Research Paper

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Influence of Stiffeners on Fracture Parameters in Isotropic and Orthotropic Materials

Engineering

KEYWORDS : J- integral, FEA, stiffener, crack length, orthotropic

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ABSTRACT

In this investigation, J-integral for the cracked panel with stiffeners is studied considering the finite element models. In the first case, the panel with two stiffeners is examined where in position of the stiffeners is increased. The crack length is varied keeping the stiffener at one inch from the crack tip is presented as case two. Isotropic (steel and aluminum) and orthotropic materials (glass epoxy and graphite epoxy) are selected for the whole stiffened panel. The finite element models for different stiffener and crack configurations are generated using ANSYS11 and the non dimensional value of the J- integral is calculated and is plotted against position of the stiffener for case one and crack length for case two. The presence of stiffeners made significant contribution in the reduction of J-integral when compared with the sample without stiffeners.

1. INTRODUCTION AND LITERATURE REVIEW

Due to light weight and high operating stresses aircraft structure is a prominent example where structural efficiency is high. There are few important parameters that need to be considered – capability to generate at a reasonable cost, adequate service life [1] and perform the required function. Sheets and stringers which include fuselage skin panels, wings, spar webs, stiffener form the important part in the making of aircraft structures. Cracks arise in these structural elements thereby reducing the total load carrying capacity and the stiffness of the structure. The need for light weight, large scale metallic structure has brought new set of problems related to fracture. The weight of the aircraft is addresses by thin skin and stringers. By adhesive bonding or riveting stringers are joined to the skin. S Habeeb [2] et al examined the load bearing characteristics and crack arresting capabilities in a stiffened and unstiffened panel subjected to uniform remote displacement field. From linear elastic analysis there is a decrease in stress intensity factor when the crack approached the stiffener. Franc2dl code was used to perform fracture analyses on adhesively bonded stiffened panel. When fuselage is pressurized and depressurized during each take off and landing cycle of aircraft, the metal skin of fuselage expands and contracts, resulting in metal fatigue. Due to the presence of large number of rivet holes, the fuselage skin has large number of high stress locations and these are locations of potential crack initiation. From the principles of displacement compatibility and superposition, Rans et al [3], presented an analytical model for estimating fracture parameters in cracked skin panels containing bonded stiffening elements. Results were validated with the experimental data available in literature. Superposition, fracture mechanics and displacement compatibility approach used by Poe [4] was adopted by Alderliesten [5-11] to understand the crack growth behavior of fiber metal laminates. Venkatesha et al [1] investigated crack initiation, crack growth, fast fracture and crack arrest features in the stiffened panel. MSC Patran software was used for modeling and MSC Nastran - Solver for linear static stress analysis of stiffened panel of fuselage. Fracture mechanics provides a tool for assessing the criticality of flaws in structures that can be used directly according to Barsom and Rolfe [12]. They also state that the science of fracture mechanics can be used to describe quantitatively the trade-offs among stresses, material toughness, and flaw size.

2. PROBLEM FORMULATION

In the present work, J-integral is estimated with the help of ANSYS package. Two problems are selected. In the first problem shown in figure 1, aircraft panel having crack is examined to evaluate J-integral. As an extension of the same, stiffeners is added and J-integral is determined with variation in the position of the stiffener is shown in figure 2. In case two, the position of the stiffener is kept constant (one inch from the crack tip) and the crack length is varied to find out the non-dimensionalised J-integral values. In the second case one stiffener is used while in the first case, two stiffeners are placed uniformly on the aircraft panel.

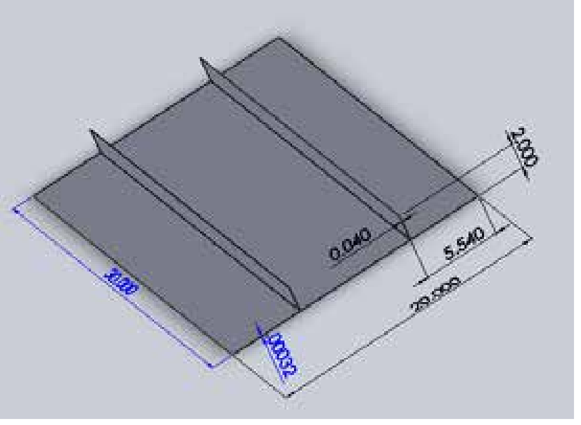

Figure 1: Plate with stiffener

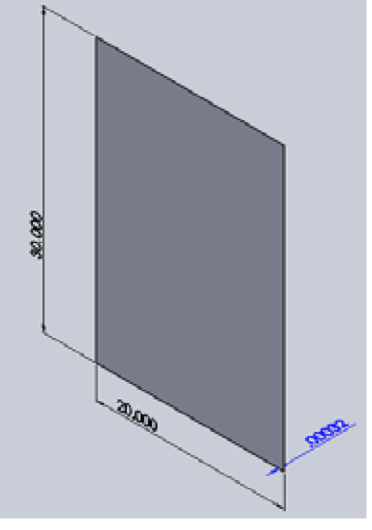

Figure 2: Plate without stiffener

3. METHODOLOGY

Rice [13] defined a path-independent J-integral for two-dimensional crack problems in linear and nonlinear elastic materials. As shown in Figure 3, J is the line integral surrounding a two-dimensional crack tip is given by the equation (1)

$$J = \int_{\Gamma} \left(W dy - T \frac{\partial u}{\partial x} ds \right) \qquad (1)$$

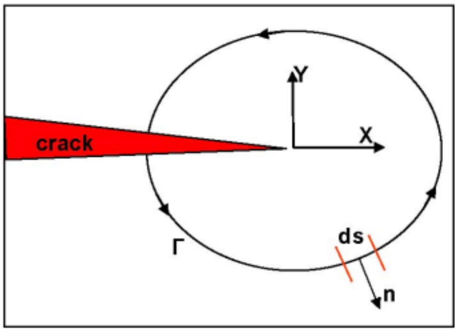

Figure 3: crack tip co-ordinate system and typical line integral contour

From the figure 3, Γ is the curve surrounding the notch tip, along the path Γ to the upper surface. In equation 1, T is the traction vector, u is the displacement vector, and ds is an element arc length along Γ. Rice [13] proved the path independent concepts and found that for small-scale yielding the stress energy release rate G is equal to the J-integral. The correctness of J-integral mentioned in ANSYS package is validated in [14]

To model the case studies mentioned in the problem forumlation, plane 82 element is selected from ANSYS [15] library. The element has four corner nodes and four mid side nodes and each node has two translational degrees of freedom at each node. Under the element behaviour, plane stress with thickness is selected to model the aircraft panel. Beam 189 element is selected to model the stiffener. For this element, there is a pre defined shape of the stiffener is used that comes with ANSYS software. The element has 3 nodes and each node has three translational and rotational degrees of freedom. To model the given structure properly, orientation keypoint is also available with this element.

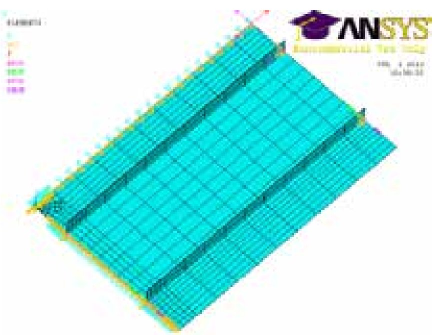

Figure 4: FE mesh of plate with stiffener

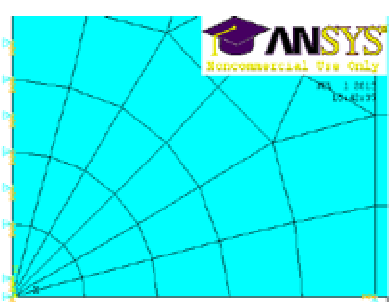

Figure 5: FE mesh at the crack tip

4. RESULTS AND DISCUSSION

From the figure 6, it is noticed that minimum values of non dimensionalised values of J-integral is observed for Aluminum material and maximum value for both steel and graphite epoxy materials when the stiffener position is placed uniformly upto 5.5. At 6.5, 7.5 and 8.5 location of the stiffener, maximum value of non dimensionalised value of J-integral is seen for Steel. Intermediate values of non dimensionalised value of J-integral are noticed for glass epoxy material. When the stiffener position is 3.5 from either side, least value of non-dimensionalised J-integral is observed for aluminum and a high value of 0.092 is seen for the same material when the stiffener position is 8.5. For steel, the maximum and minimum values of non dimensionalised J-integrals are noticed to be 0.011 and 0.006 at 8.5in and 3.5in positions of the stiffener. From these observations it is inferred that similar behavior is seen when the position of the stiffener is at 3.5 and 8.5 inches for isotropic materials used in the present work. For graphite epoxy and glass epoxy materials, when the stiffener position is 3.5in, minimum values of non dimensionalised J-integrals values are obtained whose magnitude is 0.051 and 0.019 respectively. 0.08 and 0.032 are the values of non dimensionalised J-integrals when the stiffener position is 7.5 in for graphite epoxy and glass epoxy materials.

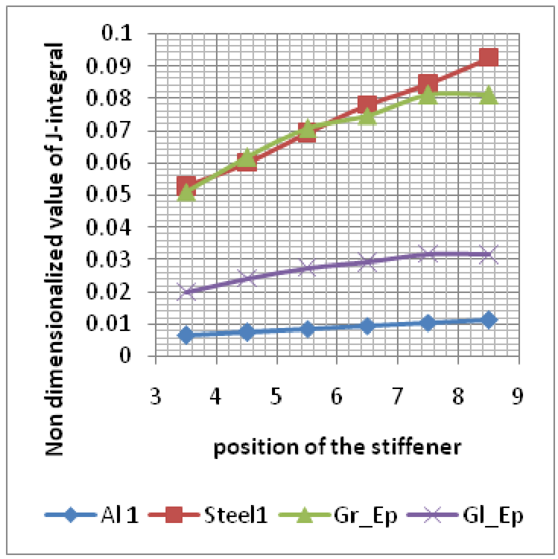

Figure 6: Variation of non dimensionalised value of J-integral for isotropic and orthotropic materials with change in position of the stiffener

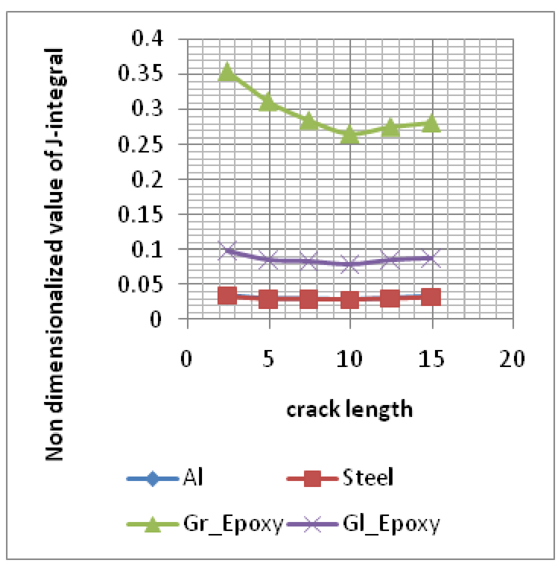

Figure 7: Variation of non dimensionalised J-integral for isotropic and orthotropic materials with increase in the crack length

From the figure 6, it is noticed that minimum values of non dimensionalised values of J-integral is observed for steel and aluminum and maximum value for graphite epoxy material with variation in crack length from 2.5 in to 15 in. Intermediate values of non dimensionalised values of J-integral are observed for Glass epoxy material. When the crack length is 2.5 in, maximum values of non dimensionalised value of strain energy release rate is achieved whose value is 0.034 (aluminum and steel), 0.35 (graphite epoxy) and 0.098 (glass epoxy). The minimum values of non dimensionalised values of J-integrals obtained are 0.027 (aluminum), 0.028 (steel), 0.265 (graphite epoxy) and 0.078 (glass epoxy) at the crack length of 10 in respectively.

5. CONCLUSIONS

1. From the inferences made in this section, least values of non dimensionalised J-integral are achieved when the position is at 3.5 in for both isotropic and orthotropic materials. When the position of the stiffener is at 8.5 in, high values of non dimensionalised J-integral is noticed for isotropic materials, while when the position of the stiffener is 7.5 in, high values of the same are seen for orthotropic materials.
2. Maximum and minimum values of non dimensionalised J-integral are achieved when the crack length is 2.5 in and 10 in for both isotropic and orthotropic materials.

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