. Further, the damage evolution and microstructural morphology of the scratches were measured through scanning electron microscopy with integrated energy dispersive X-ray analysis (SEM-EDS, JEOL 7600F, Germany). The topography of scratches was further analysed with white light interferometry (Taylor Hobson CCI-HD, France), and the 2D average cross-sectional area was extracted from a total of 2048 cross-sectional profiles obtained from the 3D scratch profile, showed in **Figure 2**. The wear volume (V) was calculated according to the relationship Eq. (1):

$$V = V_g - V_r = (A_g - A_r).\, l \quad (1)$$

where the volume parameters V_g and V_r are calculated from the area of the groove (A_g) and ridges ($A_r = A_{r_1} + A_{r_2}$) and l is the scratch length.

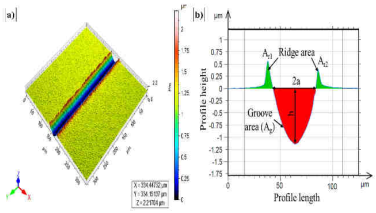

Figure 2. a) 3D scratch profile and b) 2D cross-sectional area of wear scar

3. Results and Discussion

Figure 3 illustrates the friction and wear (in terms of scratch depth and width) for both WC-cemented carbides and NbC cermets obtained from the single and multi-pass scratch test. The test results confirm that the friction and wear of NbC cermets are relatively lower than WC cemented carbides, and NbC-4 cermet provides a lower friction coefficient and scratch depth. The addition of TiCN and WC to the NbC cermet increases its micro-hardness with durable fracture toughness, resulting in a lower scratch depth [4]. The comparison between NbC-Ni cermets with a relative volume fraction of binders, such as NbC-1 (6 vol% of Ni), NbC-2 (12 vol% of Ni), and NbC-3 (18 vol% of Ni), indicates that NbC-2 offers better scratch resistance compared to cermets NbC-1 and NbC-3. A high volume fraction of the binder (NbC-3) initiates grooving wear on the surface due to the binder extrusion resulting in larger scratch width and depth. On the contrary, a less volume fraction of the binder increases the possibility of NbC-grain fracture resulting in high scratch depth.

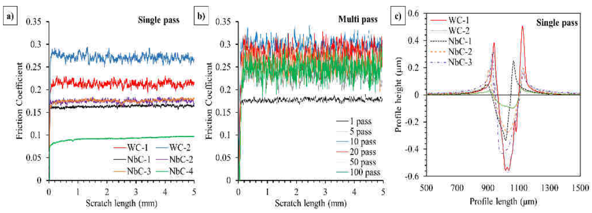

Figure 3. a) Friction coefficient of single-pass scratch and b) Friction of multi-pass scratches (NbC-2) c) Cross-sectional scratch profile of single-pass scratch test

Figure 3b shows different trends in friction during multi-pass scratching. Friction increases during the initial few passes (approximately 1-20 passes), then it either becomes stable or gradually decreases. The reason for changes in friction during multi-pass scratching is explained based on the wear mechanisms observed from scanning electron microscopy, shown in **Figure 5**. The damage between 1 and 20 scratch repeats on WC-1 mainly exhibited plastic deformation, however, after 20 passes the mechanism changed to WC grain fracture and fragmentation. The fragmented debris stuck with the wear track (scratch) further acted as a sacrificial tribo-layer. The tribo-layer from fragmentation mechanisms (re-embedding of fragmented wear debris on wear track) increases the surface hardening, which reduces the surface damage due to sliding and in turn reduces the friction coefficient [1]. On the other hand, NbC-Ni cermets show a similar trend in damage, but the NbC grain fracture at the surface starts after 10 passes, resulting in the earlier formation of the fragments. SEM observation of indenter tip before and after (adhesion of debris) multi-pass scratch test is shown in **Figure 4**.

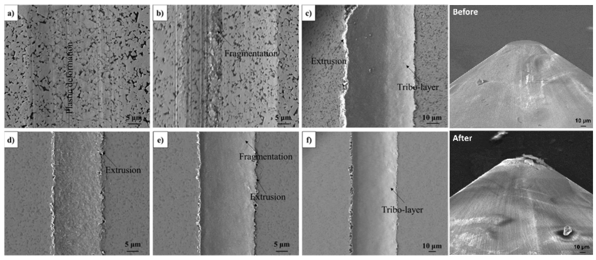

Figure 4. Damage evolution in WC-1 and NbC-2 after a and d) 20, b and e) 50, and c and f) 100 passes. Adhesion of wear debris on the indenter surface

4. Conclusions

The single-pass scratch results confirm that NbC-Ni cermets offer better scratch resistance than WC-based cemented carbides. However, multiple passes result in an earlier cause of micro-fracture and fragmentation of the NbC-cermet surface resulting in larger scratch width and depth compared to WC-Co. The addition of TiCN to the NbC-Ni cermet provides better scratch resistance due to the increased micro-hardness and similar toughness. The damage evolution of both WC cemented carbide and NbC cermet starts with micro-grooves due to plastic deformation and ends with the formation of a debris layer or tribo layer due to the re-embedding of fragmented wear debris.

4. References

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