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IMPROVEMENT OF MECHANICAL PROPERTIES OF ALUMINA-SILICON CARBIDE COMPOSITE WITH ZIRCONIA PARTICLES

Ampaporn Promsen and Sukasem Kangwantrakool*

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Abstract

The mechanical properties of Al$_2$O$_3$-SiC based composites were improved by the addition of ZrO$_2$(3Y) particles. The addition of ZrO$_2$(3Y) particles was 10, 15, 20, and 25 vol.% respectively and sintered at 1550, 1600, and 1650°C by the embedding method. Sintered Al$_2$O$_3$-SiC/ZrO$_2$(3Y) composites were characterized by the density, XRD and microstructure. Mechanical properties were measured for the flexural strength, fracture toughness and hardness. The results showed that the highest flexural strength of 250 MPa was obtained with 25 vol.% ZrO$_2$(3Y) composite sintered at 1600°C, while the maximum fracture toughness of 5.66 MPa.m$^{1/2}$ was obtained with 20 vol.% ZrO$_2$(3Y) sintered at 1600°C.

Keywords: ZrO$_2$(3Y) particles, Al$_2$O$_3$-SiC composites, mechanical properties

Introduction

Al$_2$O$_3$ ceramic has been widely used as a matrix material because of its good mechanical properties such as high hardness, low electrical conductivity, good chemical stability, and oxidation resistance, but low fracture toughness leads to a limitation of the structural applications. Thus, most research studies focused on the mechanical properties’ improvement of Al$_2$O$_3$ to increase structural applications, by using a reinforcing particle such as SiC, ZrO$_2$, TiN/TiC/TiO$_2$, BN, and metal particles (Moreno et al., 1996; Ye et al., 1998; Pastorino-Chassale et al., 2010). Much work has focused on the mechanical properties’ improvement of Al$_2$O$_3$ by SiC addition. Shi et al. (2010) studied the improvement of the mechanical properties of Al$_2$O$_3$-SiC composites with different SiC additions of 5, 10, 15, and 20 wt%. The flexural strength was increased with 20 wt% SiC and the highest fracture toughness was obtained from 5 wt% SiC. Ko et al. (2004) particularly focused their study on the effect of the SiC contents with subnanometer, reinforced in the Al$_2$O$_3$ matrix. It showed that SiC can improve the

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flexural strength properties of the Al$_2$O$_3$ matrix while the toughness properties were less improved. Ma et al. (2008) studied the ZrO$_2$ toughening mechanism in the Al$_2$O$_3$ matrix. The result showed that ZrO$_2$(2Y) and ZrO$_2$(3Y) could increase the fracture toughness of the Al$_2$O$_3$ matrix. The present work aimed to improve the mechanical properties such as the flexural strength, fracture toughness, and hardness of Al$_2$O$_3$-SiC composite with different amounts of ZrO$_2$(3Y) additive, sintered by using the embedding method which could reduce the production costs of industry.

**Experimental Procedures**

Al$_2$O$_3$ 98.50% with a mean particle size of 3 µm, β-SiC particle size (100 nm) and ZrO$_2$(3Y) with 3 mol% Y$_2$O$_3$ stabilizer were used as starting powders. Batch compositions and sintering conditions were shown in Table 1. The ZrO$_2$(3Y) with the amount of 10-25 vol.% was added to Al$_2$O$_3$-SiC matrix in order to investigate the effect of the ZrO$_2$(3Y) addition on the mechanical properties of the composite. Mixed powders of Al$_2$O$_3$-SiC/ZrO$_2$(3Y) composites were ball-milled in ethanol for 24 h using an Al$_2$O$_3$ ball and a polyethylene jar. The mixed slurry was dried, and subsequently sieved through a 60 mesh screen to prepare the granule powders. Then the granulated powders were pressed under 25 MPa to obtain the compact sample. Then compacted samples were sintered at 1550, 1600, and 1650°C for 4 h by using the embedding method. The density of the sintered material was determined by the Archimedes method using distilled water. The sintered specimens were ground and polished up to 1 µm, and then were etched thermally. The microstructure was observed by SEM. The phase identification was analyzed by XRD. The flexural strength was measured by the 3 point bending method (Mariappan et al., 2002). The hardness was measured using a Vickers indenter. The fracture toughness was determined by the indentation method from the Vickers impression marks.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Batch composition (vol.%)</th>
<th>Sintering condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95 Al$_2$O$_3$:5 SiC ZrO$_2$(3Y)</td>
<td>Temperature (°C) Time (h)</td>
</tr>
<tr>
<td>AS90Z10</td>
<td>90</td>
<td>1550 4</td>
</tr>
<tr>
<td>AS85Z15</td>
<td>85</td>
<td>1550 4</td>
</tr>
<tr>
<td>AS80Z20</td>
<td>80</td>
<td>1550 4</td>
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<tr>
<td>AS75Z25</td>
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<tr>
<td>AS75Z25</td>
<td>75</td>
<td>1650 4</td>
</tr>
</tbody>
</table>
Results and Discussion

Microstructure

Figure 1 shows the SEM micrographs of the AS90Z10 (90 vol.% (95:5 Al2O3-SiC) • 10 vol.% ZrO2(3Y)) sintered at different temperatures of 1550, 1600, and 1650°C respectively. The etched surfaces showed that the addition of nano-SiC particles can improve the microstructure of the composites and enhance the grain boundaries due to the residual compressive stress that comes from the different thermal expansion coefficients between SiC and Al2O3 which appeared as the microcrack (Gao et al., 1999). The amount of porosity is decreased with the increase of the sintering temperature resulting in a higher density of the composite as shown in Figure 1. However, with the same amount of ZrO2(3Y) vol.%, the quantity of the ZrO2 phase was increased with the sintering and located at the grains boundaries of the Al2O3 (Tuan et al., 2002). At 1650°C, with increasing the ZrO2(3Y) content up to 25 vol.%, the compressive stress around the grain boundaries of the Al2O3 is increased more than other composites and appears as the microcrack which comes from the ZrO2 phase transformation of t-ZrO2 to m-ZrO2 as shown in Figure 2.

Figure 1. SEM micrographs of thermally etched surfaces of AS90Z10 sintered at (a)1550°C (b) 1600°C, and (c) 1650°C
Figure 2. SEM micrographs of thermally etched surfaces of the composites at sintering temperature 1650°C, (a) AS90Z10 (b) AS85Z15 (c) AS80Z20 (d) AS75Z25

Figure 3 shows the XRD pattern of 90-75 vol.% (95:5 Al₂O₃-SiC) • 10-25 vol.% ZrO₂(3Y) sintered 1650°C. All the Al₂O₃-SiC/ZrO₂(3Y) composites contain the phase of Al₂O₃, β-SiC, m(monoclinic)-ZrO₂ and t(tetragonal)-ZrO₂. However, the t-ZrO₂ phase was increased while the m-ZrO₂ was decreased due to the phase transformation (Mariappan et al., 2002).

Densification

Figure 4 shows that the density of Al₂O₃-SiC/ZrO₂(3Y) composites was increased with the increase of the sintering temperature.

Mechanical Properties

Figure 5 shows the flexural strength of the composite when the values were decreased with 10-20 vol.% ZrO₂(3Y) and increased with 25 vol.% ZrO₂(3Y). The highest flexural strength was obtained from 1600°C with 25 vol.% ZrO₂(3Y) due to the higher amount of t-ZrO₂ phase transformation as appeared in the XRD pattern. At 1650°C, the t-ZrO₂ phase was increased due to the phase transformation t to m-ZrO₂ in comparison with the lower sintering temperature. However, with the same amount of 25 vol.% ZrO₂(3Y) at 1650°C the thermal expansion coefficient mismatch between SiC and Al₂O₃ could generate the microcrack yielding the lower flexural strength in comparison with 1600°C while
at the lowest sintering temperature of 1550°C the lower density with high porosity leads to poor mechanical properties.

Figure 3. XRD patterns of composite samples (a) AS75Z25 (b) AS80Z20 (c) AS85Z15 (d) AS90Z10 sintered at 1650°C, A = Al₂O₃, S = β-SiC, M = m-ZrO₂, T = t-ZrO₂

Figure 4. Densities of Al₂O₃-SiC/ZrO₂ (3Y) composites as a function of ZrO₂(3Y) content sintered at 1550, 1600, and 1650°C
Figure 5. Flexural strength of composites as a function of ZrO$_2$(3Y) content sintered at 1550, 1600, and 1650°C

Figure 6 shows the fracture toughness of the composite. The highest fracture toughness was 5.66 MPa.m$^{1/2}$ and was obtained from 1600°C with 20 vol.% ZrO$_2$(3Y). The toughening mechanisms of the composites came from the addition of the effects of ZrO$_2$(3Y) particles in Al$_2$O$_3$-SiC composites that could be determined in various kinds of toughening mechanisms. The first is the dynamic t-m phase transformation toughening effect during fracturing revealed by X-ray analysis, as shown in Figure 3. The second is the microcrack toughening effect induced by the volume expansion from the t-m phase transformation during cooling in the sintering process. In addition, ZrO$_2$(3Y) particles can effectively enhance the crack deflection to inhibit further propagation of the main crack (Lin et al., 1998).

Figure 7 shows hardness; the highest hardness was 9.16 GPa with 10 vol.% ZrO$_2$(3Y) sintered at 1600°C. This is because the larger amount of porosity at low sintering temperature results in lower hardness. Nevertheless, at 1650°C the value is lower than 1600°C because the different thermal expansion coefficients between Al$_2$O$_3$ and SiC lead to the occurrence of the microcrack, which has the effect on the hardness properties.

Conclusions

The addition of ZrO$_2$(3Y) particles can significantly enhance the mechanical properties of Al$_2$O$_3$-SiC composites. The highest fracture toughness was 5.66 MPa.m$^{1/2}$ obtained from 1600°C with 20 vol.% ZrO$_2$(3Y). The toughening mechanisms of ZrO$_2$(3Y) particles included the dynamic t-m phase transformation toughening effect during fracturing and the microcrack toughening effect by the volume expansion which comes from the t-m phase transformation during cooling in the sintering process (Wang et al., 1999). The ZrO$_2$(3Y)
particles can effectively enhance the crack deflection to inhibit further propagation of the main crack. The amount of the porosity is increased with a lower sintering temperature, while at a high sintering temperature, the higher thermal expansion and the compressive stress around the boundaries of the Al₂O₃ and SiC generated the microcrack which is correlated to the mechanical properties.

Figure 6. Fracture toughness of composites as a function of ZrO₂(3Y) content sintered at 1550, 1600, and 1650°C

Figure 7. Hardness of composites as a function of ZrO₂(3Y) content sintered at 1550, 1600, and 1650°C
Acknowledgement

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References


