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Fabrication of WC–8 wt.%Co hard materials by two rapid sintering processes

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Abstract

Two methods, high-frequency induction-heated sintering (HFIHS) and pulsed current activated sintering (PCAS), were utilized to consolidate WC–8 wt.%Co hard materials. The demonstrated advantages of these processes are rapid densification to near theoretical density in a relatively short time and without significant change in grain size. The effect of initial particle size of WC powder on the sintering behavior and mechanical properties were investigated. The hardness, fracture toughness and the relative density of the WC–8Co composites consolidated by HFIHS and PCAS were investigated.

Keywords: Rapid sintering; WC–Co composites; Microstructures; Hardness; Fracture toughness

1. Introduction

Tungsten carbide–cobalt hard materials (WC–Co) are widely used for a variety of machining, cutting, drilling, and other applications. Morphologically, they consist of a high volume fraction of the ''hard'' hexagonal WC phase embedded within a soft and tough Co binder phase [1]. WC–Co hard materials can be densified by liquid phase sintering and the mechanical properties of these materials depend on their composition, and microstructure (especially on the grain size of the carbide phase [2]). Thus, the control of grain growth of the carbide phase during liquid phase sintering is an important objective. In general, decreasing WC particle size increases such mechanical properties as hardness, wear resistance, and transverse rupture strength of the composites [3]. Increasing the volume fraction of Co increases the fracture toughness at the expense of hardness and wear resistance [4,5]. WC–cobalt and other similar cemented carbides are used as cutting tools because of a combination of desirable high hardness and high fracture toughness because of the respective contributions of the carbide and metallic phases. Densification of WC–Co has been accomplished by conventional sintering [6,7], by a spark plasma sintering (SPS) or plasma pressure compaction [8,9], and by dynamic shock compression [10]. The primary concern in all these methods is in the grain size of the WC component, because it has been established that significant improvements in the mechanical properties can be attained with finer grain size [11,12]. So, controlling grain growth during sintering is one of the keys to the commercial success of nanostructured WC–Co composites. In this regard, the pulsed current activated sintering method has been shown to be effective in achieving this goal [13,14]. And recently the high-frequency induction-heated sintering (HFIHS) technique has been shown to be effective in the sintering of nanostructured materials in very short times [15–17].

In this work, we report results on the sintering of WC–8 wt.%Co by two rapid sintering processes, pulsed current activated sintering (PCAS) and the high-frequency induction-heated sintering (HFIHS) methods which combine

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pulsed current or induction current with high-pressure application. The goal of this work is to produce dense, ultra-fine WC–8 wt.%Co hard materials in very short sintering times (<2 min). We also investigated the effect of initial particle size of tungsten carbide on the sintering behavior and mechanical properties of WC hard materials.

2. Experimental procedure

To investigate the effect of initial particle size of tungsten carbide on the sintering behavior and mechanical properties of WC hard materials, powders with five grain sizes of tungsten carbide were used: 0.5, 1.3, 2.4, 4.3 and 6.5 μm, measured by FSSS (fisher sub sieve sizer). Powder of 99.8% pure hexagonal close-packed (hcp) cobalt (<2 μm) was used as a binder material. All powders were milled in a Universal Mill with a ball-to-powder weight ratio of 6:1. Following milling, the powders were then placed in a graphite die and then introduced into the high-frequency induction-heated sintering system or the pulsed current activated sintering system made by Eltek Co. in Republic of Korea. The PCAS apparatus includes an 18 V, 2800 A DC powder supply and a 50 kN uniaxial press. In both methods, the system was first evacuated and a uniaxial pressure of 60 MPa was applied. In the case of the HFIHS method, an induced current was activated (frequency of about 50 kHz, 90% output of total power capacity, 15 kW). In the PCAS method a DC current of 2800 A was applied. In both cases, the conditions were maintained until the densification rate was negligible, as indicated by the observed shrinkage of the sample. Sample shrinkage is measured in real time by a linear gauge measuring the vertical displacement for both methods. In both cases, temperatures were measured by a pyrometer focused on the surface of the graphite die. At the end of the process, the current was turned off and the sample was allowed to cool to room temperature. The entire process of densification using the HFIHS or PCAS technique consists of four major control stages. These are chamber evacuation, pressure application, power application, and cool down. In both cases the process was carried out under a vacuum of 4×10^{-2} torr.

The relative densities of the sintered samples were measured by the Archimedes method. Microstructural information was obtained from product samples, which had been polished and etched, using a Murakami's reagent for 1–2 min at room temperature. Compositional and microstructural analyses of the products were made through X-ray diffraction (XRD) and scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS). The carbide grain size, d_{wc} was obtained by the linear intercept method [18,19]. Vickers hardness measurements were made on polished sections of the WC–Co composites using a 30 kg_f load and 15 s dwell time. Fracture toughness was calculated from cracks produced in indentations under large loads. The length of these cracks permits an estimation of the fracture toughness of the material by means of Anstis expression [20].

3. Results and discussion

The variations of shrinkage displacement and temperature with heating time for various tungsten carbide sizes during the sintering of WC–8 wt.%Co by HFIHS and PCAS under 60 MPa pressure and 90% output of total power capacity or pulsed DC current of 2800 A are shown in Fig. 1(a) and (b), respectively. In both cases, the initially the samples exhibit an increase in volume due to thermal expansion. As the currents are applied, the shrinkage displacement decreased with temperature up to about

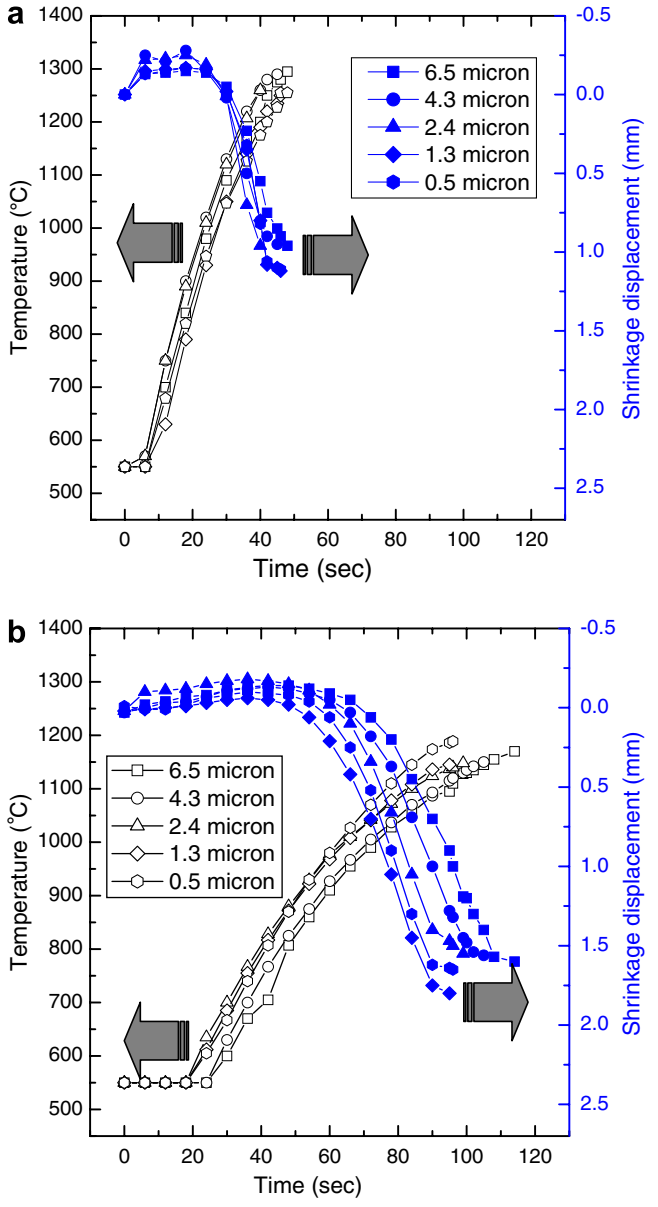

Fig. 1. Variations of temperature and shrinkage displacement with heating time for various initial particle sizes during the sintering of WC–Co hard materials (a) HFIHS and (b) PCAS.