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Reciprocating wear behavior of WC–10Ni_3Al cermet in contact with Ti6Al4V

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ABSTRACT

Cermets based cutting tools remain widely used in machining processes for their wear resistance. WC–Ni_3Al cermets are potential replacements of WC–Co cermets in titanium machining due to their superior mechanical and chemical properties, especially at elevated temperature. In present study the reciprocating sliding wear behavior of WC–10Ni_3Al was investigated using a ball-on-flat tester, with the Ti6Al4V sphere as the counter-face material. Meanwhile, the diffusion test between WC–10Ni_3Al cermet and Ti6Al4V was conducted for further study of the reciprocating sliding wear mechanisms of WC–10Ni_3Al. The WC–8Co was utilized as the reference material. The experimental results show that WC–10Ni_3Al has a higher wear resistance than WC–8Co, for all the examined contact loads. Adhesive wear is the main wear mechanism for both WC–10Ni_3Al and WC–8Co. The severer adhesion and element diffusion leads to the serious wear of WC–8Co surface, while WC–10Ni_3Al can maintain the lower wear due to its low chemical affinity and element diffusion with Ti6Al4V, even under the high contact load.

1. Introduction

Cemented carbides are widely used in cutting tools, drilling and mining equipments due to their unique combination of high hardness and moderate fracture toughness. Cemented carbides generally consist of a hard phase and a binder phase, which is usually cobalt. The addition of binder phase Co can facilitate the fabrication and improve the toughness of the Cemented carbides. However, Co binder could deteriorate the hardness, oxidation and corrosion resistance of the cermets [1]. Furthermore, Co binder could be easily extruded from the framework of carbide by plastic deformation and micro abrasion at high temperature due to its relatively low elevated temperature strength [2]. In addition, Co element is prone to diffuse from WC–Co cermets when in contact with the material with high chemical reactivity such as titanium alloy in elevated temperature, leading to the decrease of bonding strength of the cermets surface [3]. These characteristics will distinctly decrease the wear resistance of the WC–Co cermets.

To overcome the disadvantages of Co, the replacement of Co with other metals such as Ni [4] or intermetallic compounds such as Ni_3Al [5] has been attempted. Intermetallic compound Ni_3Al has many physical and mechanical properties necessary for superior wear resistance such as high hardness, high elastic modulus, good oxidation and corrosion resistance. It has an increasing yield strength with temperature to a maximum at 700–800 °C [6]. Furthermore, thermodynamic calculation shows that Ni_3Al has good wettability with WC [7]. This makes Ni_3Al be a potential replacement of cobalt in the fabrication of the hardmetal on the base of WC.

Many researchers have reported the preparation of WC–Ni_3Al cermets and the corresponding physical and mechanical properties of prepared sample. Li et al. [8] have fabricated dense bulk WC–10Ni_3Al cermet by spark plasma sintering. The obtained sample possesses a good combination of high hardness (HV_{10}), transverse rupture strength and fracture toughness. Long et al. [9] have prepared a nearly full dense WC–30 wt%(Ni_3Al–B) composites by conventional powder metallurgy technology, the prepared sample has similar fracture toughness in comparison to the commercial coarse grain cermets YGR45.

Generally, the above researches mainly focused on the processes in WC–Ni_3Al fabrication. However, as Cemented carbides are generally used in applications where their tribological properties are of great importance [10], the study of the wear resistance and associated damage mechanisms for WC–Ni_3Al cermets under different wear conditions is prerequisite for the development of these cermets. Ahmadian et al. [6] have studied the abrasion wear of the WC–Ni_3Al composites using a pin-on-drum apparatus with continuous sliding motion, and pointed out that WC–Ni_3Al have higher abrasive wear resistance comparing to the WC–Co with comparable binder content, which is attributed to the higher hardness of Ni_3Al in comparison with Co.

Compared to the continuous sliding wear, reciprocating sliding wear has specific importance as this type of contact motion is very common and always results in a higher wear rate [11]. Reciprocating

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wear is defined to occur when two contacting surfaces are subjected to oscillatory sliding motion under certain amplitude [12]. In reciprocating sliding wear, the debris is trapped between the contacting surfaces and this normally can produce severe damages from both 2 and 3-body wear modes [10]. Furthermore, the cooling condition in the reciprocating sliding wear is worse than that of the continuous sliding wear, which may results in the higher frictional temperature on the contact face. Therefore, it is of interest to examine the wear behavior of WC–Ni_3Al cermets in reciprocating sliding friction, as the Ni_3Al binder has been proven to possess higher hardness and chemical stability than that of Co binder in elevated temperature.

In the present work, the reciprocating wear of WC–10Ni_3Al is studied. Ti6Al4V was selected as the counter-face material to examine the chemical stability of WC–10Ni_3Al cermet in reciprocating wear process, since Ti6Al4V alloy is known to possess high chemical intersolubility with the commonly used WC–Co cermets in elevated temperature [3]. Meanwhile, WC–8Co was chosen as the comparator, since WC–8Co is generally regarded as the most suitable cermet available commercially in titanium alloy machining. The coefficient of friction (COF) and friction temperature during the reciprocating sliding process were recorded and the weight losses of the Ti6Al4V spheres were measured. The worn surfaces of WC–10Ni_3Al were examined by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Meanwhile, a diffusion test was conducted to study the chemical intersolubility between the investigated cermets and Ti6Al4V at the corresponding measured friction temperature. Finally, the reciprocating wear mechanism of WC–10Ni_3Al in contact with Ti6Al4V was concluded in comparison with that of WC–8Co.

2. Experimental procedure

2.1. Microstructure and physical properties of WC–10Ni_3Al cermet

In our previous study [13], the WC–Ni_3Al carbide exhibited good combination of hardness and toughness when the content of binder was 10 wt%. Hence, the Ni_3Al content was set at 10 wt% in this study. The WC–10Ni_3Al and WC–8Co used for the reciprocating sliding test were both fabricated by Spark Plasma Sintering technique (SPS, Dr. Sinter Model SPS-825, Sumitomo Coal Mining Co. Ltd., Japan), the prepared processes were documented in detail in prior publications [8]. Fig. 1 demonstrates the typical microstructures of WC–10Ni_3Al and WC–8Co. It is noted that the element with larger atom number shows a lighter color when observed by SEM in BSE mode. The WC grains of both cermets appeared white with prismatic angle. The mean WC grain size for both cermets were determined to be ~1.5 μm using the lineal intercept method, although large isolated grains were also occasionally noted.

The density of the cermets specimens were measured by the Archimedes method. The Vickers hardness (HV_{10}) was measured with an indentation load of 98 N (430SVA, Wilson Wolpert. Co. Ltd., China). And the fracture toughness K_{IC} of the cermet was calculated using the approach developed by Anstis et al. [14], which is widely applied for ceramic carbide materials. The equation for calculating the fracture toughness K_{IC} is as following:

$$K_{IC} = 0.016(E/H)^{1/2}\left(P/c_0^{\frac{3}{2}}\right) \quad (1)$$

where E is the Young's modulus, H is the hardness, P is the indentation load, and c_0 is the length from one crack tip to opposite crack tip divided by 2.

The physical properties of WC–10Ni_3Al and WC–8Co were listed in Table 1. It is noted that the hardness of WC–10Ni_3Al is higher than that of WC–8Co specimen, despite the former possesses higher binder content. The reason may be explained by the hardness model proposed by Engqvist [15], in which the hardness of the cemented carbide H can be calculated by the following equation:

$$H = (H_{WC} - H_B)e^{-\lambda/k} + H_B \quad (2)$$

where H_{WC} is the in situ hardness of WC grains, H_B is the bulk hardness of binder phase, λ is the mean free binder path and k is the hardening range factor. Given the similar mean free binder path λ and the harden range factor k of WC–10Ni_3Al and WC–8Co, the higher hardness of WC–10Ni_3Al may contribute to the fact that the micro-hardness of Ni_3Al is much higher than that of Co (2.0 GPa [16] and 1.04 GPa [17], respectively). Furthermore, it is also found in

Table 1
Physical properties of WC–10Ni_3Al and WC–8Co.

	Binder content (wt%)	Binder content (vol%)	WC grain size (μm)	Vickers Hardness HV_{10}	Density (g/cm^3)	Fracture toughness (MPa m$^{1/2}$)
WC–8Co	8	13.37	~1.5	1660	14.86	12.7
WC–10Ni_3Al	10	18.97	~1.5	1812	13.76	11.2

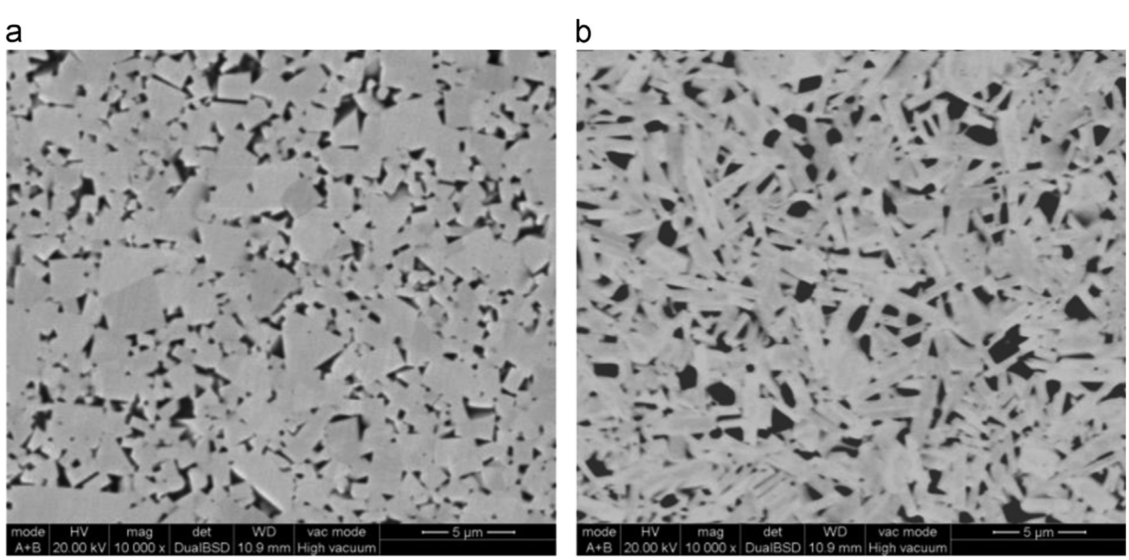

Fig. 1. Backscattered electron images revealing the microstructure of (a) WC–8Co, (b) WC–10Ni_3Al.