NUMERICAL EVALUATION OF MIXED MODE DELAMINATION IN A U-GLASS/EPOXY COMPOSITE IN 2D AND 3D STATES

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Summary In this paper the delamination phenomena in the mixed mode I+II that is one of the important causes of failure in multilayer composites, is studied. Finite element analysis is used to evaluate fracture mechanic parameters of the composite. 2D (2 Dimension), and 3D (3 Dimension) analysis are carried out. Then the obtained numerical results are compared with the existing experimental and discussed.

INTRODUCTION

The composite is a glass fiber reinforced plastic and is studied under static monotonic loading. Using Irwin-Kies criteria, usual laws of elasticity and VCCT (Virtual Crack Closure Technique), based on finite element method, the SERR (Strain Energy Release Rate) in mode I, mode II, and four ratio modes (G_I/G_{II}) is evaluated. The finite element analysis of test bars is carried out using ANSYS5.5 software in two dimensions, and boundary conditions are chosen to bring the analysis in the vicinity of reality. Our numerical results are compared with existing experimental ones and with application of the local effects, such as 3D effect in the width of the test bar with the shape of MMB (Mixed Mode Bending)[1] specimen, the scattering between experimental and numerical results is evaluated and discussed. For the 3D effect, the variation of the stress components in the plan of delamination versus the width of specimen is obtained. Then the variation of strain energy release rate in the different ratio modes, in the width of test bars is calculated.

Table 1: Mechanical properties and geometry of the test bar

Specimen Dimension	Mechanical Property
L = 65 mm	E_{11} = 25.7 GPa (±8%)
2h = 5 mm	E_{22} = 6.5 GPa (±8%)
b = 20 mm	G_{12} = 2.5 GPa (±8%)
L_T = 150 mm	υ_{12} = 0.32 (±8%)
a_0 = 35 mm	ν_{fibre} = 35.4% (±1%)
	ν_{void} = 4.2% (±1%)

FINITE ELEMENT METHOD

In this section, VCCT method is used and the components of strain energy release rate are obtained with the following relations:

$$G_I = \lim_{\Delta a \to 0} \frac{1}{2b\Delta a} p_y^0(\nu_1 - \nu_2)$$

$$G_{II} = \lim_{\Delta a \to 0} \frac{1}{2b\Delta a} P_x^0(u_1 - u_2)$$

u and v are the relative displacement between nodes 1 and 2. Da is the length of crack which should close virtually. P_x^0 and P_y^0 are the loading components, which are used for the closure of the crack.

FINITE ELEMENT MODEL OF MMB SPECIMEN

For 2D modeling, we have used eight noded solid elements and singularity elements with quarter point nodes at crack tip. As the width of specimen is higher than his thickness, the problem is studied in plane strain state. As the stress concentration zone is smaller relative to the dimensions of the specimen, only a small zone in crack tip is mesh generated with high density. The type of elements leads to the singularity of stresses and strains at the end of the crack.
In 3D finite element model, we have used twenty noded solid elements. The goal of 3D modeling is analyzing the stress and strain energy in the width of specimen [2]. The elements are refined regularly at the width of the crack. The coordinated system is situated at the end of the crack and z-axis is on the direction of the width of specimen. As the boundary conditions and dimensions of 3D specimen are symmetrical relative to xy plane, only the half of specimen is modeled.
Because of the sliding of the faces on each other, in 2D and 3D models, contact elements are used.

RUPTURES IN THE END OF THE CRACK

In the studying of delamination, identification of the beginning of the crack propagation is a discussible case. In this paper, with using the finite element analysis of specimen, different stresses in the end of the crack are calculated. Using rupture criteria in composite materials and calculated stresses in the end of the crack, we analyze the delamination. From the mechanical point of view, the composite materials with epoxy resin matrix operate as the brittle materials. So the plastic zone in the end of the crack is very small and in the theoretical analyses and in the finite element model, the rupture in the end of the crack is considered only elastic.

EXPERIMENTAL CRITERIA OF RUPTURE

The point of the initiation of crack in an experimental specimen is obtained using three methods. In the first method, the crack growth leads to a deviation of the curve of load-displacement from the linear state. The point of deviation is called NL, which is not always easily distinguishable [3]. In the second method a line with a slope less than 5% of the initial slope of the curve of load-displacement is considered [4]. The intersection of this line with the curve of load-displacement is the beginning point of crack propagation. In the third method, point AE (Acoustic Emission), which corresponds to the registration of the first signal during the test, is defined as the beginning of the crack growth.

2D RESULTS

Numerical analyses of the specimen are carried out as per experimental in pure mode I, pure mode II, and four ratios of mode (G_{II}/G_I) 0.25, 0.50, 0.75 and 0.89 with a precrack of a=35mm. The stress distribution σ_x has the same shape for all of the mode ratios and it has not a significant influence in the crack growth because of the high strength of the composite specimen in the x-axis direction. The σ_y distribution for the mode ratios, for which mode I exists, has the shape of two tangent circles (Bean Shape). The maximum stress in y direction has the highest distribution and is the principal cause of crack growth in mode I. The lowest distribution is in x direction. The τ_{xy} distribution for the mode ratios in which mode II exist has a spindle shape. The maximum stress in x direction has the highest distribution and is the principal cause of crack growth in mode II. The lowest distribution is observed in y direction. The maximum stress σ_y in pure loading of mode II and τ_{xy} in pure loading of mode I happens in a zone farther than crack tip and it can deviate the crack from it's principal route.

3D RESULTS

Results explain the variation of stress in the width of specimen and 3D effects. In all of the cases, pick of the curve is situated at crack tip. The highest value of σ_x and σ_y is on the middle of specimen width and decreases in the margins. On the mode ratios which mode II loading exists, the transversal strains of the upper and lower layers of crack plane are in opposite direction on z-axis. This phenomenon leads to slide these layers on each other, maximize τ_{xz} in the margins and use a part of the strain energy for the mode III. The τ_{xy} stress distribution is a composition of above-mentioned cases.

For all ratios in which mode II is associated, we observe a local increasing of G_{III} in the margins. The G_{total} variation in the different ratio of modes is influenced by G_I, G_{II} and G_{III} behavior.

CONCLUSION

2D model and plane strain conditions cannot explain completely the stress distribution in crack width and regarding above behaviors, the fracture toughness of the 3D model is lower than the 2D model. In pure mode II loading, sliding of layers has an important influence in the increasing of the fracture toughness of 3D relative to 2D model. 3D effects of model are applied as a percentage of error to the results of fracture toughness of 2D model. Experimental results of NL and AE have a better agreement with together, for the ratios of G_{II}/G_T, from 0 until 89%. The fracture toughness of 3D model G_{3D} has decreased in maximum 39% relative to the fracture toughness of 2D model G_{2D} and for the pure mode II loading has increased 35%. In all the cases with increasing of mode II loading component, the fracture toughness increases.

References:

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