Microstructure and fracture behaviour of composite structured Ti(C , N) based cermets

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Abstract

Microstructure and fracture behavior of composite structured Ti(C,N) based cermets were investigated, and compared to that of conventional Ti(C,N)-based cermets. Composite structure of the Ti(C,N) based cermets consists of cobalt enriched area, cobalt poor area and coarse granule. The fracture toughness of composite structured Ti(C,N) based cermets have higher than that of conventional Ti(C,N)-based cermets. The fracture morphology of the cermets were clearly observed, suggesting the effective load transfer between cobalt enriched area and cobalt poor area. Load transfer toughening mechanisms of composite structured Ti(C,N) based cermets can be deduced in this paper.

1. Introduction

Due to their excellent properties including high hardness, strength, wear resistance, thermal conductivity and chemical stability, Ti(C,N)-based cermets can be used as high-speed milling, semi-finishing and finishing works of steels [1-3]. But at the same time, the low toughness of such materials limits application for rough machining. In recent years, reports on sintering technology (such as vacuum sintering, gas pressure sintering, hot pressing sintering, spark plasma sintering, microwave sintering) were extremely active on Ti(C,N) based cermet to obtain finer grain and higher mechanical properties[4-9]. Other works show that adequate control of secondary phase (such as ZrC, WC) addition of Ti(C,N) based cermets can obtain better mechanical properties[10-12].

Microstructure design is a novel approach to obtain the materials with excellent properties. Double cemented carbide design the double structure to keep hardness and fracture toughness[13-14]. The microstructure of Ti(C,N)-based cermet can be designed to ensure suitable mechanical properties[15-17], there is little research on structure design to toughening mechanism of Ti(C,N) based cermets. Based on above works, one kind of composite structure Ti(C,N) based cermets was developed. The paper has investigated the mechanical properties, microstructure and fracture behavior of composite structure Ti(C,N) based cermets. It is the objective of the present paper to identify the mechanism of toughening of composite structure.

2. Experimental Procedure

Commercially-obtained powders of TiC($2.56\mu\text{m}$), nano TiN (20nm), Co($1.6\mu\text{m}$), Mo($2.33\mu\text{m}$), WC($1.44\mu\text{m}$) and C($2.7\mu\text{m}$) were used as raw materials. The nominal composition of Ti(C,N) based cermet granules is 72wt%TiC-8wt%TiN(nm)-15wt%Co-4wt%Mo-1wt%C. Powder mixtures were milled by a planetary ball for 24h in an ethanol bath and then dried. Green compacts were sintered at 1430°C for 1 h in vacuum ($0.01\text{--}0.1\text{Pa}$), and then smash, and finally sieved. The mean size of Ti(C,N)-based composite granules was $101\mu\text{m}$, and the morphology of Ti(C,N)-based composite granules is shown in Fig.1. Two compositions were designed, and their nominal compositions of composite Ti(C,N) based cermets and conventional Ti(C,N) based cermets are shown in Table 1 and Table 2, respectively. The nominal compositions of the cermets A are the same as that of the cermet B. Powder mixtures were milled with WC-Co balls by a

planetary ball for 24h in an ethanol bath and then dried. Green compacts were sintered at 1400°C for 1 h in vacuum (0.01-0.1 Pa).

Table 1 Nominal composition of composite Ti(C,N) based cermets

Composite Number	Average size of the granules (μm)	The granules Cermet (wt%)	Co(wt%)	WC(wt%)
A	101	77.27	22.73	0

Table 2 Nominal composition of the conventional Ti(C,N) based cermets (wt%)

Cermets	TiC	TiN	Co	Mo	C	WC
B	55.63	6.18	34.32	3.10	0.77	0

The microstructure of polished specimen was observed by scanning electron microscope (SEM) (SU8020, Japan) in back-scattered electron mode coupled with an energy-dispersive spectrometer. The fracture surface morphology was observed by SEM (JSM-6490LV, Japan and Quanta 400, American) in secondary electron mode. The Vickers hardness (HV) testing was conducted on hardness tester with an indenting load of 30 kg and a dwell time of 15 s. Transverse rupture strength testing was carried out at room temperature by a three-point bending method on an universal testing machine (Span is 30 mm, 0.5 mm/min). Fracture toughness (K_{IC}) was tested by the single edge notched beam (SENB) method on the same machine (Span is 24 mm, 0.5 mm/min). The value of fracture toughness was calculated by the following formula [18]. Specimen geometric sizes were 6 mm × 6 mm × 30 mm and 3 mm × 6 mm × 30 mm for transverse rupture strength and fracture toughness testing, respectively.

3. Results And Discussion

3.1 Microstructure

Composite structure Ti(C,N) based cermets as shown in Figs. 2a consists of cobalt enriched area, cobalt poor area and coarse granule, which is different from conventional Ti(C,N) based cermets as shown in Figs. 2b. The microstructure of cobalt enriched area are lots of Co and small amount of core-rim structure, while the microstructure of cobalt poor area has an opposite trend as shown in Fig. 3. The formation of the composite structure can be explained as follows. Firstly, the fine granules as shown with white arrow in Fig. 4 and Co mixed during milling process, the mixed powders after mill have more Co element in some area as shown in Fig. 5, and the Co and fine granules form as a cobalt enriched area at sintering stage. Secondly, the more raw granule is reduced to form fine granules with the increase of milling time, the Co and the fine granules mixed to form cobalt poor area at sintering stage. In addition, a little raw granules retain after mills.

3.2 Mechanical properties

Basic mechanical properties of composite structure Ti(C,N) based cermets are compared to conventional Ti(C,N) based cermets as shown in Table 3. It can be seen that the fracture toughness of composite structure Ti(C,N) based cermets is higher than that of conventional Ti(C,N) based cermets, while the transverse rupture strength has an opposite trend, and the hardness has no change obviously. The higher fracture toughness of Cermet A can be mainly contributed by composite structure effect. The reason why lower TRS of cermet A is explained based on Hall-Petch formula. The nominal composites of the cermets A are the same as that of the cermet B, therefore the hardness changes little.

Table 3 Mechanical properties of each cermet system

Specimen	HRA	TRS(MPa)	$K_{IC}(Mpa \cdot \sqrt{m})$
A	86.6	807.4	13.83
B	88.1	892.4	11.84

3.3 Fracture morphology

SEM images obtained from the fractured surface of the cermet are shown in Fig.6. Compared to the fracture surface of conventional Ti(C,N) based cermets, the tearing ridge and cleavage of coarse granule can be observed obviously in composite structure Ti(C,N) based cermets. The BSE/SE of the fracture surface are shown in Fig.7. It can be seen that the tearing ridge as shown in zone A in Fig.7a consists of cleavage of coreless(subordinate) and tear of binder (primary) fracture (see Fig.7b).

3.4 Toughening Mechanisms

Main toughening mechanisms of the composite structure Ti(C,N) based cermets are the tear ridge and large granule of cleavage of coarse granule induced by composite structure. The fracture process of the cermets consists of elastic loading, ductile loading and crack initiation[17,19]. In order to better understand the toughening mechanisms, the fracture surfaces of the cermets obtained by fracture toughness testing were shown in Fig.8, crack deflection, branch and bridge can be found. Crack bridge of composite structure Ti(C,N) based cermets at the starting stage of crack propagation are shown with black arrow in Fig.8. With the increase of load, the microstructure of cobalt poor area fracture, while the microstructure of cobalt enriched area occur plastic deformation, the process of load transfer misfit between the cobalt enriched area and cobalt poor area, and then crack bridge of composite structure Ti(C,N) based cermets at the starting stage of crack propagation occur. It is concluded that the load transfer between the cobalt enriched area and cobalt poor area during loading process can induce crack deflection, branch and bridge and dissipate the energy during elastic loading stage, which is advantageous to toughness.

4. Conclusions

Ti(C,N) based cermets with composite structure consists of cobalt enriched area, cobalt poor area and coarse granule. The fracture toughness of composite structure Ti(C,N) based cermets is higher than that of conventional Ti(C,N) based cermets, while the transverse rupture strength has an opposite trend, and the hardness has no change obviously. Load transfer of composite structure of Ti(C,N) based cermets may be a toughening mechanism.

Declarations

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Figures

Figure 1

SEM images showing the different size granules (101µm)

Figure 2

BSE/SEM images showing the microstructure of the cermets (a) cermet A, (b) cermet B

Figure 3

High magnification microstructure of cermet A

Figure 4

SEM images showing the morphology of the raw granule(a)the granule, (b) high magnification of location A of Fig.3a

Figure 5

Elemental mapping of green compact of cermet A with high binder zone (a) high binder zone, (b) Co element mapping, (c) high binder zone, (d) Co element mapping

Figure 6

SEM images of fracture surface of the cermets (a)cermetA,(b)cermet B

Figure 7

SEM/BSE fracture images of the cermets (a)cermet A, (b) higher magnification of zone A of Fig.7a

Figure 8

Fractured surface of the cermet A obtained by fracture toughness testing (a) the sample fractured surface of the cermet A, (b) higher magnification of zone A of Fig.8a, (c) higher magnification of zone B of Fig.8a, (d) higher magnification of zone C of Fig.8a