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Effect of electric field on crack propagation of ceramics composite dispersed with piezoelectric material

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We have already reported strength changes of $BaTiO_3$/8YSZ(8 mol% yttria stabirized zirconia) composite in relation to the polarization treatment. In this composite, bending strength increased on longitudinal poling and decreased on transverse one. Median crack propagation formed by Vickers indentation is known to be related to the main crack propagation behavior at the tension side of a sample subjected to the bending test. In this study, Vickers indentation was performed on similarly fabricated composite after polarization treatment. We observed the propagation behavior of median cracks formed parallel and perpendicular to the poling direction and compared the crack length in both directions statistically. Crack growth in the poled sample tended to be suppressed parallel to the poling direction and be enhanced perpendicular to that direction. Such crack propagation behavior was discussed based on the residual strain of $BaTiO_3$ by polarization treatment.
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1. INTRODUCTION

Ceramic material is widely used for structural parts because it has advantages such as high thermal resistance, corrosion resistance and wear resistance. Such advantages, however, turned to be a drawback in recent environmental conscious days because it is often hard for recycling. Then it is desired to design a ceramic-base material which has a high reliability during the operation period and can easily be abandoned when it becomes unnecessary.

There are some toughening or strengthening method for ceramics such as transformation toughening, fiber toughening and dispersion toughening. Partially stabilized zirconia (PSZ), especially 3 mol% yttria stabirized zirconia is known to show a large mechanical strength due to the transformation toughening[1]. Furthermore, strength of PSZ can be degraded on heating at 200 – 500 °C also due to the phase transformation accompanied by specific volume change [2],[3]. However, such transformation toughening and strength degradation can be useful only in zirconia ceramics.

Fiber incorporation into ceramic matrix is commonly used to fabricate ceramic base composite. However, once a fiber reinforced composite is fabricated, it becomes more difficult for recycling due to the complicated structure and composition. The particle dispersed composites often show nonlinear effects due partly to the internal stress, since their internal stress is derived from the difference in thermal expansion coefficients among the components [4]. If the internal residual stress is the predominant strengthening factor, the final strength is determined by the difference of thermal expansion coefficients between matrix and dispersoid, and it is not possible for this method to control the strength of composites once fabricated.

To control the internal stress, we employed the piezoelectric ceramics as dispersoid [5-7]. Sun and Park et al. have reported an anisotropic crack growth of median cracks parallel and parpendicular to the poling direction on Vickers indentation in PZT ceramics [8]. In an electric field piezoelectric ceramics expand parallel to the electric field and shrink vertical to the electric field. If a piezoelectric ceramics is dispersed into a non-piezoelectric matrix and electric field is applied to the composite, anisotropic internal stress would be generated.

We have already reported that the strength of dielectric material (8 mol% yttria stabilized zirconia, 8YSZ) dispersed with piezoelectric particles (barium titanate) is controllable, namely, weakened or strengthened by polarization treatment [5, 6]. In this study, Vickers indentation was performed on similarly fabricated composite after polarization treatment. We observed the propagation behavior of median cracks formed parallel and perpendicular to the poling direction and compared the crack length in both directions.

2. EXPERIMENTAL PROCEDURE

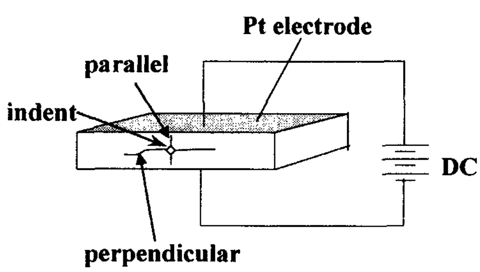
2-1 Preparation of specimen

Commercial barium titanate (BT) powder (Central Glass Co. Ltd., purity >99.9%) and 8 mol% yttria stabilized zirconia (8YSZ) powder (Tosho, TZ8Y) were used as starting powders for piezoelectric dispersoid and non-piezoelectric matrix, respectively. They were weight in a predetermined ratio (BT/(BT + 8YSZ) = 10, 17.5 vol%) and mixed in a planetary ball mill (Fritch, pulverisette 6) using zirconia ball and ethanol for 2 h. After dried, resultant powder mixture was uniaxially pressed in a steel die (diameter, 20 mm) under 80 MPa, followed by hydrostatic pressing under 140 MPa. The pressed powder compacts were sintered at 1400 °C for 4 h in air. The obtained sintered bodies were all mixtures of barium titanate and cubic zirconia, which was confirmed by XRD. The relative densities of the sintered bodies were all more than 95 %.

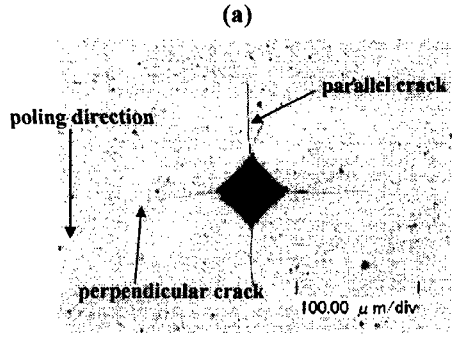
The sintered bodies were cut into rectangular bars with the dimension of 1.0 X 1.8 X 10 mm^3 for Vickers indentation. Each surface of the rectangular specimens was mirror polished by diamond paste. For polarization treatment before Vickers indentation test, platinum pastes were painted as electrodes, which were heat treated at 800 °C for 1 h to connect platinum lead wire. On the other hand, platinum was spputered on the specimen for three point bending test.

2-2 Polarization treatment and measurement of mechanical properties

Polarization treatments were performed in silicone oil at 80 °C using a high voltage power supply (Matsusada Precision, HEELL-30P4-LV). The schematic sample setup is illustrated in Fig.1 (a). In order to protect the surface flushover during polarization treatment, surfaces of the specimen were covered by silicone rubber.



(a)



(b)

Fig.1 (a) The schematic sample setup
(b) The relation between crack propagation and poling direction

After the polarization treatment, Vickers indentation was performed under 9.8 N for 5 sec. and generated cracks in the parallel or perpendicular direction to poling were observed. The relation between crack propagation and poling direction is illustrated in Fig.1 (b). Similarly polarization treated specimens were subjected to three point bending test with span length of 10 mm and cross-head speed of 0.5 mm/min.

Crack lecgth generated by the Vickers indentation was measured through and optical microscope (Keyence, VH-8000) and crack propagation profile as well as fracture surface were observed by a scanning electron microscope (SEM). Vickers indentation was conducted more than 50 times for one condition and results were treated statistically. Bending strength was measured on more than 10 sample treated with the same condition.

Moreover, the polarization treated specimens were heated at 200°C which is over the Tc (- 120°C) of barium titanate transforming from ferroelectrics to paraelectrics, because the resiual polarization or the deformation of barium titanate after poling is expected to be released by heating over Tc.

3. RESULTS and DISCUSSION

Figure 2 illustrates the XRD patters of barium titanate/yttria stabilized zirconia sintered body. No other peaks except barium titanate and cubic yttria stabirized zirconia can be seen in any samples with different compositions. The XRD peaks assigned for barium titanate shift to the lower angle by forming the composites. This result can be ascribed to the substitution of Zr^{4+} ion (ionic radius of 0.86 Å) for the Ti^{4+} ion (ionic radius 0.745 Å) located at the B-site of the barium titanate having the perovskite structure. It is suggested that samples have already reached to the solubility limit of zirconium ion since the shift of the peak remains constant irrespective of amount of barium titanate.

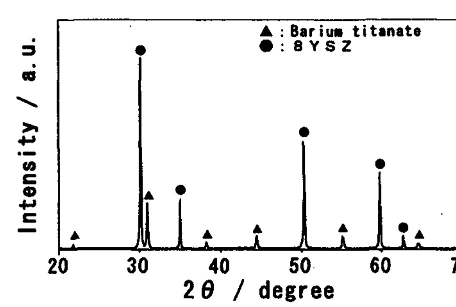


Fig.2 XRD pattern of the 17.5 vol% $BaTiO_3$ / 8YSZ.

Increase in bending strength similar to our previously reported results [5][6] was confirmed in all the samples poled on the longitudinal direction. On such samples Vickers indentation was performed and the generated crack length was measured in both parallel and perpendicular directions to the applied field. Distributions of crack length in both directions were investigated by measuring the crack length on 60 indentations for one polarization treatment condition. The results are shown in Fig. 3. Comparing the two sets of histograms of crack length, the peak of the distribution of crack length in the poling direction locates at the left of that in the perpendicular to the poling direction.

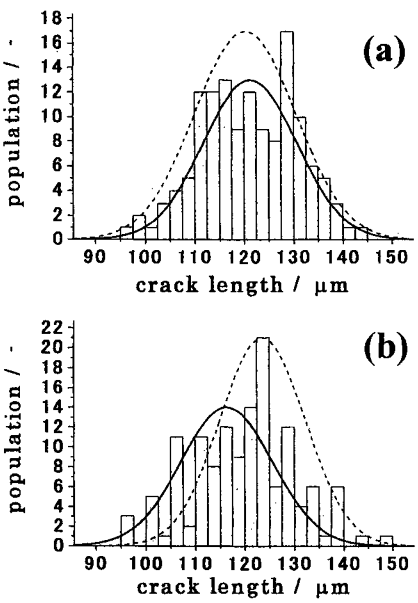


Fig.3 Frequency distribution of crack length
(a)non poled samlpe
(b)polarization-treated sample
parallel
perpendicular

Figure 4 illustrates the change in crack length depending on the applied electric field for 8YSZ base composite containing 10 to 17.5 mol% of barium titanate. The error bar (= average ± 1.96XS.E.) indicates the 95% confidence limit of the average of crack length, and the width of box (=average±S.E.) indicates the 70% one. In any samples crack length parallel to the poling direction continuously decreases and crack length perpendicular to the poling direction increases with the applied field. The change rate of the former is much larger than the latter.

Crack length differences between parallel and perpendicular to the poling direction were calculated and plotted in Fig.5. Crack length differences are almost linear to the applied field and those increase rates are large in sample with large barium titanate content.

If the crack growth anisotropy is due to the distortion of barium titanate accompanied by the internal stress on polarization treatment, the crack growth anisotropy disappears by removing the distortion.

When barium titanate transformed from ferroelectric phase to the paraelectric one by heat treatment, spontaneous polarization disappears. Then, if it returns to the ferroelectric phase again, spontaneous polarization orients at random, resulting in no apparent spontaneous polarization and no distortion.

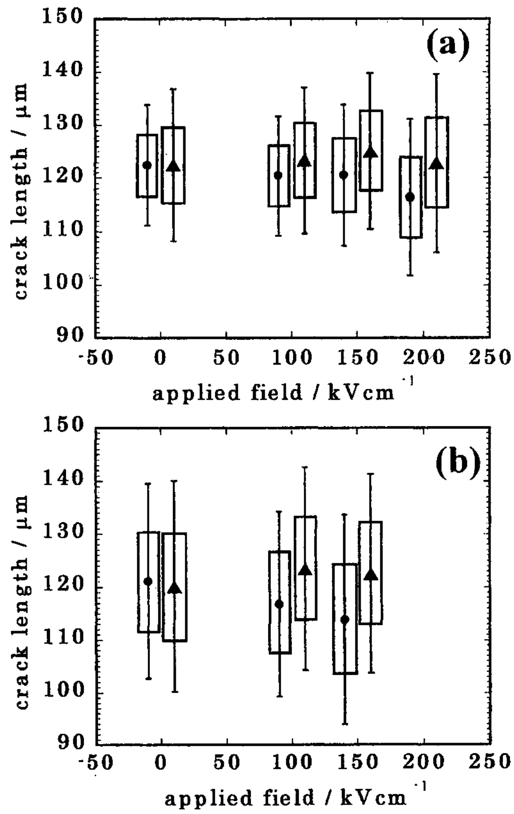


Fig.4 Change in crack length depending on applied field
(a)10vol% $BaTiO_3$ / 8YSZ
(b)17.5vol% $BaTiO_3$ / 8YSZ

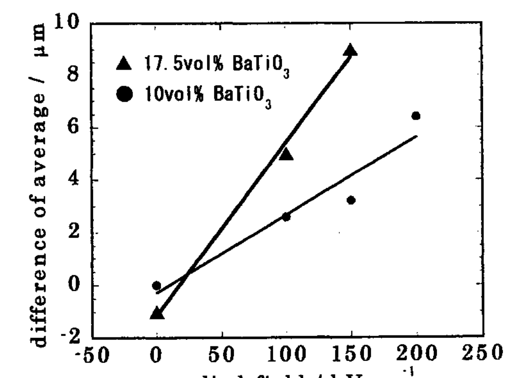


Fig.5 Crack length diffrrences between parallel and perpendicular to the poling direction

Then, poled sample was heated at 200°C, above the transition temperature (~ 120°C) to remove the spontaneous polarization, and they were cooled down to room temperature. Median crack propagation by Vickers indentation on such sample was compared with the original and polarization treated sample. The results are shown in Fig. 6. There is a tendency that the crack length of polarization-treated sample almost returns to that of original one by heating at 200 °C. This result strongly suggests that the residual distortion accompanied by residual polarization is the origin of the anisotropic crack growth.

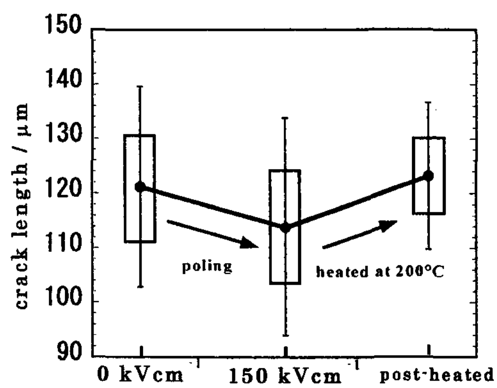


Fig.6 Change in median crack length parallel to the applied field with polarization treatment and post-heating after poling

Kroupa et al. [9] proposed a theoretical model to describe the anisotropic distribution of internal stresses on polarization treated PZT ceramics, which is based on the Eshelby's solution of the "elliptical inclusion" problem [10]. They hypothesize that one spherical ferroelectric grain surrounded by matrix with different relative orientation of spontaneous polarization. Their result can be applied to our results, while the surrounding matrix is a paraelectric ceramics in our study. Their result indicates that the stress in the surrounding matrix is very complicated and decays inversely proportional to third power of distance from the particle. Then the crack length change should be based on the short range interaction which would exist between the particle-matrix interface and the cracks.

4. CONCLUSIONS

We observed the propagation behavior of median cracks formed parallel and perpendicular to the poling direction and compared the crack length in both directions statistically. Crack growth in the poled sample tended to be suppressed parallel to the poling direction and be enhanced perpendicular to that direction. Such crack propagation behavior was discussed based on the residual strain of $BaTiO_3$ by polarization treatment.

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