Spark plasma sintering of WC-Co-YSZ-cBN composites: Densification mechanism and mechanical property evaluation.

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Highlights

- Incorporation of YSZ and cBN in WC-Co composite was successfully achieved.
- Binder content is the main driver for densification.
- High hardness and moderate fracture toughness was achieved for the WC-Co-YSZ-cBN composites.

1. Introduction

Advances in the ceramic-metal composites has been of critical importance especially in the cutting tool industry were advanced materials with extremely high hardness, fracture toughness and wear resistance are required. WC-Co cermets are widely used materials for cutting tools mainly due to their high hardness and excellent fracture toughness. However, WC-Co has specific limits in application as a structural component were high temperature strength, oxidation and corrosion resistance are required. The less refractory metallic binder also softens at high temperatures and may lead to failure or reduced lifespan of the insert during operation. Different binder combinations have been proposed to improve the physicomechanical properties by replacing cobalt with nickel or iron binder. WC-Ni has shown to possess better corrosion and oxidative resistance than WC-Co and WC-Fe, however it has lower mechanical properties compared to WC-Co. WC-Fe has inferior oxidative and corrosion to WC-Co and WC-Ni. To overcome this limitations, ceramic additives have been identified as a possible replacement for the metallic binder phase since they exhibit high mechanical properties, thermal stability at high temperatures, chemical inertness, wear and corrosion resistance. Recent studies have recently been reported on the use of zirconia, having good binding strength and adhesion with the matrix, as a novel binding phase for WC. Zirconia possesses excellent fracture toughness mainly due to transformation toughening from tetragonal to monoclinic phase which is accompanied by a 4-5% volume change. The incorporation of ZrO_2 into the WC-Co matrix is expected to improve the fracture toughness of the material. cBN is one of hardest known materials which is thermally stable as a cutting tool and has excellent wear resistance. Its incorporation into the WC-Co matrix is expected to improve the hardness and wear resistance of the cutting tool material. This study focusses on the partial replacement of cobalt with milled ZrO_2 stabilized with 7.5wt% Y_2O_3 (YSZ) reinforced with cubic boron nitride (cBN). Spark plasma sintering (SPS) technique was used to consolidate WC-Co-YSZ-cBN composites at varying amounts of cobalt (Co), at a constant temperature and pressure of 1300°C and 50MPa respectively, and a holding time of 5 and 10 minutes. The effect of individually adding YSZ and cBN and the synergistic effect of adding both on the WC-Co composite were investigated. The effect of binder concentration and addition of cBN on the densification mechanism and behavior, microstructural evolution and mechanical properties were also studied.

2. Methods

The powders were characterized using a scanning electron microscope (FE-SEM JSM 7600F). The WC, Co and YSZ powders were ball milled (Retch PM 100) in anhydrous ethanol at a ball to powder ratio(BPR) of 10:1 for 24, 24 and 18 h respectively. A PANalytical Empyrean X-ray diffractometer was used to identify phase, crystal structure and crystallite size of the powders. The powders were subsequently dried and mixed in a turbula® mixer (Type T2F). The consolidation of the mixed powders was carried out using a spark plasma sintering unit apparatus (HHPD 25 FCT Systeme) at a temperature of 1300 °C and pressure of 50 MPa for all samples. The relative density of the samples was measured using the Archimedes principle. The quantification of the phases (monoclinic and tetragonal) is calculated using Toraya equations. The hardness (HV30) was carried out using a Vickers hardness tester (Future-tech FV-810) with a load of 30 kgf for 15 s. The fracture toughness (K_{1C}) was calculated using the measured radial cracks emanating from the Vickers diagonals according to Shetty's formula The reported hardness and fracture toughness are the average values of five indentations.

3. Results and discussion

Poor densification and large carbide pools were observed for the low binder composite. The XRD revealed a monoclinic YSZ phase for the WC1Co7YSZ2cBN HT10 and no hBN conversion post sintering. Compared to the control samples (WC10Co), improvements in hardness from 13 GPa to between 17–20 GPa and relatively excellent fracture toughness of ~9 MPa.m$^{1/2}$ were achieved for the quaternary phase composites shown in Fig. 1.

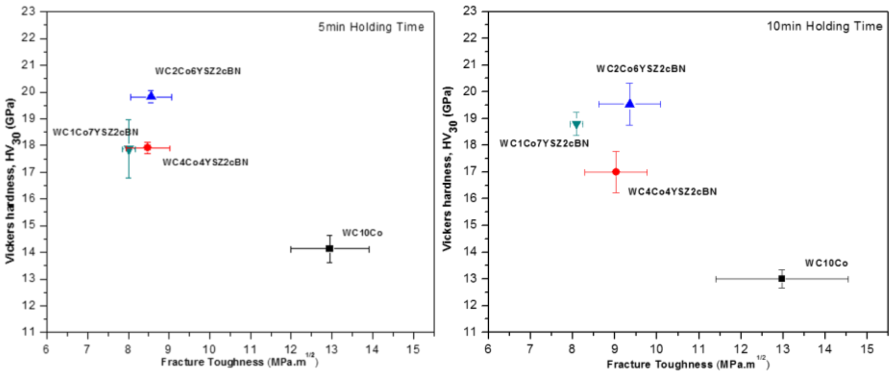

Figure 1. Relationship between Vickers hardness and fracture toughness of WC-Co-YSZ-cBN composite at 5 and 10 minutes holding time.

4. Conclusions

The partial replacement of the cobalt binder phase with YSZ and reinforcing it with cBN was successfully sintered. Cobalt was identified as the main driving force in sintering of WC-Co composites. Improvements in hardness and moderate fracture toughness were observed with the addition of YSZ and cBN. Further optimization of the sintering parameters including higher pressures (100 MPa) and lower temperature (1200°C) should be explored which may lead to binderless WC-YSZ-cBN composites are recommended.

References

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Keywords

Spark Plasma Sintering; Partial Replacement; Densification; Mechanical Properties