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Electric-discharge compaction of graded WC–Co composites

Xiyong Wu, Jingdong Guo *

Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, China

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Abstract

Electric-discharge compaction (EDC) of nanocrystalline and coarse WC–Co powders to produce graded WC–Co cemented carbides was conducted in this work. Coarse and ultrafine graded WC–Co cemented carbides which offer high hardness and excellent fracture toughness was produced simply by EDC; the microstructure and mechanical properties of graded materials are also investigated. As a consequence of the short holding time in EDC, cobalt migration which always occurred in graded WC–Co during liquid phase sintering process due to the difference in WC grain sizes was kinetically constrained in the present study. It may offer a novel simple processing route to fabricate graded materials.
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Keywords: WC–Co; Graded materials; Liquid phase sintering (LPS); Electric-discharge compaction (EDC)

1. Introduction

Graded WC–Co hard metals have wide potential application in the drilling and cutting industry due to the microstructural gradient (gradient in WC grain size or cobalt content) which offers advantages in terms of the fracture toughness and wear resistance combinations in comparison to conventional homogeneous WC–Co cemented carbides. Homogeneous cemented carbides are always fabricated by liquid phase sintering (LPS). However, in LPS of graded hard metals cobalt migration takes place and the desired microstructural gradient is eliminated, which make the processing of graded cemented carbides difficult [1–3]. Accordingly, some other methods are developed, such as hot isostatic pressing (HIP), spark plasma sintering (SPS), microwave sintering, electroplating, chemical vapor deposition (CVD), tape casting and so on [4–8]. But those alternative processes have limitations, such as high cost and complicated procedure. LPS is still the only economic process for manufacturing conventional WC–Co cemented carbides as well as graded WC–Co hard metals, and the challenge is to maintain the cobalt gradation in LPS [9,10]. The driving force for cobalt migration in LPS is the difference in capillary force between two layers, which is attributed to the difference in WC grain size or cobalt content between them [10]. Then great importance should be attached to kinetically inhibiting cobalt migration to produce graded WC–Co cemented carbides. If the heating and cooling rate are high enough to keep the holding time as short as possible, the cobalt migration may be restricted.

In electric-discharge compaction (EDC), an insulating tube is filled with the powders to be pressed, consolidation of powders under external pressure is achieved by using a high-voltage and high-density current pulse treatment. Therefore, the ultra-short discharge time may restrict cobalt migration. Although this method has been used to compact metallic powders, intermetallic powders and cemented carbides [11–15], it is seldom applied to fabrication of graded materials. We think that the EDC process may be a promising method.

In the present work, nanocrystalline and coarse WC–Co powders are simply consolidated by EDC to produce graded WC–Co cemented carbides. The microstructure

* Corresponding author. Tel.: +86 24 23971491; fax: +86 24 23971215.
E-mail address: jdguo@imr.ac.cn (J. Guo).

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and mechanical properties of graded cemented carbides are also investigated.

2. Experimental procedure

The initial nanocrystalline WC–10 wt.% Co powders were prepared via the spray conversion process (SCP). The WC grain size is about 50 nm measured by XRD, and the particle size is about 200 nm investigated by a scanning electron microscope, as shown in Fig. 1a. The grain size of coarse WC–11 wt.% Co powders was about 3 μm, as shown in Fig. 1b. Two layers of loose powders without additives were placed into the die with a diameter of 5.5 mm under external pressure up to 300 MPa. The schematic of the EDC system has been shown previously [14,15]. The powders under pressure were heated by a discharge from a 360 μF capacitor with different current densities, varying from 1.5 to 2.4 kA mm^{-2}. The waveform of EDC was detected in situ by a Rogowski coil and a digital storage oscilloscope (TDS3012, Tektronix Inc., Beaverton, OR), a typical waveform in EDC is shown in Fig. 2. The sintered bi-layer samples were ground and polished to 1 μm finish for mechanical evaluation and microstructural examinations. Micro-indentation experiments with a load of 1 kg were performed by a Vickers tip. The micro-hardness value was taken as

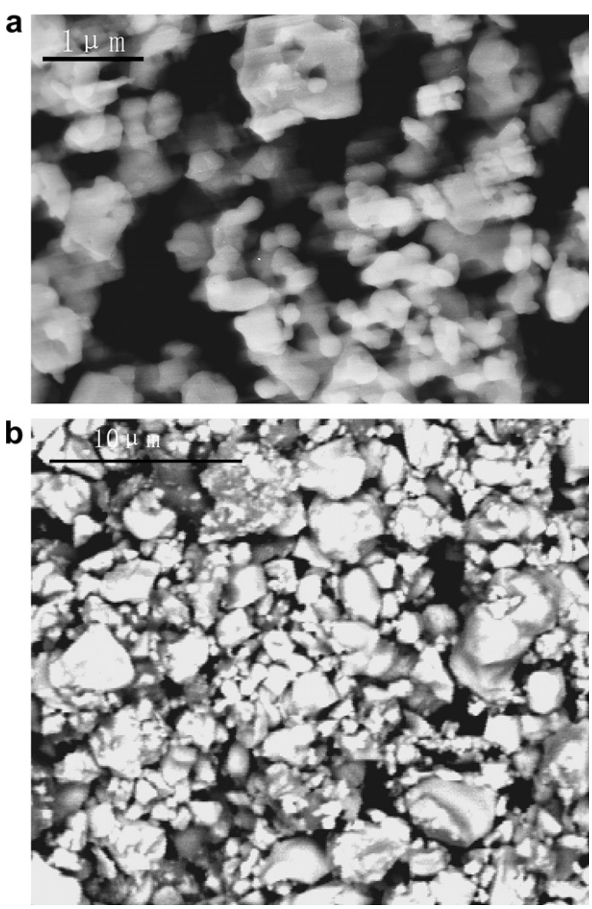

Fig. 1. (a) Microstructure of nanocrystalline WC–Co powders and (b) microstructure of coarse WC–Co powders.

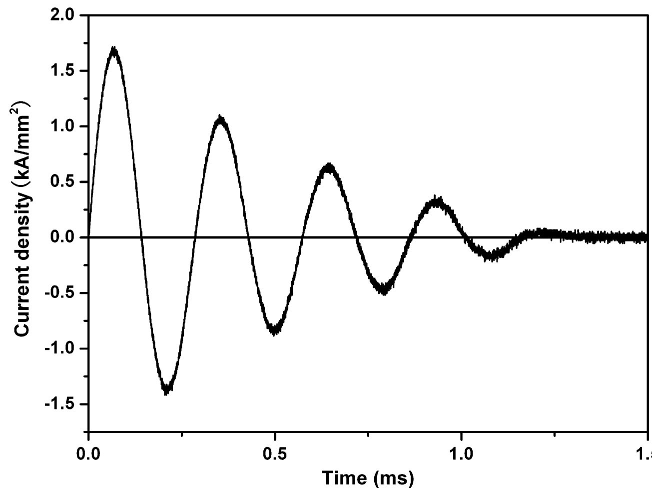

Fig. 2. Typical waveform in EDC of graded WC–Co composites.

$$\mathrm{HV} = \frac{2P\sin(136^\circ/2)}{L^2}, \tag{1}$$

where P was the load, and L the average length of the diagonals of the indentation.

Fracture toughness was calculated by Vickers indentations with a load of 30 kg, which was derived from following equation [14,16–18]:

$$K_{\mathrm{IC}} = 0.016(E/H)^{1/2}P/L^{3/2}, \tag{2}$$

where K_{IC}, E, H, P, and L are fracture toughness, Young's modulus, hardness, indentation load and crack length from the center of indentation, respectively. The cobalt distribution in the WC–Co bi-layers was measured using energy dispersive spectroscopy (EDS) in scanning electron microscope. Each data point on the cobalt distribution profile was generated by averaging EDS scans over an area of 60 μm × 40 μm. For the lower analysis accuracy of carbon in EDS, the cobalt concentration reported in this work was only quantified from cobalt and tungsten. The characteristics of powders and graded WC–Co cemented carbides after EDC were examined by X-ray diffractometry with Cu Kα radiation.

3. Results and discussion

3.1. Microstructure investigation

Fig. 3 shows typical XRD patterns of powders and graded WC–Co cemented carbides after EDC. The nanocrystlline WC–Co powders are composed of FCC cobalt, WC and Co_3W_3C. The coarse WC–Co powders consist of only FCC cobalt and WC. In graded WC–Co cemented carbides, only FCC cobalt and WC are found, η phase was not observed. The disappearance of Co_3W_3C phase in the compacted sample is attributed to carbonization of

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