Poling parallel to crack in magnetoelectroelastic composite subjected to anti-plane shear

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Piezoelectric and piezomagnetic materials have the special properties that when strained and/or stressed, they can induced coupled magnetoelctric effects needed to trigger signals in electronic devices such as switches, sensors, transducers, etc. Because of their multifunctions, they have been exploited by the electronic industry mostly from the viewpoint electro- magnetic performance. Not sufficient attention has been given to understand how the constituent phase of the composite would affect the mechanical integrity of this class of materials. This represents a new challenge for those in mechanics and material science because it requires a combined knowledge of at least two disciplines, if not more. To begin with, the analytical model should reflect the lattice structure of the material. In this case, the piezoelectric coefficient of ferrite phase has a cubic spinel structure and the piezoelectric coefficient of ferroelectric phase has a tetragonal perovskite structure. The application of electric and magnetic fields can alter the magneto- electric response. This translates into certain preferred directions for energy transfer and storage. Anisotropy and homogeneity of the system cannot be avoided in addition to the inherent existence of defects. It is therefore important to know energy transfer rate and magnitude at which the material would be operating in order to determine the size and time scale needed for the analysis. In order to reflect microstructure effects at the continuum scale, previous works [4-6] have shown that the analysis should have three orders of magnitude accuracy in size. This has been loosely referred to as the micro-macro scale range. To meet these objectives, it is necessary not only to have a reliable analytical solution but also a valid criterion that would yield non-contradictory results. The latter is not difficult to avoid if the stress and/ strain solutions are ill-matched with the failure criteria.

In this work, anti-plane deformation is considered for simplicity such that attention can be focused on the interaction of crack growth with the microstructure of the magnetoelectroelastic materials. Keep in mind that the physics of anti-plane and in-plane crack growth characteristics do not possess the kind of similarity for the corresponding problems in isotropic elasticity. This is particularly true for poling directions referenced to the applied electric and magnetic field. The influence of the volume fraction of the composite inclusions made of $BaTiO_3$ with reference to the matrix being made of $CoFe_2O_4$ will also be examined with reference to crack growth enhancement and impediment. Many of the physical implications of the results need to be further studied.

The determination of crack initiation behavior requires only the use of the factor S which can be obtained from the energy density function dW/dV that has been widely used as a failure criterion in fracture mechanics. If attention is focused on a fixed distance, say r, from the crack tip then the relationship S= r(dW/dV) prevails in general regardless of whether the asymptotic or the full solution is used. To this end, the distance r represents the ligament of material that is assumed to break for initiating the first step of crack growth such that crack would extend from an initial length of 2a to 2(a + r) assuming a finite length crack that extends from both ends. The crack path coincides with the loci of the broken elements that coalesce to form the trajectory. Initiation and growth are in fact assumed to be the same. Only in this way that the same criterion can be applied to describe the fracture process in a consistent fashion without ambiguity. The discrete nature of crack initiation and growth is fact what has been observed experimentally for polycrystals. It coincides essentially with the assumption of void nucleation leading to local failure. The onset of rapid crack propagation is assumed to occur when the terminal element reaches a critical energy density factor S_c with corresponding critical ligament r_c. At this instance, $(dW/dV)_c = S_c/r_c$ where $(dW/dV)_c$ represents the area under the true stress and strain curve. It can be found in handbooks for many alloys used in engineering application. The initiation of stable crack growth is thus distinguished from the onset of rapid crack propagation.

The enhancement and impediment of crack growth can be determined by assuming that the ratio S/r is constant for each segment of crack growth. The volume fractions, the applied electric field and magnetic field can be varied. It is interesting to note that crack growth enhancement occurs for all directions of electric poling while the magnetic poling direction is positve, the effect being more pronounced when the electric poling is in the same direction as that of the applied electric field. In genral, positive electric poling tends to encourage crack growth while negative electric poling tends to discourage crack growth.