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Delamination Damage Propagation Studies of Laminated Composite Stiffened Panels

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Abstract

Delamination and debonding may lower the buckling load of the stiffened panel causing structural instability. Integrally stiffened composite panels are susceptible to two types of defects: skin delamination and stringer debonding. A defect is defined as structurally significant if its presence will produce a marked change in the structural characteristics of the component. The changes to the physical state and mechanical properties of the composite component are such that they would cause unacceptable load responses. . A further approach namely postbuckling is to design structures that can withstand high loads even after they have buckled. The concept of postbuckling design offers possibilities to improve the structural efficiency, particularly in combination with composite materials. By allowing buckling in a structure, the ultimate load can be increased. composites, offer plasticity effects to evade high stress concentrations during postbuckling. The aim of the paper is to study the delaminaton damage of composite stiffened panel made of carbon epoxy. The delamination between interfaces of stiffeners and skin, in between layers skin and in between stiffeners may be studied to predict the design of defect free panel.

Key words: Strees intensity factor; Energy realease rate; Stress; Opening mode; tearing mode.

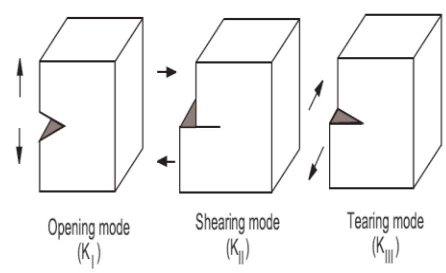
INTRODUCTION

Cracks and flaws occur in many structures and components for several reasons. The material may be inherently defective. Cracks may be introduced during the manufacturing stage, or later as a result of environmental conditions. The presence of such cracks or flaws can significantly degrade the structural integrity of a component under the action of applied loads and environmental conditions.

Fracture Modes

Depending on the failure kinematics (that is, the relative movement of the two surfaces of the crack), three fracture modes are distinguishable, as shown in

- **Mode I** – Opening or tensile mode
- **Mode II** – Shearing or sliding mode
- **Mode III** – Tearing or out-of-plane mode



The following parameters are widely used in fracture mechanics analysis:

I)Stress-intensityfactor

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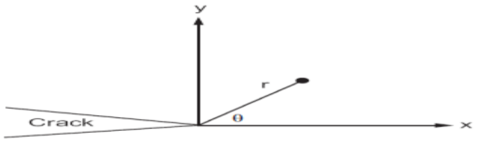


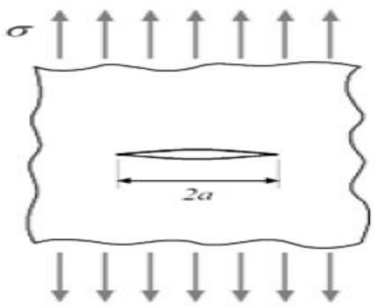
For a Mode I crack, the stress field is given as:

$$\sigma_x = \frac{K_I}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)\left(1 - \sin\left(\frac{\theta}{2}\right)\sin\left(\frac{3\theta}{2}\right)\right)$$

$$\sigma_y = \frac{K_I}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)\left(1 + \sin\left(\frac{\theta}{2}\right)\sin\left(\frac{3\theta}{2}\right)\right)$$

$$\sigma_{xy} = \frac{K_I}{\sqrt{2\pi r}} \cos\left(\frac{\theta}{2}\right)\sin\left(\frac{\theta}{2}\right)\cos\left(\frac{3\theta}{2}\right)$$

II)Energy-Release Rate: The energy-release rate G is defined in elastic materials as the rate of change of potential energy released from a structure when a crack opens.



The energy-release rate is given by:

$$G = \frac{\pi\sigma^2 a}{E}$$

At the moment of fracture, G is equal to the critical energy-release rate Gc, a function of the fracture toughness. The value of Gc for a material can be determined via a relatively straightforward set of crack experiments.

III)J-Integral:

J-Integral is one of the most widely accepted parameters for elastic-plastic fracture mechanics. The J-Integral is defined as follows:

$$J = \lim_{\Gamma \to 0} \int_{\Gamma_0} \left[(w + T)\delta_{li} - \sigma_{ij} \frac{\partial u_j}{\partial x_l} \right] n_l \, d\Gamma$$

W is the strain energy density,
T is the kinematic energy density,
u is the displacement vector, Γ
Γ is the contour over which the integration is carried out.

Delamination, a type of damage that is unique to laminated structures, it is the interlaminar separation of a composite laminate and is one of the primary failure modes of laminated composite materials. Delamination can produce asymmetric sub-laminates and final failure of the laminate is due to the resultant increase in the net section stresses and out-of-plane bending and twisting due to asymmetry. Failure of an intact stiffened panel is often associated with the separation of the stiffener from the skin, as opposed to an in-plane material failure. In the post buckling regime, failure of a composite stiffened panel is usually induced by the separation failure of a skin–stiffener interface. If the stiffened panel contains an initial defect of stringer debonding, premature failure of the structure may result if the loading conditions promote separation of stringer and skin. The torsional and rotational stiffness of the stringer plays an important role in the failure of stiffened panels.

Delamination and debonding may lower the buckling load of the stiffened panel causing structural instability. The local stiffness degrades with the creation of sub laminates and local buckling strains are substantially reduced. Local delamination or debonding can be considered as a crack in the bond between two plies and propagation can be treated as crack growth. It is reasonable to adopt the concepts of fracture mechanics forthe analysis of damage growth using linear elastic assumptions. The stresses at the crack front may promote further splitting/separation when buckling occurs. Integrally stiffened composite panels are susceptible to two types of defects: skin delamination and stringer debonding. A defect is defined as structurally significant if its presence will produce a marked change in the structural characteristics of the component. The changes to the physical

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state and mechanical properties of the composite component are such that they would cause unacceptable load responses.

In recent years carbon fibre-reinforced polymers (CFRP) emerged in aerospace engineering. Due to their high specific strength and stiffness these composites offer considerable advantages compared to metals. A further approach namely postbuckling is to design structures that can withstand high loads even after they have buckled. The concept of postbuckling design offers possibilities to improve the structural efficiency, particularly in combination with composite materials. By allowing buckling in a structure, the ultimate load can be increased. Metals, unlike composites, offer plasticity effects to evade high stress concentrations during postbuckling. Under compressive load, composite structures show a wide range of damage mechanisms where a set of damage modes combined together might lead to the eventual structural collapse.

FEA Modeling of Composite stiffened Panel:

Description:

- The assembly model consists of three parts. They are skin, stiffener and web.
- The element type used is solid 186. Hexahedral mesh has been used.
- The crack front has kept at distance of 126mm from one end.
- The load has applied in the different cases.
- Virtual Crack Closure technique has been used.
- Appropriate commands which supports for VCCT technique has used to extract results.

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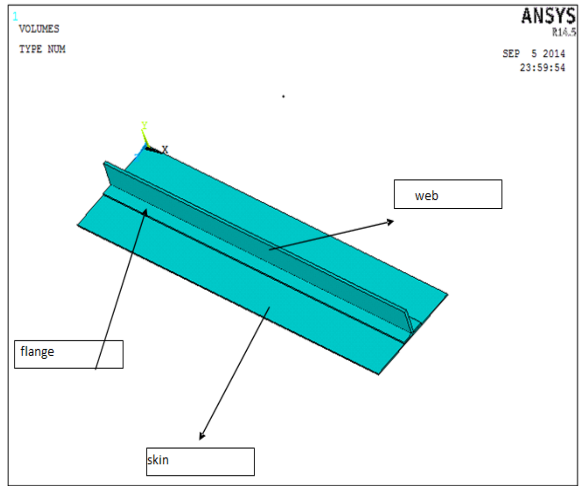
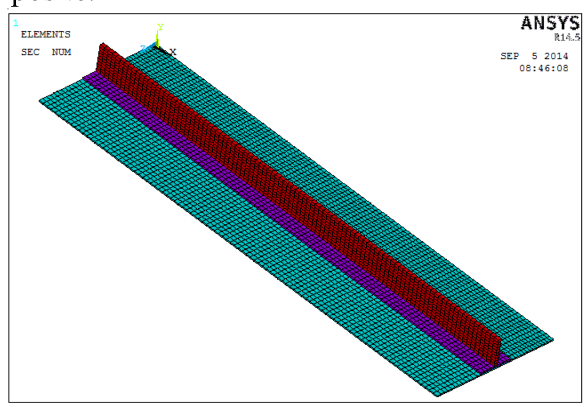


The element type used is solid 186. Hexahedral mesh has been used. The crack front has kept at distance of 126mm from one end

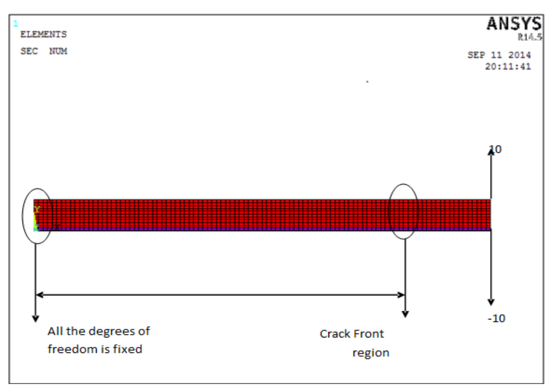
Hexahedral mesh has used.

Element type is solid186.

The material used is glass epoxy composite.



Boundary conditions:



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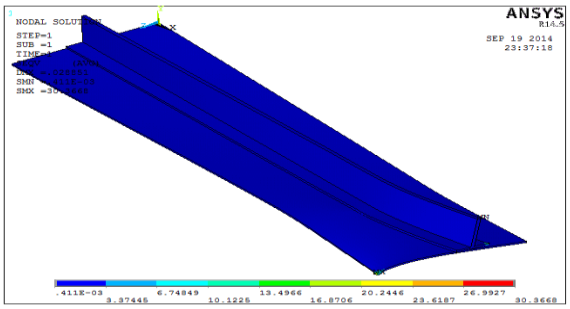
The load has applied in the different cases:

The load applied on the panel in different modes with different orientations 0,30,45,90 degrees.

Load case tearing mode:30Deg Orientation of Interface Plate:

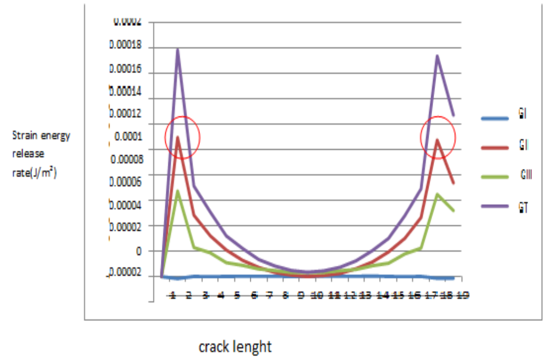
Stress Plot



Strain Energy Release Rate Values:

S.No:	Crack Front Node	GI	GII	GIII	GT
1	5777	0	0	0	0
2	3008	-1.47E-06	1.10E-04	6.74E-05	1.79E-04
3	3007	2.41E-07	4.83E-05	2.29E-05	7.15E-05
4	3006	-1.71E-08	3.21E-05	1.87E-05	5.09E-05
5	3005	1.66E-07	2.09E-05	1.09E-05	3.20E-05
6	3004	3.65E-07	1.29E-05	8.89E-06	2.21E-05
7	3003	3.15E-07	7.25E-06	5.90E-06	1.35E-05
8	3002	3.13E-07	3.25E-06	4.77E-06	8.33E-06
9	3001	2.42E-07	1.28E-06	3.28E-06	4.80E-06
10	3000	2.15E-07	7.14E-08	3.09E-06	3.38E-06
11	2999	2.94E-07	9.46E-07	3.20E-06	4.44E-06
12	2998	3.38E-07	2.53E-06	4.54E-06	7.41E-06
13	2997	3.87E-07	6.30E-06	5.69E-06	1.24E-05
14	2996	4.98E-07	1.14E-05	8.50E-06	2.04E-05
15	2995	2.39E-07	1.94E-05	1.05E-05	3.01E-05
16	2994	3.83E-08	3.00E-05	1.79E-05	4.80E-05
17	2993	1.09E-07	4.65E-05	2.25E-05	6.91E-05
18	2992	-1.40E-06	1.08E-04	6.48E-05	1.74E-04
19	5877	-1.34E-06	7.38E-05	5.20E-05	1.27E-04

Graph of Strain Energy Release Rate Values:



All stresses are in mpa
The highlighted points are the crack initiations for the particular load and the curve indicates the shearing mode in which the crack initiation starts.

VCCT Energy-Release Rate Calculation

The approach for evaluating the energy-release rate is based on the virtual crack-closure technique (VCCT). The energy-release rate calculation occurs during the solution phase of the analysis and the results are saved for postprocessing.

The following energy-release rate calculation topics are available

1) Using VCCT for Energy-Release Rate Calculation.
2) Process for Calculating the Energy-Release Rate

1)Using VCCT for Energy-Release Rate Calculation

VCCT is based on the assumption that the energy needed to separate a surface is the same as the energy needed to close the same surface. The implementation described here uses the modified crack-closure method (a VCCT-based method) and assumes further that stress states around the crack tip do not change significantly when the crack grows by a small amount

i)2-D Crack Geometry

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For 2-D crack geometry with a low-order element mesh, the energy-release rate is defined as:

$$G_I = -\frac{1}{2\Delta a} R_Y \Delta v$$

$$G_{II} = -\frac{1}{2\Delta a} R_X \Delta u$$

where:

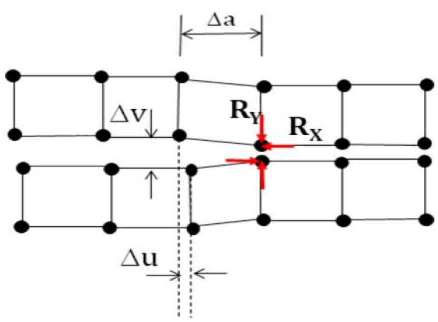
G_I and G_{II} = mode I and II energy-release rate, respectively

Δu and Δv = relative displacement between the top and bottom nodes of the crack face in local coordinates x and y, respectively

R_x and R_y = reaction forces at the crack-tip node

Δa = crack extension, as shown in the following figure:

2D-Crack geometry schematic:



In most cases, ANSYS, Inc. recommends using linear elements including PLANE182 and SOLID185. The accuracy of the VCCT calculation depends on the meshes. To ensure the greatest accuracy, use equal element sizes ahead of and behind the crack-tip node. The mesh size affects the solution; therefore, it is helpful to examine mesh-size convergence prior to attempting the finite element solution.

The VCCT method for energy-release rate calculation supports the following material behaviors:

Linear isotropic elasticity, Orthotropic elasticity,Anisotropic elasticity

2)Process for Calculating the Energy-Release Rate

The **CINT** command's VCCT option initiates the energy-release rate calculation.

Similar to the J-integral calculation, **CINT** specifies the parameters necessary for the calculation. For **CINT** element-type and material-behavior support, see Element Selection and Material Behavior

Following is the general process for calculating the energy-release rate:

Step 1: Initiate a New Energy-Release Rate Calculation.

Step 2: Define Crack Information.

Step 3: Define a Crack Symmetry Condition.

Step 4: Specify Output Controls.

Appropriate commands which supports for VCCT technique has used to extract results.

Input commands for Commands used for the Analysis:

- CINT,NEW,1
- CINT,TYPE,VCCT
- CINT,CTNC,CRACKTIP
- CINT,SYMM,OFF
- CINT,NORMAL

Output Command for strain energy release rate

- PRCINT,1

where:

G_I and G_{II} = mode I and II energy-release rate, respectively

Δu and Δv = relative displacement between the top and bottom nodes of the crack face in local coordinates x and y, respectively

R_x and R_y = reaction forces at the crack-tip node

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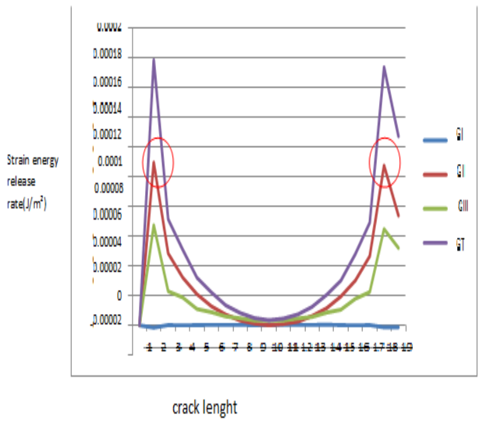
Results Summary
Tearing mode
Orientation 30deg



Stesses and Displacements:

The yield strength of the material is 450 MPa

Tearing Load				
S.No	Angle of orientation(Degrees)	Stress(MPa)	Displacement	Factor of Safety
1	0	52.69	0.28	8.54
2	30	30.36	0.28	14.82
3	45	30.36	0.28	14.82

CONCLUSIONS:

1. The Von Mises stresses for opening Load has reduced from 0^0 to 90^0 orientation.

2. In the shearing load, 90^0 orientation has very good factor of safety.

3.In case of tearing load, 30^0 &45^0 have very less stresses and can yield better results.

4. For buckling load, all the orientations has very good factor safety for the external loading.

5. Tensile loading has very less displacement in the case of 60^0 orientation

6. In case of Contact condition, shearing and buckling loads has very less stresses with factor of safety more than 3 and they will be fit various applications.

7. The energy required to crack initiation for the opening mode is 0.62 J/m^2 at 0^0 orientation at opening mode. Being a opening load, the crack initiation has started at opening mode only.

8.For the shearing load, 90^0 has some high energy 0.023 J/m^2 required for the crack initiation in the shearing mode only

9. In the tearing mode, almost all the analyzed orientations have equal energy release rates for the crack initiation. Opening, shearing and tearing modes have respective highest values for their orientations.

10. In the buckling mode, 60^0 has highest energy release rate and 90^0 has lowest energy release rate. Shearing mode has highest energy release rate values.

11. For tensile mode, 60^0 has highest energy and 0^0 has lowest energy release rate values.

12. In case of contact non-linear anlaysis-buckling load, 30^0 orientation has highest energy release rate with tearing mode playing an important role.

13. All the three modes(opening, shearing & tearing) has got highest energy release rate values with respect to loading and orientations.

14. Delamination of skin with T-stiffener has got very good crack initiation points(nodes) which will be used for wide range of products where we can predict the crack propagation with in the manufacturing stage or later on in working condition.

Future Scope:

The Crack propagation study with the same model(composite stiffened panel would) would yield bettered results. The number of iterations can be done by using other stiffeners for example T Stiffener.

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