Hypersingular Integral Equation Method to 3D Crack in Fully Coupled Electromagnetothermoelastic Multiphase Composites

By

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Abstract

Nowadays, fully coupled electromagnetothermoelastic multiphase composites (FC-EMTE-MCs) are being used more and more widely in space planes (sensors), supersonic airplanes (gas turbines), rockets, missiles, nuclear fusion reactor, power generation, petroleum and petrochemical industries as well as submarines (smart skin systems) due to their capabilities to respond in an advantageous manner to changing environment (e.g. When missile accelerated to the 1 mach, it will meet sound barrier, and when missile accelerated to the (3)5 mach, it will meet heat barrier). However, relatively little works have been made for the 3D crack (growth) problem because of the present limitations both practical (computing time) and theoretical (accurate 3D formulations of dislocation shielding and image force).These require us to provide with general precious and accurate theoretical method by use of mathematics tools, and found efficiently numerical method. This work presents hypersingular integral equation (HIE) method proposed by the author for modeling 3D crack (growth) under extended loads through the intricate theoretical analysis and numerical simulations. The main contributions of the dissertation are as follows:

1. The extended fundamental solutions of FC-EMTE-MCs in literatures are further studied by tensor transfer method and elastic theory. The compact formula of extended fundamental solutions

(elastic displacement, electrical potential, magnetic potential and thermal potential) are obtained, which can be used as extended Green's functions in the crack problems analysis. Then, applying main part method and extended boundary conditions, an arbitrary shaped 3D crack in FC-EMTE-MCs subjected to the extended loads (mechanical loads, electrical loads, magnetic loads and thermal loads) are reduced to solve a set of HIEs. The unknown functions are the extended displacement discontinuities (elastic displacement discontinuities, electric potential discontinuities, magnetic potential discontinuities and thermo flow potential discontinuities) of the crack surface. Also, the singularity of the extended displacement discontinuities is analyzed. The analytical solutions of the extended singular stresses (singular mechanical stresses, electric displacements, magnetic displacements and thermal stresses), the extended SIFs (mechanical SIFs corresponding to the crack mode I, II and III, electric SIFs K_4, magnetic SIFs K_5 and thermal SIFs K_6)、the extended strain energy factors(SEDFs) and the extended energy release rate are given. In addition, the numerical method for rectangular 3D crack is proposed by the body force method and some numerical solutions are calculated. For the special case, the results are compared with those obtained in literatures. Finally, the numerical solutions of extended SIFs (SEDFs) with varying the shape of crack are discussed.

2. Based on the above method, the arbitrary angle (stochastic) 3D cracks in FC-EMTE-MCs subjected to the electro-magneto-thermo-elastic coupled loads are reduced to solve a set of HIEs coupled with extended boundary conditions. The unknown functions are the extended displacement discontinuities of the multiple cracks surface. Then, the analytical solutions of the extended singular stresses, the extended SIFs, the extended SEDFs and the extended energy release rate are presented, respectively. Also, the numerical method for multiple 3D cracks is proposed by the extended body force method, and some numerical solutions are calculated under extended boundary condition to illustrate the accuracy and efficiency of the method. Finally, the relationship between extended SIFs (SEDFs) and the shape of flaw, the distance between two interface cracks, the properties of the materials and the electro-magneto-elastic coupling effects is discussed.

3. FC-EMTE-MCs typically exhibit pronounced nonlinear response under sufficiently higher electromagnetothermoelastic loading conditions. These extended loads are causing higher local extended stresses than under corresponding static loads and may induce crack initiation, crack growth and finally lead to fracture or failure of structures. Due to the importance of the reliability of these structures, viscoplastic fracture and failure analysis have received considerable interest in the recent decade. In this part, the general solutions of extended incremental displacement rate (creep viscoplastic incremental displacement rate, electrical incremental potential rate, magnetic incremental potential rate and thermal incremental potential rate) are obtained by time domain boundary element method. Then, applying main part method and extended boundary conditions, a 3D crack growth problem subjected to the extended incremental loads rate (incremental mechanical load rate, incremental electrical load rate, incremental magnetic load rate and incremental thermal

load rate) is reduced to solve a set of HIEs. The unknown functions are the extended incremental displacement discontinuities gradient (incremental creep viscoplastic displacement discontinuities gradient, incremental electrical potential gradient, incremental magnetic potential gradient and incremental thermal potential gradient) of the crack surface. Also, the singularity of the extended incremental displacement discontinuities gradient is analyzed. The analytical solution of the extended incremental singular stresses gradient (incremental singular stress gradient, incremental singular electric displacement gradient, incremental singular magnetic displacement gradient and incremental singular thermal stress gradient) and extended incremental $\dot{J}_i^g$ integral near the crack front are given. In addition, the numerical method of the HIE for a 3D crack subjected to extended incremental loads rate is proposed and some numerical solutions are calculated. For the special case, the results are compared with those obtained in literature. Finally, the results show that the present method yields smooth variations of extended crack incremental opening displacements (CIOD) along the crack front accurately.

4. The extended fundamental solutions of fully coupled electromagnetoelastic (anisotropic) multiphase composites in literatures are further studied by tensor transfer method and elastic theory. The compact formula of extended fundamental solution (elastic displacement, electrical potential and magnetic potential) is obtained. Then, applying main part method and extended boundary conditions, a 3D crack perpendicular to the interface of anisotropic electromagnetoelastic multiphase composites subjected to the extended loads (mechanical loads, electrical loads and magnetic loads) are reduced to solve a set of HIEs. The unknown functions are the extended displacement discontinuities (elastic displacement discontinuities, electric potential discontinuities, and magnetic potential discontinuities) of the crack surface. Also, the singularity of the extended displacement discontinuities is analyzed. The analytical solutions of the extended singular stresses (singular mechanical stresses, singular electric displacements and singular magnetic displacements), the extended SIFs (mechanical SIFs corresponding to the crack mode I, II and III, electric SIF K_4 and magnetic SIF K_5), the extended SEDFs and the extended strain release rate are carried out. In addition, a numerical method for rectangular 3D crack is proposed by the body force method and some numerical solutions are calculated. For the special case, the results are compared with those obtained in literature. Finally, the numerical solutions of extended SIFs with varying the shape of crack are discussed.

Key words: Fully coupled electromagnetothermalelastic multiple composites, Three-dimensional crack, Hypersingular integral equation method, Stress intensity factor, Strain energy intensity factor.

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