Simultaneous Synthesis and Densification of WC-$x$vol.%Co Hard Materials by High-Frequency Induction Heated Combustion

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1. Introduction

Tungsten carbide-cobalt hard materials are widely used for a variety of machining, cutting, drilling, and other applications. In all of the reported studies the preparation of dense, bulk WC or WC-Co involves two steps; the synthesis of the carbide phase and the subsequent consolidation with or without the metallic additive. Recently, a new approach has been developed in which synthesis and densification can be effected simultaneously. This new process, referred to as the high-frequency induction heated combustion synthesis (HFIHCS), has been successfully used to synthesize and densify, in one step, some materials in a relatively short period of time (several minutes). In this paper we report on the synthesis of WC composite and dense WC-$x$vol.% Co ($5 \leq x \leq 20$) hard materials using elemental reactants by the high-frequency, pressure assisted method and evaluate their mechanical properties.

2. Experimental procedure

Powders of 99.9% pure tungsten (<0.6μm) and 99.9% pure activated (amorphous) carbon (<20μm), and 99.8% pure hexagonal close-packed (hcp) cobalt(<44μm) were used as a starting materials. The tungsten and carbon powders were weighed in equiatomic ratios and the Co powder was added in amounts to give concentrations $x$vol.% in the final product. The tungsten and carbon ratio were varied from 1:1 to 1:1.3 to investigate the effect of carbon ration on the microstructure, and mechanical properties in WC-$x$vol.%Co system. All powders were milled in alcohol in a Universal Mill. The mixed powders were placed in a graphite die and then introduced into the high-frequency induction heated combustion system. The system was first evacuated and a uniaxial pressure of 60 MPa was applied. An induced current was then activated and maintained until densification was observed, as indicating by the observed shrinkage of the sample. At the end of the process, the current was turned off and the sample cooled to room temperature at a rate of about 600 ℃/min.

The relative density of the synthesized sample was measured by the Archimedes method. Compositional and microstructural analyses of the products were made through X-ray diffraction (XRD), scanning electron microscopy (SEM) with energy dispersive spectroscopy (EDS) and field-emission scanning electron microscopy (FE-SEM). Vickers hardness and fracture toughness were measured by performing indentations at a load of 30 kg and a dwell time of 15 s. The structure parameters, i.e. the carbide grain size and the mean free path of the binder phase are obtained by the linear intercept method.

3. Summary

Using a developed high-frequency induction heated combustion method, the simultaneous synthesis and densification of WC-$x$vol.%Co($0 \leq x \leq 20$) hard materials was accomplished using elemental powders of W, C and Co. A complete synthesis and densification of the materials was achieved in one step within a duration of 1min. The final relative densities of the composite were over 98.5% for all cases, under the applied

pressure of 60 MPa and the induced current. The hardness of the composites decreases and the fracture toughness increases with increasing cobalt content. As the carbon to tungsten ration increases, the hardness increases, but the fracture toughness decreases. The maximum values for the fracture toughness and hardness are 15.1 MPa · $m^{1/2}$(at 20vol.%Co, W:C=1:1), and 1928 kg/mm^2(at 5vol.%Co, W:C=1:1.3), respectively. Therefore we concluded that the HFIHCS method, which can produce WC-*x*vol.%Co within 1 minute in one step, is superior to conventional ones.

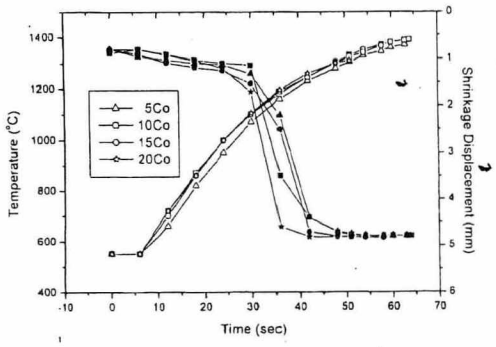

Fig. 1. Variations of temperature and shrinkage displacement with heating-time during HFIHCS

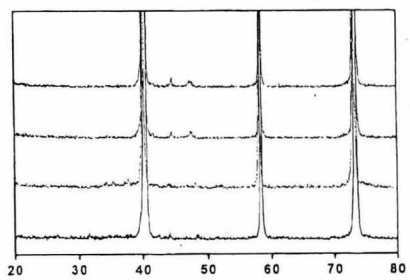

Fig. 2. XRD patterns of the W+C+*x*vol.%Co system heated to 980℃(W:C=1:1.3) (a)x=5 (b)x =10, (c)x=15 (d) x=20.

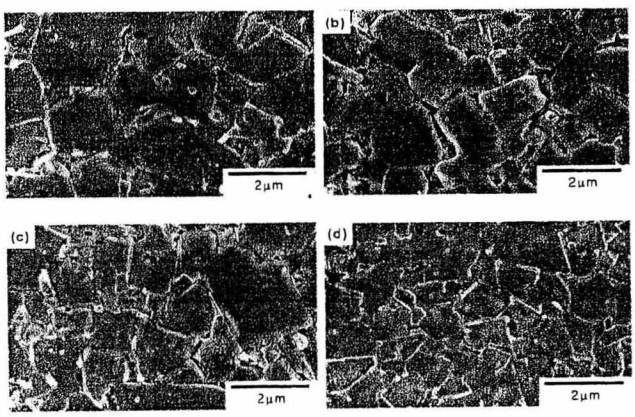

Fig. 3. FE-SEM images of the W+C+*x*vol.% system after combustion synthesis(W:C=1:1.3) (a) x = 5, (b) x = 10, (c) x = 15, (d) x = 20.

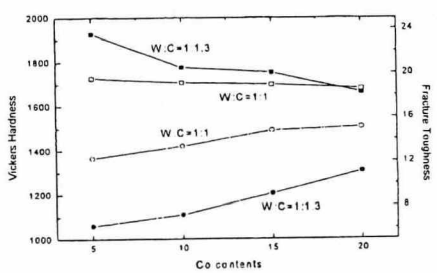

Fig. 4. Variation of fracture toughness and hardness in WC-*x*vol.% Co composites with Co content.