Effect of Delamination on Prepeg Composite Laminate

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Abstract
The pre-peg model was developed to check the effect of Delamination region due to uni-Axial load with different number of plies, and to check the resistance to Delamination. If purely axial load is applied, the plate is bent due to the Poisson effect, and the crack is opening, through the strain variation is uniform in length direction for prepeg model ($\pm25/0_2$)s and ($\pm45/0_2$)s. The problem of crack opening due to load parallel to the crack face can be overcome by changing the fiber orientation. For a stacking sequence ($\pm90/0_4$) s, the crack is not opening. The variation of three different G values is compared. It is found that for two prepeg models the value of strain energy varies. The total strain energy release rate for Off-Axis Edge Delamination is compared for the prepeg model ($\pm25/0_2$) s and ($\pm45/0_2$)s. This analysis does not consider thermal effects.

Keywords
Delamination, Ansys, Strain Energy

I. Introduction

The term composites mean combining of two or more natural or artificial materials to maximize their useful properties and to minimize their weakness. Thus a material having two or more distinct constituent material or phase may be considered a composite material. The advantages of composites are very well known today, due to these advantages they have find a large number of applications in aircraft and aerospace industry. They have low weight, high stiffness, high strength and use in light weight structures. These advantages should lead to aircraft and spacecrafts design as resulted to weight reduction. Fiber reinforced composites material are now an important class of engineering materials. They have unique flexibility in design capabilities, outstanding mechanical properties and case of fabrication. Additional advantages include corrosion resistance, impact resistance and excellent fatigue strength. Now a days, fibers composites are routinely used in such diverse applications as automobiles, both commercial and military aircraft industries, offshore structure, sporting goods and electronics etc. The most important advantage of Composites is that they can be formed into complex shapes, i.e. why they have found extensive applications in aerospace industry. Composite materials are both inhomogeneous and orthotropic. The orthotropic materials are those where the material properties are different in three mutually perpendicular directions at a point in body, and have three mutually perpendicular planes of symmetry. Thus, the properties are functions of orientation at a point in the body. For orthotropic materials application of normal stress (uni axial load) parallel to one of its edge or in arbitrary direction to principal material axis results in tension in the direction of stress and contraction in the perpendicular direction. However, the extension in different direction under the same load is different. So the uni axial load will produce changes in both lengths and in angle, i.e. shearing deformation. Conversely, applications of a shearing stress cause extension and contraction in addition to the expected shearing deformation. Delamination is a failure mechanism for Laminate composites. In this process the laminae separate from each other due to poor interlaminar fracture toughness and interlaminar stresses. Delamination results in loss in stiffness lose in strength, and the expected life of material. Due to delamination many accidents have occurred in past like the "composite armour plate delamination". Interlaminar fracture Toughness is the energy absorbed by the laminate to the ratio of the newly formed delamination crack area.

II. Consequences of Delamination

Delamination defects in layered composite materials may occur due to the variety of reasons, such as low energy impact, manufacturing defects, or high stress concentration at geometric or material discontinuities. One of the factors which contribute to acceleration of the delamination growth process is the local buckling of defects lips which may results in fast defect opening [5]. Delamination can be often pre-existing or generated during service life. For example, delamination often occur at stress free edges due to the mismatch of properties at ply to ply interfaces and it can also be generated by external forces such as out of plane loading of impact during the service life.
Delamination can promote "early" failure as compared to the load carrying capability of the structure based solely on in plane failure mechanisms and stresses. It can promote and interact with other damage modes and thereby prompt failure. It can break down the "combined action" of a laminate resulting in the individual layers straining independent of the neighboring layers. It can reduce the local stiffness of a structure, due to the breakdown in "combined action".

III. Delamination in the Model

Depending on the ply lay up, delamination can occur either at the mid plane, or the off axis plane. The off axis delamination is shown in fig. 1 it results in three set of plies along each edge. Each set of plies, formed after delamination, is referred to as "sub laminate". In the off-axis plane delamination case, the model is based on half the specimen, which encompasses one edge delamination. The current is based on mid plane off axis edge delamination. The prepeg model is as shown in fig. 1.

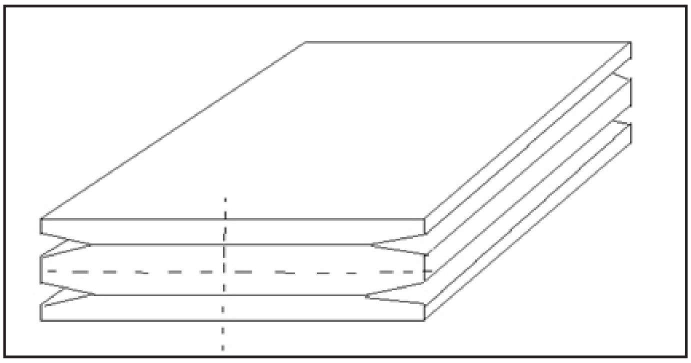

Fig. 1: Off-axis Delamination

IV. Fracture Modes in Laminates

There are three failure modes in the edge delamination, which are shown in fig. 2, 3, 4 [4]. Corresponding to the three dimensional stress states in the body. The modes of delamination are Mode I or the opening mode, Mode II or the sliding mode and Mode III or the tearing mode. In general when an edge delamination occurs, all three modes would co-exist in different ratios depending on the lay up use in the laminate. Composite being orthotropic, will behave differently under different load conditions. This results in mode ratios that will change with the applied load condition, for a given lay up.

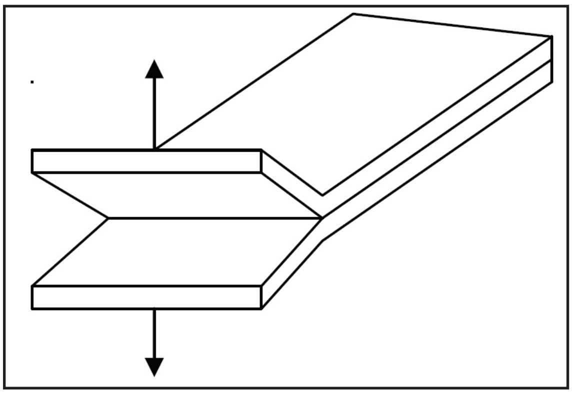

Fig. 2: Mode I (Opening Mode)

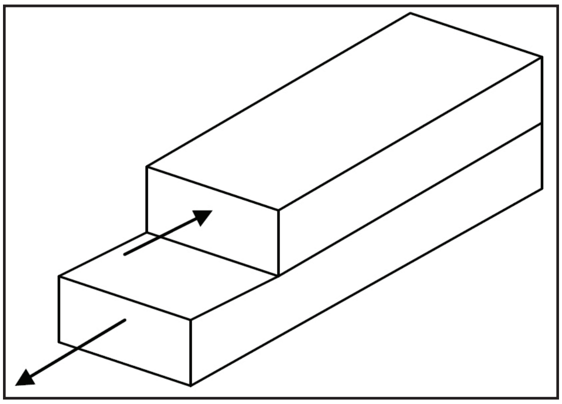

Fig. 3: Mode II (Sliding Mode)

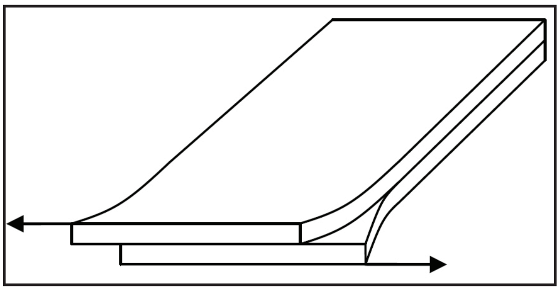

Fig. 4: Mode III (Tearing Mode)

A. Application of Fracture Mechanics to Composite Materials

The mechanics of fracture including crack propagation or extension are of extreme importance in the design analysis of composite structure. The fracture process generally takes place in three stages. First a macro crack is initiated (or a pre existing flaw or imperfection can be present). Second, the macro crack growth in a stable fashion and might link with other macro cracks to attain micro crack size. Third the micro crack propagates in an unstable fashion at a critical stress level. These three stages are found and clearly defined only in ductile materials. Some of stages, for example, stage two are not found in brittle materials [4].

B. Prediction of Failure

There are two main approaches for failure prediction [4]. The strength based criterion based failure on the strength of the material and in effect. Ignores the presence of cracks in the material. The delamination may cause failure at a much lower load, than predicted by the strength criterion. The second approach is based on damage theory and hence gives a more accurate prediction, as it takes into account the damage in the material which causes stiffness reduction.

Classical fracture mechanics is based on the actual process of the fracture starting with a given crack. When a crack is induced in a body under load, energy is dissipated. The strain energy release rate G for a crack area A is defined as the difference between the rate of work done, dW/dA and the rate at which elastic energy is stored in the body, dU/dA:

$$G = (dW/dA) - (dU/dA) \quad (1)$$

Under the assumption that the crack extension can be accomplished for a normal strain (ε), the work term in Equation. 2.1 [4] would vanish. This redefines the strain energy release rate as a function of the elastic strain energy stored in the body:

$$G = -(dU/dA) \quad (2)$$

If G_c is defined as the critical strain energy release rate, which corresponds to the strain energy at the onset of a crack growth then $G > G_c$. This defines the criterion for the crack propagation.

Crack extension occurs when G reaches a critical value G_c, the energy release rate G, is the driving force for fracture, while G_c of the material quantifies resistance to delamination, it is a material property. The application of the load that will give a strain energy release rate, G, a driving force, which is of same magnitude as G_c, will initiate crack growth. In a mixed mode failure the total strain energy release rate is equal to the sum of G_I, G_{II} and G_{III}. The mixed mode ratio is the ration of GII and the total strain energy release rate.

V. The Strain Energy Release Rate (SERR) (G)

It represents the total amount of work associated with a crack opening or closure. Its also define as the rate of change in potential energy with the crack surface area [4].

A. Modified Crack Closure Integral Method (MCCI)

This method evaluates G, from a single finite element analysis based on Irwin‟s crack closure integral approach [1] [4]. In the delamination region, stress field near the crack tip will be the mixed state in the composite material structure; this method is simple and widely used for evaluating G from finite element analysis output. The MCCI expressions for SERR components can be derived from stress and displacement distributions consistent with the finite element formulation in the elements ahead and behind the crack tip. The MCCI expressions for parabolic iso-parametric quadratic elements for GI, GII and GIII are given in the following equations [5],

G_I =[(Fy)b * (wdc) + (Fy)g *(wfe)]/[2 *Δa * h]

G_{II} = Σ [{(Fx) * u}/{2 * Δa * h}]

G_{III} = Σ [{(Fz) * v}/{2 * Δa * h}]

Where, 'Fx', 'Fy' and 'Fz' are the elemental nodal forces in the 'x', 'y' and 'z' directions at the crack tip element.

'u', 'v' and 'w' are the relative nodal displacements in 'x', 'y' and 'z' directions at the crack tip element.

B. Creation of the Model

The geometry of the pre-peg model with the edge crack is as delamination at both edges is located symmetrically about the mid plane (at the -25,-45/0 interfaces above the mid plane and at the 0/-25,-45 interfaces below the mid plane). A 3D FE model has been constructed so that length is in the z-direction, thickness in the y-direction and width is in the x-direction. The model

dimensions are based on the test specimen dimensions used by Mr. Srinivasa Rao who performed experiment on pre-peg models to determine the strain energy release rate. For the pre-peg model, the dimensions are as given below.
Ply thickness (h) = 0.00014 m.
Semi Width (b) = 70 * h m.
Crack length (a) = 6 * h m.
Dimensions in y direction = h
Length in z-direction = 0.05m
Material properties
The stiffness properties in principal directions are given below,

Table 1: (Material Properties)

Lay up	$(\pm25,\pm45/0_n)s$
E_{11} (GPa)	142.2
E_{22}(GPa)	7.27
G_{12}(GPa)	3.43
G_{23}(GPa)	2.85
ν_{12}	0.246
ν_{23}	0.27

C. Mesh Generation

The Ansys 10 finite element code is used, with 3D eight nodded liner layered element (SOLID 46). Mesh is chosen suitably to simulate structural behavior of the component. A mesh of 0.00083 m by 0.0007 5m in the proximity of the delamination tip has chosen. Fig 5 shows the pre-peg meshed laminate with a mesh element size of 0.00075 m in the crack length (x-direction) and 0.00083 m, in the length wise direction (z-direction).

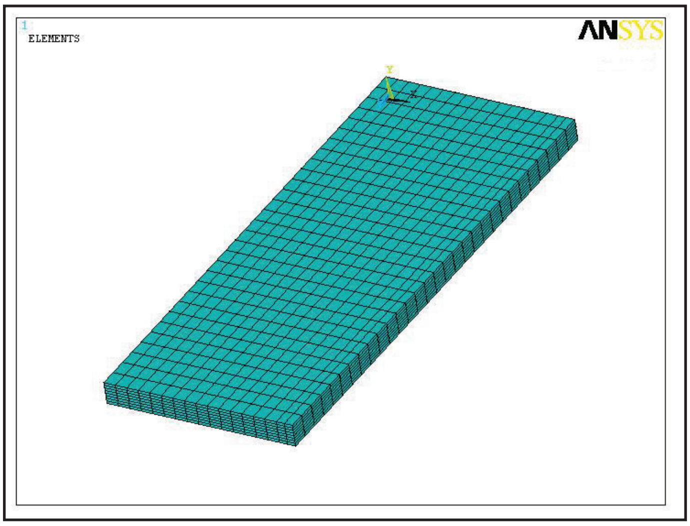

Fig. 5: Pre-peg Meshed Laminate

Boundary Conditions
Here One-Fourth Model is used. Strain is applied on the face z = 0.025m.
On the other faces,
At x = 0, Ux = 0
At z = 0, Uz = 0
At y = h, Uy = 0
Strain Applied = 1% of the Total Length
Under this applied load, which is arbitrary, the analysis is carried out and the solution is obtained. From amongst the options available, using suitable ones, the output is plotted and listed are desired. The plots for the deformed corresponds with can be expected.
The lists of results options allow the user to list out the nodal displacements as well as the nodal forces. The required nodal displacements are noted down for the nodes on the surface defining the crack. In order to calculate the nodal forces at a node is the sum of the nodal forces at that node as listed under all the elements on either side of the crack, upper or lower, to which the node belongs. Thus the individual G is calculated.

VI. Result Analysis

A. Strain Energy Release Rate: Total (GT) and Individual (G_I, G_{II}, G_{III})

Based on output from the analysis and using the formulate listed above, the three
components of the total strain energy release rate are calculated and are listed in table 2.The mixed mode ratio (GII/GT) also listed in the table.
STRAIN ENERGY RELEASE RATE FOR OFF-AXIS DELAMINATION.
The values of the Strain Energy release rate for off-axis Delamination are listed in table 2.

Table 2: (Strain Energy release rate for off-axis Delamination)

	G_I	G_{II}	G_{III}	G_T	G_{II}/G_T
(±25/02)s	31.36	25.56	8.71	65.83	0.388
(±45/02)s	51.7	67.38	15.65	80.22	0.595

VII. Conclusion

The pre-peg model has been developed to check the effect of Delamination region due to uni-Axial load with different number of plies, we see that if purely axial load is applied, the plate is bent due to the Poisson effect, and the crack is opening, through the strain variation is uniform in length direction for pre-peg model $(\pm25/0_2)$s and $(\pm45/0_2)$s.The variation of three different G values is compared. The value of strain energy for$(\pm25/0_2)$s and $(\pm45/0_2)$s varies a lot, we can see that for $(\pm45/0_2)$s it is more in all the plies as compared to$(\pm25/0_2)$s.The total strain energy release rate is varying a lot. But this problem of crack opening can be eradicated if change the stack sequence and change the angle to 90 degrees.

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