Appendix A: Publication:

MICROSTRUCTURE INVESTIGATION OF WEAR BEHAVIOUR DURING FACE-MILLING OF Ti-6A1-4V AND 300WA STEEL USING CERMETS

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Cermets consist of hard and wear resistant metal carbide grains (e.g. WC, NbC) embedded in a ductile metal binder matrix (Co, Ni and/or Fe)[1]. Due to their good combination of hot hardness, toughness, wear resistance and strength, they are used in wide range tribological applications such as cutting and mining[1]. Titanium machining is generally difficult because of its high chemical reactivity, low thermal conductivity and high strength at elevated temperatures, leading to rapid flank wear[2]. During steel machining, plain WC-Co inserts fail due to chemical reactivity resulting in flank and crater wear. This study aims to improve the high temperature properties and chemical stability of WC inserts through spark plasma sintering (SPS), TiC and Mo_2C additions, use of Ni as a binder, and complete substitution of WC with NbC[1].

Milling inserts were produced from sintered WC-10Co (wt%) (Sample 1) and WC-5TiC-5.5Mo2C-7Ni (wt%) (Sample 2). Sample 1 was liquid phase sintered at 1430°C for 75 minutes, while Sample 2 was spark plasma sintered at 1380°C for 5 minutes. The inserts were used for face-milling of 300WA steel at 250 m/min with a depth of cut (a_p) of 0.5 mm, face-milling of Ti-6Al-4V at 100 m/min and a_p of 0.5 mm. Flank and crater wear were characterised by optical microscopy, scanning electron microscopy (SEM) and high angle annular dark field (HAADF) scanning transmission electron microscopy (STEM). Cutting forces and temperatures were measured using force gauges and a thermal camera. Workpiece surface roughness was measured using a profilometer.

Fig. 1a shows the cutting edge/workpiece interface of Sample 1 after milling 300WA steel, revealing a curved interface with smoothly worn WC grains, suggesting diffusion between the insert and the workpiece[1]. Diffusion occurs due to iron's higher affinity for carbon than tungsten, leading to rapid chemical wear on the cutting edge along the flank and rake (crater wear)[1].

Fig. 1b shows the cutting edge/workpiece interface of Sample 2 after milling 300WA steel. A straight interface was observed, demonstrating a better chemical stability than Sample 1. The exact locations of TiC and Mo_2C could not be determined in Fig. 1b, but were confirmed to be present in the (W,Ti,Mo)C solid solution in Fig. 2. The (W,Ti,Mo)C solid solution was distributed between the WC grains, improving the chemical stability and hot hardness[1].

During Ti-6Al-4V machining, Sample 1 had a lower flank wear rate (FWR) than Sample 2, reducing the average resultant force, giving a better workpiece surface finish[1] (Table 1). Sample 2 had a higher FWR than Sample 1 because of its lower fracture toughness (K_{IC}) and transverse rupture strength (TRS) due to SPS, lower binder amount and formation of the brittle (W,Ti,Mo)C solid solution[1]. Rapid cooling during SPS results in retained stresses that lower the K_{IC} and TRS. The brittle (W,Ti,Mo)C solid solution was located between the WC skeleton (Fig. 2), facilitating ease of crack propagation. Thus, the tougher LPS insert performed better than the much harder SPS insert.

References

1. Upahyaya S.G. (1998) Cemented Tungsten Carbide Production, Properties and Testing. USA, Westwood.
2. Rahim, E.A, and Sharif, S. (2006) JSME, 49(2), 341

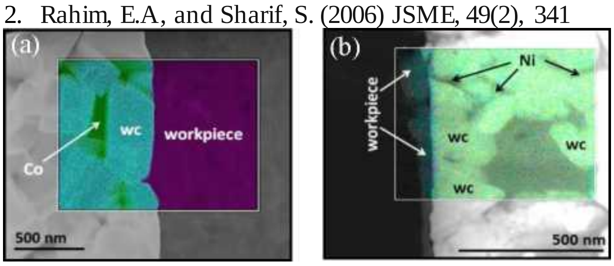

Figure 1. HAADF-STEM images of cutting edge/workpiece interfaces of (a) Sample 1: showing curved, smoothly worn WC grains and Co, and (b) Sample 2: showing a straight interface, WC and Ni.

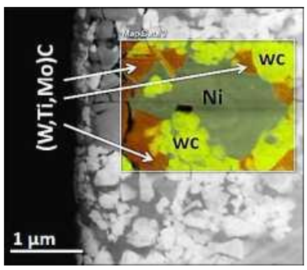

Figure 2. HAADF-STEM EDX mapping image of Sample 2, showing WC (yellow), Ni (light green) and (W,Ti,Mo)C (orange).

Sample	Flank wear rate (gm/min)	Average resultant force, (N)	Surface roughness (gm)
1	148.97	301.95 ± 6.03	0.48 ± 0.03
2	324.50	548.73 ± 10.97	0.78 ± 0.07

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