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Fabrication, thermal stability and mechanical properties of novel $(W_{0.5}Al_{0.5})C_{0.8}$–Co composite prepared by mechanical alloying and hot-pressing sintering

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Abstract

A novel cemented carbides $(W_{0.5}Al_{0.5})C_{0.8}$–Co with different cobalt contents were prepared by mechanical alloying and hot-pressing technique. Hot-pressing technique as a common technique was performed to fabricate the bulk bodies of the hard alloys. The novel cemented carbides have superior mechanical properties compared to WC–Co. The density, operating cost of the novel material were much lower than WC–Co. There is almost no η-phase in the $(W_{0.5}Al_{0.5})C_{0.8}$–Co cemented carbides system although the carbon deficient get the value of 20%, and successfully got the nanostructured rounded $(W_{0.5}Al_{0.5})C_{0.8}$ particles.

Keywords: Novel cemented carbide; $(W_{0.5}Al_{0.5})C_{0.8}$–Co; Hot-pressing sintering; Mechanical properties

1. Introduction

Tungsten carbide–cobalt composite hard materials (WC–Co) are widely used for a variety of machining, cutting, drilling, and other applications. However, pure WC has many inherent shortcomings, such as room-temperature brittleness, high density and high operating costs. Therefore, in recent years, many studies have been focused on how to improve the physical and chemical properties of WC, as well as to reduce its high operating cost. In this sense, one first approach is partial substitution of WC by other nonoxide compounds, such as, Ti(C, N), MoC, Cr_2C_3, and VC [1–3], which results in a lower density while maintaining the high hardness and wear resistance. The second alternative is to modify the binder component, such as, Co, Fe, Ni, etc. to improve the corrosion resistance and/or mechanical strength.[4–7] Nowadays, some researcher begin to study dissolving metals into WC system, such as molybdenum.[8] Aluminum is more ductile and lighter than tungsten, so dissolving aluminum into the lattice of WC to form a solid solution is expected to reduce its high density. However, to date no work has been done on the solid solution of aluminum in WC, because of the very little mutual solid solubility (<13 at.%) and the very large difference between the melting points of tungsten (3683 K) and aluminum (933 K), it is very difficult to prepare Al–W–C ternary system by melting or other equilibrium methods. In addition, aluminum is inexpensive compared to tungsten, thus operating cost of ternary carbide Al–W–C are surely less than that of WC. But non-equilibrium processes [9], such as sputter-deposition[10–12] and mechanical alloying (MA) [13–16] technique can solve this problem.

In our previous paper [16,17], we reported that $(W_{1-x}Al_x)C_y$ (x = 0.1–0.86, y = 0.5–1.0) powder could be synthesized by mechanical alloying and solid state reaction. Because $(W_{1-x}Al_x)C_y$ (x = 0.1–0.86, y = 0.5–1.0) has the same hexagonal structure as WC [17], so we choose cobalt as the binder which is a good binder for WC sintering. One aim of this work is to fabricate the $W_{0.5}Al_{0.5}C_{0.8}$–Co alloy bulk bodies. Hot-pressing (HP) as a common technique is a suitable method to facilitate the sintering of $(W_{0.5}Al_{0.5})C_{0.8}$–Co hard alloy. Additionally, the mechanical

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properties and the microstructures of $(W_{0.5}Al_{0.5})C_{0.8}$–Co bulk bodies were also discussed.

2. Experimental details

Elemental powders of tungsten (0.98 μm, 99.8% purity), aluminium (3.59 μm, 99.5% purity), cobalt (4.5 μm, 99.7%) and carbon (<30 μm, 99% purity) were used as raw materials. The $(W_{0.5}Al_{0.5}C_{0.8}$ powders were prepared by mechanical alloying and solid state reaction.[16,17] The $(W_{0.5}Al_{0.5})C_{0.8}$–Co powders with different cobalt contents (8.5, 11.7, 14.9 vol%; 8.7, 11.9, 15.2 wt%) were used for this study. All the raw materials of $(W_{0.5}Al_{0.5})C_{0.8}$–Co powders had carbon deficient, because it is reported that deficient in carbides has a profound influence on the physical properties of materials.[18,19]

The $(W_{0.5}Al_{0.5})C_{0.8}$ powders and cobalt powders were enclosed in assembling graphite dice under argon atmosphere, and then were sintered in an inductive hot-pressing vacuum furnace with the following cycle: (a) heated from room temperature to sintering temperature (1350–1450 °C) with a heating rate of about 150 °C min^{-1}; (b) kept the sintering temperature for the desired duration (15–20 min); (c) cooled down from the sintering temperature to 600 °C at about 400 °C min^{-1}, and then furnace cooled from 600 °C to room temperature. The pressure in the die was kept as 40 MPa and the vacuum degree was 80 Pa in the furnace. After hot-pressing sintering, the bulk specimens were grinded and polished.

The specimens were investigated by X-ray diffraction (XRD), environment scanning electron microscopy (ESEM). XRD analyses were performed on a Rigaku D/max-IIB X-ray diffractometer with Cu Kα radiation (λ = 1.5406 Å), operating at 40 kV and 20 mA. The scanning speed was 4° min^{-1}. The microstructures of fracture surfaces were examined using environment scanning electron microscope (ESEM, Philips, XL30). The densities of the sintered specimens were determined by the Archimedes water immersion method. Microhardnesses of the hard alloy bulk bodies were measured by the Vickers micro-hardness tester (FM-700, Japan) with a load of 300 gf and dwell time of 15 s. The transverse strengths were measured by three-point bending test. Bending tests were performed on an Instron model 1125 test machine at a crosshead speed of 2 mm min^{-1}; the gap length of bending test was 30 mm, bending specimens (4 mm × 3 mm × 40 mm) were cut from the hot-pressed alloy bulk bodies. All the reported data were the average of at least three test results.

3. Results and discussion

3.1. X-ray diffractometry and thermal stability

Fig. 1 shows XRD pattern of $(W_{0.5}Al_{0.5})C_{0.8}$–11.7 vol% Co bulk alloy obtained at 1450 °C and 40 MPa for 20 min. The peaks of $(W_{0.5}Al_{0.5})C_{0.8}$ phase are still stable and clear. That suggested that the novel solid solution $(W_{0.5}Al_{0.5})C_{0.8}$ has excellent thermal stability even up to 1450 °C during hot-pressing sintering by reason of finding no peaks of Al and/or aluminous compounds in XRD pattern. Only cobalt peaks were found in Fig. 1, and no other compounds of cobalt were formed during the sintering process. From Fig. 1 it was also concluded that the $(W_{0.5}Al_{0.5})C_{0.8}$–11.7 vol% Co hard alloy was not obviously contaminated by oxygen and/or other elements during ball milling and hot-pressing.

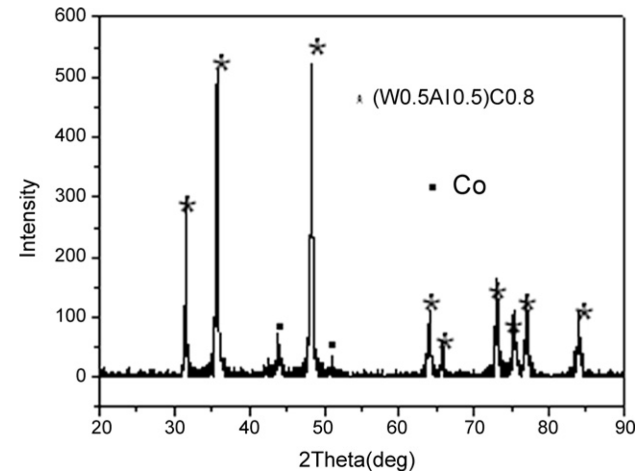

Fig. 1. The XRD pattern of $(W_{0.5}Al_{0.5})C_{0.8}$–11.7 vol% Co bulk alloy obtained at 1400 °C and 40 MPa for 20 min.

3.2. Microstructures and mechanical properties

Table 1 shows the experimental density, relative density of $(W_{0.5}Al_{0.5})C_{0.8}$–Co bulk specimens with different cobalt contents. The theoretical density of $(W_{0.5}Al_{0.5})C_{0.8}$ is only 8.665 g cm^{-3}, it is much lower than the normal hard material WC (15.63 g cm^{-3}). The measured $(W_{0.5}Al_{0.5})C_{0.8}$ density is more consistent with a substitutional solid solution than a interstitial solid solution and also consistent with the XRD result that the $(W_{0.5}Al_{0.5})C_{0.8}$ compound still has the WC-type after the HP-sintering. The relative density of the specimens reached over 98%. It indicates that cobalt is a good binder for

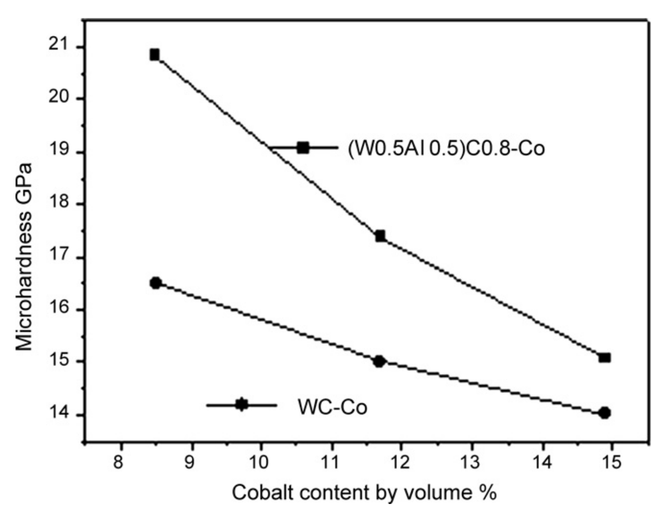

Fig. 2. The microhardnesses of the $(W_{0.5}Al_{0.5})C_{0.8}$–Co bulk specimens sintered with different cobalt contents compared with WC–Co hard alloy.

Table 1
The experimental density, relative density and the electronic conductivity of $(W_{0.5}Al_{0.5})C_{0.8}$–Co bulk specimens with different cobalt contents

Specimen specification	Theoretical density (g cm^{-3})	Experimental density (g cm^{-3})	Relative density (%)
$(W_{0.5}Al_{0.5})C_{0.8}$–8.5 vol% Co	8.682	8.552	98.5
$(W_{0.5}Al_{0.5})C_{0.8}$–11.7 vol% Co	8.688	8.566	98.6
$(W_{0.5}Al_{0.5})C_{0.8}$–14.9 vol% Co	8.694	8.607	99.0