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Fracture Behaviour of Functionally Graded Materials Using Graded Finite Elements

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Abstract : In this research fracture behaviour of linear elastic isotropic functionally graded materials (FGMs) are investigated using modified finite element method (FEM). FGMs are advantageous because they enhance the bonding strength of two incompatible materials, and reduce the residual stress and thermal stress. Ceramic/metals are a main type of FGMs. Ceramic materials are brittle. So, there is high possibility of crack existence during fabrication or in-service loading. In addition, damage analysis is necessary for a safe and efficient design. FEM is a strong numerical tool for analyzing complicated problems. Thus, FEM is used to investigate the fracture behaviour of FGMs. Here an accurate 9-node biquadratic quadrilateral graded element is proposed in which the influence of the variation of material properties is considered at the element level. The stiffness matrix of graded elements is obtained using the principle of minimum potential energy. The implementation of graded elements prevents the forced sudden jump of material properties in traditional finite elements for modelling FGMs. Numerical results are verified with existing solutions. Different numerical simulations are carried out to model stationary crack problems in nonhomogeneous plates. In these simulations, material variation is supposed to happen in directions perpendicular and parallel to the crack line. Two special linear and exponential functions have been utilized to model the material gradient as they are mostly discussed in literature. Also, various sizes of the crack length are considered. A major difference in the fracture behaviour of FGMs and homogeneous materials is related to the break of material symmetry. For example, when the material gradation direction is normal to the crack line, even under applying the mode I loading there exists coupled modes I and II of fracture which originates from the induced shear in the model. Therefore, the necessity of the proper modelling of the material variation should be considered in capturing the fracture behaviour of FGMs specially, when the material gradient index is high. Fracture properties such as mode I and mode II stress intensity factors (SIFs), energy release rates, and field variables near the crack tip are investigated and compared with results obtained using conventional homogeneous elements. It is revealed that graded elements provide higher accuracy with less effort in comparison with conventional homogeneous elements.

Keywords : finite element, fracture mechanics, functionally graded materials, graded element
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