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MICROSTRUCTURE AND MECHANICAL PROPERTIES OF $LiTaO_3/Al_2O_3$ COMPOSITE CERAMICS

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SUMMARY: Composite ceramics with a piezoelectric second phase were studied. Lithium tantalate ($LiTaO_3$) was found to be phase compatible with alumina (Al_2O_3) during sintering. $LiTaO_3/Al_2O_3$ (LA) composite ceramics were fabricated by two processing routes: hot pressing (HP) at 1500℃ (No.1 route), cold isostatically pressing (CIP) and sintering in air at 1300℃ followed by hot isostatically pressing (HIP) at 1300℃ (No.2 route). The microstructure and mechanical properties of the composite ceramics were investigated. The LA composite ceramics with modest amount of $LiTaO_3$ fabricated by No.2 route showed a significant increase in mechanical properties. σ_f and K_{IC} reached 438.7MPa and 5.4MPa •$m^{1/2}$, respectively, for 5vol%$LiTaO_3/Al_2O_3$ composite ceramic by No.2 processing route. Energy dissipation duo to the piezoelectric effect or/and domain wall motion is suggested as a new toughening mechanism when a compatible piezoelectric secondary phase is introduced into alumina ceramics by suitable processing route. The toughening effect is limited for higher concentrations of such piezoelectric secondary phase.

KEYWORDS: Al_2O_3, $LiTaO_3$, composite ceramic, toughening

1. INTRODUCTION

Structural ceramics and functional ceramics have been developing on their own. Recently, the effective strengthening and toughening mechanisms in structural ceramics have been introduced into functional ceramics to improve their mechanical properties significantly[1-3]. Incorporating functional ceramics into structural ceramics has also been reported[4-6]. Though some of their mechanical properties have been also improved, phase compatibility between structural and functional ceramics during sintering is still an urgent problem. In this study, lithium tantalate ($LiTaO_3$) was found to be phase compatible with alumina (Al_2O_3) during sintering, and a Al_2O_3 matrix $LiTaO_3$ composite ceramic was successfully fabricated by two processing routes. The microstructure and mechanical properties of the composite ceramics were investigated.

2. EXPERIMENTAL PROCEDURE

Commercially available Al_2O_3 powder (High Tech Ceramic Institute, Beijing, China) and

$LiTaO_3$ powder (Dongfang Tantalum Joint-stock Corporation, Ningxia, China) were used as starting powders. The average particle sizes of Al_2O_3 and $LiTaO_3$ powders were ~2μm and 6μm, respectively. The amount of $LiTaO_3$ varied as 5, 10, 15, and 20vol%. Al_2O_3 and $LiTaO_3$ were weighed and then mixed for 24h with Al_2O_3 balls. Ethanol was used as a medium for the ball milling. The slurry was stirred and dried slowly to remove the ethanol. Two processing routes were applied to fabricate the composites: hot pressing (HP) at 1500℃ for 30min under a pressure of 25MPa (No.1 route), cold isostatically pressing (CIP) under a pressure of 200MPa and then sintering in air at 1300℃ for 3h followed by hot isostatically pressing (HIP) at 1300℃ under a presure of 150MPa (No.2 route). The sintered samples were cut by a diamond-blade saw to sizes of 3mm×4mm×30mm for strength test and 2mm×4mm×20mm for fracture toughness test. The crystalline phase was examined via X-ray diffractometry (XRD) with Cu$K\alpha$ radiation as X-ray source. The microstructure was investigated using scanning electron microscopy (SEM). The bending strength was measured via three-point-bending technique with a span of 30mm and a crosshead speed of 0.5mm/min. The fracture toughness was determined via single-edge-notched-beam (SENB) test with a span of 16mm and a crosshead speed of 0.05mm/min. Three to five specimens were tested to determine the bending strength and fracture toughness of each condition.

3. RESULTS AND DISCUSSION

3.1 XRD ANALYSIS OF LA COMPOSITE CERAMICS

Fig.1 shows the XRD profiles of 20vol%$LiTaO_3/Al_2O_3$ (20LA) composite ceramics fabricated by different routes. All the peaks of 20LA composite ceramics were assigned to Al_2O_3 or $LiTaO_3$, and no reaction phase between Al_2O_3 and $LiTaO_3$ was detected. Thus, Al_2O_3 was found to be phase compatible with piezoelectric $LiTaO_3$ during sintering.

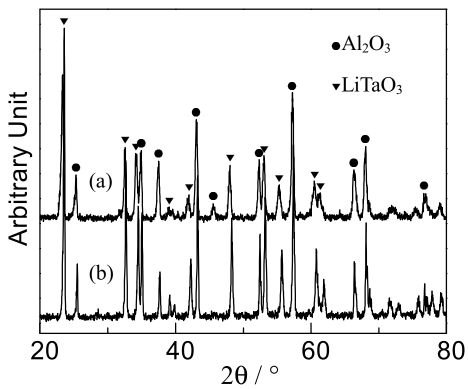


Fig.1 XRD patterns of 20LA ceramic composites fabricated by (a) No.1 route (b) No.2 route

3.2 MICROSTRUCTURE OF LA COMPOSITE CERAMICS

Typical microstructures of LA composite ceramics fabricated by different routes are shown in Fig.2. When applying No.1 processing route, the addition of piezoelectric $LiTaO_3$ increased the grain size of Al_2O_3 matrix significantly mainly due to the melting and volatilizing of $LiTaO_3$ during sintering. In addition, piezoelectric $LiTaO_3$ was distributed like net along the grain boundaries of Al_2O_3 matrix. While $LiTaO_3$ particles were uniformly distributed in Al_2O_3 matrix when applying No.2 processing route. But with the increase of $LiTaO_3$ content, more $LiTaO_3$ particles agglomerated and the density of the composites decreased sharply.

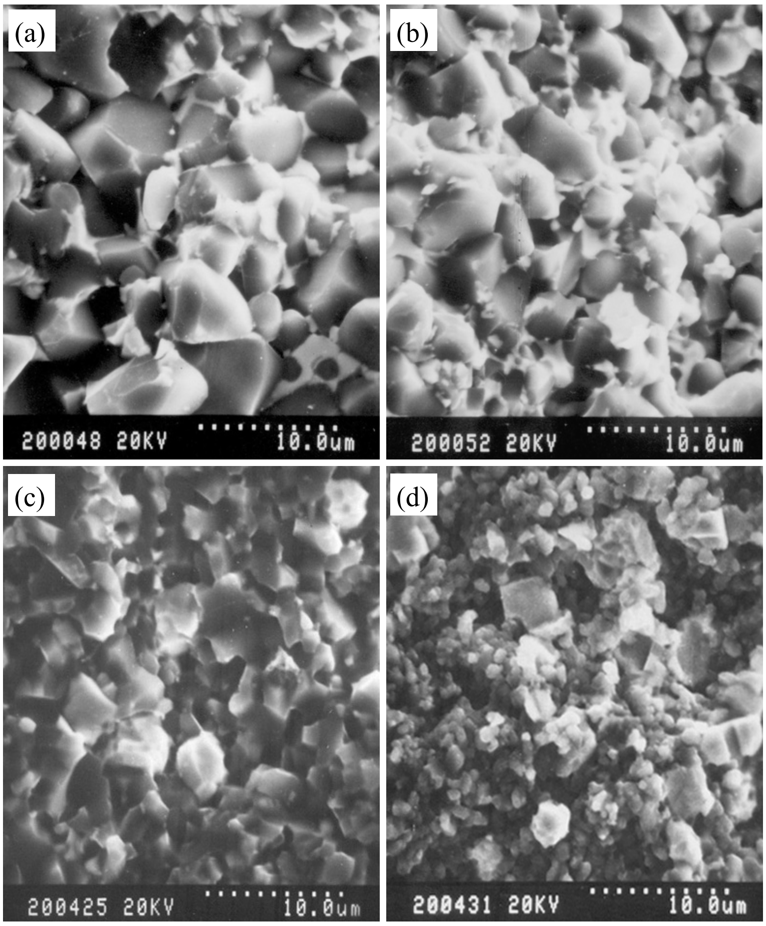
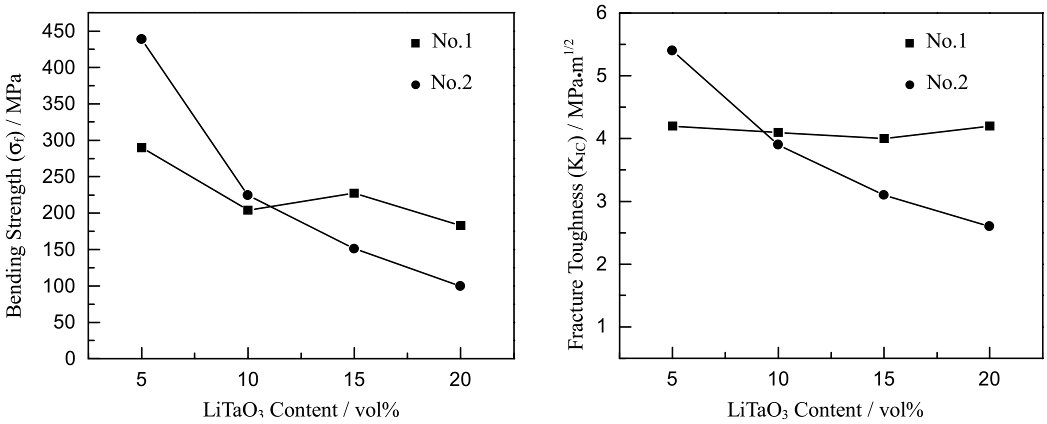


Fig.2 SEM fractograghs of (a)5LA, (b)20LA fabricated by No.1 route and (c) 5LA, (d)20LA fabricated by No.2 route

3.3 MICHANICAL PROPERTIES OF LA COMPOSITE CERAMICS

The mechanical properties of LA composite ceramics fabricated by different routes are shown in Fig.3. When applying No.1 processing route, the addition of piezoelectric $LiTaO_3$ decreased the bending strength and fracture toughness of LA composite ceramics due to the larger Al_2O_3 grains and netlike $LiTaO_3$ with lower strength along the grain boundaries of Al_2O_3 matrix. While the LA composite ceramics with modest amount of $LiTaO_3$ by No.2 processing route showed a significant increase in mechanical properties. σ_f and K_{IC} reached 438.7MPa and 5.4MPa • $m^{1/2}$, respectively, for 5vol%$LiTaO_3$/Al_2O_3 composite ceramic. With further increase of $LiTaO_3$ content, the mechanical properties of the composites decreased instead duo to their lower density. It indicates that a toughening effect results when a compatible piezoelectric secondary phase is introduced into alumina ceramics by suitable processing route. The toughening effect is limited for higher concentrations of such piezoelectric secondary phase.



(a) (b)

Fig. 3 (a) Three-point bending strength and (b) fracture toughness of LA ceramic composites fabricated by different routes vs. $LiTaO_3$ content

3.4 DISCUSSION

According to the previous work by Wahi et al. [7], the necessary condition for brittle particle toughening is:

$$\Delta E>0,\ \Delta\gamma>0 \qquad (1)$$

where, ΔE and $\Delta\gamma$ are the differences of Young's modulus and fracture surface energy between particles and matrix. In the present system, however, the condition is unsatisfied. As shown in Fig. 3, the crack doesn't deflect at $LiTaO_3$ particles and goes almost through $LiTaO_3$ particles. It indicates that some special toughening mechanism results. For ferroelectric/piezoelectric ceramics under mechanical loading, a part of mechanical energy, causing a crack extension, may be transformed into electrical energy duo to piezoelectric effect or dissipated by stress-induced ferroelastic phase transformation and domain wall motion [4][8]. Thus, when a compatible piezoelectric secondary is introduced into alumina ceramics by suitable processing route, the energy dissipation duo to the piezoelectric effect or/and domain wall motion is suggested as a new toughening mechanism.

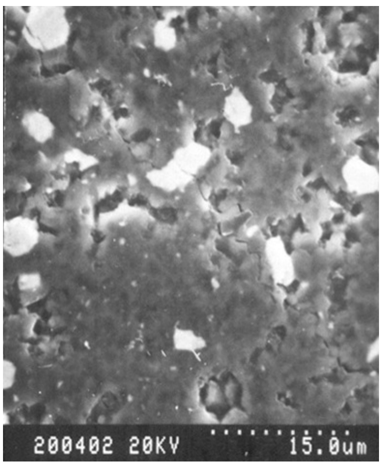


Fig. 4 Crack propagation path in 5LA composite ceramic fabricated by No. 2 route

4. CONCLUSIONS

In this study, piezoelectric $LiTaO_3$ was added into Al_2O_3 matrix to explore the influence of piezoelectric phase on the mechanical properties of structural ceramics. Conclusions were made as follows.

(1) When hot pressed at 1500℃, the bending strength and fracture toughness of the LA composite ceramics decreased greatly due to the larger Al_2O_3 grains and netlike $LiTaO_3$ along the grain boundaries of Al_2O_3 matrix as a result of melting and volatilizing of $LiTaO_3$ during sintering.

(2) $LiTaO_3$ particles were uniformly distributed in Al_2O_3 matrix after CIP and sintering in air at 1300℃ followed by HIP at 1300℃. The LA composite ceramics with modest amount of $LiTaO_3$ showed a significant increase in mechanical properties. With further increase of $LiTaO_3$ content, the mechanical properties of the composites decreased instead.

(3) Energy dissipation duo to the piezoelectric effect or/and domain wall motion is suggested as a new toughening mechanism when a compatible piezoelectric secondary phase is introduced into alumina ceramics by suitable processing route. The toughening effect is limited for higher concentrations of such piezoelectric secondary phase.

ACKNOWLEGEMENTS

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