行政院國家科學委員會專題研究計畫成果報告

雙重韌化之基礎研究

Basic Research on the Synergy Effect Induced by Adding Two Toughening Agents

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一. 摘要

本研究探討在陶瓷中加入金屬及陶瓷韌化劑的複合材料的韌化行為. 本研究所使用的陶瓷韌化劑為氧化鋯, 金屬韌化劑為鎳或銀, 因金屬的加入, 氧化鋯的相變化會增加, 故使同時含氧化鋯及金屬韌化劑的複合材料的韌性較只含氧化鋯的複合材料的韌性為高.

關鍵詞：複合材料, 韌性, 氧化鋯, 金屬

Abstract

In the present study, both ceramic and metallic inclusions were incorporated into an alumina matrix, the effect of the interactions between ceramic and metallic inclusions on the toughening behaviour is investigated. The ceramic inclusions used are tetragonal zirconia particles, which generate transformation stresses during fracturing process. The metallic inclusions used are nickel or silver particles, which deform plastically during fracture. More tetragonal zirconia particles transform to monoclinic phase due to the presence of metals which elastic moduli are relatively low. The toughness of the composites containing both zirconia and metallic inclusions is therefore higher than that of Al_2O_3-ZrO_2 composites.

Keywords : composites, toughness, zirconia, metallic inclusions

二. 緣由與目的

The applications of ceramics as engineering components are often limited by their brittleness. To improve the toughness of ceramics is therefore a challenging task for most ceramists. The addition of second-phase inclusions that influence the propagation of cracks has been one much-studied approach. Among the second-phase inclusions studied, zirconia particles [1,2] and metallic particles [3,4] have received great attention.

The presence of metallic inclusions can bridge the flaws by the ductile phase in the wake zone behind the crack tip [3,4]. The phase transformation of zirconia can induce stresses to prohibit the opening of crack surfaces [1,2]. The toughness of a zirconia-toughened composite, $K_{IC,c}$, is composed of matrix toughness, $K_{IC,matrix}$, and a toughness enhancement, ΔK_{IC}, attributed to the phase transformation as

$$K_{IC,c} = K_{IC,matrix} + \Delta K_{IC} \quad (1).$$

The phase transformation of zirconia mainly takes place in a region, process zone, near an advancing crack, where the constraint applied by the rigid matrix is diminished. The toughness enhancement is also a function of matrix toughness, Eq.(1) can thus be expressed as [5],

$$K_{IC,c} = K_{IC,matrix} + C * E * F * K_{IC,matrix} \quad (2),$$

where C, E and F are a constant, elastic modulus and volume fraction, respectively. The above equation implies that the toughness of a ceramic can be significantly increased by choosing a toughened matrix. The toughened matrix can be a composite, it thus implies that the toughness of ceramics can be significantly enhanced through the addition of two toughening agents simultaneously (one toughening agent has to be transformable ZrO_2). In the present study, t-ZrO_2 and metallic particles, Ni or Ag, are added into an Al_2O_3 matrix. The toughness of the composites are determined.

三. 研究步驟

Alumina (TM-DR, Taimei Chem. Co. Ltd., Tokyo, Japan), nickel oxide (NiO, Johnson Matthey Co., U.S.A.) or silver oxide (Ag_2O, Johnson Matthey Co., U.K.) and zirconia (TZP, ZrO_2 + 3 mol.% Y_2O_3, Hanwha Ceramics Co., Australia) powders were ball milled together in ethyl alcohol for 24 hours. The volume content of zirconia added was controlled to be the same as that of the resulting metals. The slurry of the powder mixtures was dried and subsequently sieved. Powder compacts were prepared by uniaxially pressing at 44 MPa. The sintering was carried out at 1600C for 1 hour. The heating rate and cooling rate were 5C/min. The Al_2O_3-ZrO_2-Ni composites were sintered in a CO atmosphere. Nickel oxide would reduce to nickel during sintering. The Al_2O_3-ZrO_2-Ag composites were sintered in air, Ag_2O would decompose to result in Ag during the heating stage [6]. Some Al_2O_3-ZrO_2 composites were also prepared with the same techniques for comparison purpose. The sintered specimens were machined longitudinally with a 325 grit resin-bonded diamond wheel at a cutting depth of 5 μm/pass. The final dimensions of the specimens were 3 x 4 x 36 mm. The fracture toughness was determined by the single-edge-notched-beam (SENB) technique. Phase identification of sintered and machined specimens was performed by X-ray diffractometry (XRD). The relative phase content of zirconia was estimated by using the method proposed by Evans et al [7]. The final density of the specimens was determined by the Archimedes method. The solubility between the materials used in the present study was low, the relative density of the sintered composites was thus estimated by using the theoretical density of 3.98 g/cm^3 for Al_2O_3, 6.05 g/cm^3 for ZrO_2, 8.90 g/cm^3 for Ni and 10.5 g/cm^3 for Ag. Nickel and silver could vaporize during sintering, the volume fraction of Ag in the specimens after sintering was determined by counting the point fraction on the polished surfaces. Microstructural characterization used scanning electron microscopy (SEM). The size of metallic inclusions was determined by using the line intercept technique. The interconnectivity of metallic inclusions in the alumina matrix was determined by measuring the electrical resistivity at room temperature.

四. 結果與討論

XRD analysis reveals α-Al_2O_3, t-ZrO_2, Ni or Ag in the sintered Al_2O_3-ZrO_2-Ni or Al_2O_3-ZrO_2-Ag composites, respectively. The NiO and Ag_2O are fully reduced into their metallic form after sintering. Fig. 1 shows the relative density of the composites as a function of total inclusion content. The presence of the metallic inclusions prohibits the densification of composites. It may result from the poor wetting of the metallic melt on alumina [8,9].

In the composites containing two toughening agents, the added volume fraction of Ni or Ag was the same as that of ZrO_2 in the beginning. Ni or Ag can vaporize during sintering; nevertheless, the final volume content of metallic inclusions is only slightly lower than that of ZrO_2. The maximum metallic content is thus lower than 15vol.%. The electrical resistivity of the composites is higher than 10^{14} Ω-m, indicating that the metallic particles are isolated from each other within the alumina matrix. Fig. 2 shows the size of metallic inclusions within alumina matrix as a function of metal content. The figure indicates that the coalescence of metallic inclusions can take place during sintering despite the metallic particles are separated from each other.

Fig. 3 shows the strength of composites as a function of total inclusion content. The strength of alumina is enhanced by adding both ceramic and metallic inclusions. Fig. 4 shows the toughness of composites as a function of total inclusion content. The toughness of the composites containing two toughening agents is higher than that of Al_2O_3-ZrO_2 composites. Furthermore, the toughness of Al_2O_3-ZrO_2-Ni composites is higher than that of Al_2O_3-ZrO_2-Ag composites.

XRD analysis detects only tetragonal ZrO_2 phase on the surface of the sintered composites. Fig. 5 shows the percentage of phase transformation of ZrO_2 on the fracture surface as a function of zirconia content. On the fracture surface, more t-ZrO_2 particles in the composites containing two toughening agents are transformed to m-phase. Fig. 5 demonstrates the same trend as the results shown in Fig. 4. It indicates that the toughness enhancement of the composites is contributed by transformation toughening. The presence of metals lowers the elastic modulus of composites, less constraint is thus imposed on ZrO_2 particles. More phase transformation in the metal-containing composites takes place during fracturing process, higher toughness is therefore resulted.

五. 結論

Both zirconia and metallic particles were added into an alumina matrix. The strength and toughness of the composites containing two toughening agents are higher than that of matrix alone and of Al_2O_3-ZrO_2 composites. The strengthening effect is contributed by microstructural refinement. More tetragonal zirconia particles are transformed into monoclinic phase due to the presence of metals. The toughness of the composites containing both zirconia and metals is therefore high. Furthermore, as the metal content is lower than 15 vol.%, as the cases investigated in the present study, the electrical resistivity of the composites is high. It suggests that the composites can be applied as electrical insulators; however, with better toughness.

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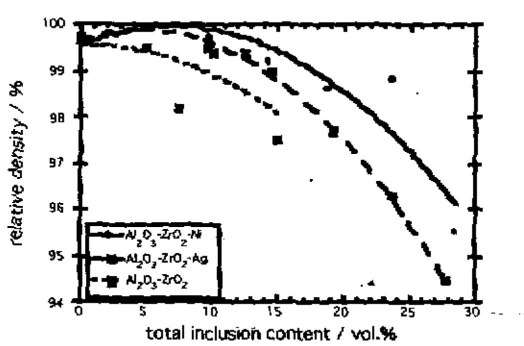

Fig 1., Relative density of composites as function of total inclusion content.

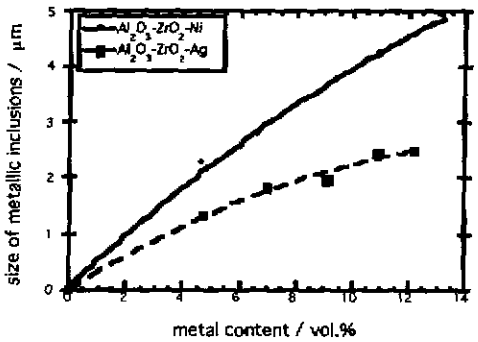

Fig. 2, Size of metallic inclusions as a function of metal content.

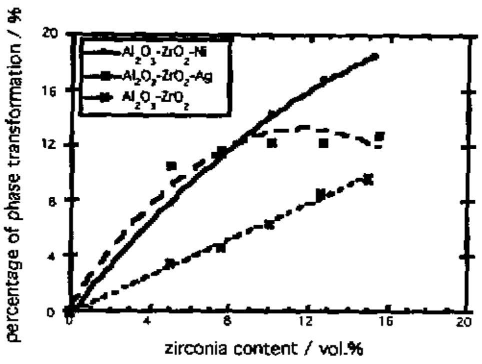

Fig. 5, Percentage of phase transformation of zirconia as function of zirconia content.

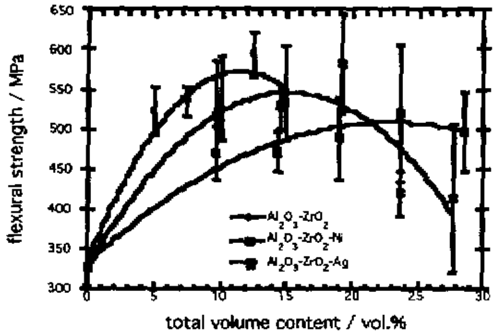

Fig. 3, Strength as composites as function of total inclusion content.

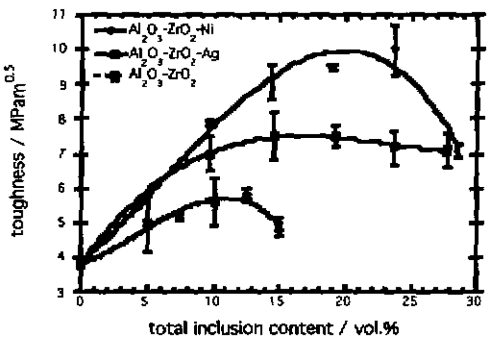

Fig. 4, Toughness of composites as function of total inclusion content.