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The effect of Co particle structures on the mechanical properties and microstructure of TiCN-based cermets

Y. Deng [a,c], X.Q. Jiang [b], Y.H. Zhang [a], H. Chen [a], M.J. Tu [a], L. Deng [d,*], J.P. Zou [c,*]

[a] Chongqing University of Arts and Science, Chongqing 402160, PR China
[b] Southwest University, Chongqing Academy Science and Technology, Chongqing 4100715, PR China
[c] State Key Laboratory of Powder Metallurgy, Central South University, Changsha 410083, PR China
[d] Chengdu Chengliang Tool Group Co., Ltd., Chengdu 610056, PR China

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ABSTRACT

Ti(C,N) based cermets are composite materials composed of a hard phase and a binder phase structure. Cubic-structured Co particles are the best choice for the binder phase of Ti(C,N) based cermets due to their excellent toughness performance. However, the application of β-Co particles in cermets has not been reported in the literature so far. In this pioneer study, ultrafine Ti(C,N) based cermet samples were prepared by separately using Co particles of different structures as the binder phase, and the effect of the Co particle structures on the mechanical properties and microstructure of the cermets were studied: First, the Empirical Electron Theory was used to calculate the difference in the interface density (Δρ) for different crystals, and the interface combined strength between the hard phase of different structures containing Co particles were evaluated. Second, we systematically investigated the evolution of the microstructures of the two cermets during the sintering process, and evaluated the characteristics of the microstructure (which determines the properties of the cermets). Finally, the mechanical properties of the samples were tested, and the performances of the Co structures were evaluated. The results show that β-Co particles can optimize the cermet microstructure, which leads to excellent mechanical performance.

1. Introduction

Cutting tools play a significant role in the manufacturing industry [1]. Ti(C,N) based cermets are composite materials that have a hard phase and binder phase structure, low density, high red hardness, high wear resistance, and are the best choice for cutting tool materials [2]. However, their areas of application have been limited due to their lack of toughness and defects contained within their interface structures. Therefore, the toughness performance of cermets has become one of the main research directions of current cermet material studies.

As a source of cermet toughness, the binder phase is the most important. In previous reports, Ti(C,N) based cermets mostly had Ni particle as a binding phase [3–5]; however, too large Ni content leads to the formation of a brittle Ni_3M phase [4]. Ni and Co have similar mechanical properties [6], but Co is tougher as its wettability to the hard phase is better than that of Ni. Early tests confirmed that Ti(C,N) based cermets, by using Co particles as the binder phase, and adding metal elements such as Ta, V, Mo to doping, resulted in satisfactory toughness performances [7,8].

Cobalt, at room temperature, usually contains a mixture of two kinds of structures: the close-pack hexagonal α-Co (hcp) and face central cubic β-Co (fcc) with higher free energy. α-Co, with three slip systems, is weaker than β-Co, which contains 12 slip systems [9]. In addition, β-Co has unique annealing twins which can effectively block cracks, reduce grain boundary fractures and improve the ductility of the material [10]. Therefore, β-Co has better strength and toughness than α-Co.

Single phase β-Co particles have a high free energy, are not easily obtained at room temperature, and were synthesized successfully in our laboratory [10]. At present, single phase β-Co particles have not been used in preparing cermet and alloy materials, therefore, a study of β-Co powders application has important significance to optimize the microstructure of cermets and improve their toughness performance.

2. Experimental procedures

According to the previous experiments of ultrafine Ti(C,N)-based cermet, 1450 °C is the suitable maximum sintering

* Corresponding authors.
E-mail addresses: dengying.163@163.com (L. Deng), 1042551842@qq.com (J.P. Zou).

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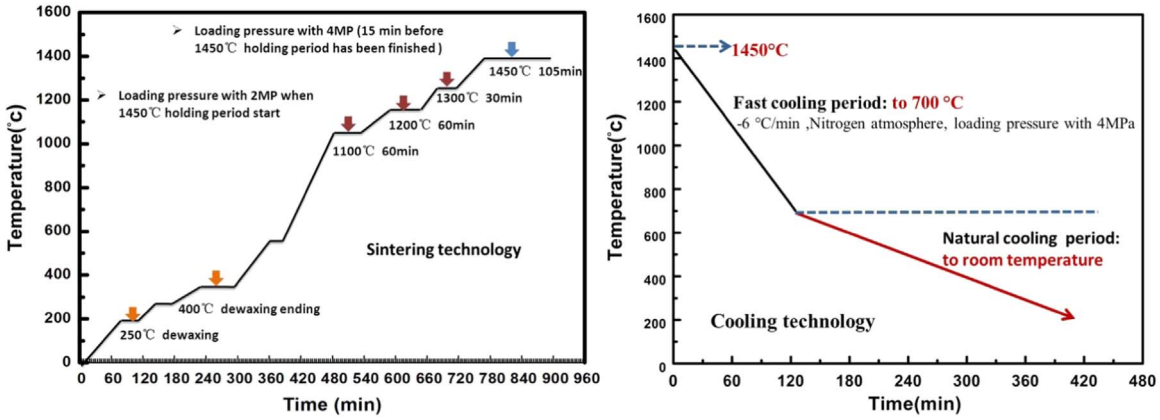

Fig. 1. Sintering and Cooling technology used for the ultrafine Ti(C,N) based cermet.

Table 1
The chemical composition of the samples.

Raw materials		Ti ($C_{0.7}N_{0.3}$)	WC	Mo_2C	TaC	α/β-Co	β-Co
Particle size		0.4 μm	0.4 μm	0.3 μm	0.3 μm	0.2 μm	0.2 μm
Chemical compositions % (mass fraction)	A	50	15	10	8	17	–
	B	50	15	10	8	–	17

temperature of samples. The technology used in our experiments, and the chemical composition of the constructed ultrafine Ti(C,N) based cermet are shown in Fig. 1 and Table 1. In this experiment, the subzero treatment method was used to relieve residual stress. Sample A was prepared using commercial Co particles which are a mixture α and β structures, while sample B was prepared with β-Co particles. Both cermets contained 17% Co, and both were made using the same process and under the same laboratory conditions.

According to Table 1, we placed the raw materials, which had a predetermined ratio and 4 wt% paraffin wax, into a mill pot, and then added 0.5–0.6 L/kg of alcohol (weight ratio of ball/powders was 5:1). The mill pot was vacuumed after being sealed, filled with nitrogen, and then subjected to high-speed milling for 72 h at a rate of 500 rpm. After milling, the powdered slurry was discharged and spray-dried, and then the powders mixture was pressed into rectangular samples and sintered by a pressure sintering furnace, as according to Fig. 1. After the sintering process was completed, the target samples were obtained.

For cermets, the physical properties are suitable when x, y values of $Ti(C_xN_y)$ solid solution is: $x+y=1$. Normally, the C/N should be controlled in the range of 7/3–3/7. Some reports show that [11], when C/N is 7/3 or 5/5, the properties of cermet will better. Meanwhile, the high N content in $Ti(C_xN_y)$ will decrease the solid solubility and wetting characteristics [12]. So in this study, we selected $Ti(C_{0.7}N_{0.3})$ powders to prepare cermets. $Ti(C_{0.7}N_{0.3})$, WC, Mo_2C, and TaC particles were prepared using carbothermal reduction technology, and β-Co particles were prepared from the reaction of low thermal salt-salt solid phase by high-energy ball milling in our laboratory. The commercial Co particles were provided by the Umicore Group, Brussels, Belgium. The purity of all the raw powders was higher than 99%. Fig. 2 shows X-ray diffraction (XRD) and transmission electron microscopy (TEM) images of the commercial Co and β-Co particles.

The sample microstructures were observed using a JEOL-6490LV scanning electron microscope with the backscattered electron (back-scattered-electron, BSE) model and JEOL-2100F transmission electron microscope (TEM), the distribution of the elements was determined by Energy Dispersive Spectrometer analysis (EDS). XRD was performed using a D/MAX2500 V (CuKα, $\lambda=0.154$ nm). Transverse rupture strength (TRS) was determined using a WE-100B-type universal material testing machine and the three-point bending test method. The Rockwell hardness (HRA) was determined using an AR-600 Rockwell hardness, and Vickers hardness (H_V) was determined using an HV-10 Vickers hardness tester. We used the Shetty fracture toughness formula to calculate the fracture toughness values [13]:

$$KIC = 0.0889(H_V \cdot P/4L)^{1/2}\left(MPa \cdot m^{1/2}\right) \quad (1)$$

where P is the applied load value (N), and L is the average value of the crack length of the indentation apex (m).

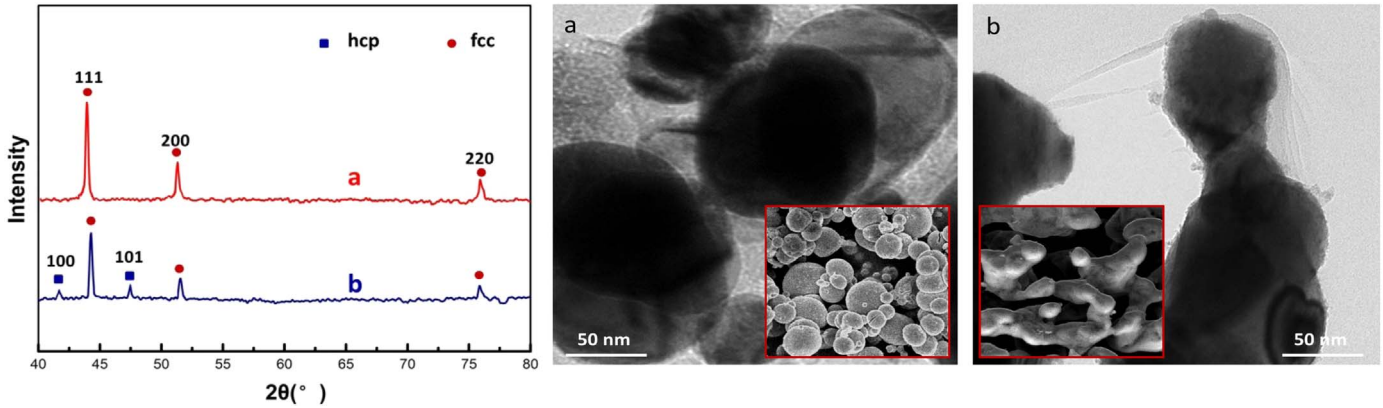

Fig. 2. XRD and TEM images of Co particles: β-Co prepared in our laboratory; b. Commercial Co powders.