

Effects of WC particle size on sintering behavior and mechanical properties of coarse grained WC–8Co cemented carbides fabricated by unmilled composite powders

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Abstract

Three sets of coarse grained WC–8Co cemented carbides were fabricated by unmilled composite powders using three different-sized raw WC powders. Effects of WC particle sizes on shrinkage behavior and microstructure evolution of coarse grained WC–8Co cemented carbides during a sintering process were investigated by dilatometer and a scanning electron microscope. Furthermore, the mechanical properties and their wear properties were evaluated for the forthcoming potential applications. It was found that during the sintering process the densification and grain growth of the WC–8Co cemented carbides with finer carbide particles as raw materials started earlier than coarser powders regardless of the effects of lattice distortion. With increasing initial WC particle size from 2.01 μm to 4.37 μm , mean WC grain size of coarse grained WC–8Co cemented carbides rose from 3.19 μm to 6.03 μm , the Co mean free path rose from 0.67 μm to 1.24 μm . At the same time, with the increasing grain size, the transgranular fracture through the carbide phase and binder phase increased, while intergranular fracture decreased, correlating to that the transverse rupture strength and fracture toughness increased from 2264 MPa, 19.13 MPa $\text{m}^{1/2}$ to 2769 MPa and 25.24 MPa $\text{m}^{1/2}$, respectively. The dominant wear mechanism in sliding wear test for the WC–8Co cemented carbides transferred from extraction of small WC grains to cracking and fragmentation of the large carbide grains with the increasing grain size.

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1. Introduction

WC–Co cemented carbides are widely used as tool materials due to their unique combination of high hardness from hard phase WC and toughness from binder Co [1,2]. In recent years, coarse grained WC–Co cemented carbides (generally the mean WC grain size between 2.5 μm and 6 μm) with 5–10 wt% Co have received increasing attentions because of their superior thermal conductivity, toughness and shock resistance, which are extremely suitable for applying in tunnel boring, gas and oil drilling, mining and construction [3,4].

One of the most important factors determining the properties of coarse grained WC–Co cemented carbides is the size of WC grains [5]. However, it remains a critical challenge to control the grain growth of coarse grained WC–Co cemented carbides in the sintering process due to its higher sintering temperature than traditional ones [6,7]. Intensive efforts have been made to manufacture coarse grained WC–Co cemented carbides with grain size in certain range, in order to obtain the required characteristics for applying in specified working conditions.

The straight forward method to control grain size of cemented carbides is ball milling, which is considered a prominent method in controlling initial powder size through effective refinement of both WC and Co particles [8]. Generally, ultra-coarsed WC particles are requisite raw materials for preparing coarse grained WC–Co cemented carbides, due

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to their inevitable pulverization in a conventional milling process. However, ultra-coarsed carbide particles have wide size distribution, making it difficult control the grain size of WC–Co cemented carbides. In addition, it is reported that ball milling process always leads to high distortion of WC particles which, in turn, have strong tendency for abnormal grain growth for the following sintering process, where a few grains grow much larger than the average [9,10]. This is devastating for the mechanical properties since these abnormal grains could act as initiation points of stress accumulation for cracking and breakage [11]. Although several carbide materials such as VC, TaC and Cr_3C_2 have been added in cemented carbides to inhibit the abnormal grain growth [12], some researches indicate that the carbide additives lead to inhomogeneous microstructures and reduce the fracture toughness of cemented carbides [13,14].

Furthermore, various attempts have been made to control the grain size of cemented carbides without sacrificing the required mechanical properties. Most of them focused on avoiding the milling process and improving the quality of the WC–Co composite powders in terms of chemical, physical or electro-chemical methods [15–17]. Unfortunately, these methods suffered from the disadvantages of high cost and energy consumption due to the complicated process, long reaction time or high reaction temperature. To overcome these issues, a new non-milling process to prepare coarse grained cemented carbides was illustrated by the present authors [18,19]. The

previous results showed that the new coarse grained WC–Co cemented carbides had better controllability and uniformity of WC grains [18]. It is well known that grain size of WC–Co cemented carbides is highly dependent on the particle size of initial powders. Therefore, it can be expected that the mechanical requirements of coarse grained WC–Co cemented carbides are able to be accomplished by adjusting the size of initial powders using the new method. However, it is worth noting that WC–Co composite powders prepared by the non-milling process have significant distinctions with conventional WC–Co powders, such as morphologies, lattice distortion and size distribution of particles [10,18]. There has been little reported in the literature that provides the details of microstructure evolution and corresponding mechanisms of unmilled powders during the sintering process. Therefore, further study is to clarify the influences of particle size on the sintering process behavior, the evolution of microstructure and the mechanical properties of coarse grained WC–8Co cemented carbides fabricated by unmilled composite powders.

In present work, three sets of coarse grained WC–8Co cemented carbides with different WC grain sizes were novelly fabricated by unmilled WC–8Co composite powders. All composite powders were prepared through hydrogen reduction of WC– CoC_2O_4 precursors using three different-sized raw WC powders. Shrinkage behavior and microstructure evolution of powders along with the sintering process were analyzed to determine the effects of the WC particle size on the densification of WC–8Co cemented carbides. Additionally, the micro-

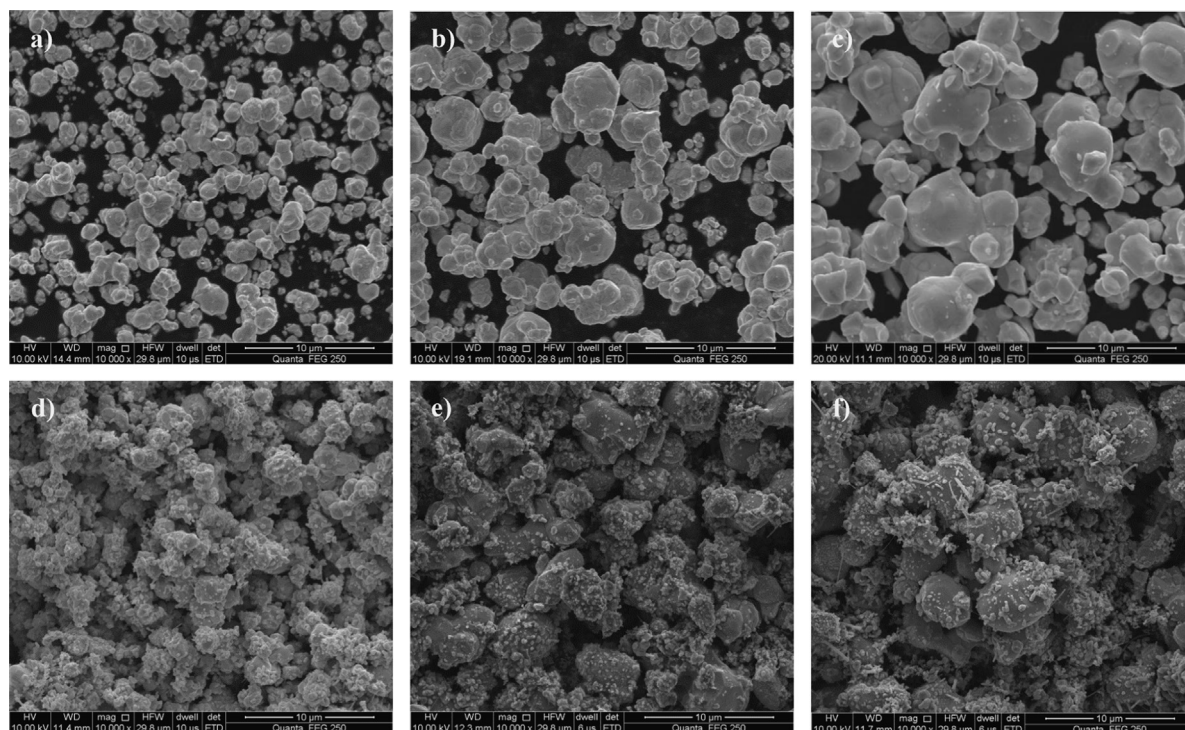


Fig. 1. SEM micrographs showing the morphologies of raw WC particles with average size of 2.01 μm (a), 3.16 μm (b) and 4.37 μm (c) and their corresponding WC–8Co composite powder P1 (d), P2 (e) and P3 (f) obtained by the novel unmilling method.

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