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Keywords

Circular disk; Functionally graded material; Stress intensity factor; Central crack

Abbreviations

FEA: Finite Element Analysis; LEFM: Linear Elastic Fracture Mechanics; SIFs: Stress Intensity Factors; APDL: Ansys Parametric Design Language; FGM: Functionally Graded Material; DCT: Displacement Correlation Technique

Mini Review

Numerical Study of the Fracture Behavior of a FGM Circular Disk

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Abstract

Finite element analysis (FEA) combined with the concepts of Linear Elastic fracture mechanics (LEFM) provides a practical and convenient means to study the fracture and crack growth of materials. In this paper, the mixed mode stress intensity factors (SIFs) for functionally graded material (FGM) are evaluated by means of the displacement correlation technique (DCT). Using the Ansys Parametric Design Language (APDL), the variation continues of the material properties is incorporated by specifying the material parameters at the centroid of each finite element. In this work, a circular disk with a center crack inclined is investigated. The developed approach is validated using available numerical results reported in the literature.

Introduction

Functionally Graded Materials (FGMs) are inhomogeneous materials which are widely used in technological application [1]. In recent years, those materials have been especially studied its mechanical behaviors using different approaches. Several results have been obtained in the linear elastic fracture context. Stress intensity factors for FGMs have been analytically computed or numerically evaluated by FE analyses under various loading conditions. The objective of this study is to present a numerical modeling of mixed-mode fracture in isotropic FGM disk. Using the APDL code, the DCT method is investigated to determine numerically the SIFs. In this work, the effect of material gradation and crack direction is analyzed. Good agreement and high convergence are observed between the proposed method results and the reference results available in the literature. Using the displacement correlation method, the SIFs are expressed by [2]:

$$K_I = \frac{G}{1+k_{tip}}\sqrt{\frac{2\pi}{L}}\left[4\left(v_b - v_d\right) - \left(v_c - v_e\right)\right] \quad (1)$$

$$K_{II} = \frac{G}{1+k_{tip}}\sqrt{\frac{2\pi}{L}}\left[4\left(u_b - u_d\right) - \left(v_c - v_e\right)\right] \quad (2)$$

Where G is the shear modulus, L is the element length, k_{tip} is defined as $\left(3-4\upsilon_{tip}\right)$ for plane strain and for plane stress, υ_{tip} is Poisson's ratio. u and v are the displacement components in the x and y directions (Figure 1).

Numerical Results and Discussion

Figure 2(a) shows a circular disk with a center crack inclined by 30°, subjected to concentrated couple forces. The structure considered is meshed by quadratic elements with 8 nodes and particularly, special elements were used to characterize the singularity around the crack, as shown in Figure 2(b). The variation of Young's modulus E along the radial direction R is given by $E(R) = \bar{E}e^{\beta R}$. The following data were used for the FEM analysis: a=1, R=10, β=-0.75, $\bar{E} = 1$, ν=0.3, P=100 units. The FGM disk is considered under plane stress conditions [3]. Figures (3a) & (3b) show respectively, the variation of the SIFs K_I and K_{II} as a function of β, with a/R=0.1.The FE results obtained for mixed mode SIFs are compared with those obtained in reference [4], using MMC and M-Integral methods. This comparison indicates a good agreement between the three approaches. Figures (4a) & (4b) illustrate the evolution of SIF as a function of the crack orientation θ, using different sizes (a/w). The FE results obtained for β=-0.75 which are only when the angle is zero, the SIF K_I takes maximum values, then it decreases progressively when the angle θ increases in absolute value, as shown in Figure 4a. When the (a/w) ratio increases, we notice the same pace of evolution but with higher SIF levels. The curves drawn for the negative and positive angles are symmetrical with respect to the vertical axis (MM'). The K_{II} curves evaluated are symmetric compared to the point P of coordinates (x, y)=(0,0), for a given crack length.

Conclusion

In this work, the SIFs in FGMs subject to quasi-static loadings are estimation by means of a displacement correlation approach in combination with the FE analysis. The present results showed very good agreement with the numerical results reported in the literature. The crack orientation and the material gradation have an influence on the mixed-mode SIFs evaluation under mixed mode conditions.

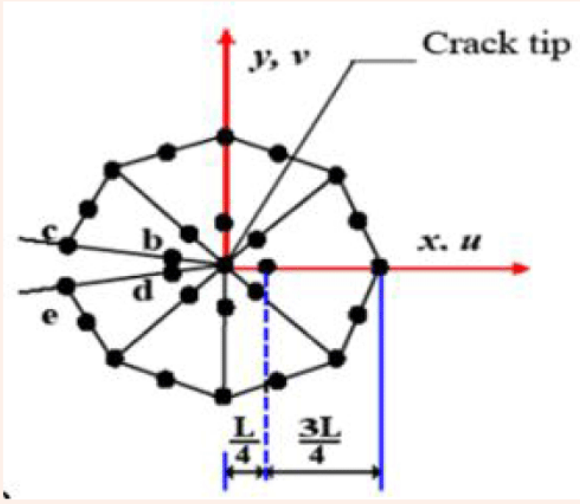

Figure 1: Special quarter point FE.

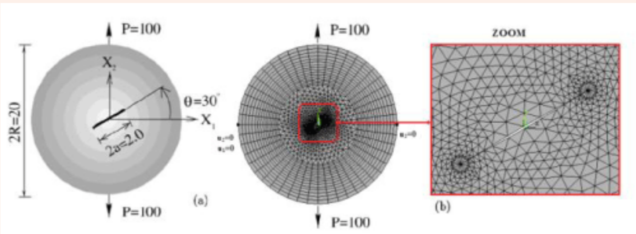

Figure 2: FGM circular Disk: a) Geometrical model, b) Typical FE mesh.

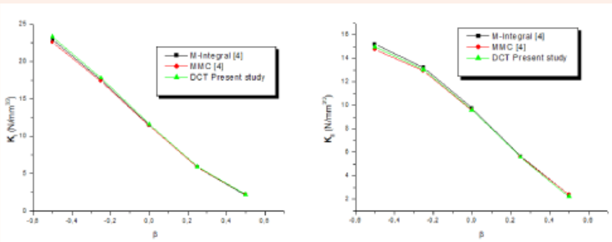

Figure 3: SIFs KI and KII vs. β.

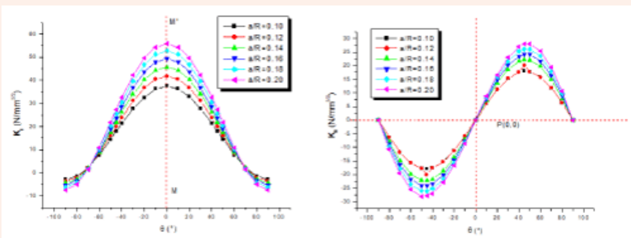

Figure 4: Evolution of KI and KII vs. crack direction θ.

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