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Cemented carbides with highly oriented WC grains and formation mechanisms

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ABSTRACT

A novel fabrication method combining in situ reactions and reactive sintering to prepare WC-Co cemented carbides with highly oriented WC grains and specific mechanical properties was developed. Low synthesis temperature and short holding time were used to synthesize WC-Co based composite powder through in situ reduction and carbonization reactions, and the subsequent consolidation was performed in the spark plasma sintering system. The microstructure of the resultant cemented carbide bulk material has obviously higher fraction of the WC basal planes on the cross-section which is perpendicular to the pressing direction of the sintering powder, the area percentage reaches 5 times of that on the cross-section parallel to the pressure direction. Correspondingly, the hardness, elastic modulus and wear resistance measured on the cross-section perpendicular to the pressing direction are simultaneously increased greatly with highly oriented WC grains in the microstructure.

1. Introduction

The WC-Co cemented carbides are widely used as hard materials for cutting, forming and machining tools in various industrial applications because of their high hardness and strength, good fracture toughness and excellent wear resistance [1–3]. The WC crystal has a hexagonal lattice structure with type P−6 m2 and lattice parameters of a=0.2906 nm and c=0.2837 nm [4]. The individual WC grains in the cemented carbide are single crystals having different orientation-dependent mechanical properties. The micro [5–9] and nanoindentation [3,10,11] studies on the hardness of the single WC grains showed that, the hardness values measured in different orientations of the WC grains are clearly different, the hardness in the basal planes are significantly higher than the values measured in the prismatic orientation.

It has been generally found that the fracture toughness of the cemented carbides decreases when the grain size is decreased to submicron or nanoscale [12,13]. Several strategies to obtain simultaneous enhancement in hardness and ductility have been put forward [14–20]. Examples of the successful strategies include: the bimodal grain size distribution [14,15], mixing of two or more phases with varying size scales and properties [16], utilization of nanoscale growth twins [17], enhanced nano-precipitation through severe plastic deformation [18], nanostructural hierarchy combining high dislocation density [19] and intragranular solute clusters and intergranular solute nanostructures [20]. Cemented carbides with the WC platelet microstructure have been studied in the literature [21–24]. From the previous reports, it was proposed that the plate-like WC grains could increase the hardness due to the thin thickness and offer superior toughness through a high aspect ratio. Though the single WC grains have shown special anisotropic properties, it is still very challenging to produce WC-Co cemented carbides with highly oriented WC grains which results in the macroscopic anisotropy of the mechanical properties. At present, the information concerning the preparation of the cemented carbides containing plate-like WC grains and the orientation distribution of certain WC planes are quite limited.

In the present work, we have developed a new method to fabricate the WC-Co cemented carbides with highly oriented WC grains. The microstructures, particularly the distribution of certain WC planes are characterized, and the corresponding mechanical properties were measured and analyzed.

2. Preparation process

2.1. Synthesis of composite powder

The blue tungsten oxide ($WO_{2.9}$), cobalt oxide (Co_3O_4) and carbon black powders were used as the raw materials, whose

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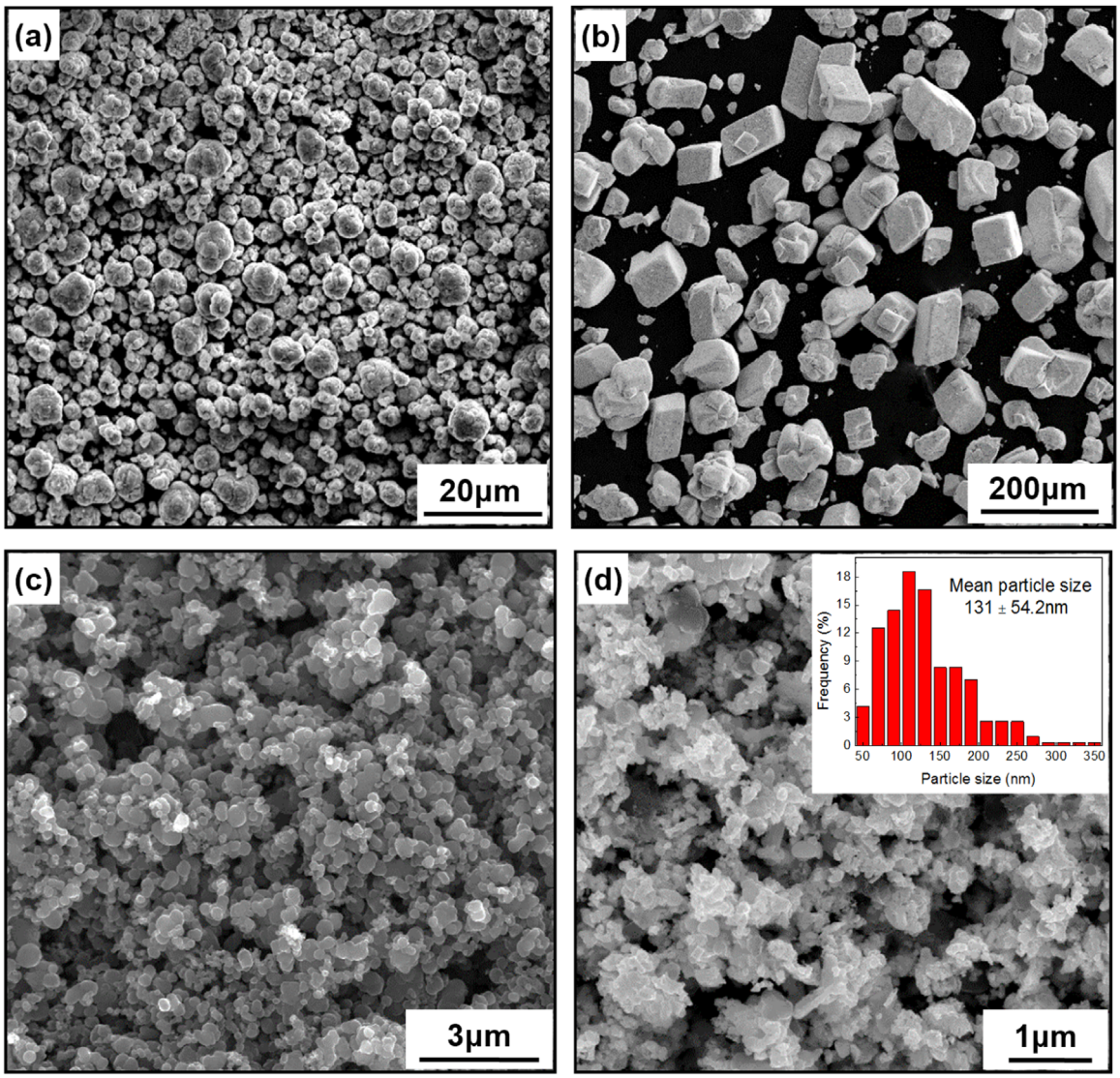

Fig. 1. Morphology of the raw materials and the as-synthesized composite powder: (*a*) Co_3O_4 micrometer-scale powder; (b) $WO_{2.9}$ μm-scale powder; (c) carbon black nanoscale powder; (d) in situ synthesized composite powder.

morphologies are shown in Fig. 1(a–c). In the present work, WC – 12 wt%Co cemented carbide bulk is the target material. The raw materials were mixed by the planet ball-milling at a speed of 180 rpm for 50 h, using pure ethanol as the liquid medium. Both the vial and the milling balls are made of cemented carbides. The as-milled powder mixture was compacted and put in a vacuum furnace for the in situ reduction and carbonization reactions. In this process, the powder mixture was heated to 500 °C at a rate of 10 °C/min and kept at this temperature for 10 min. Subsequently, it was heated to 850 °C at a rate of 10 °C/min and then kept at this temperature for 60 min. Finally, the compacted powder was cooled down to the room temperature. From the above procedures, the composite powder was synthesized, with the morphology shown in Fig. 1(d).

2.2. Sintering of cemented carbide

The as-synthesized composite powder was put into a graphite die and sintered in the spark plasma sintering (SPS) system. The composite powder was firstly heated to 880 °C with a heating rate of 100 °C/min under an external pressure of 30 MPa, and was kept at this temperature for 30 min. Then the powder was heated up to 1250 °C with a heating rate of 100 °C/min and was kept at this temperature for 10 min under a sintering pressure of 60 MPa. Finally, the sintered bulk sample was cooled down to the room temperature. The schematic for the preparation of the cemented carbide bulk material is shown in Fig. 2. Two typical directions are defined: PD denotes the direction parallel to the sintering pressure, VD denotes the direction that is vertical to the sintering pressure.

2.3. Characterization of powder and bulk materials

The constituent phases of the synthesized composite powder and the sintered bulk materials were examined by X-ray diffraction (XRD, Rigaku D/max – 3c) with CuK_α radiation. The morphology and microstructure of the powder and bulk materials were observed by the scanning electron microscopy (SEM, Nova 200 NanoSEM). The orientation analysis of the microstructure was performed by the electron back scattering diffraction (EBSD) technique using a high speed Hikiari camera incorporated in the field emission environmental scanning electron microscope. The mechanical properties were characterized by the nanoindentation (agilent, G200) method on the selected microstructures in the