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Review

Powder refinement, consolidation and mechanical properties of cemented carbides — An overview

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ABSTRACT

Cemented carbides, owing to their excellent mechanical properties, have been of immense interest in the field of hard materials for the past few decades. Although a number of processing techniques have been developed to obtain nanostructured cemented carbide powders with grain size of less than 100 nm, they are expensive, as such, the challenge remains for producing nano-sized powders economically. The lack of understanding and control of grain growth and its effect on deformation and fracture of the resulting carbide materials is another area that requires proper attention. In addition, the effect of binder materials and their content on the mechanical properties of cemented carbides is not clearly understood yet. This review aims to address some of the key issues and challenges faced in the research and development of cemented carbides, especially on powder refinement and consolidation, and their effect on mechanical properties.

Contents

1. Introduction

The first synthesis of cemented tungsten carbides, also known as cemented carbides, dates back to a century ago [1]. They have been the subject of intensive research and industrial applications for the past few decades, especially for metal cutting, forming and earth drilling industries [2–6]. Cemented carbides have very high melting temperatures; consequently, it is quite impractical to fabricate carbide parts by casting route. Historically, powder metallurgy (P/M) was used to manufacture this class of materials, and so far has been the predominant processing technique. The properties of cemented carbides prepared by this technique are quite high and unparalleled, as compared to those fabricated by other methods [7–9].

It is worth noting that most studies on cemented carbides used coarse (3.5–5 μm) to ultrafine powders (0.2–0.5 μm) [9]. Recent developments in the field of nanostructured materials [10] suggest that the formation of nanocrystalline grain structure has the potential to significantly improve the mechanical properties of cemented carbides. However, the mechanisms that govern the deformation of nanocrystalline carbides have not been well explored and understood yet. On the other hand, the possibilities of improving the properties of tungsten carbide based materials through nanostructural engineering have triggered considerable interest in manufacturing fine, nanoscale powders. Processes used to synthesize nanosized tungsten carbide powders include, but not limited to, ball milling, spray conversion and chemical vapor phase reaction [11–13]. In addition, various consolidation methods have been utilized and modified in an attempt to control grain growth during sintering stage and to produce bulk nanocrystalline materials [14,15], which is an active research area considered to be critical in the studies of cemented carbides. To optimize mechanical,

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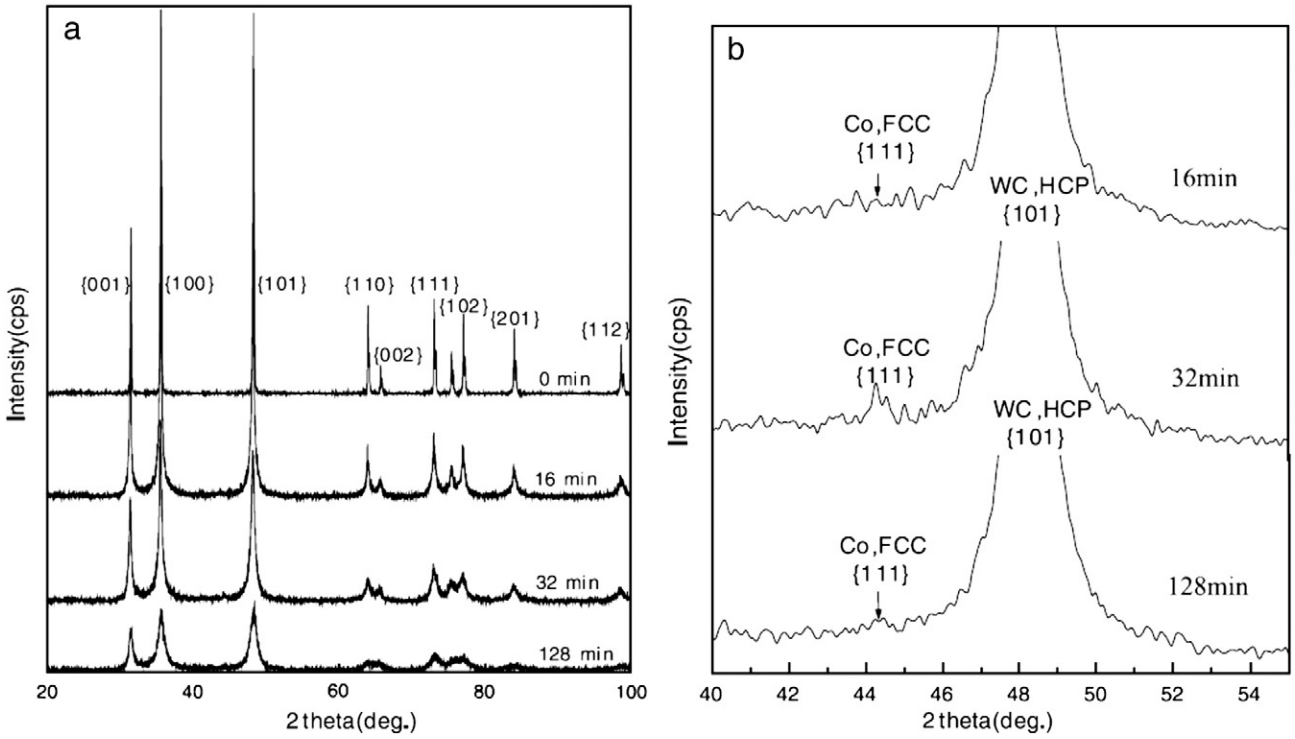

Fig. 1. X-ray diffraction patterns of WC–10Co–0.8VC–0.2Cr_3C_2 powders after milling for different times: (a) full spectrum; (b) partial enlarged spectrum [20].

physical and chemical properties, focus has been placed on selecting appropriate binder materials, ranging from soft and ductile metals to their alloys [16]. While many studies indicate high hardness can result from powder refinement and/or grain growth control [17,18], the literature is still insufficient in clarifying whether or not nanosized particles have any effect on the fracture toughness of the materials.

This paper presents an overview of recent developments of nanostructured cemented carbides, with a focus on some non-conventional processing approaches having the potential to be commercialized. To do so, first, we will look into various methods used for powder refinement and synthesis to establish general requirements for such process. Second, techniques used for consolidation of cemented carbides will be discussed, in which some of the promising methods will be highlighted. Finally, the overview will take a close look at the microstructure and mechanical properties of cemented carbides and some key challenges.

2. Powder refinement and synthesis

Fine grain size has proven to be quite effective in improving the mechanical properties of cemented carbides. This is one of the main reasons why numerous studies in the past two decades have focused on synthesis of nanocrystalline powders, involving various processing methods. Here it is important to emphasize that particle size and grain size are quite different in nature, although they can be correlated depending on the process parameters employed during the consolidation stage. Before consolidation of powders, be it at room or elevated temperature, we are necessarily focusing on particle size of powders. These particles may consist of one single grain or multiple grains, which can only be differentiated through further microstructural analysis. By powder refinement, it is referred to the process or mechanism by which particle size is reduced, through breaking of either particles or

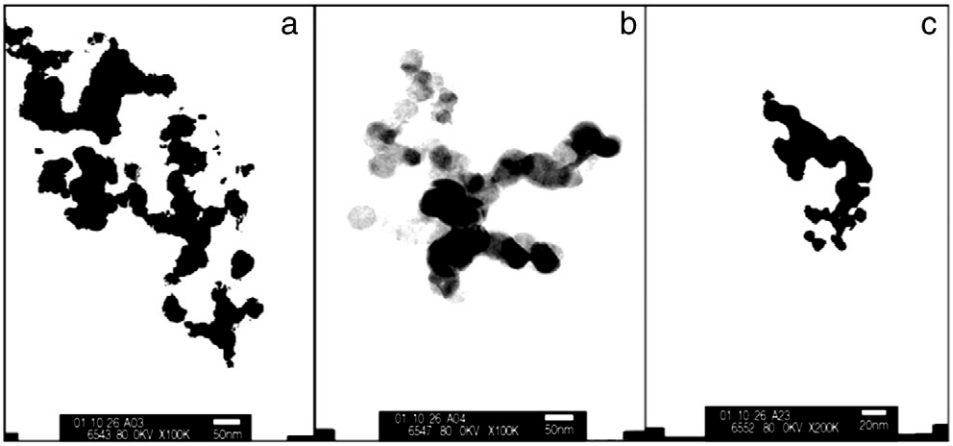

Fig. 2. TEM images of nanocrystalline WC–Co powder mixture milled for (a) 16 min, (b) 32 min and (c) 128 min [20].