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Microstructure and Mechanical Properties of Al_2O_3/WC Composites with Ca-PSZ Addition

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Alumina reinforced with tungsten carbide particles have been successfully used as cutting tool materials. Even the composite (Al_2O_3/WC) meets most cutting tool requirements e.g. high hardness, good chemical and thermal stability as well as wear resistance, its poor fracture toughness are still the main disadvantages. In this work, a variation in hardness and fracture toughness of Al_2O_3/WC composites according to a presence of calcia-doped zirconia (CA-PSZ) was investigated. Ca-PSZ up to 6 wt% was added to the Al_2O_3/WC composites. The powder mixtures were uni-axially pressed and sintered at 1600 °C for 2 hours in argon. The microstructures of the composites were observed by SEM. Hardness and fracture toughness were determined by Vickers hardness. Relatively densities of the specimens higher than 96%TD were achieved after sintering. An Addition of WC resulted in a decrease in grain size of Al_2O_3 matrix. Hardness values of the Al_2O_3/WC composites were similar when compared with the monolithic Al_2O_3. A presence of Ca-PSZ led to higher fracture toughness, but slightly reduced hardnes. It indicated that the Ca-PSZ could enhance fracture toughness of the Al_2O_3/WC composites.

Keywords: alumina/tungsten carbide, zirconia, characterization

INTRODUCTION

At present, a variety of materials were selected for superior and more efficient cutting tools. Ceramic materials, such as, diamond, oxides, carbides and nitrides are candidates. Alumina (Al_2O_3) meets most of these significant requirements, however, it is limited by low fracture toughness. It is common that a composite material can improve mechanical properties as required for certain applications. The dispersion of hard carbide particles such NbC, TiC, WC and (W, Ti)C into Al_2O_3 matrix can be benefit to mechanical properties due to crack deflection. Examples of properties of various hard materials are shown in Table 1. Although all carbides show relatively similar hardness, tungsten carbide (WC) has elastic modulus, flexural strength and fracture toughness higher than others. It also provides chemical inertness and wear resistance. Therefore, the Al_2O_3/WC composites are expected to be alternative material for cutting tools [1-5].

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Mechanical properties of the alumina matrix composite, especially fracture toughness, can be improved with and addition of zirconia. Pure ZrO_2 has a monoclinic crystal structure at room temperature and transforms to tetragonal and cubic at around 1170 °C and 2370 °C, respectively. The dopants such as MgO, CaO, Y_2O_3 and CeO can control phase transformation by stabilizing tetragonal or cubic crystals at ambient temperature, consequently, enhancing fracture toughness [6, 7]. The higher toughness of the Al_2O_3/WC composites may be possible. The aim of this work is to study the effects of Ca-PSZ on microstructure and mechanical properties of the Al_2O_3/WC composite.

TABLE 1
Selected properties of hard materials used for cutting tool applications [1-3]

Materials	H_v (GPa)	K_{IC} (MPa.m$^{1/2}$)	E (GPa)
Diamond	30	1	1000
BN	27	1-2	700
Al_2O_3	18-20	2-4	310-410
ZrO_2	13-14	6-10	200-300
SiC	22	3-5	450
NbC	20-24	3-6	340-730
TiC	18-22	4-6	300-500
WC	17-24	11-12	520-700
Si_3N_4	16	4-7	320

METHODS AND MATERIALS

The materials used in the present study were high purity alumina AKP30 (99.99% purity, Sumitomo Chemical Co., Ltd, Japan, D_{50} = 0.3 μm), WC powder (ATI Alldyne, United states, D_{50} = 1.2 μm) and Ca-PSZ powder (Fukushima, Japan, D_{50} = 1.9 μm). The Al_2O_3 matrix was reinforced by 10 wt% WC particles, accompanied by the addition of Ca-PSZ of 0-6 wt%. The amount of WC powder was kept constant at 10 wt% in the Al_2O_3 matrix. Details of compositions of the powder mixture are shown in Table 2. These powder mixtures were wet-mixed with ethanol for 4 hours in a polyethylene bottle, using alumina milling media. The slurry was dried in an oven at 60 °C. The pellets of 13 mm in diameter were prepared using a uniaxially press at 30 MPa and sintered at 1600 °C for 2 hours in an argon atmosphere The sintered pellets were subjected to density measurement, phase analysis, microstructural investigation as well as hardness and fracture toughness evaluation. For the microstructural investigation the composites were observed using scanning electron microscopy (SEM, JSM-6480LV, JEOL). The samples were polished and thermally etched at 1500 °C for 15 minutes in order to reveal the grain boundaries.

TABLE 2
Compositions of the powder mixture

Composition (wt.%)		
Al_2O_3	WC	Ca-PSZ
100	0	0
90	10	0
88.65	9.85	1.5
87.30	9.70	3.0
85.95	9.55	4.5
84.60	9.40	6.0

RESULTS AND DISCUSSION

Microstructure

Fig. 1 presents microstructure of (a) monolithic Al_2O_3 (b) Al_2O_3/WC composite and (c) Al_2O_3/WC composite with 6 wt% Ca-PSZ. In the Al_2O_3/WC composite (*Fig. 1(b)*) and Al_2O_3/WC composite with Ca-PSZ addition (*Fig. 1(c)*), WC particles (bright phase) were observed at grain junction and along grain boundaries of the Al_2O_3 matrix (dark phase). The ZrO_2 could also be detected by EDS analysis. The grain size of Al_2O_3 in the monolithic form (*Fig. 1(a)*) were relatively large compared to those of the composites which could result in lower strength. The grain size of Al_2O_3 in these three specimens were 3.47, 1.28 and 2.75 μm, respectively. The grain size of Al_2O_3 matrix reduced considerably with the presence of WC particles. The finer grains in these microstructures were expected to improve the properties of the materials.

Density

The relative density of the composites were in range of 96 –99 % theoretical density (%TD). The relative density of monolithic Al_2O_3 was 99 %TD while addition of WC and Ca-PSZ into alumina experimentally led to a slight decrease in relative density. This might be caused by porosity in the structure owing to incomplete densification.

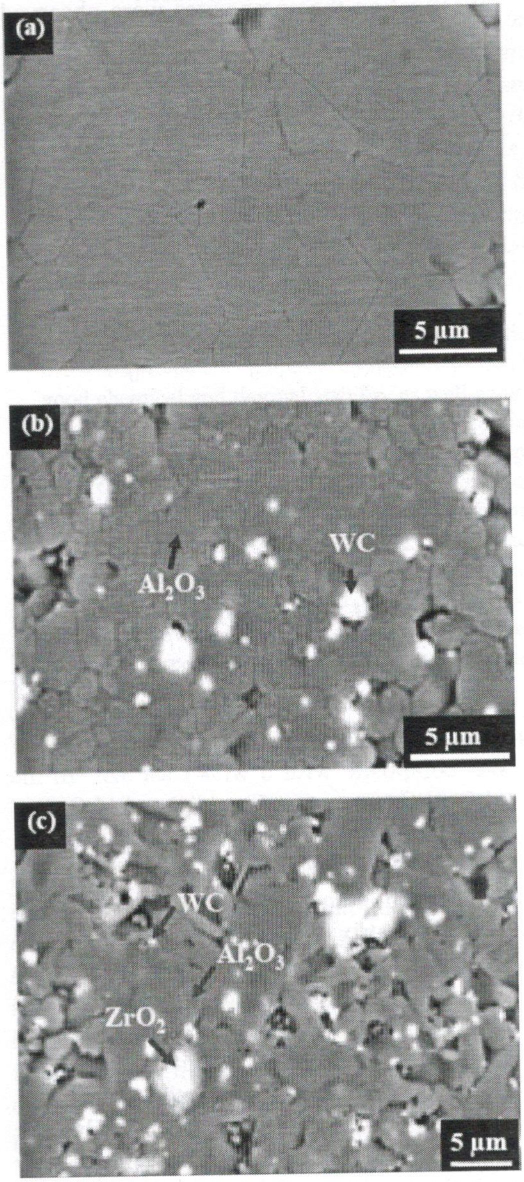

Fig. 1: Backscattered electron micrographs of (a) monolithic Al_2O_3 (b) Al_2O_3/WC composite and (c) Al_2O_3/WC composite with 6 wt% Ca-PSZ

Hardness and Fracture Toughness

The hardness values of the Al_2O_3 and Al_2O_3/WC composites were 16.85±0.80 GPa and 19.05±0.79 GPa, respectively. Hardness of the composite specimens with an addition of Ca-PSZ is shown in *Fig. 3*. It was observed that the hardness values of the composites decreased with an increase in Ca-PSZ content. However, the hardness values of the composites with Ca-PSZ additions were in the similar range of that of the monolithic Al_2O_3. Fracture toughness of the composite specimens with various Ca-PSZ additions is presented in *Fig. 4*. The fracture toughness was improved when increasing the Ca-PSZ content. Since the microstructure of the composites with Ca-PSZ contained porosity, as shown in *Fig. 1*, these pores were thought to reduce stress field developed during service and led to slightly higher value of fracture toughness.

CONCLUSIONS

It was possible to fabricate Ca-PSZ doped Al_2O_3/WC composites by conventional powder pressing and pressureless sintering. The hardness value of the composites slightly decreased whereas the fracture toughness increased with increasing Ca-PSZ content. The microstructure revealed decreasing of the alumina matrix grain sizes when WC particles and Ca-PSZ were added into the specimens. This suggested that Al_2O_3/WC composite with Ca-PSZ addition could possibly be used as alternative material for cutting tools applications.

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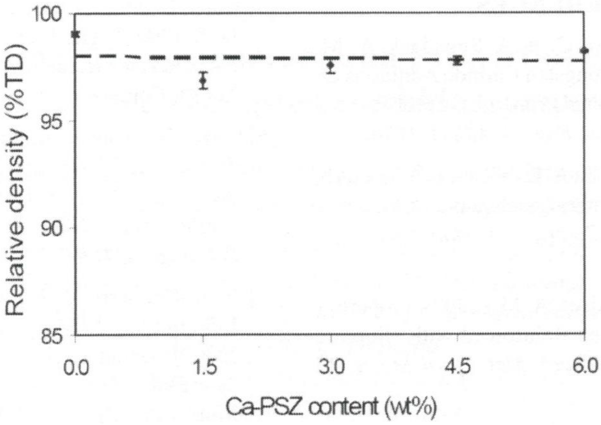

Fig. 2: Relative density of Al_2O_3/WC composites as function of Ca-PSZ content

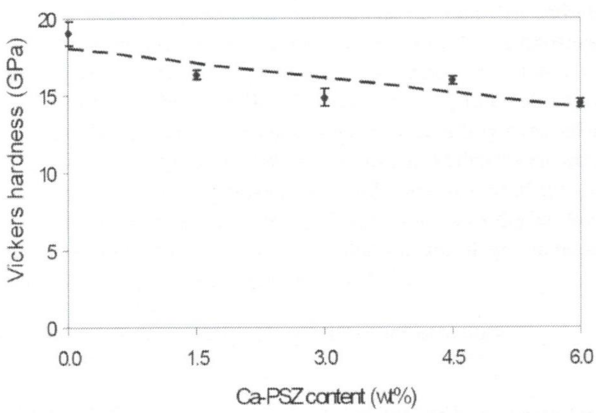

Fig. 3: Vickers hardness of the Al_2O_3/WC composites as a function of Ca-PSZ content

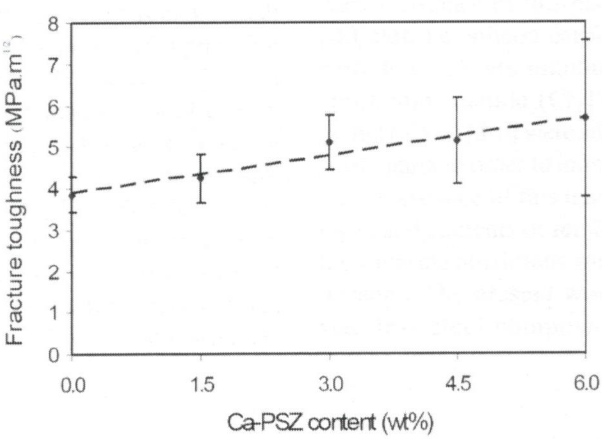

Fig. 4: Fracture toughness of the Al_2O_3/WC composites as a function of Ca-PSZ content

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