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The analysis of the behavior crack in different materials

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ABSTRACT/RESUME

Abstract: *The aims of this study present a three-dimensional finite element method for the analysis of fractures in a mixed mode of two materials the Functionally Graded (FGM) and the composite materials. The modeling was carried out on a hull containing an inclined crack, provided by a fine mesh around these crack points due to singular elements. The structure is examined under the effect of transient thermal stresses. The singularity of the deformations around the crack front is simulated by singular elements. The stress intensity factors of modes I, II are calculated by applying the displacement extrapolation technique (DET) and presented as a function of time. The different types of FGM are examined in parametric analyzes which are rich in metals, rich in ceramics. The results provided illustrate the influences of the inclination angle of the cracks on the transient behavior of the stress intensity factors in mixed mode. The mechanical behavior of this material has been described by the exponential function The numerical evaluation of this factor is determined using the Numerical code.*

I. Introduction

The transition from metallic materials to composite materials entails significant costs, but it is in fact a medium and long-term investment. The in-homogeneity and anisotropy of composite materials make their damage mechanisms more numerous and more complex. Within a composite structure, we can see a damage consisting of micro- décohesions and micro-cracks, breaks in folds, fractures of fibers and dies, décohesion of the interface [17]. Composite materials are as their name suggests, consisting of various materials, each with specific properties and functions. Generally, a composite comprises a matrix (resin) in which a reinforcement (fibers) is dispensed in order to improve the properties of the product.

Functionally Graded Materials (FGM) or functionally graded materials are a new class of composite materials whose microstructure and composition very gradually and continuously with the position to optimize the mechanical and thermal performance of the structure that 'they constitute. They are considered as intelligent materials whose desired functions are integrated, from the design, at the very heart of the material. At each interface, the material is chosen according to specific applications and environmental loads. These materials have multiple advantages which can make them attractive from their application potential. It can be an improvement in rigidity, resistance to fatigue, resistance to corrosion or thermal conductivity. The original idea of the concept of FGM materials was proposed in 1984 by Japanese researchers, for the preparation of new materials in the construction of the thermal barrier [1]. This technology solves the problem of

the interface between two materials by eliminating discontinuities and improves resistance to delamination and crack propagation [2].
The use of this type of material in space structures and fusion reactors subjected to severe thermal loads which can lead to the engagement of structural components [3]. The increased use of advanced materials in structural elements has aroused the interest of researchers for the study of the response of FGM plates used in fields with high mechanical and thermal stresses.
The study of crack behavior is a fundamental axis in the study of the lifetime of a structure. It is based on the principles of fracture mechanics, in particular by calculating the stress intensity factor. In recent years a lot of research has been devoted to analyzing the static and dynamic behavior of different structural elements, such as thin plates, pipes, FGM beams under mechanical loading, as well as thermal loads. For functionally graduated materials, analytical solutions to study the behavior of cracks are limited to relatively simple geometries and also to loading conditions. The first analytical model was proposed by Erdogan et al. [4] to describe the behavior of cracks of FGM plates, they treated the problem of plane elasticity for two glued half-planes containing a crack perpendicular to the interface and to identify the effect of variation of properties of materials near the plane of diffusion on the stress intensity factor. Rousseau et al. [5]. Several numerical methods have been proposed to evaluate the state of stresses in the vicinity of crack, among which, one finds the method of the finite elements which becomes an essential tool to analyze the behavior of cracks. Ozturk and Erdogan [6] have examined the problem of symmetric cracking in FGM materials for which they have assumed that the properties of the medium vary in one direction and symmetrical in the other direction solicited in mixed mode. The study is based on the determination of the stress intensity factors FIC by the method of extrapolation of the displacement DET. The effect of non-homogeneity on the numerical computation of J-integral was also studied in this research. Paneda et al. [9], based on the exponential law which describes the continuous variation of FGM material by the integration of subroutines written in FORTRAN for the analysis of the stress field near the crack. R.J.Butcher [10] used optical measurements to know the parameters of the rupture of the behavior at the tip of a crack in functionally graduated materials and these results are also compared with numerical calculations by finite elements. Sevcıka et al. [11] have developed an FE model, using the power law to study the influence of the material distribution of the FGM layer on the variation of the stress intensity factor in mode I.
In this work, we will focus on determining the intensity factor of mixed-mode stress and buckling factor in the case of a central crack supposedly initiated in a composite cylinder, stressed at uni-axial loading. These numerical calculations are done using the finite element method using the numerical code. The evolution of the FIC is based on the displacement extrapolation method

II. Materials and methods

II.1. Stress Intensity Factors

Within the framework of the linear fracture mechanics, the stress intensity factors for the case of homogeneous materials can calculate from several techniques (integral method J [12]; method of a virtual extension of the crack [13]; displacement correlation method [14]; displacement extrapolation method [7]). In this numerical study, we used the last technique to determine the stress intensity factors KI and KII in the case of FGMs materials. In this case, the factors KI and KII can be calculated from the relations [7]:

$$K_I = \frac{E_{tip}}{3(1+\nu_{tip})(1+k_{tip})}\sqrt{\frac{2\pi}{L}}\,[4(v_b - v_d) - \frac{(v_c - v_e)}{2}],$$

$$K_{II} = \frac{E_{tip}}{3(1+\nu_{tip})(1+k_{tip})}\sqrt{\frac{2\pi}{L}}\,(4(u_b - u_d) - \frac{(u_c - u_e)}{2}),$$

Where:
E_{tip} is Young's module
ν_{tip} is the Poisson coefficient.
These parameters are calculated with the point of the crack.
.K is stress intensity factors MPa $\sqrt{m}$
a, b, c and d represent the position of the nodes around the point of crack (figure 1).
L is the length of the singular element.
u and v are respectively the displacements according to the directions x and y (figure 1).
In linear elasticity, the parameter k is defined by:

$$k_{tip} = \begin{cases} \frac{3-\vartheta_{tip}}{1+\vartheta_{tip}} & \text{in plane stress} \\ 3 - 4\,\vartheta_{tip} & \text{in plane deformation} \end{cases} \quad (3)$$

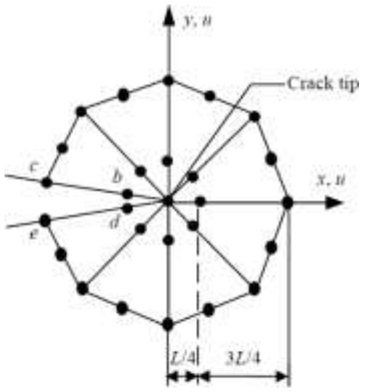

Figure 1. *Singular elements with knots at the quarter of the sides.*

II.2. The stress – strain relationships

The stress – strain relationships are given by the material low [16] :

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{Bmatrix}=\begin{bmatrix}\overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16}\\ \overline{Q}_{12} & \overline{Q}_{22} & \overline{Q}_{26}\\ \overline{Q}_{16} & \overline{Q}_{26} & \overline{Q}_{66}\end{bmatrix}\begin{Bmatrix}\varepsilon_x^0\\ \varepsilon_y^0\\ \gamma_{xy}^0\end{Bmatrix}+z\begin{bmatrix}\overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16}\\ \overline{Q}_{12} & \overline{Q}_{22} & \overline{Q}_{26}\\ \overline{Q}_{16} & \overline{Q}_{26} & \overline{Q}_{66}\end{bmatrix}\begin{Bmatrix}k_x\\ k_y\\ k_{xy}\end{Bmatrix}$$

III. Results and discussion

III.1. Influence of the fold orientation on the buckling parameter

III.1. 1. Geometrical model

In this study, we consider a hull of length H = 3000mm and diameter d = 1000mm. The ratio of the shell is H / d = 3 and the total thickness is e = 2.4mm. The plate consists of twelve folds, each of which is 0.2mm thick. The layers are crossed in an orderly fashion at an angle θ and -θ respectively (Figure 2). The hull is considered as biased in axial compression in the vertical direction. We used the finite element analyze and quadrilateral elements with a refined and structured mesh near the crack. The resolution was made in the state of aircraft constraints. The plate is embedded in the lower part and in the upper part, only the displacement u2 is free.

III.1.2. Mechanical properties of the hull

Table 1. *Mechanical characteristics of carbon/epoxy*

E_1 (MPa)	E_2 (MPa)	E_3 (MPa)	ν_{12}	G_{12} (MPa)	G_{13} (MPa)	G_{23} (MPa)
130000	10000	10000	0.31	4850	3620	4850

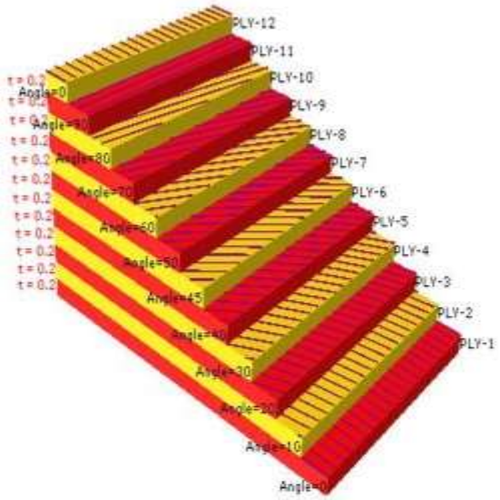

Figure 2. *Orientation of the folds in the laminated plate*

III.2. Effect of inclined crack

The aim of this work is to have a comparative state between the behavior of a crack at the level of a composite material and a functionally graduated material.

III.2.1. The behavior of a crack in a composite material

In Figures 3,4 and 5 we illustrate the evolution of the buckling parameter as a function of the orientation angle of the folds of the composite material in the presence of the crack inclined with respect to the horizontal at 10 °respectively. The size of the crack considered is 20mm. Figures (3 and 4) show an alternation between the value of λ between a maximum and a minimum value between 45 ° - 60 ° and 10 ° - 30 ° respectively.
When the crack is inclined, we observe that the results represented on the Fig 3,4and Fig 5 is identical following the weak value of the angle which is 10°.

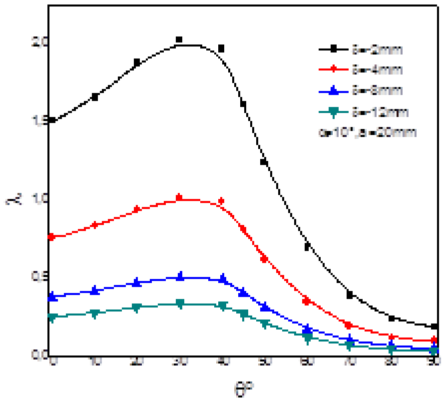

Figure 3. *Variation of the buckling parameter of the inclined crack (α=10°) depending on the orientation of the folds*

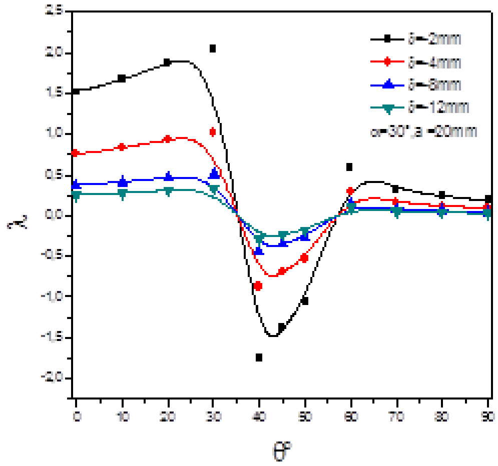

Figure 4. *Variation of the buckling parameter of the inclined crack (α = 30 °) depending on the orientation of the folds*

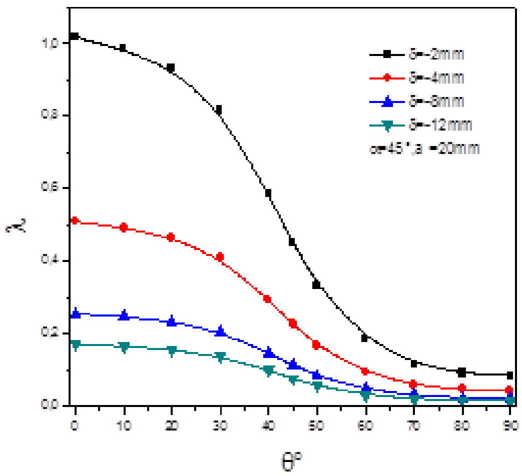

Figure 5. *Variation of the buckling parameter of the inclined crack (α=45°) depending on the orientation of the folds.*

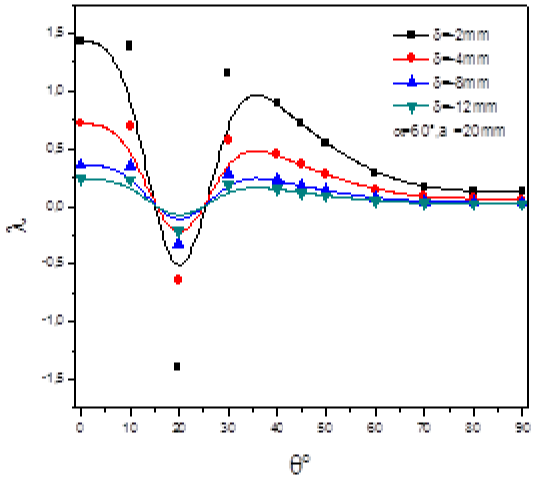

Figure 6. *Variation of the buckling parameter of the inclined crack (α = 60 °) depending on the orientation of the folds.*

III.2.2. The behavior of a crack in a Functionally Graded Materials

In Figures 7,8 we observed that the increase in the stress intensity factor **KI** is proportional to the length of the crack as an exponential figure.

In the Figure.9 represents the distribution of the dimensionless radial stress **σrr / Pi**, according to the radius through the wall of the cylinder for different values of the parameter of inhomogeneity **β** = [- 2, −1,0,1,2].

For negative values of **β**, the radial stress is greater, while for positive values of **β**, the stress is weaker.

We present the variation of the stress intensity factor as a function of **a / c** in Figure.10.

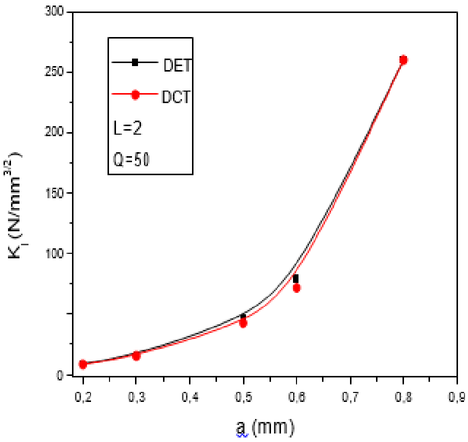

Figure 7. *Variation of K_I depending on the inclined angles in comparison with two method DET and DCT charge(Q=50)*

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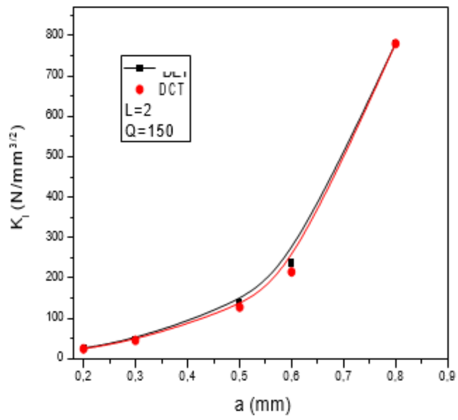

Figure 8. *Variation of K_I depending on the inclined angles in comparison with two method DET and DCT charge(Q=150)*

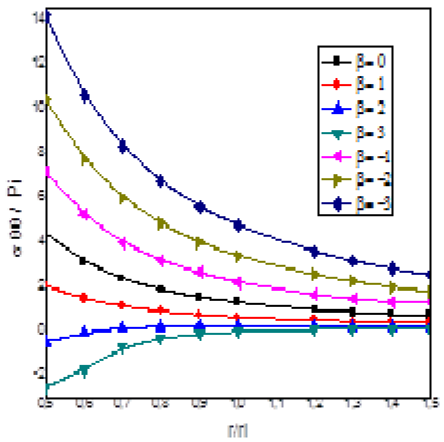

Figure 9. *Distribution of circumferential stress across the wall of the pressurized cylinder.*

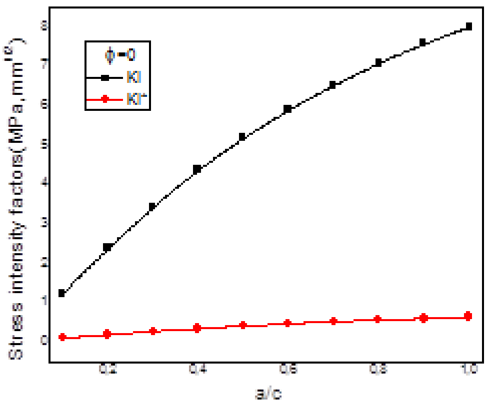

Figure 10. *Variation of the stress intensity factor as a function of a / c*

IV. Conclusion

The objective of the study is to determine the effect of the fibers (folds) orientation on the buckling parameter factor λ evolution, the effect of the inclined crack in the middle of the circular hull. geometric effect and the position of the crack.

We had observed that when one is in the edge of shell the behavior of the crack changes

The displacement extrapolation (DET) technique has been successfully implemented in the finite element code, using the ANSYS Parametric Design Language (APDL) scripting language. This characterization can be very interesting to simulate the propagation of cracks in materials with a functional gradient.

In the future work, we will analyze the variation the stress intensity factor with the J-integral.

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