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Influence of NbC and VC on microstructures and mechanical properties of WC–Co functionally graded cemented carbides

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ABSTRACT

Functionally graded cemented carbides (FGCCs) usually have a coarse-grained surface layer. In order to refine the grain size of WC and to improve the mechanical properties, VC and NbC as grain growth inhibitors, were added to WC–6Co FGCCs. The grain growth kinetics of WC was investigated, and both the room temperature and high temperature mechanical properties were tested. The results show that the additions of NbC and VC reduce the thickness of the gradient layer in FGCCs. The addition of VC reduces the thickness of the gradient layer by half, while that of NbC is less effective. The additions of NbC and VC refine the grain size by suppressing the adsorption/desorption processes of WC grains in Co phase during the pre-sintering and the carburizing processes, and VC is more effective than NbC. The addition of NbC increases the transverse rupture strength of FGCCs, because of the fine microstructure, and the solution strengthening in Co phase. Both the additions of NbC and VC increase the high temperature hardness of FGCCs due to improved oxidation resistance, more homogeneous and finer microstructures.

1. Introduction

WC–Co cemented carbides have been used as tooling materials for cutting, drilling, and molding in the last several decades due to their excellent mechanical properties [1–5]. Meanwhile, the grain size is a critical aspect for the properties of cemented carbides. The mechanical properties of WC–Co cemented carbides, such as hardness and strength, can be greatly improved by reducing the grain size of WC [6–8]. The Ostwald ripening is considered to be the main mechanism for the coarsening of WC grain in cemented carbides [9–12]. So suppressing the Ostwald ripening process is vitally important for controlling the grain growth of cemented carbides [13]. Grain growth inhibitors, such as VC, NbC, Cr_3C_2 or TaC are frequently applied in suppressing the grain growth of WC–Co cemented carbides [14,15]. The role of grain growth inhibitors is to hinder the dissolution/re-precipitation process of WC in liquid Co phase [16,17].

Functionally gradient cemented carbides (FGCCs), developed by Sandvik in the 1980s, are a new type of cemented carbide materials [18–20]. FGCCs offer a solution to the compromise of hardness and toughness by varying the content of cobalt from the surface to the interior of a sintered piece [21]. Fang et al. produced FGCCs by carburizing pre-sintered samples in an atmosphere consisting of the mixtures of methane and hydrogen [21–24]. The authors also prepared FGCCs by pre-sintering and carburizing carbon-deficient WC–Co cemented carbides [25–27]. The carburization was usually conducted at high temperatures [21–28], so the grain growth of WC is inevitable in producing FGCCs. The coarse WC grains on the surface will decrease the hardness and wear resistance of FGCCs. Although there are many reports on suppressing the grain growth of WC in homogeneous WC–Co cemented carbides [12–17], few studies have been conducted on FGCCs. Since the grain growth of WC in FGCCs involves the diffusion and reaction of carbon in liquid cobalt, the process may be more complicated compared with that in homogeneous cemented carbides. This work focused on the addition of VC and NbC in WC–Co FGCCs, in order to study their influences on the microstructural evolution in the pre-sintering and carburization process and mechanical properties.

2. Experimental

Cemented carbides with a nominal composition of WC–6 wt.% Co were used. WC and Co powder were used in an average particle size of 2.0 μm. The total carbon content of the mixed powders was adjusted to 5.27 wt.% by adding pure W powder, with an average particle size of 0.8 μm. 0.5 wt.% of NbC/VC powder (99.5%), with an average particle size of 0.8 μm, was also added in the mixed powders before the milling process, respectively. Mechanical milling was conducted in gasoline, with 2 wt.% paraffin as the binder. The ball-to-powder weight ratio was 4:1 and the rotation speed was 240 rpm. After a milling of 36 h, the powders were dried in a vacuum oven at 80 °C, and then pressed at 200 MPa. Sintering was performed at 1420 °C for 60 min in a sinter-HIP furnace under an argon pressure of 6 MPa. Carburization was conducted at 1420 °C for 40–160 min in a resistance furnace under hydrogen

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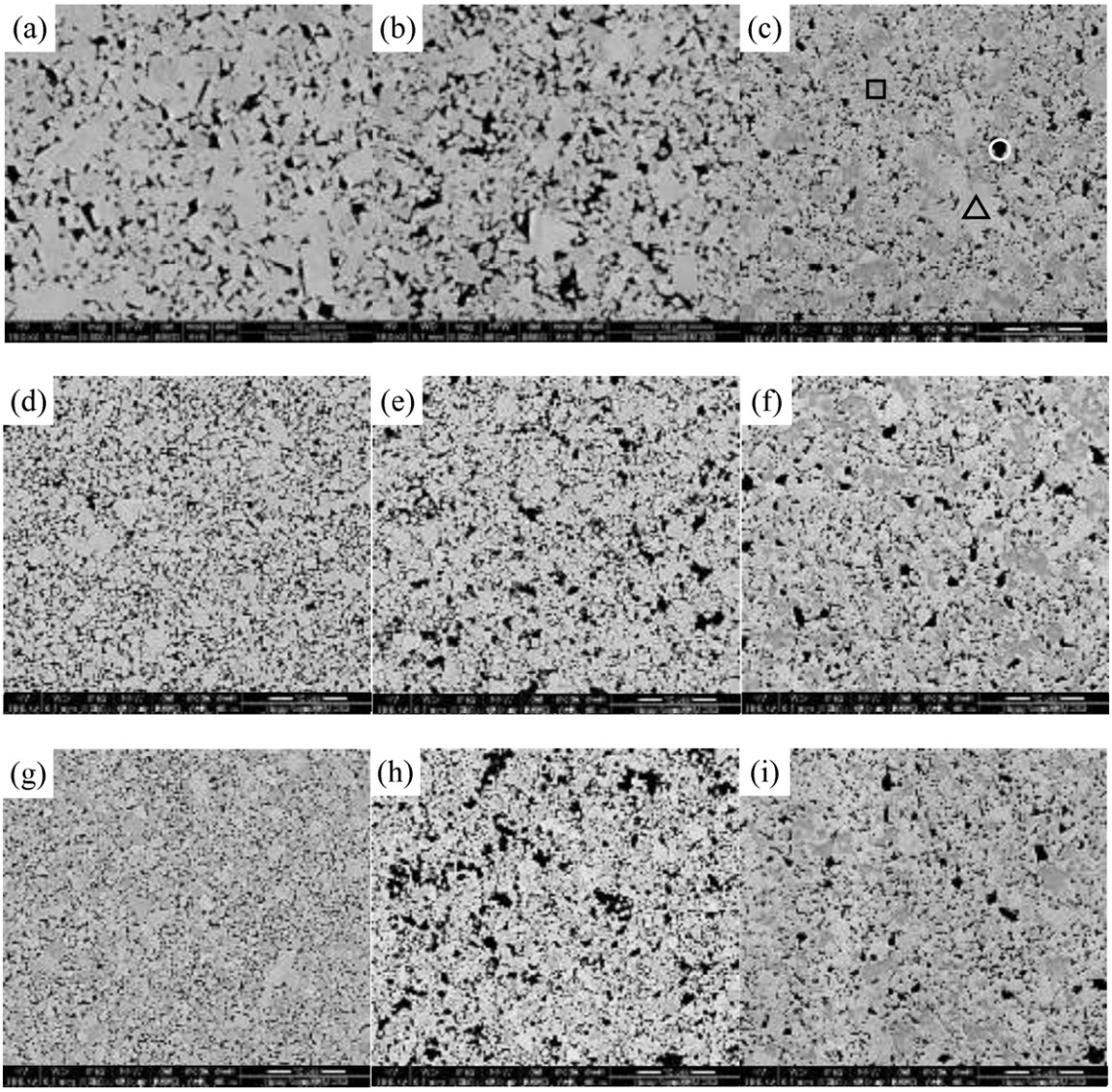

Fig. 1. SEM images of the FGCCs with and without the addition of NbC/VC after carburization at 1420 °C for 80 min: (a) outer layer, (b) middle layer and (c) inner part of conventional FGCC; (d) outer layer, (e) middle layer and (f) inner part of NbC-containing FGCC; (g) outer layer, (h) middle layer and (i) inner part of VC-containing FGCC.

atmosphere. During carburizing, the alloys were covered with graphite powder in the graphite boat, and the average particle size of graphite was 40 μm.

Scanning electron microscopy (SEM, Nova nano 230) was used for the observation of the microstructures. The thickness of gradient layers and the grain size of WC were measured by the software of Image-Pro Plus on optical microscopic images. The gradient layer included the outer layer with a low Co content and the middle layer with a high Co content. The grain size of WC was calculated by adding total polygon sides of WC in SEM, then the average diameter of the grains were

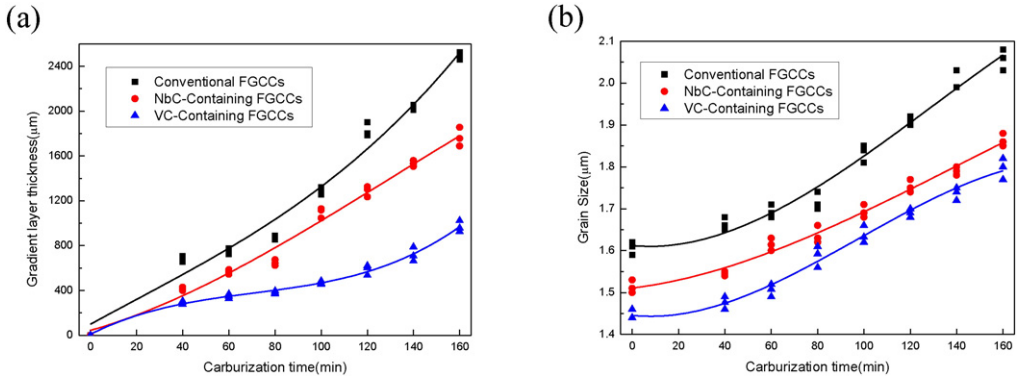

Fig. 2. Characteristics of gradient structures of FGCCs vs. carburizing time. (a) Thickness of gradient layer; (b) grain size of the surface layer.