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Effect of Cu on the microstructures and properties of WC-6Co cemented carbides fabricated by SPS

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ABSTRACT

The aim of this work is to study the effect of Cu on sintering temperature, densification, microstructure and mechanical properties of WC-6Co cemented carbides fabricated by spark plasma sintering (SPS). Fine grained WC powders with an average size of 1.2 μm, were investigated. Microstructures, hardness, fracture toughness and wear resistance of WC-6(Co/Cu) cemented carbides were measured and observed using SEM, mechanical property test. The results show that the sintering temperature of WC-6Co cemented carbides can be decreased obviously with Cu added; addition of Cu reduced grain size to 0.85 μm, but led to lower density. The adding amount of Cu should be controlled within a certain range, and the samples adding the appropriate proportion of Cu can obtain higher hardness and wear resistance.

1. Introduction

WC-Co cemented carbides are widely used for a variety of machining, cutting, and drilling application for their high hardness, suitable wear resistance, good fracture toughness and high temperature strength [1–3]. WC-Co cemented carbides are typically composed of a metallic ceramic and a cobalt binder. However, because the cobalt is a scarce and strategic resource, and its price is higher [4], their application has been limited. Hence, researchers have tried for many years to find new metals to replace cobalt as binder phase. Iron and nickel have been regarded as suitable substitution of cobalt in cemented carbides over a period of time [5–7]. Nevertheless, it has been found that with the same binder fraction, WC-Ni/Fe cemented carbides are inferior to their WC-Co cemented carbides counterparts in mechanical properties [8–11].

It is well known that significant improvement in the mechanical properties could be achieved in the cemented carbides with finer grain size [12–14]. Lin et al. [15] added Cu powder into WC-Co cemented carbides and proved that Cu adding has a positive effect on the hardness of WC-Co cemented carbides. On the one hand, due to the insufficient diffusion of element Cu powder and the poor wetting between WC and element Cu, the dissolution of WC hard phase and the growth of finer WC particles can be inhibited effectively in the Cu-added WC-Co cemented carbides [16,17], on the other hand, owing to the fact that Cu can decrease the sintering temperature of WC-6Co cemented carbides because of the lower melting point of Cu, which will also inhibit the grain growth of finer WC particles to a certain extent.

Spark plasma sintering (SPS), is a newly developed sintering method, which enables a powder compact to be sintered by Joule heat by high pulsed electric current through the compact. During the past few years, this kind of sintering method has been described for sintering different kind of materials [18–20], and WC-Co cemented carbides are also included. However, to our knowledge, little studies on the WC-Co composites with Cu added fabricated by SPS by other researchers have been reported in the literature.

In this paper, WC-6Co powders with various amounts of Cu added were consolidated to full density by SPS. The effects of the added amount of Cu on the microstructure, hardness, fracture toughness and wear resistance were investigated and compared with samples without Cu.

2. Experiment section

2.1. Material preparation

WC powder (≥99.5%, ~1.2 μm, shown in Fig. 1a) and Co powder (≥99.6%, ~1.4 μm shown in Fig. 1b) were used as raw materials. A small quantity (0–1.5 wt.%) of Cu powder (~1.5 μm, shown in Fig. 1c) was added into WC-6Co to replace Co. The properties of the WC-6Co composite powders are summarized in Table 1. The nominal composition of the cemented carbides is shown in Table 2. WC-6(Co/Cu) composite powders were wet ball-milled for 48 h in a three-roller grinder system using WC media of 5 mm, ethanol as the liquid medium. The ball-to-

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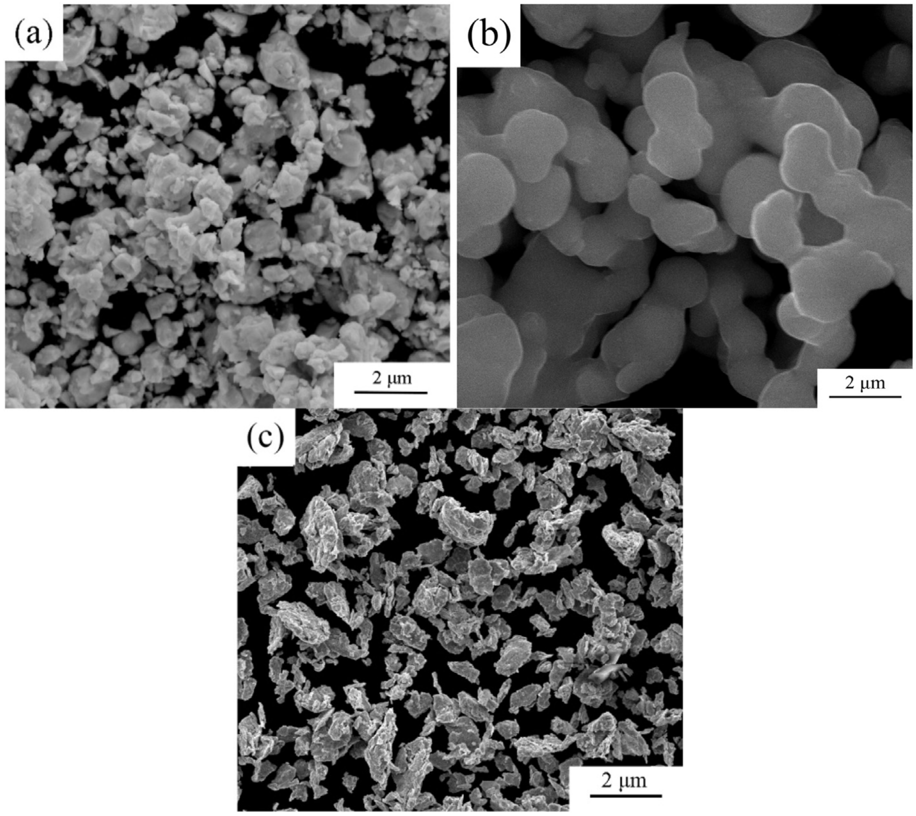

Fig. 1. SEM images of WC powder (a), Co powder (b), and Cu powder (c).

powder ratio was 8:1 and the rotation speed was 200 rpm. After wet milling it was dried at 80 °C in a vacuum oven for 4 h.

Composite powders were then sintered using an SPS apparatus. In the SPS system, powders in the graphite were heated by applied pulsed electric current. Samples with a diameter of 20 mm and a thickness of 6 mm were densified by SPS for 5 min at a temperature of 1250 °C and under a pressure of 45 Mpa in vacuum. The heating rate was maintained as 100 °C/min.

2.2. Characterization of WC-6(Co/Cu) samples

The WC-6(Co/Cu) composite powders were identified by XRD analysis. The microstructure observation of the cemented carbides was conducted using SEM. The mean WC grain sizes were measured by the linear intercept method. The density of samples was measured by Archimedes method according to ISO 1183. Hardness was measured by Vickers hardness tester under a constant load of 30 kg, the fracture toughness (K_{IC}) of samples was determined by the crack length measured from the tip of the indentation generated by a Vickers indentation load of 30 kg, and the Palmqvist indentation toughness was calculated as follows

$$K_{IC} = 0.15\sqrt{\frac{HV_{30}}{\sum l_i}}$$

where l_i is the length of crack tip from the hardness indent in millimeters. And the samples are polished with successively finer polishes (7 μm → 1 μm) after face grinding. For accuracy, the samples will be polished to near-mirror finish before testing.

The sliding wear resistance of samples was carried out using a block-on-ring tribometer (MRH-3G). The quenched 45 steel with a radius of 20 mm and a thickness of 8 mm was used as the counter material (shown in Fig. 2); the samples have the form of cuboids with 30 mm × 7 mm × 6 mm. The sliding wear tests were conducted at the load of 200 N with sliding speed of 25.12 m/min and total time of 1 h. All tests were conducted in controlled conditions (25 ± 2 °C and

Table 1
Properties of WC-6Co composite powders.

Total carbon content (%)	6.11
Free carbon content (%)	0.31
Oxygen content (%)	0.22
Scott density (g/cm^3)	1.45

Table 2
The nominal composition of alloys (mass %).

Sample no.	WC	Co	Cu
1	94	6	0
2	94	5.5	0.5
3	94	5	1
4	94	4.5	1.5

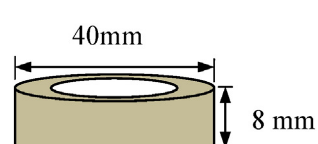

Fig. 2. Schematic diagram of the counter material used in this investigation.