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Sintering behavior and mechanical properties of WC–10Co, WC–10Ni and WC–10Fe hard materials produced by high-frequency induction heated sintering

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Abstract

The comparison of sintering behavior and mechanical properties of WC–10 wt.%Co, WC–10 wt.%Ni and WC–10 wt.%Fe hard materials produced by high-frequency induction heated sintering (HFIHS) method was accomplished using ultra-fine powder of WC and binders (Co, Ni, Fe). The advantage of this process allows very quick densification to near theoretical density and prohibition of grain growth in nano-structured materials. Highly dense WC–10Co, WC–10Ni and WC–10Fe with a relative density of up to 99% could be obtained with simultaneous application of 60 MPa pressure and induced current within 1 min without significant change in grain size. The hardness and fracture toughness of the dense WC–10Co, WC–10Ni and WC–10Fe composites produced by HFIHS were investigated.

Keywords: Rapid sintering; High-frequency induction heated sintering; Hard materials; Fracture toughness

1. Introduction

Tungsten carbide hard materials 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 or Ni binder phase [1]. WC–Co and WC–Ni 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. However, cobalt is not economically attractive and the resulted cemented carbide has a low corrosion resistance [3]. This has prompted considerable effort to find a satisfactory alternative binder [4–6]. The focus on Ni as a binder has been motivated by results showing a higher corrosion and oxidation resistance [3]. However, the mechanical properties (hardness and toughness) for WC–Ni are relatively lower than those of WC–Co [6]. The corrosion and oxidation resistance of Fe binder is inferior to that of Co and Ni but is cheaper than Co and Fe.

In general, decreasing WC particle size increases such mechanical properties as hardness, wear resistance and transverse rupture strength of the composites [7]. Increasing the volume fraction of binder increases the fracture toughness at the expense of hardness and wear resistance [8,9]. 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 [10,11], by sintering in a spark plasma sintering (SPS) apparatus or plasma pressure compaction apparatus [12,13] and by sintering by dynamic shock compression [14]. The primary concern in all these methods is in the grain size of the WC component,

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because it has been established that significant improvements in the mechanical properties can be attained with finer grain size [15,16].

Nanocrystalline materials have received much attention as advanced engineering materials with improved physical and mechanical properties [11,12]. As nano-materials possess high strength, high hardness and excellent ductility and toughness, undoubtedly, more attention has been paid for the application of nano-materials [17,18]. In recent days, nanocrystalline WC–Co cemented carbides have been developed by the thermochemical and thermomechanical process named as the spray conversion process (SCP) [19]. The advantage of SCP is that the WC particle size can be reduced below 100 nm. However, the WC grain size in sintered WC–Co cemented carbides becomes much larger than that in pre-sintered powders due to a fast diffusion through liquid phase during conventional liquid phase sintering process. Therefore, even though the initial WC size is less than 100 nm, the grain size increases rapidly up to 500 nm or larger during the conventional liquid phase sintering [20]. Even though the grain growth inhibitors were added in WC–Co, the WC grains size increases up to 300 nm during the liquid phase sintering process [2,21,22]. So, controlling grain growth during sintering is one of the keys to the commercial success of nano-structured WC, WC–Co and WC–Ni composites. And recently the high-frequency induction heated sintering (HFIHS) technique has been shown to be effective in the sintering of nano-structured materials in very short times (within 1 min) [23,24].

In this work, we report results on the sintering of WC–10 wt.%Co, WC–10 wt.%Ni and WC–10 wt.%Fe by a rapid sintering process, HFIHS, a method which combines induced current with high-pressure application. The goal of this work is to produce dense, ultra-fine WC–10 wt.%Co, WC–10 wt.%Ni and WC–10 wt.%Fe hard materials in very short sintering times (<1 min). And we investigated the effect of binder on the sintering behavior and mechanical properties of WC hard materials.

2. Experimental procedure

The tungsten carbide powder used in this research was supplied by TaeguTec Ltd. (Taegu, Korea). The powder had a grain size of 0.4 μm measured by FSSS and was reported to be 99.5% pure. Cobalt (∼3 μm, 99.7% pure, Sigma–Aldrich), nickel (<2 μm, 99.8% pure, Sigma–Aldrich) and iron (<10 μm, 99.9% pure, Alfa) were used as binder materials. Three different compositions were investigated: WC–10 wt.%Co, WC–10 wt.%Ni and WC–10 wt.%Fe. Scanning electron microscope (SEM) images of the starting powders are shown in Fig. 1. Three different compositions with WC–10 wt.%Co, WC–10 wt.%Ni and WC–10 wt.%Fe were investigated. As can be seen from Fig. 1, all the powder grains are generally round and WC exhibit some agglomeration. Tungsten carbide and binder powders (Co, Ni, Fe) were milled in a Universal Mill with a ball-to-powder weight ratio of 6:1. Milling was done in polyethylene bottles using zirconia balls and was performed at a horizontal rotation velocity of 300 rpm for 24 h.

The mixed powders were placed in a graphite die (outside diameter, 45 mm; inside diameter, 20 mm; height, 40 mm) and then introduced into the high-frequency induction heated sintering system made by Eltek Co. in Republic of Korea.

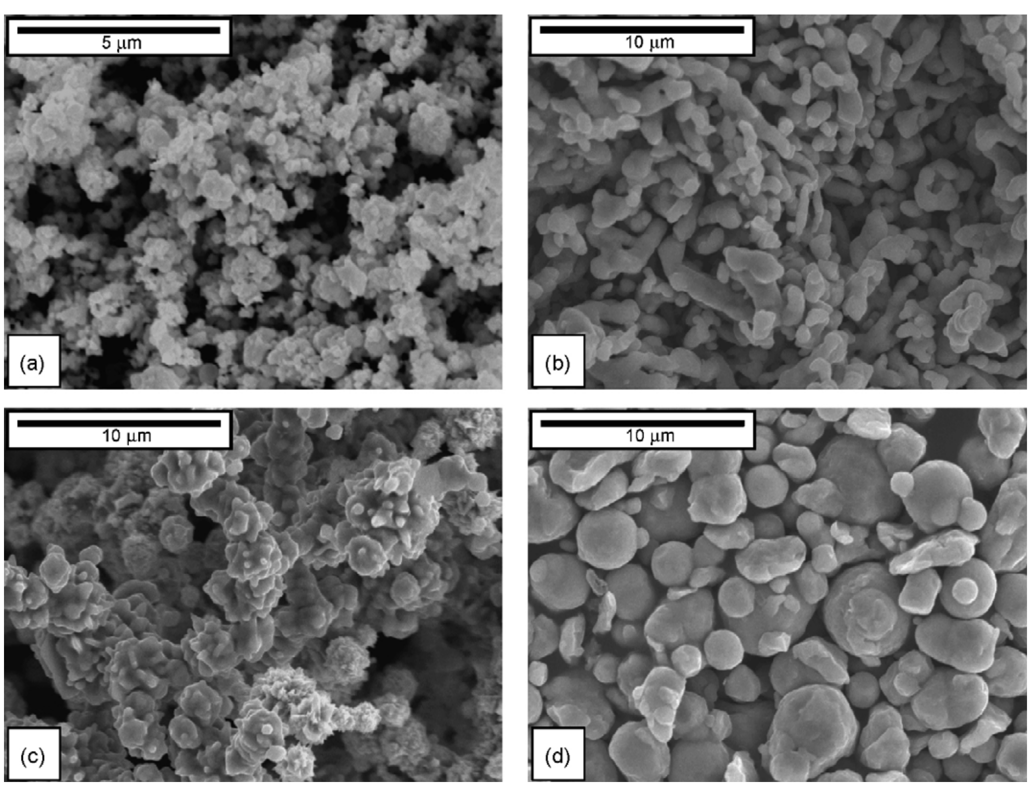

Fig. 1. Scanning electron microscope images of raw materials: (a) tungsten carbide powder, (b) cobalt powder, (c) nickel powder and (d) iron powder.