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Fabrication and wear mechanism of Ti(C,N)-based cermets tools with designed microstructures used for machining aluminum alloy

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ABSTRACT

In this work, microstructure of Ti(C,N)-based cermets can be designed and controlled with extra carbon additions. The influences of microstructure on the mechanical properties and wear mechanism of cermets tools are investigated systematically by scanning electron microscope, X-ray diffraction and machining test of 7075 aluminum alloys. The increasing carbon additions in cermets can react with alloy elements dissolved in binder phase of cermets and promote the formation of rim phase, which may induce the disappearance of $Co_3W_3(C,N)$ phase (η phase), reduction of core phase content and increase of rim phase content. With increasing carbon additions, the hardness of cermets decreases slightly, while transverse rupture strength of cermets can increase firstly and then decrease. Moreover, increasing carbon additions can augment the friction coefficient of Ti(C,N)-based cermets, which may induce improvement of cutting temperature and aggravation of abrasion at a relatively low cutting speed. However, with increasing cutting speeds, the existence of $Co_3W_3(C,N)$ phase in cermets tools can accelerate wear process of tools.

1. Introduction

Ti(C,N)-based cermets have drawn greater attention in the past decades due to their high hardness, low friction coefficient, excellent resistance to creep and outstanding chemical stability [1–5]. Ti(C,N)-based cermets are composed of ceramic phase and binder phase, which are carbonitrides and Ni-Co solid solution. The ceramic phase in Ti(C,N)-based cermets can possess the typical core phase and rim phase, which are undissolved Ti(C,N) particles and (Ti,M) (C,N) (M refers to W, Ta, etc.) solid solution formed by Ostwald ripening during the liquid sintering stage [6,7]. The core phase provides high hardness, while rim phase can inhibit the growth of core phase and improve the wettability between core phase and binder phase, which can enhance the fracture toughness and ductility of Ti(C,N)-based cermets. The binder phase in cermets plays a role in bonding the core-rim phase ceramic particles and contributes to the strength and roughness of materials [8].

As a superhard material with improved properties and low price, Ti(C,N)-based cermets are considered as a substitution of WC-Co cemented carbides, which can be used as a high speed cutting tools [9,10]. However, the disadvantages of Ti(C,N)-based cermets, such as low strength, poor ductility and low fracture toughness, can limit their application in cutting fields greatly [3,4,11]. Hence, the various carbides (WC, Mo_2C and VC, etc.) can be added into Ti(C,N)-based cermets for improving the strength and ductility of cermets. The effects of carbides additives on the microstructure and properties Ti(C,N)-based cermets have been studied by researchers [12–16]. In the preparation process of cermets, developing ultrafine composites through inhibiting grain growth and controlling the parameters of sintering process are focused, which may contribute to the application of Ti(C,N)-based cermets in cutting field [17–19].

7075 aluminum alloy is an ultralumin material with the highest strength, which has a basic composition of Al-Zn-Mg-Cu [20]. Owing to its superior strength and stress corrosion resistance, 7075 aluminum alloy has been widely utilized in the aircraft, weapon and other industries [21–24]. However, as a superb engineering structure materials, 7075 aluminum alloy has a poor weldability, which means that the machining for aluminum alloy components and parts should be completed in one step [25]. Nowadays, compared to cemented carbides and PCD cutting tools, Ti(C,N)-based cermets cutting tools possess the higher hardness and strength at high temperature, which can make cermets to be an optional tools for machining 7075 aluminum. The cutting performance of Ti(C,N)-based cermets tools should be properly meet the demand of complete machining. Moreover, owing to the fact that cermets have low friction coefficient and excellent resistance to creep, 7075 aluminum alloy work-piece machined by Ti(C,N)-based cermets tools can obtain outstanding surface finish and dimensional

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precision [26,27]. Besides, dry turning aluminum alloy has a significant advantage of high machine efficiency and reduced cost, which is also a more reasonable machining method to lessen environmental pollution [28]. The avoidance of cutting fluid in cutting process also contributes to tool life, owing to fact that the repeated heating and cooling caused by existence of cutting fluid may accelerate tool failure induced by thermal stress. Therefore, 7075 aluminum alloy can be machined in dry turning in present work.

The researches about cutting performance and wear mechanism of Ti(C,N)-based cermets in dry machining 7075 aluminum alloy are still rare. Furthermore, the relationship between microstructure and cutting performance of cermets tools is still unknown. Herein we prepare Ti(C,N)-based cermets with various microstructure by adjusting extra carbon additions, and machine 7075 aluminum alloys in dry turning by the prepared cermets cutting tools. Moreover, the interaction mechanism between microstructure and cutting performance of Ti(C,N)-based cermets could be revealed.

2. Experimental procedure

The original powders in present work are commercial Ti(C,N), WC, Mo_2C, TaC, Ni, Co, C powders. The mean particle size and oxygen content of the starting powders are listed in Table 1. The designed component ratio of cermets in present work can be listed in Table 2. The five samples can be labeled as 0 wt.% C, 0.6 wt.% C, 1.2 wt.% C, 1.8 wt.% C and 2.4 wt.% C, respectively.

The designed powders were mixed with anhydrous ethanol, which can prevent the oxidation of mixed powders during the milling procession. The mixed powders were milled with WC-Co balls (ball-to-powder weight ratio: 5:1) for 48 h on planetary ball-milling at a speed of 250 r/min. Subsequently, the slurry was dry in a vacuum evaporate at 90 °C for 6 h. The dried powders were sieved through 20-mesh and 40-mesh sieve for further use. Then, the sieved powders were loaded in the steel die through double action pressing to gain a uniform density at 150 MPa. The green compaction was sintered by sinter-HIP at a temperature of 1500 °C in argon atmosphere with a gas-pressure of 3 MPa. The microstructure of Ti(C,N)-based cermets as well as the phase composition can be observed by the FEI FEG-250 scanning electron microscope (SEM), EDAX Energy Disperse Spectroscopy equipment and TEAM software. In the testing process, EDS data of cermets can be obtained and calibrated from ZAF corrections automatically. Hardness was measured by a standard Rockwell hardness tester under a constant load of 60 kg. The transverse rupture strength (TRS) of Ti(C,N)-based cermets was tested at room temperature by the 3-point bending method. The measurement of hardness and transverse rupture strength can be repeated three times.

The sintered cermets were manufactured into cutting tools, as shown in Fig. 1. The five sintered samples with increasing carbon addition contents corresponding to T1, T2, T3, T4 and T5, respectively. The dry cylindrical cutting test of cermets tools was investigated through continuous turning 7075 aluminum alloy, which was carried out in the computer numerical control machine (CNC). The 7075 aluminum alloy were commercially available and removed the skin layer in advance. The hardness of 7075 aluminum alloy in present work was HV170. The cutting test included the basic test for cutting tools with various carbon contents and the extended test for cutting tools T1 and T4 with different cutting parameters, as exhibited in Table 3. For the basic test, the cutting speed, feed rate and cutting depth were 200 m/min, 0.02 mm/r and 0.3 mm, respectively, which can reveal effects of microstructure on cutting performance of cermets tool. Moreover, the extended test with different cutting speed (125 m/min, 200 m/min, 275 m/min) can be carried out for investigating the further wear mechanism of cermets tool. The flank wear values of various tools were measured through toolmakers microscope every 20 min. After machining tests, the worn flank surface of cutting tool was observed by SEM. And the elemental distribution on the worn surface can be analyzed by Energy Dispersive Spectroscope (EDS). In order to study the wear mechanism and analyze cutting performance further, the friction coefficient of cermets was tested in high speed reciprocating friction testing machine (HRS-2M) at the load of 90 N by sliding against a WC-6Co ball with a rotate speed of 600 r/min.

Table 1
Mean particle sizes and oxygen content of the starting powders.

Powders	Ti(C,N)	WC	Mo_2C	TaC	Ni	Co	C
Particle size (μm)	3.5	1.2	3	1.8	1.2	2	1.2
Oxygen content (wt.%)	0.30	0.12	0.28	0.20	0.28	0.35	0.50

Table 2
Designed composition of the experimental materials (wt.%).

Cermets	Ti(C,N)	WC	Mo_2C	TaC	Ni	Co	C
0 wt.% C	balance	20	9	5	7.5	7.5	0
0.6 wt.% C	balance	20	9	5	7.5	7.5	0.6
1.2 wt.% C	balance	20	9	5	7.5	7.5	1.2
1.8 wt.% C	balance	20	9	5	7.5	7.5	1.8
2.4 wt.% C	balance	20	9	5	7.5	7.5	2.4

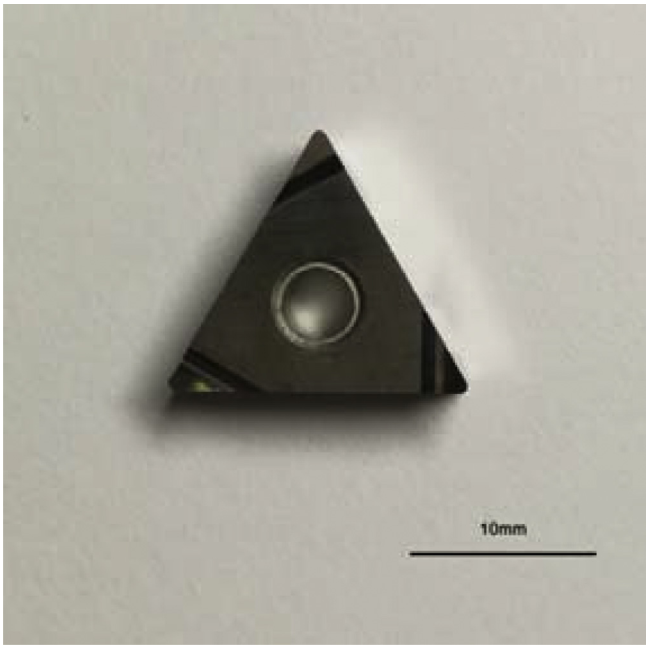

Fig. 1. Main view of Ti(C,N)-based cermets tools in present work.

Table 3
Dry turning tests of cermets with different cutting parameters.

Series	Cutting tool	V_c/(m/min)	f (mm/r)	ap (mm)
I	T1	200	0.02	0.3
	T2			
	T3			
	T4			
	T5			
II	T1	125	0.02	0.3
		200		0.3
		275		0.3
III	T4	125	0.02	0.3
		200		0.3
		275		0.3

Note: V_c — linear speed; f — feed rate: ap — cutting depth.