A Project Report

ON

"DELAMINATION ANALYSIS OF PRE-PEG COMPOSITES USING FEM"

Submitted in partial fulfillment of the requirements for the award of the degree of

B.TECH (AEROSPACE ENGINEERING)

By

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CERTIFICATE

This is to certify that the project work titled **"Delamination Analysis of Pre-peg Composites using Fem submitted by Shivani (R180206061),** to the University of Petroleum and Energy Studies in partial fulfillment of the requirement for the award of the degree of Bachelor of Technology in Aerospace Engineering, is a bonafide record of research work carried out by them under the guidance of Mr. **Vijay Kumar** Patidar during the academic year **2006-2010.**

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Place: Dehradun

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ABSTRACT

Composites materials have emerged as a boost for aircraft and aerospace industry, due to their high stiffness, high strength and very good high strength to weight ratio. Fiber-reinforced polymer composite materials are fast gaining ground as preferred materials for construction of aircraft and spacecraft. In particular, their use as primary structural materials in recent years in several technology-demonstrator front-line aerospace projects world-wide has provided confidence leading to their acceptance as prime materials for aerospace vehicles. Composites, considered high-tech items, play an important role in achieving a competitive edge in aerospace. Composites have excellent static and dynamic mechanical Performance, outstanding impact behavior, self- adhesive resin formulation, perfect adhesion to core materials.

Design of structural component requires reliable failure criteria for the safe design of the components. Laminated composite structures can be made by two techniques: Prepeg technique and Resin Transfer Molding (RTM). Laminated composites structures, manufactured using prepeg technique are prone to free edge delamination. Delamination is a problem which is occurs in laminated composites, even though the loading on the structure may be simple, often the stress fields in the vicinity of the delamination are three dimensional. Fracture mechanics approaches are generally employed to analyze delamination and predict delamination growth induced failure loads. In view of 3-D stress fields, the delamination growth has to be treated as multimode.In the current, an analysis on delamination of prepeg composites has been done using finite element method with the help of software package ANSYS10.AS4/PR500. Laminated plates having a stacking sequence (±25/0n)s and (45/0n)s are used for prepeg model. Where n = 2. A contact element has been used in the current analysis to avoid material penetration. A uni-axial strain of

1% is applied to the model and strain energy release rate for all the three modes of delamination are obtained using modified crack closure integral (MCCI) method together with the finite element method. The variations of strain energy release rate have been calculated.

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CHAPTER 1
COMPOSITE MATERIALS

1.1 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. Most composites consist of fibers of one material tightly bound with another material called a matrix. The matrix binds the fibers together, and makes them more resistant towards the external damage, whereas the fiber makes the matrix stronger and stiffer and helps it resist cracks and fracture.

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.

1.2 MECHANICAL BEHAVIOR OF COMPOSITE MATERIALS

Composite materials have many characteristics that are different from more conventional engineering materials. Some characteristics are merely modifications of conventional behavior. Most common engineering materials are homogeneous and isotropic. A homogeneous body has uniform properties, i.e. the properties are not a function of position in the body. An isotropic has material properties are not a function of orientation at a point in the body.

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.

An isotropic body has material properties that are different in all directions at a point in the body. No plane of material symmetry exists. Thus here too, the properties depend on the orientation.

Laminated composites come under the class of orthotropic materials. The behavior of a laminated plate can be shown in Fig. 1.1 [3] or Fig 1.3. For isotropic material application of normal stresses causes extension in the direction of stress and contraction in the perpendicular direction, but no shearing deformation as shown in in Fig. 1.2. Also application of shear stress causes only shearing deformation. But no extension or contraction as shown in Fig. 1.4. Only two material properties are necessary to fully define the material.

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. This is shown in Fig. 1.6 [2].

Laminated composites are in general anisotropic materials but when load is applied in the certain direction; they behaves as isotropic materials. These directions are called the axes of symmetry and hence laminated composites come under class of especially orthotropic materials. The axes of symmetry are also sometimes referred to as the natural material axes.

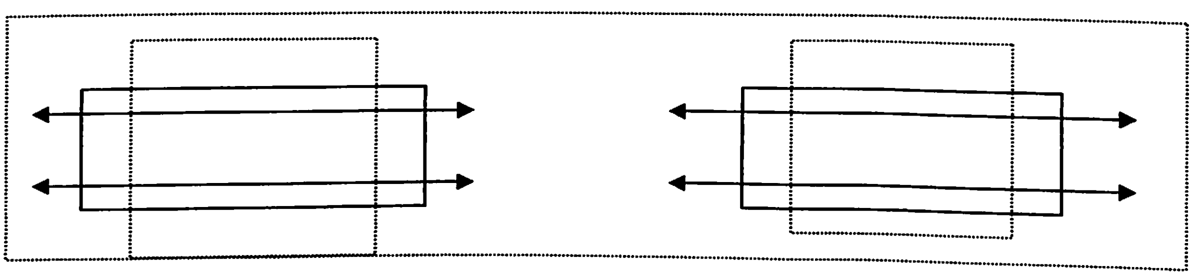

Fig 1.1 Behavior of Isotropic Materials

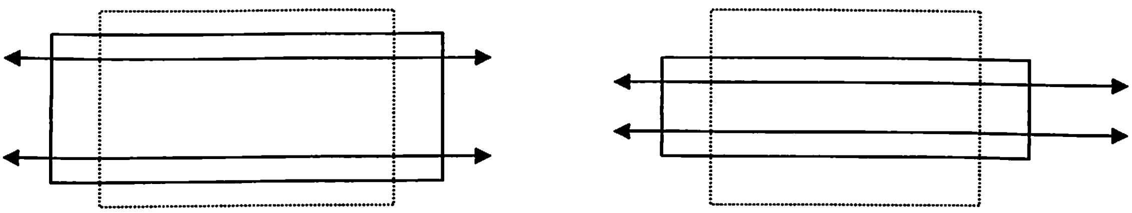

Fig. 1.2 Behavior of Anisotropic Materials

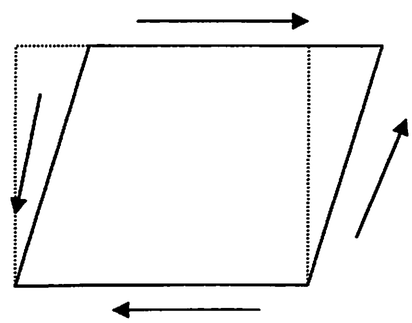

Fig 1.3 Isotopic materials in Shear

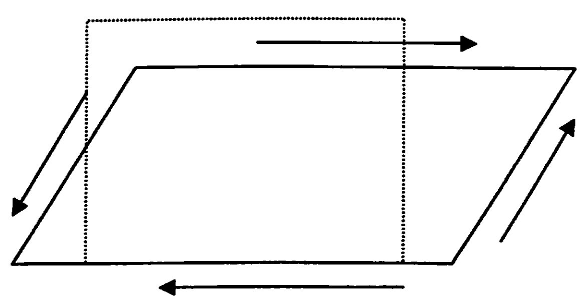

Fig 1.4 Anisotropic Materials in Shear

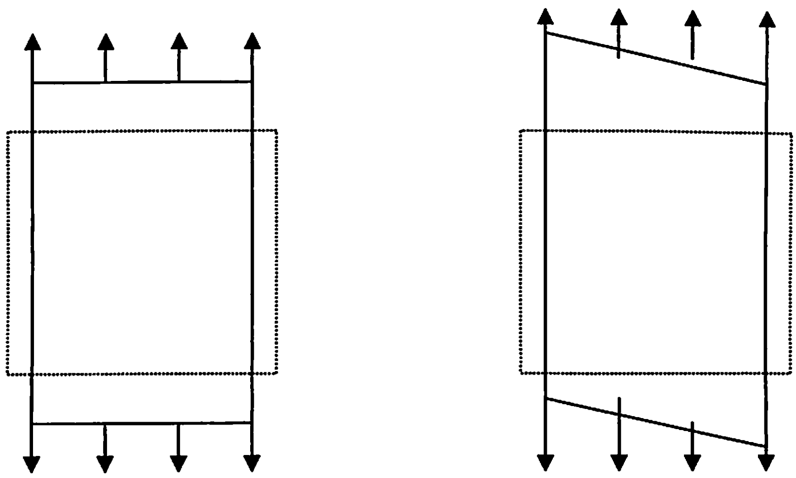

Fig. 1.5 Deformation of Unidirectional Composite Laminate Subjected to Load

(a) Parallel to Principal Axis (b) In Arbitrary Direction

1.3 TYPES OF COMPOSITE MATERIALS

Most composite materials developed thus for have been fabricated to improved mechanical properties.

Composites materials are mainly of two types:

1. Fiber-Reinforced Composites
2. Particulate –reinforced composites

Particulate composites are divided into two sub-parts namely random orientation and preferred orientation, while the fiber-reinforced composites which are popular then particulate composites are divided into many sub-parts.Some are listed below:

A) Single Layered Composites

a) Continuous-Fiber Reinforced Composites

b) Discontinuous- Fiber reinforced Composites

B) Multi-Layered Composites

a) Laminates

b) Hybrids

1.3.1 DESCRIPTION OF DIFFERENT TYPES OF COMPOSITES;

A) PARTICULATE COMPOSITES:

A Particulate composite that consists of tiny particles of one material embedded in another material. A Particulate is a non-fibrous and generally has no long dimensions exception of platelets. Therefore, the composites whose reinforcement may be defined as particulates are called particulate composites. The dimensions of the reinforcement determine its capability of contribution its properties to the stiffness of two composites but do net offer the potential for much strengthening.

B) LAMINATE COMPOSITES:

A Laminate is uniting of two or more layers of material together. The process of creating a laminate is called lamination. A Laminate act as an integral structural element. The laminate principle material directions are oriented to produce a structural element capable of resisting load in several directions. The stiffness of such a composites material configuration is obtained from the properties of the constituent laminate, the theory enables the analysis of laminates that we have individual lamiae with principle material directions oriented at arbitrary angles to the chosen or natural axis of the laminate. Laminate are fabricated such that they act as single layer materials, the bond between two lamina in a laminate is assumed to be perfect, that is infinitesimally thin and shear deformable. Thus the laminate cannot slip over each other, and the displacement remains continuous across the bond.

C) FIBROUS COMPOSITES:

A fiber-reinforced composite (FRC) consists of three components: (i) the fibers as the discontinuous or dispersed phase, (ii) the matrix as the continuous phase, and (iii) the fine interphase region, also known as the interface. It is well known that the measured strength of most materials is found to be much smaller than the theoretical strengths. The discrepancy in strength values due to the presence of imperfection or inherent flaws in the materials. An attempt to minimize or eliminate flaws enhances the strength. Fiber-reinforced composites, exhibit the higher strength, compare with the strength of the bulk material, because of the smaller cross sectional dimensions of the fiber. Unlike other composites, fibrous composites can be recycled up to 20 times

CHAPTER 2

DELAMINATION IN COMPOSITES

2.1 What is Delamination?

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, Q is the energy absorbed by the laminate to the ratio of the the newly formed delamination crack area.

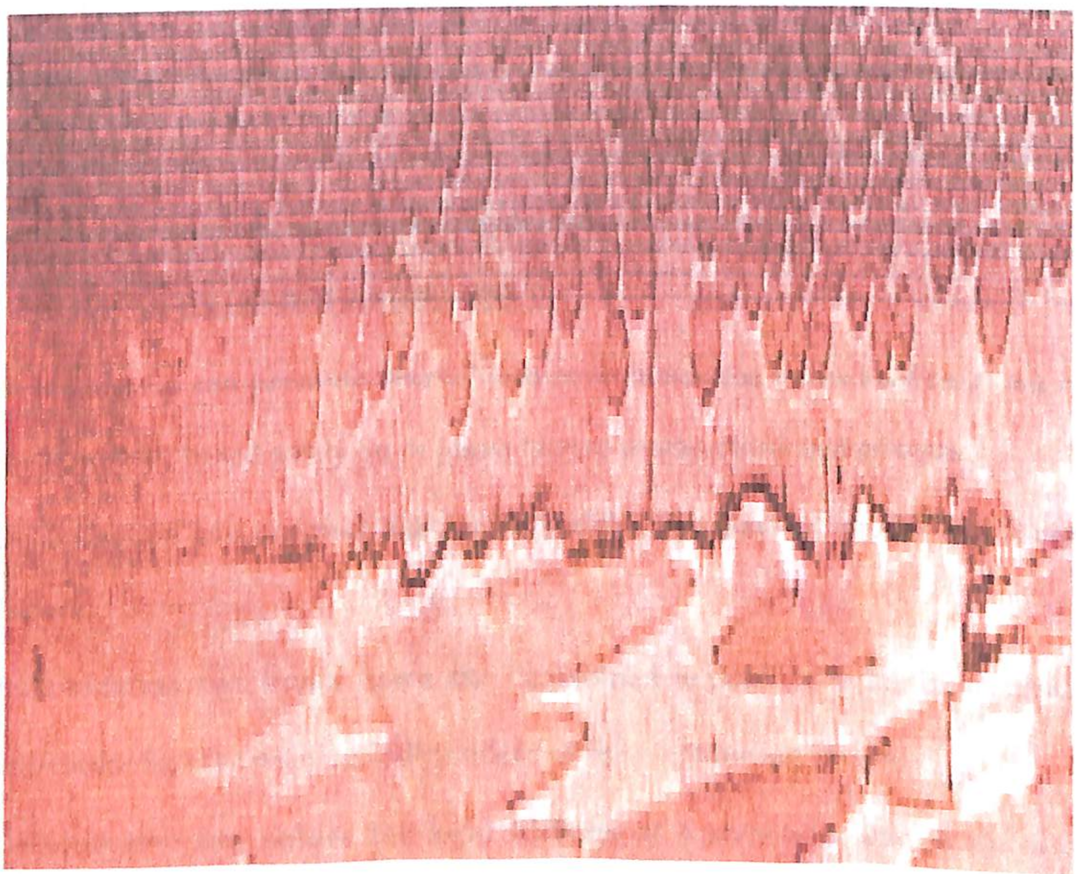

Fig: 2.1 A Delamination crack at the tip of the cross-ply crack.

2.2 DELAMINATION CAUSES

Delamination may occur due to many types of reasons. The variety of reasons may be low-energy impact, high stress concentration at geometric and material discontinuities or many manufacturing defects. The delamination process increase due to the local buckling of defect lips which results in fast opening of defect. Delaminations are of many types, one of them is Edge Delamination.

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 ao impact during the service life.

Delamination along the free edge of laminate initiated by interlaminar stresses. Delamination can also be caused due to a host of reasons, such as incomplete curing, interlaminate stresses at the free edges, ply-drop off, manufacturing defects.

2.3 CONSEQUENCES OF DELAMINATION

- Delamination can promote "early" failure as compared to the load carrying capability of the structure based solely on in plane failure mechanisms and stresses.
- Delamination can promote and interact with other damage modes and thereby prompt failure.
- Delamination can break down the "combined action" of a laminate resulting in the individual layers straining independent of the neighboring layers.
- Delamination can reduce the local stiffness of a structure, due to the breakdown in "combined action".

- Delamination initiated by Interlaminar stresses or manufacturing defects causes redistribution of stresses in the laminate resulting in reduction of stiffness and strength and fatigue properties.
- Delamination creates a local component, which can buckle well below the designed load.
- Delamination creates reduction in natural frequencies and increase in vibration damping.
- The delamination has practically no effect on the tensile strength but compressive strength is reduced.

2.4 DELAMINATION IN THE MODEL

Depending on the ply layup, delamination can occur either at the mid plane, or the off axis plane. The latter case in Fig 2.3 will result in three set of plies along each edge and mid plane edge delamination shown in fig 2.2 splits the laminate into two sets of plies. Each set of plies, formed after delamination, is referred to as "sub laminate". In the mid plane delamination case, the model is based on half the specimen, which encompasses one edge delamination. The current is based on mid plane edge delamination. The prepeg model is as shown in Fig.2.4

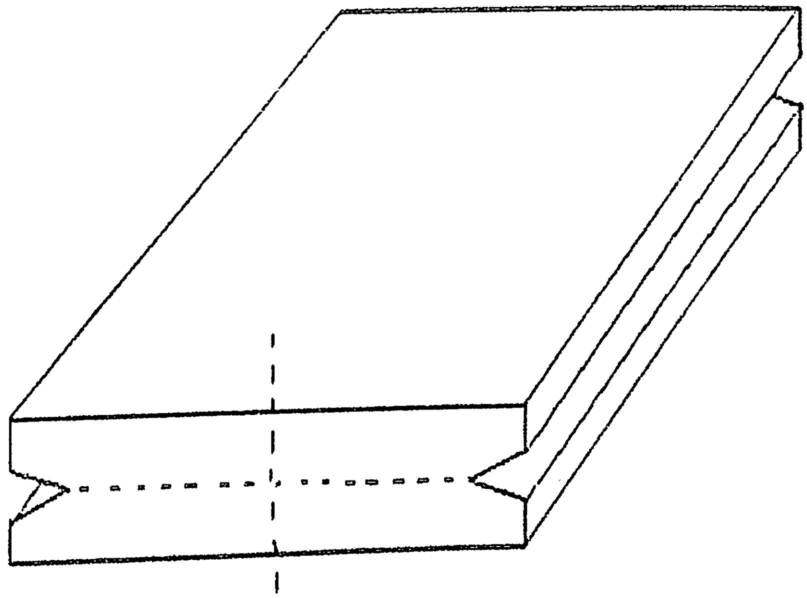

Fig. 2.2 Mid- Axis Delamination

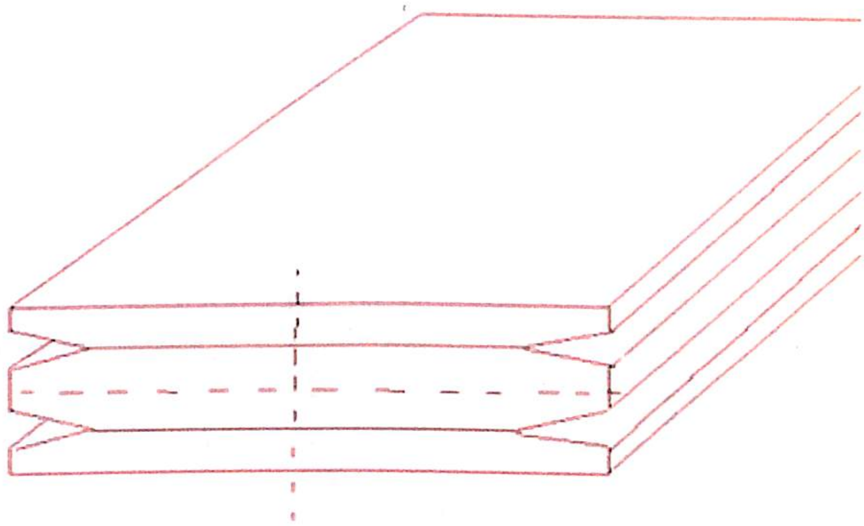

Fig. 2.3 Off- Axis Delamination

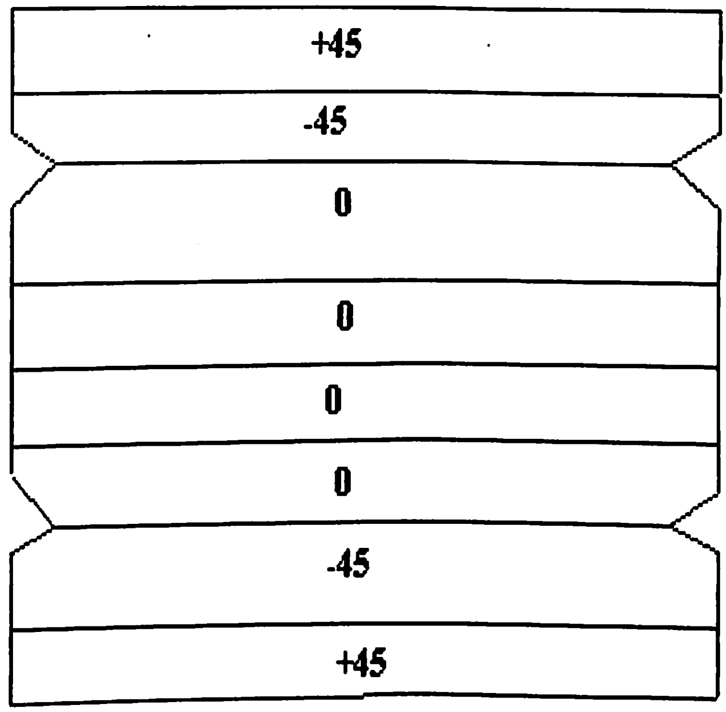

Fig. 2.4 Front View of the Laminated Plate with cracks on symmetry

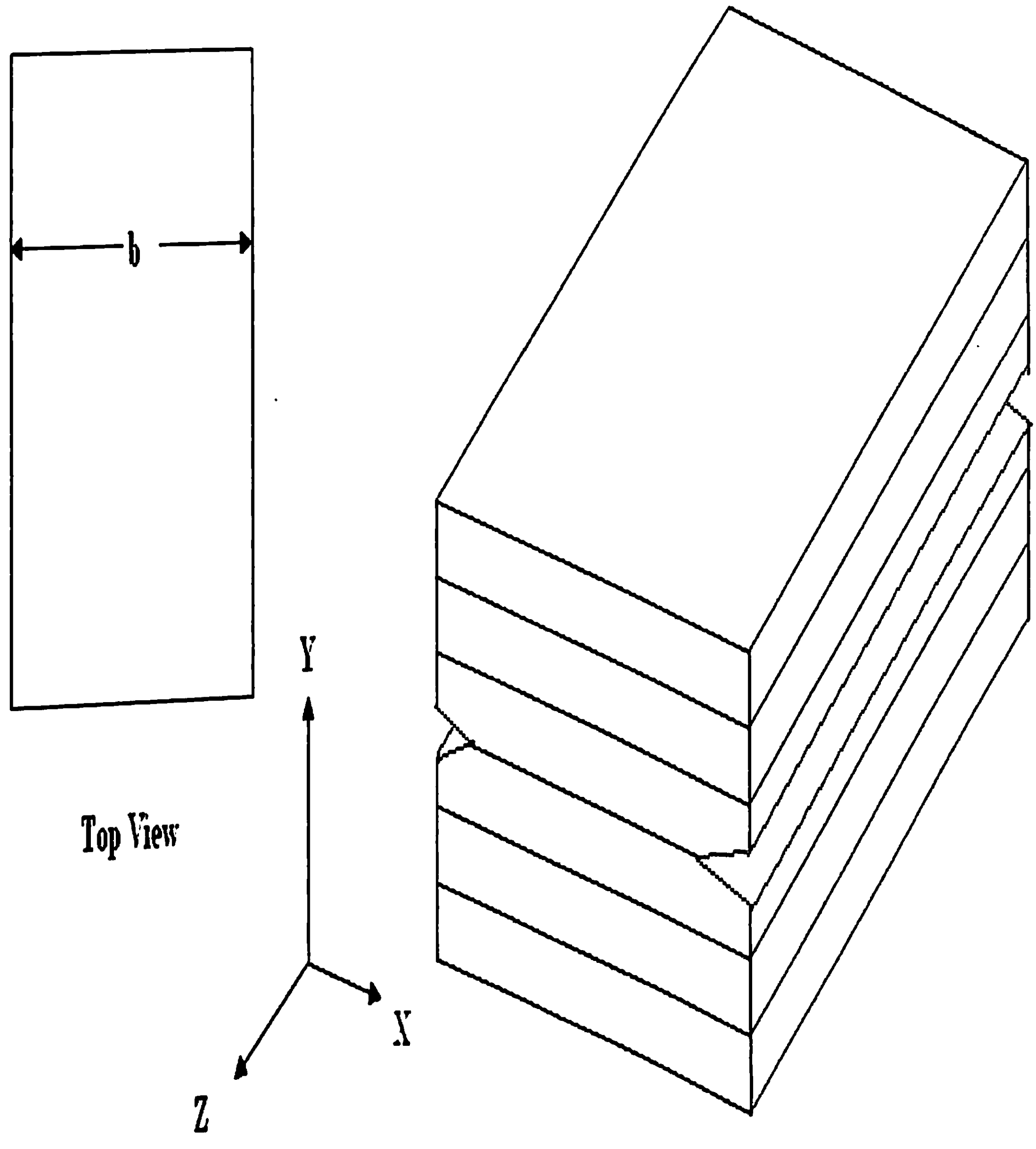

Fig. 2.5 Prepeg Model

CHAPTER- 3

FRACTURE MECHANICS

3.1 WHAT IS FRACTIURE MECHANICS?

Fracture mechanics is the field of mechanics which deals with the study of the formation of cracks in materials. It uses different analytical methods used in solid mechanics, to calculate the forces acting on the crack surface. Fracture mechanics is a very important tool in improving the mechanical performance of the material. With the development of fracture mechanics and understanding of fatigue failure enables to use much lower factor f of safety, thus reducing cost of structure components. At the same time the weight of the components is reduced and reliability is enhanced.

Fracture mechanics was first developed by A.A Griffith, but his work didn't found many applications, and it was Irwin whose work found applications, and the formulation of strain energy release rate which we use presently is due to Irwin.

The energy release rate G, is defined as the rate of change of potential energy with crack area for a linear elastic material. At the moment of fracture mechanics G = Gc, the critical energy release rate, which is a measure of fracture toughness.

3.2 MODES OF FRACTURE IN LAMINATES

Primarily, there are three modes in the edge delamination, which are shown in the fig.3.1. 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.

3.2 APPLICATION OF FRACTURE MECHANICS TO COMPOSITE MATERIALS

The Fracture Mechanics including crack propagation or extension are very important in the design analysis of composite structure. There are three stages in fracture process. First a macro crack is initiated (or a pre existing flaw or imperfection can be present). Second, the macro crack growth and it might link with other macro cracks to get the micro crack size. Third the micro crack propagates in an unstable way at a critical stress level. These types of stages are only found in the ductile materials, not in any other materials.

As discussed before, laminated composites are usually made up of plies or laminate at different orientation, depending on the strength and stiffness requirement for the component. Each of these laminates can be made up of unidirectional fibers or fabric. Due to the high length to width or thickness ration, fibers exhibits significantly more strength along the fiber direction than is other directions. The ply orientation will result in varied ply response to load. Highly concentrated stresses exists near the intersection of the free edge and the laminate interface and these high stress gradients near the free edge.

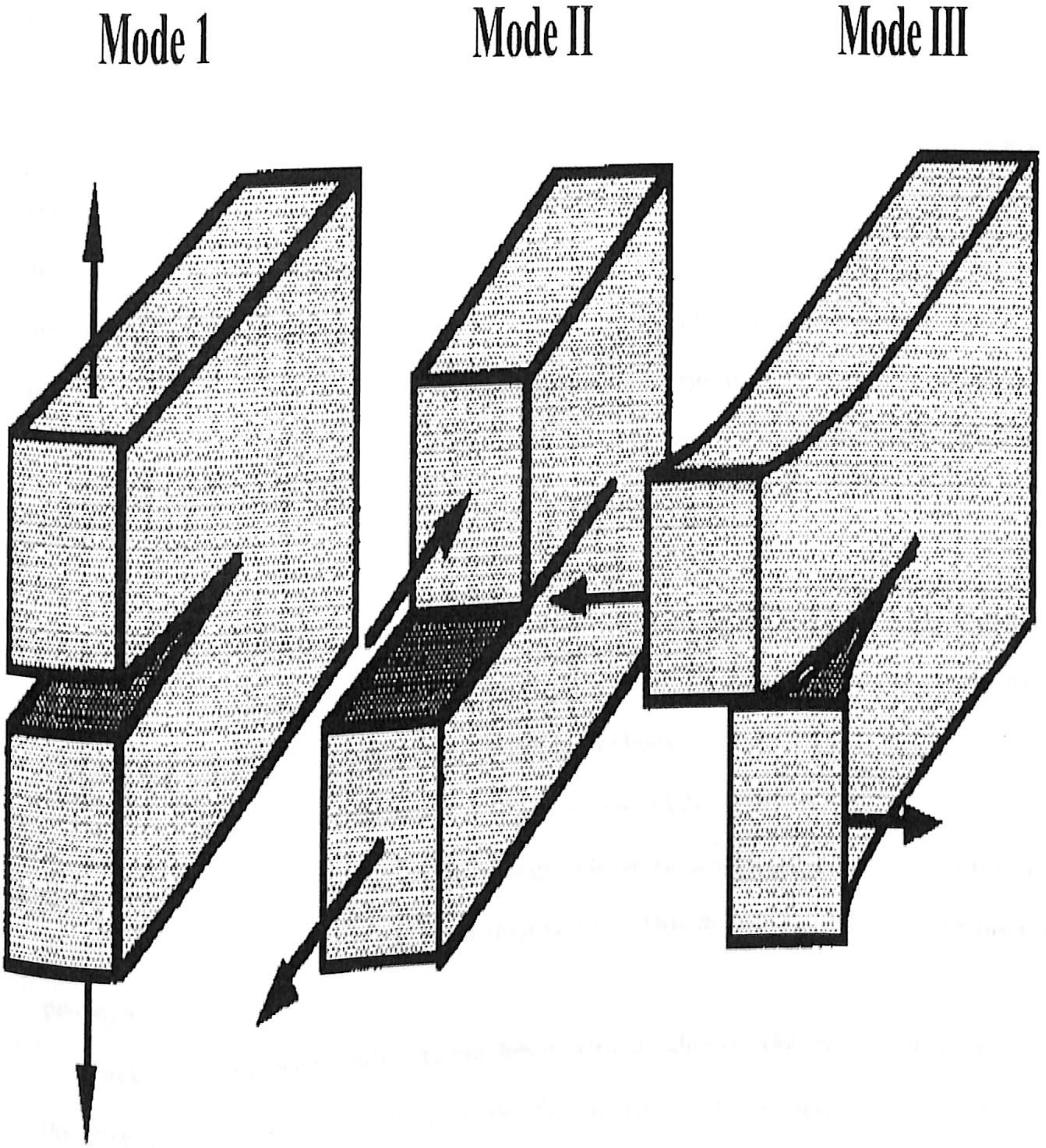

Fig. 3.1 Modes of failure

3.3 PREDICTION OF FAILURE

There can be two types of approach for failure process. 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:

$$G = (dW/dA) - (dU/dA) \qquad \text{---------} \ (3.1)$$

Under the assumption that the crack extension can be accomplished for a normal strain (ε), the work term in Eqn. 3.1 [4] would vanish. This redefines the strain energy release rate as a function of the elastic strain energy stored in the body:

$$G = -(dU/dA) \qquad \text{--------} \ (3.2)$$

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 G_{II} and the total strain energy release rate.

CHAPTER 4

FINITE ELEMENT ANALYSIS AND MODELING

4.1 INTRODUCTION

The finite element method was developed originally for the analysis of aircraft structures [10], but the general nature of this theory makes it applicable to a wide variety of boundary value problems in engineering field. A boundary value problem is one in which a solution is sought in the domain of a body subject to the satisfaction of prescribed boundary condition on the dependent variables or their derivatives. The Boundary value problems are of three categories.

- Equilibrium or study state or time independent problems, where we need to find the steady state displacement or stress distribution is it's a solid mechanics problem.
- Eigen value problems, where we need to find critical values of certain parameters are to be determined in addition to the corresponding steady state configuration. Time will not appear explicitly.
- Propagation or transient problems, we need to find the response of a body under time varying force in the area of solid mechanics. Time dependent problems.

In the finite element method, the actual continuum or body of matter like solid, liquid or gas is represented as an assemblage of subdivisions or sub domain called finite elements. These elements are considered to be interconnected at specified joints nodes or nodal points. The nodes usually lie on the element boundaries, where adjacent elements are considered to be connected. Since the actual variation of the variable inside the continuum is not known, we assume that the variation of the field variable inside a finite element can be approximated by a simple function. These approximating functions (interpolation models) are defined in terms of the values of the field variables at the nodes. The interpolation model is taken in the form of a polynomial. When field equations for the whole continuum are written, the new unknowns will be the nodal values of the field variables. By solving the field equations, the nodal values of the field variables will be known. Once these are known, the approximating functions define the fiend variable throughout the assemblage of elements.

For the static structural problems the step by step procedure can be stated as follows [10].

(i) Discretization of the structure.

(ii) Selection of proper interpolation or displacement model.

(iii) Derivation of element stiffness matrix and load vectors.

(iv) Assemblage of element equations to obtain the overall equilibrium equations.

(v) Solution for the unknown nodal displacements.

(vi) Computation of element stress and strain.

The approximation procedure may be variation method or weighted residual methods.

4.2 THE STRAIN ENERGY RELEASE RATE (SERR) (G)

It is 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. G can be found out by several methods for a composite material structure.

4.1.1 Nodal release method or the crack closure method or two step virtual crack closure techniques.

This method may be called as the crack closure method, because the crack is physically extended or closed, during two complete finite element analysis as shown in the Fig. 4.1. The figure shows a crack modeled with two dimensional four nodded elements.

In this method two analysis are performed, one for crack length another for a crack length $a + \Delta a$.

$$G = [(U_{a+\Delta a} - U_a)/(B^*\Delta a)] \qquad \text{------------ (4.1)}$$

The strain energy release rate can be find by the Eqn. no 4.1 [5.1]. This procedure, however, is not preferred since boundary value problems needs to be solved twice.

4.1.2 Modified Crack Closure Integral Method (MCCI)

A simple and accurate method is used for calculating strain energy release rates(G).There are many advantages of this method over the other methods used for calculating strain energy release rate.

1. MCCI avoids the details of stress singular fields around crack tip.
2. The strain energy release rate 'G' can be separated into its components, G (-I, II, III) in a mixed mode fracture problem.
3. It provides higher accuracy even with a coarse mesh of conventional elements. Both the higher and lower materials can be used.
4. The strain energy release rate is calculated using directly crack surface open displacement and nodal forces acting at the and ahead of the crack tips.

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 isoparametric quadratic elements for G_I, G_{II} and G_{III} are given in the following equations [5],

$$G_I = [(F_y)_b * (w_{dc}) + (F_y)_g * (w_{fc})]/[2 * \Delta a * h]$$

$$G_{II} = \sum [\{(F_x) * u\}/\{2 * \Delta a * h\}]$$

$$G_{III} = \sum [\{(F_z) * v\}/\{2 * \Delta a * h\}]$$

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. This is shown in Fig 4.1.

As seen from the above equations all that is required to calculate the nodal values are of the relative displacement of the nodes of the elements just ahead of the crack tip and element nodal forces just behind the crack tip.

4.2 CREATION OF THE MODEL

4.2.1 Geometry

The geometry of the prepeg model with the edge crack is shown in the Fig. 2.5. Delamination at both edge is located symmetrically about the mid plane (at the -45/0 interfaces above the mid plane ant at the 0/-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. Vijay Kumar who performed experiment on prepeg models to determine the strain energy release rate. For the prepeg model, the dimensions are as given below [7].

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

4.2.2 Material properties

The stiffness properties in principal directions are given below,

Lay up	E_{11} (GP	E_{22} (GPa)	G_{12} (GPa)	G_{23} (GPa)	ν_{12}	ν_{23}
$(\pm 25/0_n)s$	142.	7.27	3.43	2.85	0.246	0.27

4.2.3 Mesh Generation

The Ansys 10 finite element code is used, with 3D eight nodded liner layered element (SOLID 46). Solid 46 elements shown in Fig 4.1. [8].

The element has three degree of freedom at each node; translations in the nodal X, Y, Z directions. It is designed to model layered solids especially composites. The layer configuration is defined layer by layer from bottom to top. The bottom layer is defined as layer 1; thickness is in the y-direction. Mesh is chosen suitably to simulate structural behavior of the component. A mesh of 0.00083 m by 0.00075m in the proximity of the delamination tip has chosen.

Fig 4.1 shows the prepeg meshed laminate with a mesh element size of 0.00075 m in the crack length (x-direction) and 0.0005 m, in the length wise direction (z-direction).

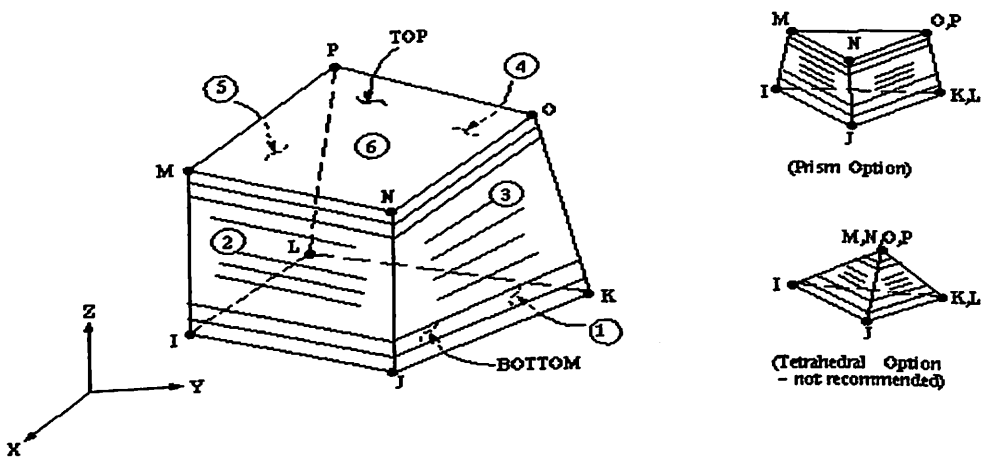

Fig 4.1 Layered Solid 46 Elements

4.2.4 Delamination Region Model

The delamination region must be locally modeled by means of two overlapped layers of identical elements, with reference plane places in the defect plane. Both the layers of the elements have distinct nodes, so in the defect plane two layers of nodes exists with the same coordinates but different identification numbers. The contact area between defect lips has been modeled with friction contact elements which allow opening but avoid element interference in case of defect plane.

With considering the contact elements some negative G values have been evaluated due to elements overlapping. The non delamination region around the delamination region must be continuity. The delamination region is assumed to be through crack along the length of the bar.

4.2.5 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.

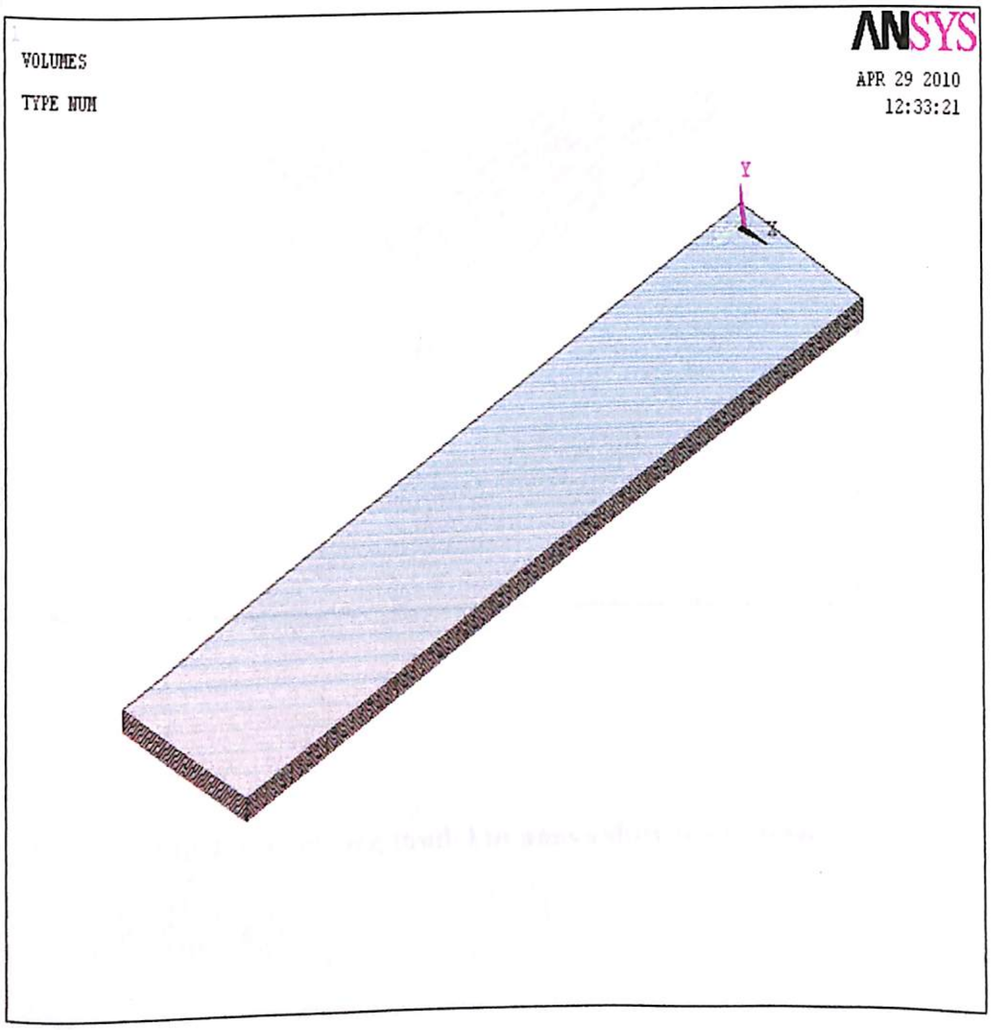

Fig 4.2 A prepeg model in ansys.

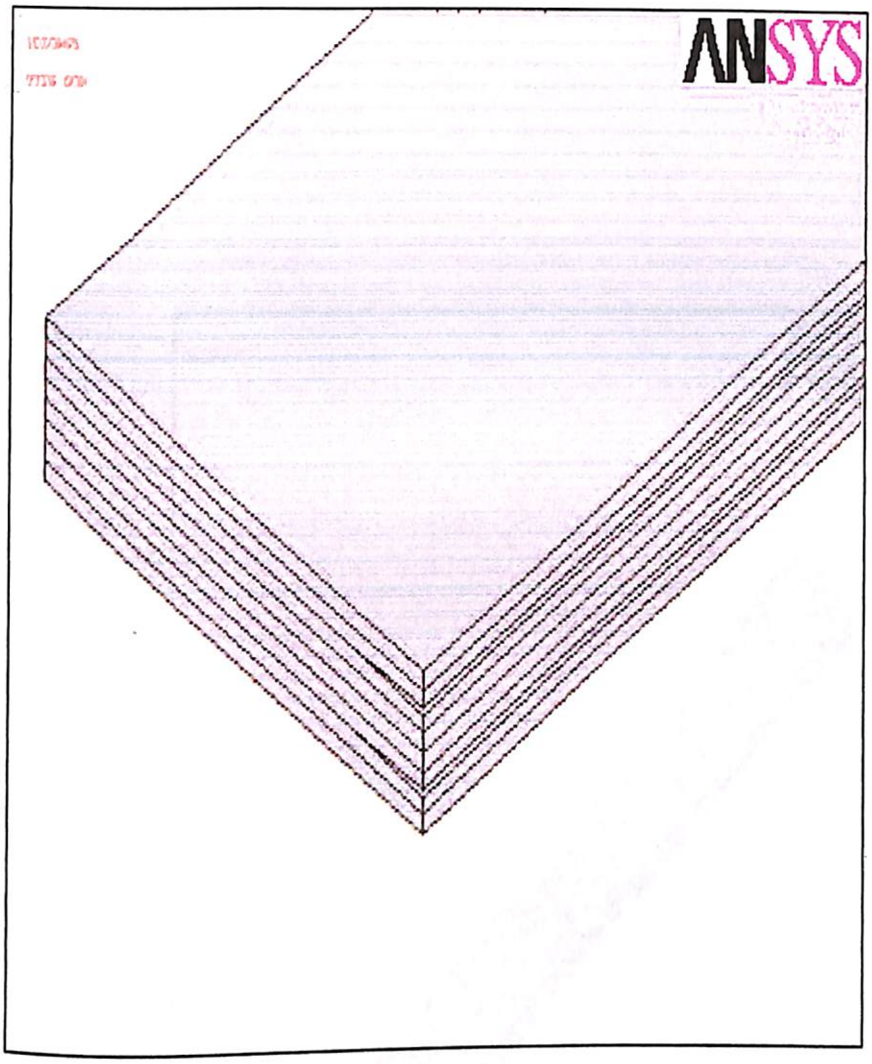

Fig 4.3 A prepeg model in ansys showing cracks

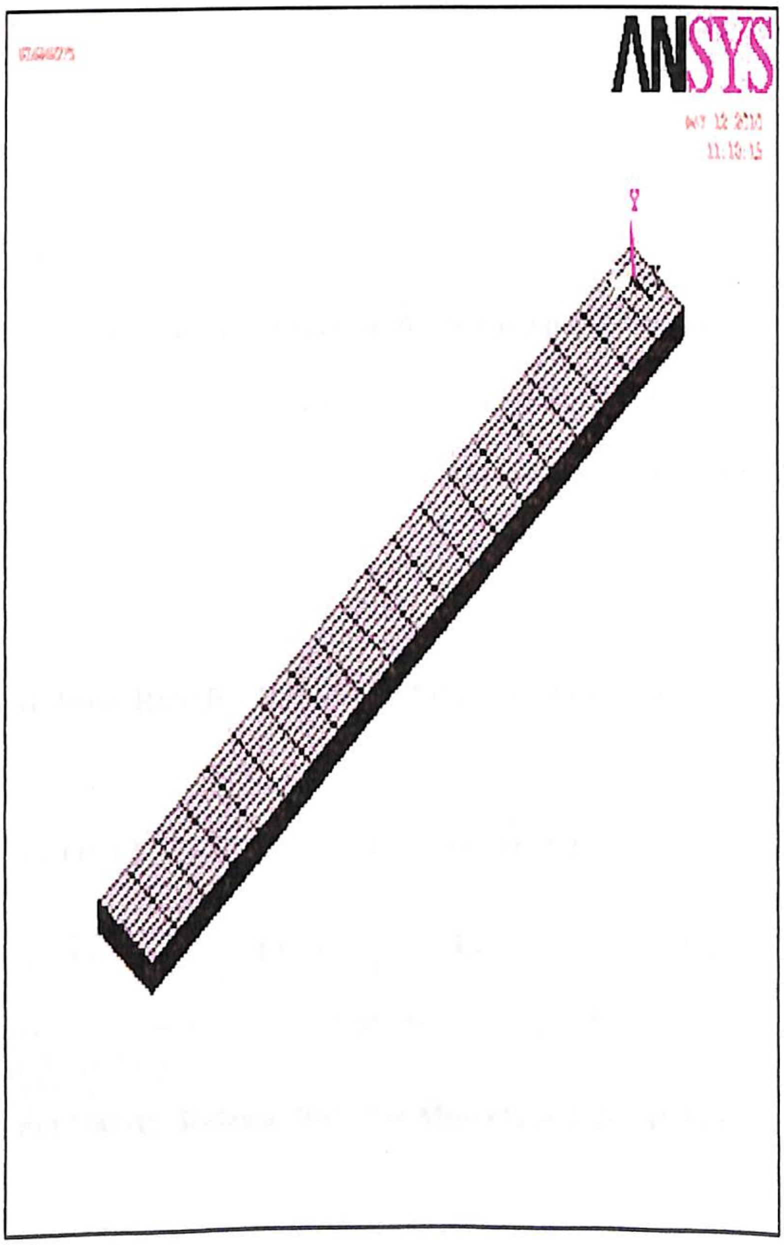

Fig 4.4 A Meshed model in ansys

CHAPTER 5

RESULTS

STRAIN ENERGY RELEASE RATE: TOTAL (G_T) AND INDIVIDUAL (G_I, G_{II}, G_{III})

Using all the Formulas above and using the analysis output, the three components of total strain energy are given in the table below. The mixed mode ratio (Gt/GII) is also listed below in the table.

5.1 DISPLACEMENT

Fig 5.1 shows the displacement in z-direction for the prepeg ($\pm 25/0_2$)s. It is clear from the figure that the crack is opening, through the stress variation is uniform, and also the plate is bend due to Poisson effect, the following figures shows the displacement shows the displacement in x and y directions respectively.

5.1 Strain Energy Release Rate for Mid-Plane Edge Delamination

	G_I (J/m^2)	G_{II} (J/m^2)	G_{III} (J/m^2)	G_T (J/m^2)	G_{II}/G_T
$(\pm 25/0_2)_s$	19.43	15.53	4.24	39.20	0.3908

Table 5.1 Strain Energy Release Rate for Mid-Plane Edge Delamination

5.2 STRAIN ENERGY RELEASE RATE FOR OFF-AXIS DELAMINATION.

The values of the Strain Energy release rate for off-axis Delamination are listed in table 5.2.

	G_I	G_{II}	G_{III}	G_T	G_{II}/G_T
$(\pm 25/0_2)_s$	31.36	25.56	8.71	65.83	0.388
$(\pm 45/0_2)_s$	51.7	67.38	15.65	80.22	0.595

Table 5.2 Strain Energy Release Rate for Off-Axis Delamination

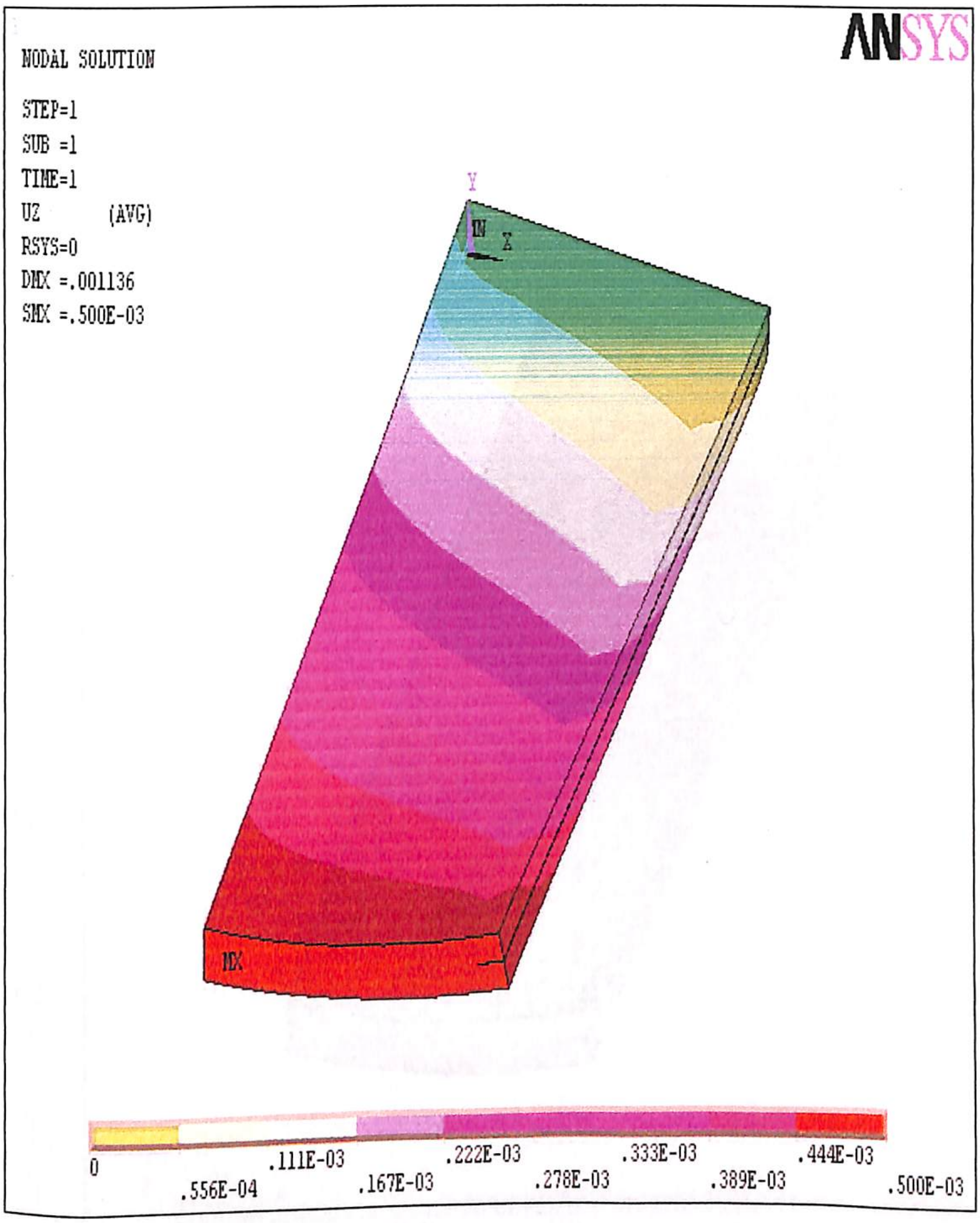

Fig 5.1 Displacement in Z-Direction Prepeg ($\pm 25/0_2$)s

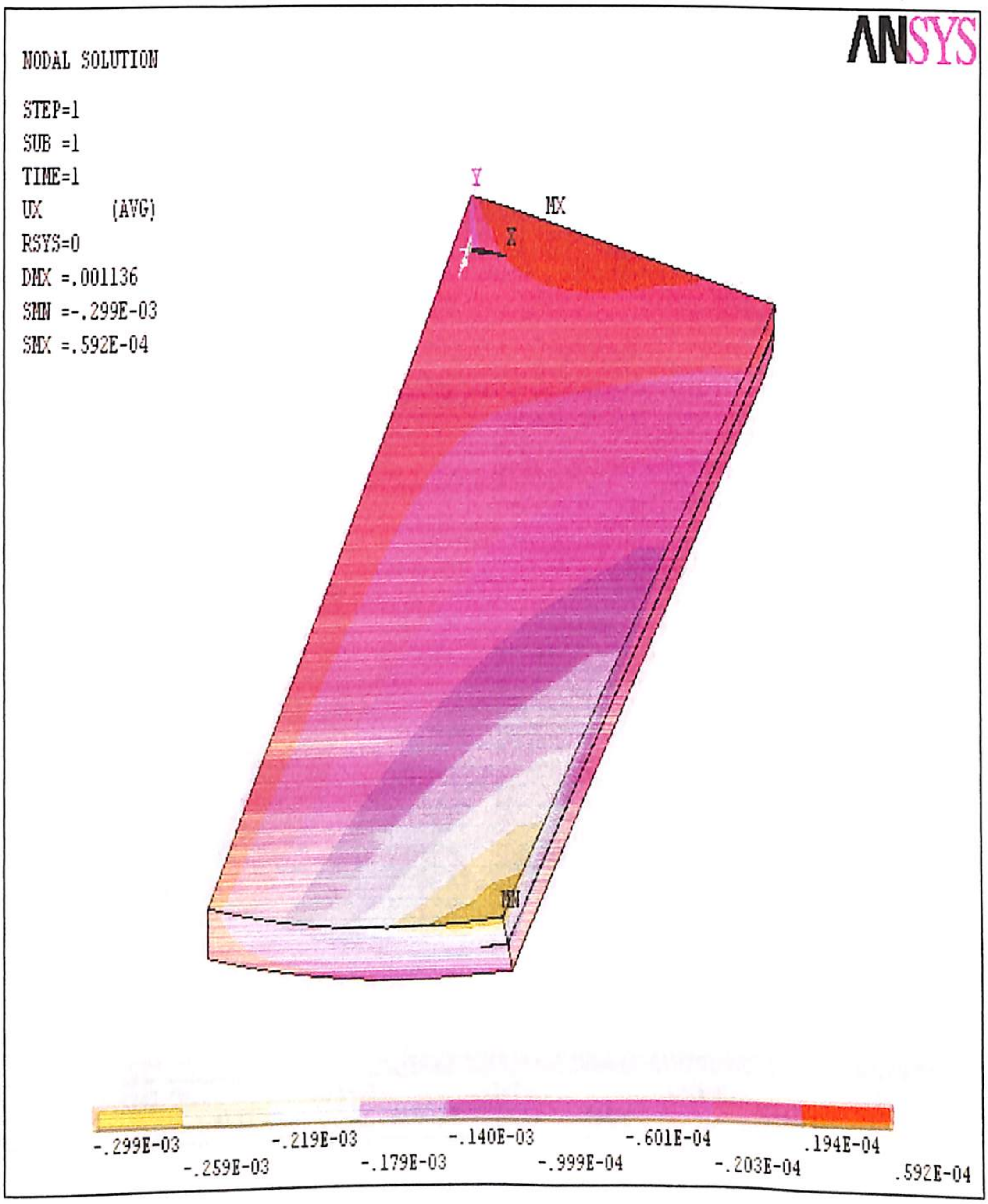

Fig 5.2 Displacement in X-Direction Prepeg (±25/0_2)s

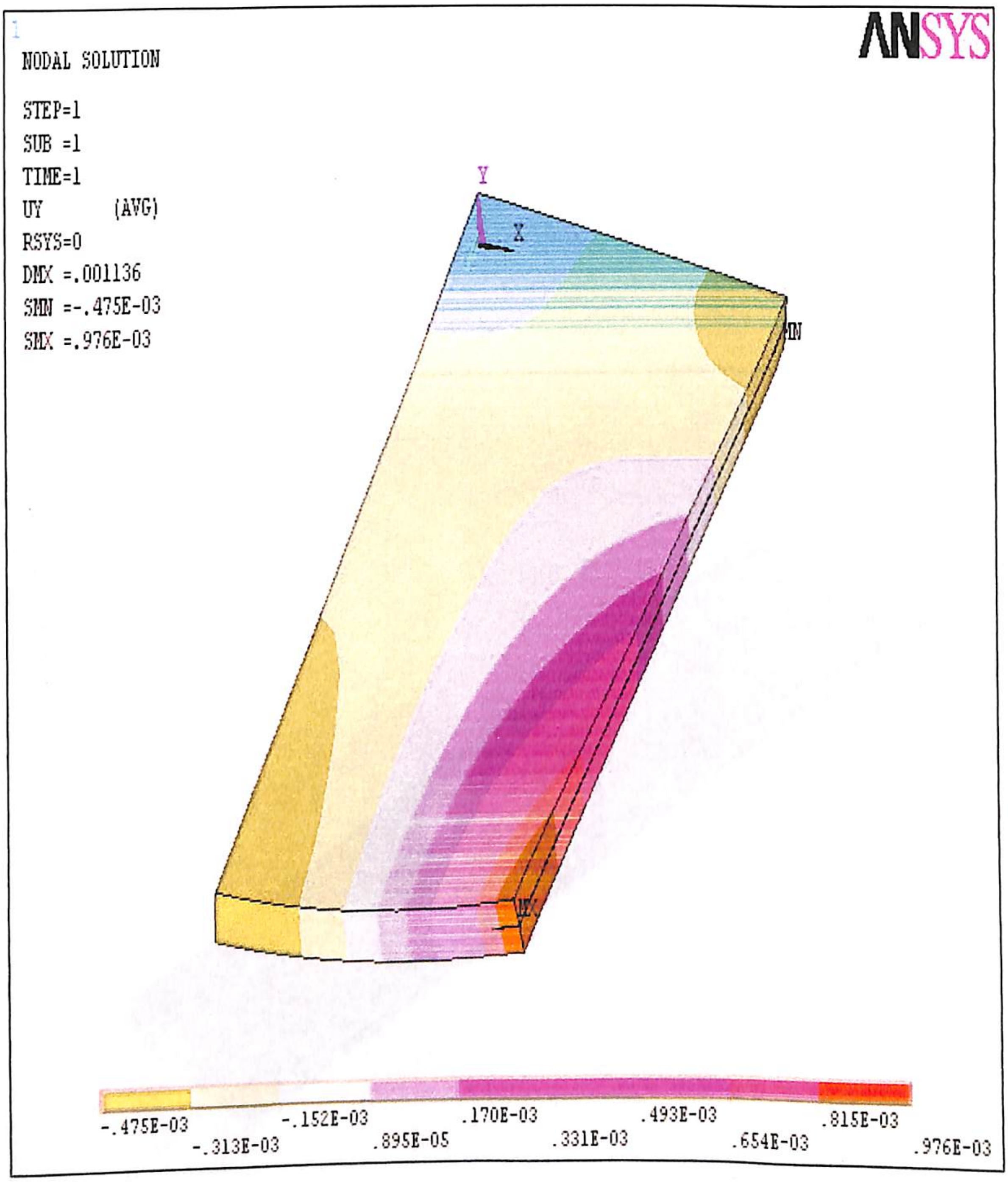

Fig 5.3 Displacement in Y-Direction Prepeg (±25/0$_2$)s

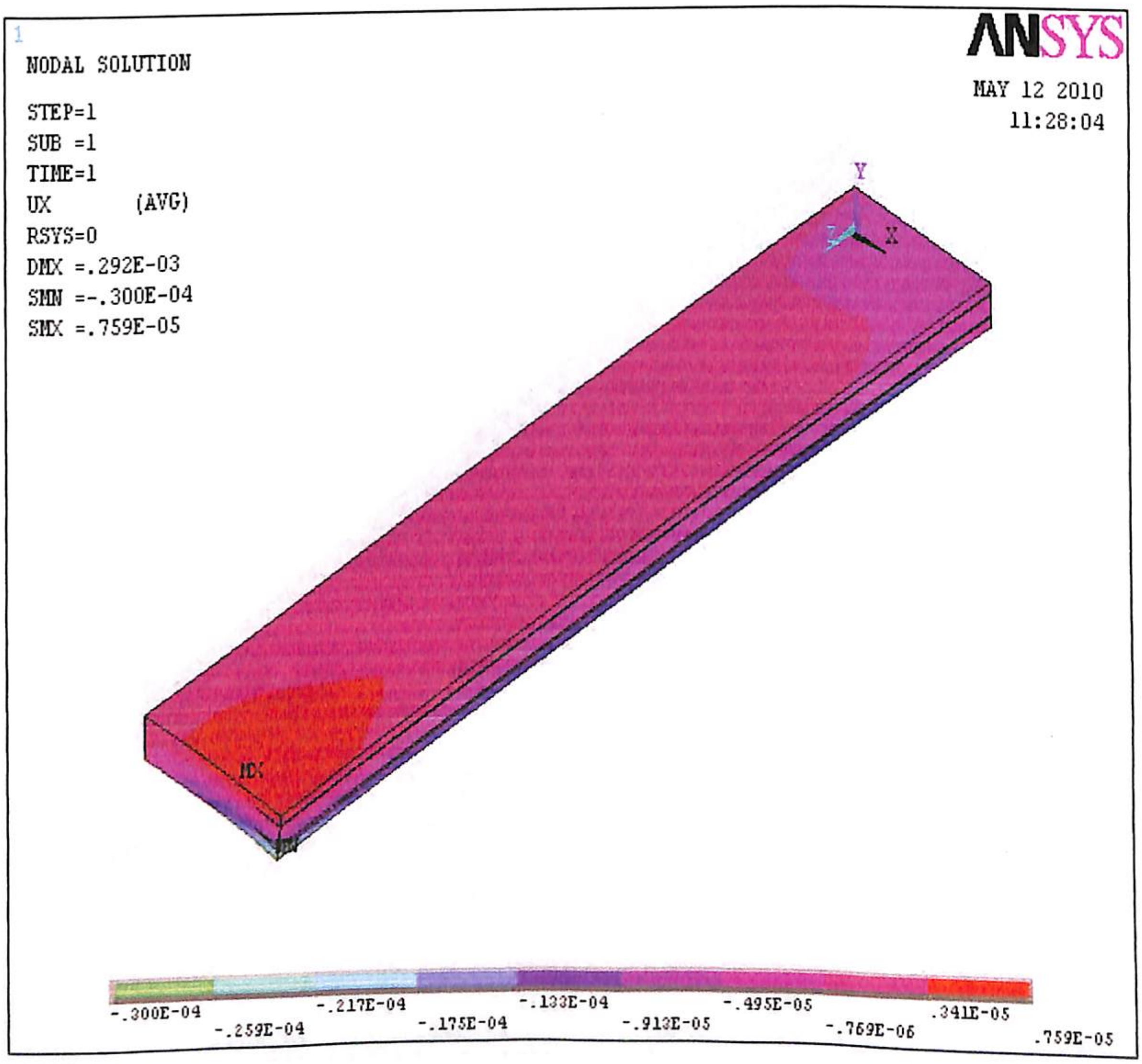

Fig.5.4 Displacement in y-direction (45/02)s

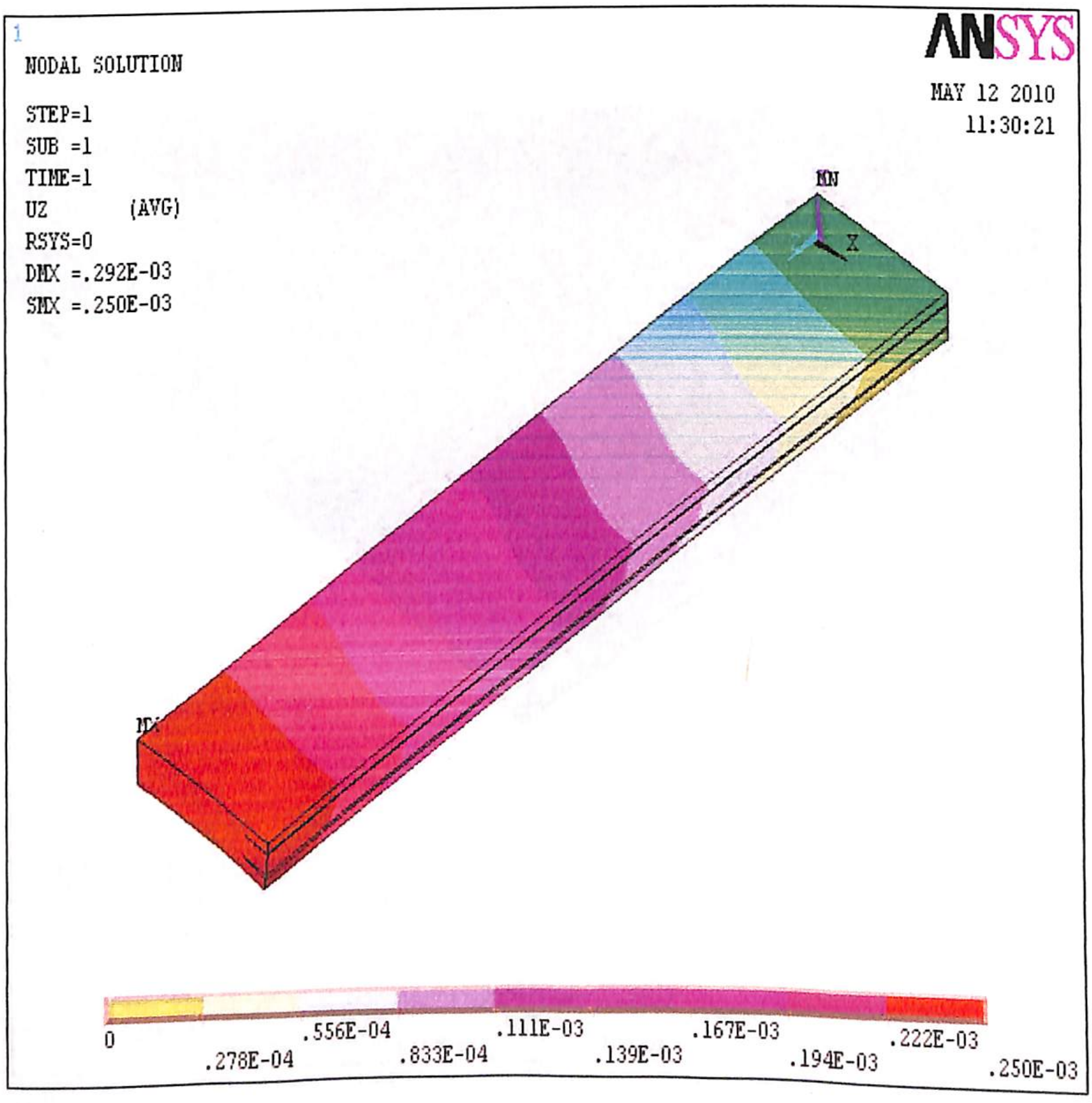

Fig: 5.5 Displacement in z-direction(45/02)s

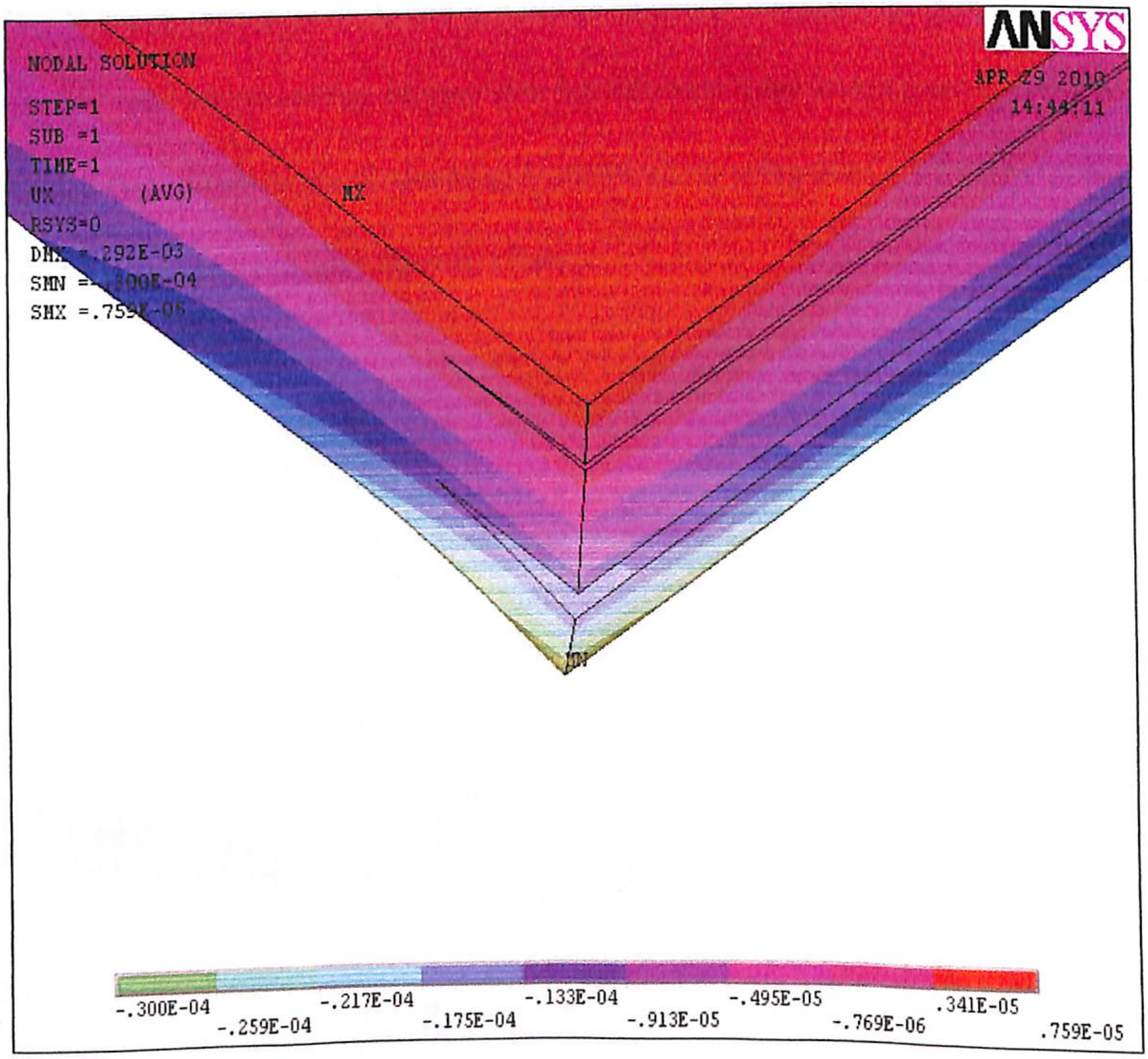

Fig. 5.6 Crack analysis of prepeg model

CHAPTER 6

CONCLUSION

The prepeg 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. The results do meet expectation to a certain degree, as mixed mode failure is observe.

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 (±25, 45/0_2)s. The total strain energy release rate for Off-Axis Edge Delamination and the Mid-Plane Edge Delamination are observed and calculated by using MCCI TECHNIQUE.

This analysis does not consider thermal effects.

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