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Stress-Strain Analysis of Carbon-Epoxy Laminated Composites during Delamination by Finite Element Method

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ABSTRACT

Delamination in laminated composites is one type of failure that has long been the centre of materials research. The failure is known due to separation at an interphase region, caused by manufacturing defects, object impacts, or high stress concentrations from geometrical discontinuity. Its occurrence can result in significant loss in the structural stiffness, especially under compressive load, and is dangerous because it often occurs inside the components, thus difficult to detect from the surface until catastrophic failure is imminent.

Finite Element Method (FEM) is one of the numerical techniques used to study the stress-strain behavior in engineering materials. In the present work, FEM approach using ANSYS software is employed to simulate the delamination process in Carbon/Epoxy laminated composite and to study the stress-strain behavior during the process. The laminated composite is assumed to be a four layered Double Cantilever Beam (DCB) with the composite material properties given as input. The FE models employ a cohesive layer that is used to simulate the debonding and crack propagation. Parametric study is carried out for a range of displacement of the beam and displacement conditions are varied from 10mm to 18mm with a variation of 2mm and stresses-displacement, shear stresses-displacement, strains-displacement, shear strains-displacement, Load-displacement response is studied.

Keywords: Delamination, Finite Element Method, DCB, Laminated composites.

INTRODUCTION

Composites are extensively used in automobile, aerospace, and civil engineering structures due to their high strength-to-weight ratios. The brittle nature of the fiber reinforced polymer (FRP) composites follows some forms of energy absorption mechanisms such as matrix cracking, fiber breakage, debonding at the fiber matrix interface and most importantly plies delamination, which are the major reasons for progressive failure modes and energy absorption in composite structures.

Delamination is a common kind of failure observed in various composites. Various experimental techniques and numerical methods have been used to study the behavior of delamination in composite materials. Finite element (FE) models have been utilized in the past to study the stress distribution and the strain energy release rate in cracked composite laminates subject to Mode I, Mode II, and mixed-mode loadings. Vander Zande and Grootenboer [1] have performed finite element modeling of delamination to study the interface cracks and compared their model of an interface crack in an isotropic bi-material with Comninou's results [2,3]. They model contact zones at the crack tips with special contact elements, which do not permit wrinkling of the two faces and transmit the compressive stresses in the contact zone of the crack. Hwu et al. [4] use a FE model for delamination analysis of glass/epoxy multidirectional specimens, with various lay ups and varying the layers between 3 to 6. Their results compare very well with the experiments in predicting first interface debonding in non-pre-cracked specimens and for the onset of the delamination in pre-cracked specimens.

Analytical and numerical techniques have been developed to study the interlaminar stresses. Dakshina Moorthy and Reddy [5] compared four methods for calculating the interlaminar stress and energy

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release rate: layerwise theory, virtual crack closure, crack closure, and potential energy change. Different methods have been used to calculate strain energy release rate and mode mixity. The Rayleigh–Ritz method is used with classical plate theory by Davidson and Schapery [6]. An analytical crack tip element based on classical plate theory was introduced by Davidson et al. [7]. The virtual crack closure technique was used by Davidson [8] and Polaha et al. [9].

The advancement of the finite element methods has provided a robust and flexible tool to solve the nonlinear problems [10-14]. For example, a global-local FE analysis used 3D FE models with either layered shell or solid brick elements in the fracture critical zones with the boundary conditions obtained from the global analysis [15]. It has the capability to study in details the damage development in the key areas and optimize the computational effort [16].

Wimmer et al [17] presented an approach for the numerical treatment of delamination in laminated composite components by employing the first fly criterion and delamination propagation is analyzed using linear elastic fracture mechanics. Effects of different mesh sizes and pre-existing crack length on the delamination growth and postbuckling properties of composite laminates are investigated [18]

PROBLEM STATEMNT

The focus of this study is on the finite element modeling for the assessment of static delamination and to evaluate stresses and strains in Carbon&Epoxy laminated composite plates. The specimen is assumed with 4 layers or laminates with the boundary conditions and geometry as shown in figure 2.1. The length of the specimen 'L' is 100mm, height of the specimen 'h' is 1.5mm, width 'w' is 20mm and a debonding length 'a' of 30mm in delaminated layers. The specimen is fixed at one end and displacement loading is applied at the other end. Necessary orthotropic material properties are assumed.

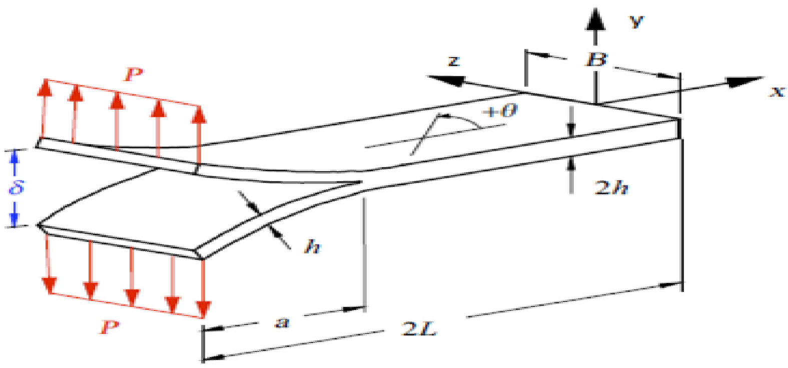

Fig2.1. *Specimen for Modeling*

FINITE ELEMENT MODELLING

The x-y-z coordinate system is used to study the behavior of Stresses and Strains of Carbon Epoxy Laminated composite during delamination. The x-axis is aligned with direction of length, the y-axis is aligned with direction of height and the z-axis is aligned with the direction of width. In this analysis four layers are used and after these layers will be overlapped with each other. In between layer1 and layer2 a contact layer is used for bonding and in between layer 2 and layer 3 a contact layer is used for bonding and similarly in between layer3 and layer4 another contact layer is used for bonding. After that a debonding length of 30mm is provided in delaminated layer, and a displacement of 10mm is applied in y-direction. The layered composite with specifications is as shown in figure 3.1.

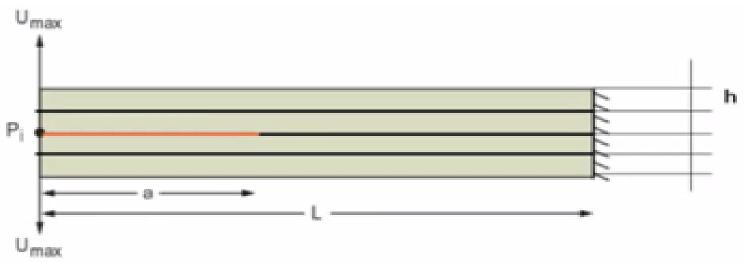

Figure3.1. *DCB model*

Meshing

The finite element mesh is generated using a three-dimensional solid element SOLID185.

SOLID185 is a higher order 3-D 8-node solid element that exhibits quadratic displacement behaviour. The element is defined by 8 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions.

DCB loading: Area mesh is taken with an optimum element size of 5.The material properties are taken as mentioned above for carbon/epoxy composite respectively. Additional cohesive zone region is added between both the overlapped areas up to 3/4th the original area that is modelled.

Solid Brick 8 node 185 is taken as the element type to satisfy the model behaviour in case of loading conditions. The FE mesh of the model is shown in figure-3.1

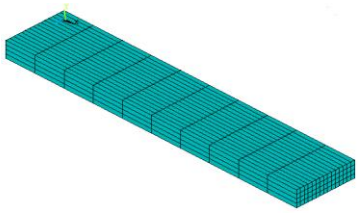

Figure3.1. *Finite Element Mesh*

Loading and Boundary Conditions

The structural displacement load is applied in the y- direction, with displacement of 10mm is given on the front surface of the elemental structure. One side of rectangular surface is fixed with all degrees of freedom to be zero and other end forces are applied to rip apart the areas. This kind of loading condition is said to be DCB loading. In this case Displacements are varied from 10mm to 18mm with a variation of 2mm.

Materials Properties

The following orthotropic properties of Carbon Epoxy materials are used in the present analysis. E_1 =126Gpa, E_2=9.5Gpa, E_3=9.5Gpa, V_{12}=0.263, V_{23}=0.263, V_{13}=0.27, G_{12}=1.07Gpa, G_{23}= 0.8063Gpa, G_{13} = 1.07Gpa

The contact between layers are modeled with zero friction coefficient, penalty normal and tangent stiffness of 1e6

RESULTS AND DISCUSSION

Numerical results are obtained for variation of stresses in three directions with a change in y-displacement. The results obtained include Normal Stresses, Shear stresses, Normal Strains, Shear strains and Reaction forces of the Delaminated Composite. Some of the deformed shapes of the specimen after delamination with stresses in x, y and z-directions with the amount of displacement are shown figures-4.1, 4.2 and 4.3 respectively.

Stresses

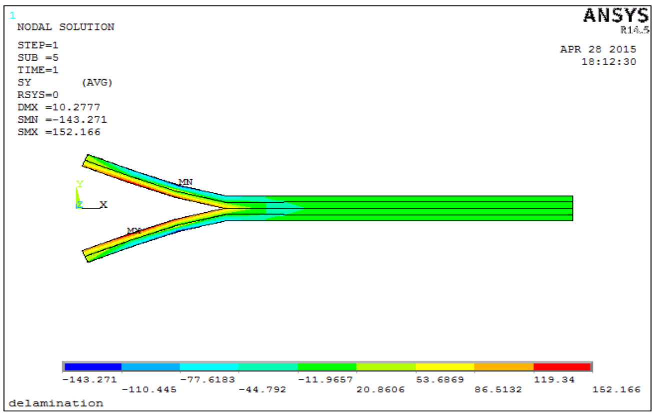

Figure4.1. *X-component of stress with displacement 10mm*

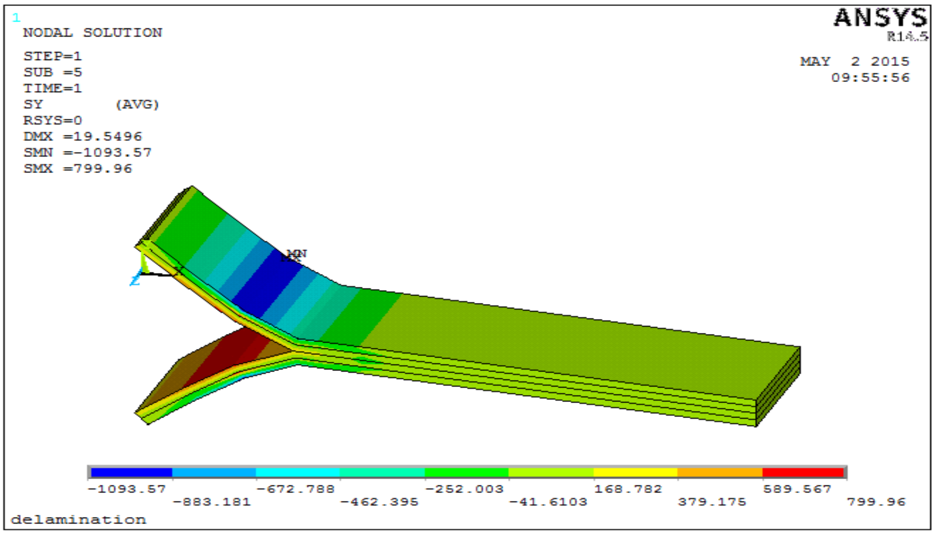

Figure4.2. *Y-component of stress with displacement 18mm*

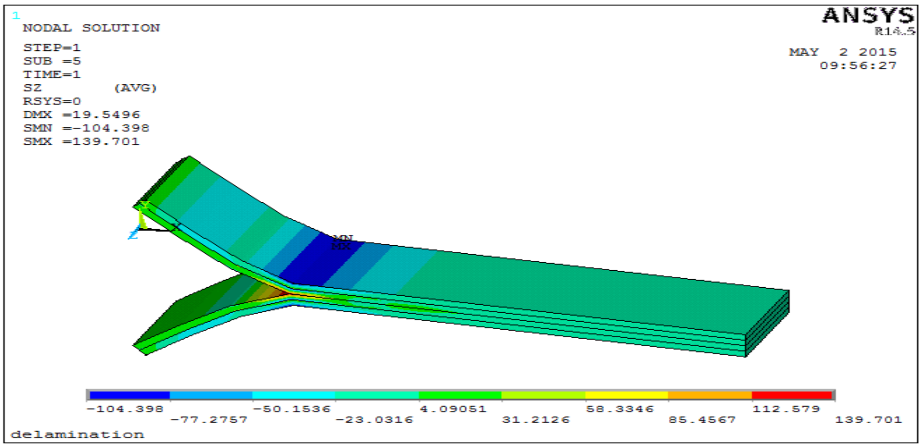

Figure4.3. *Z-component of stress with displacement 18mm*

Normal Stresses

The variation of normal stresses with increase in displacement are as shown in Figures-4.4, 4.5 and 4.6 respectively.

The stresses in X-direction increases up to a displacement of 14mm and then decreases as shown in Figure-4.4. The maximum stress in x-direction is found to be 1678MPa. The variation of normal stress in Y-direction with increase in displacement is shown in figure-4.5.and it is found that the stresses are increasing uniformly with displacement and is maximum at 18mm. Similarly the stresses in z-direction are shown in figure- 4.6 and straight-line variation is observed with increase in displacement. Similarly the variation of von mises stress is shown in figure-4.7.

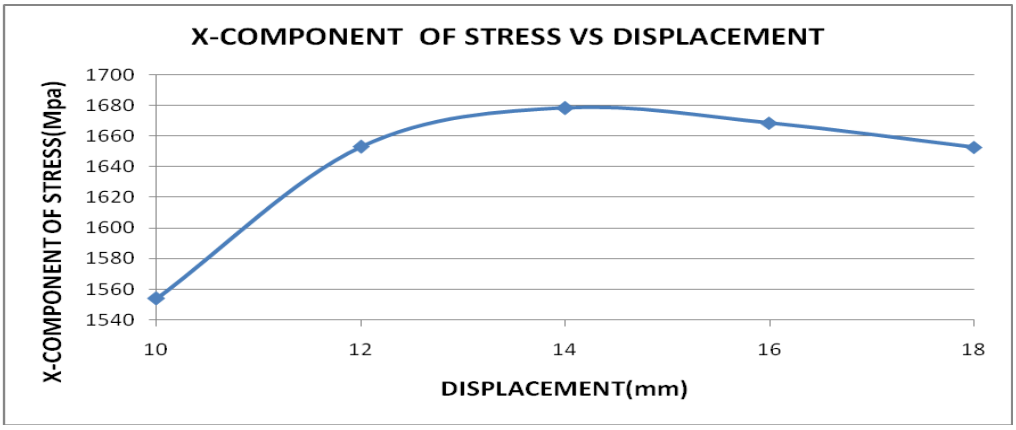

Figure4.4: *Variation of X-component of stress to Displacement*

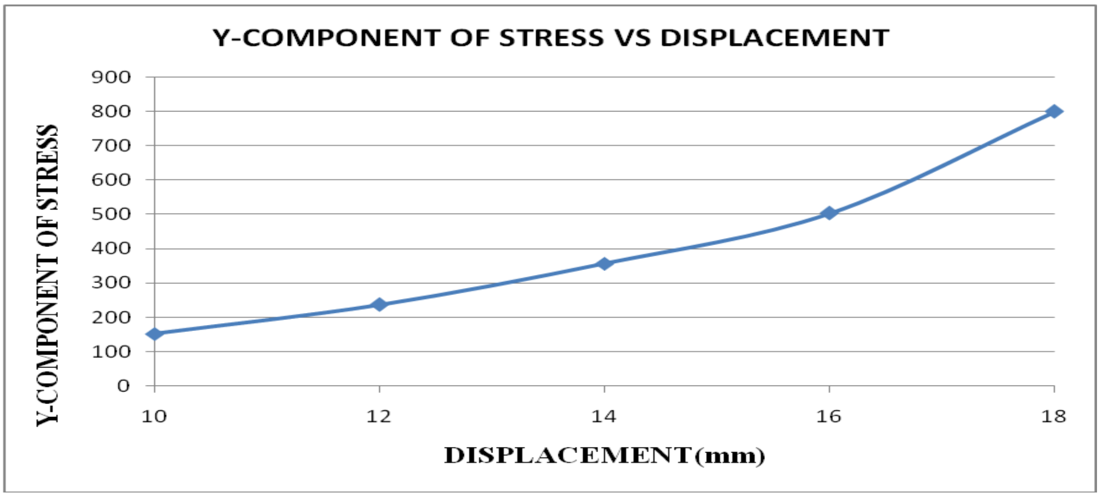

Figure4.5. *Variation of Y-component of stress to Displacement*

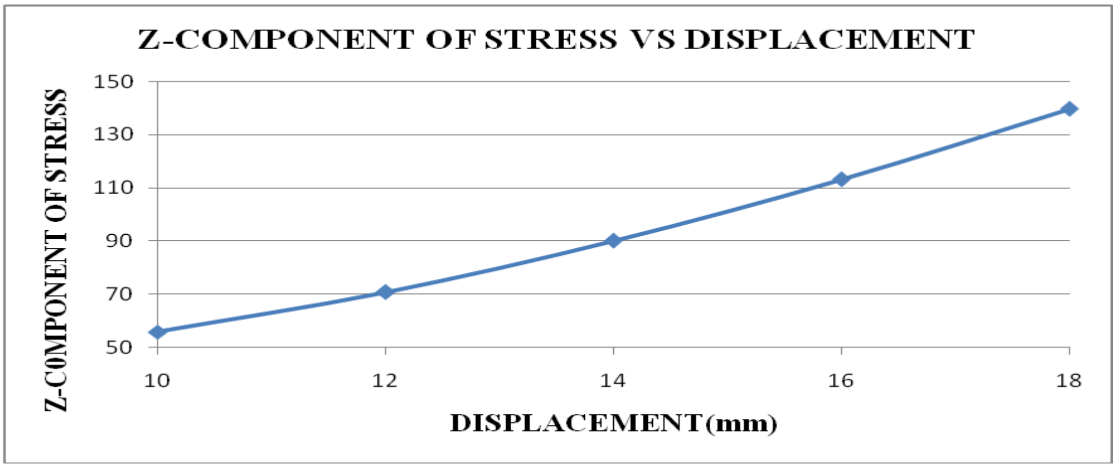

Figure4.6. *Variation of Z -component of stress to Displacement*

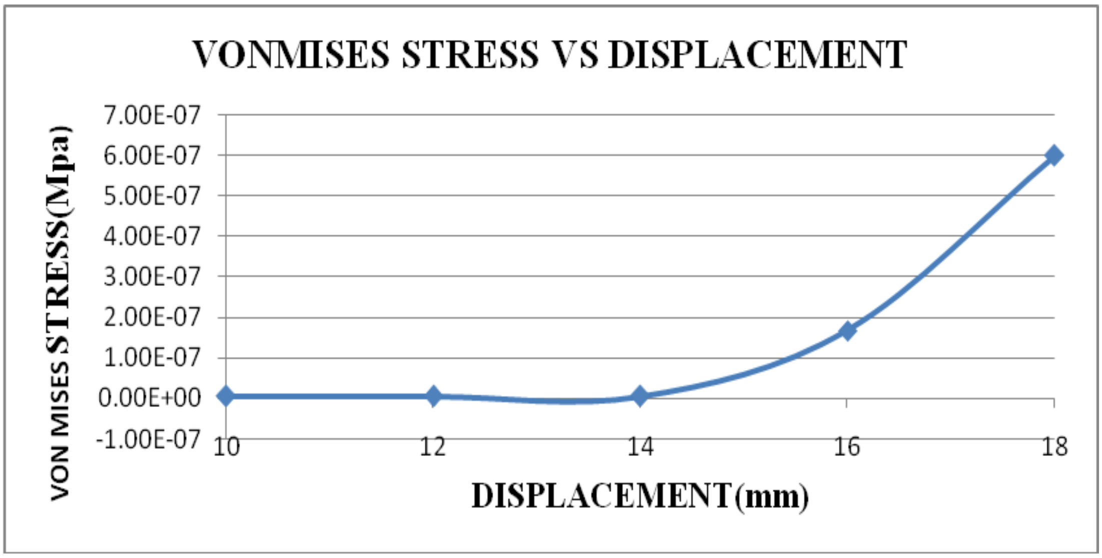

Figure4.7. *Variation of Von Mises stress to Displacement*

Shear Stresses

The variation of shear stresses with increase in displacement are as shown in Figures-4.8, 4.9 and 4.10.

The stresses in XY plane increases linearly up to a displacement of 18mm and the maximum value is 1627MPa as shown in figure- 4.8. The shear stresses developed in yz and xz plane are negligible and the variation is shown in figure-4.9 and 4.10 respectively.

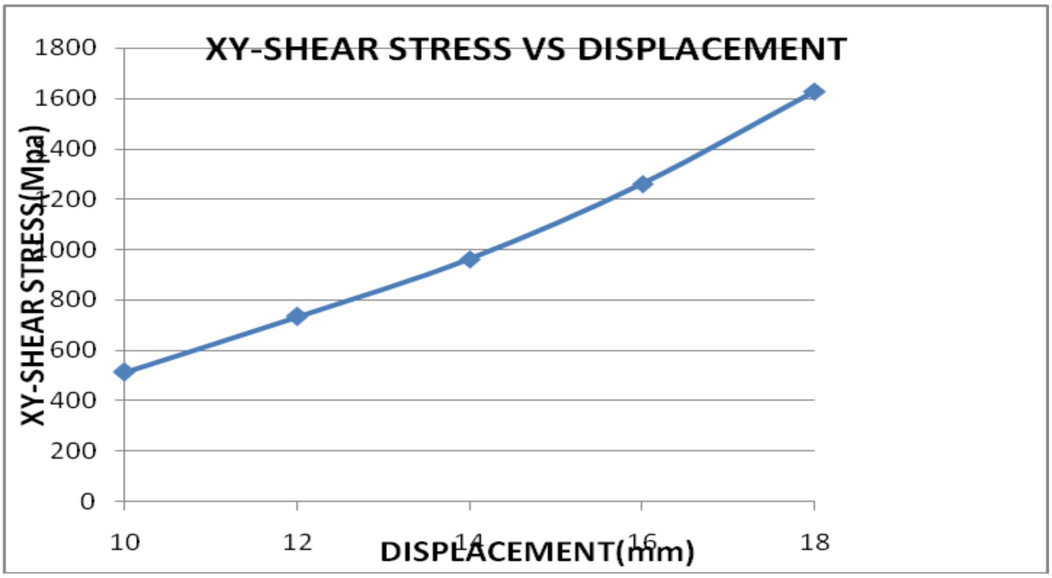

Figure4.8. *Variation of XY-shear stress to Displacement*

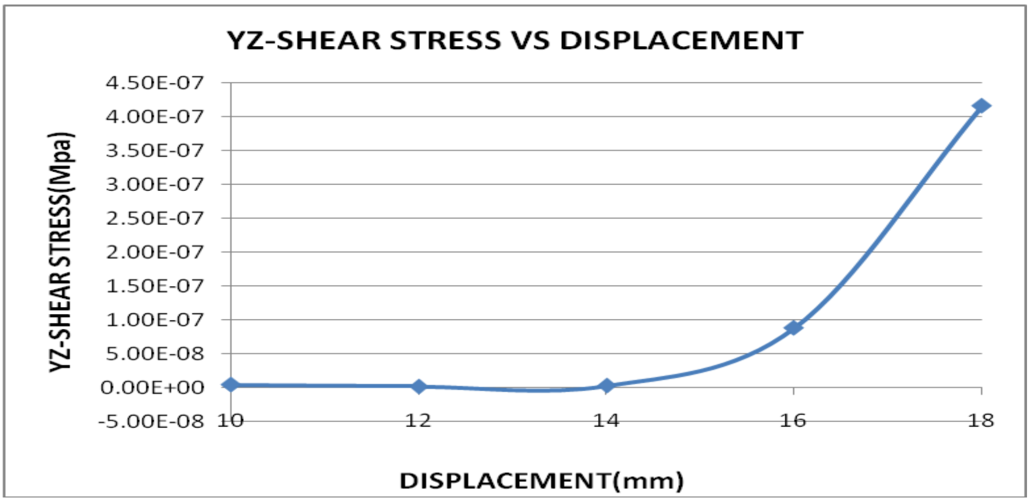

Figure4.9. *Variation of YZ-shear stress to Displacement*

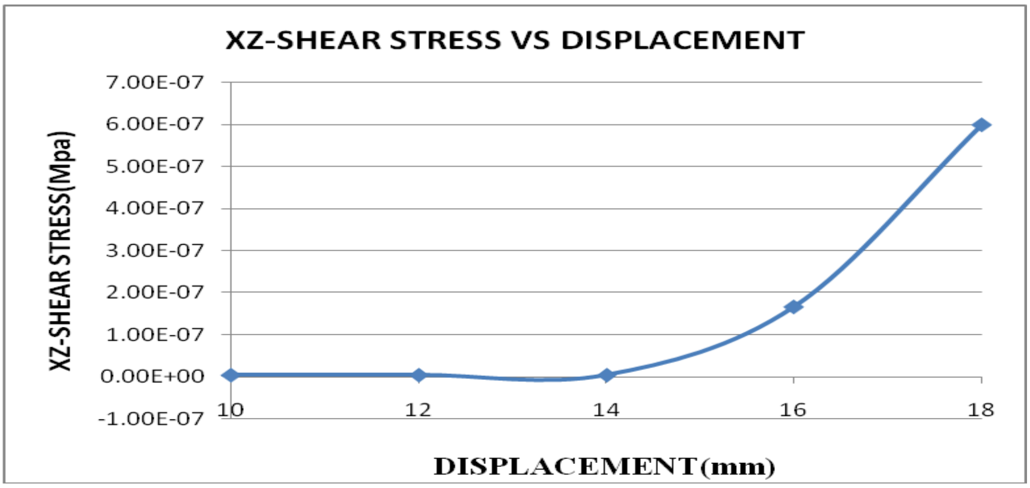

Figure4.10. *Variation of XZ-shear stress to Displacement*

Strains

The variation of normal strains with increase in displacement are as shown in Figures-4.11, 4.12 and 4.13.

In X-direction, the strains are increasing linearly and are maximum 0.03 at 18mm displacement as sown in figure-4.11. Similarly, the normal strains in Y and Z-directions are shown in fig and it is observed that the strains developed along width are negligible. As the Displacement increases, the x-component of total mechanical strain, the y-component of total mechanical strain, the z-component of total mechanical strain, obtained from FEM analysis increases.

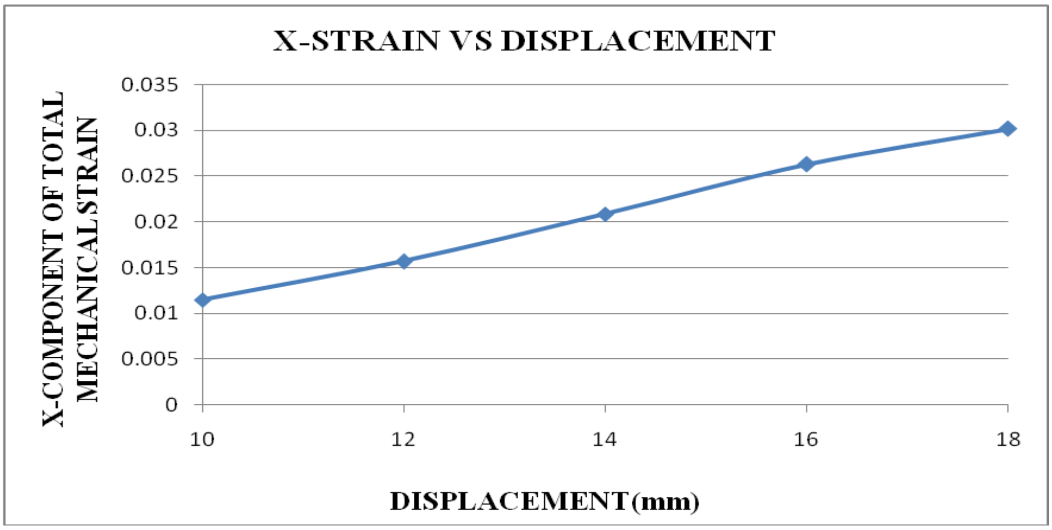

Figure4.11. *Variation of X-component of total mechanical strain to Displacement*

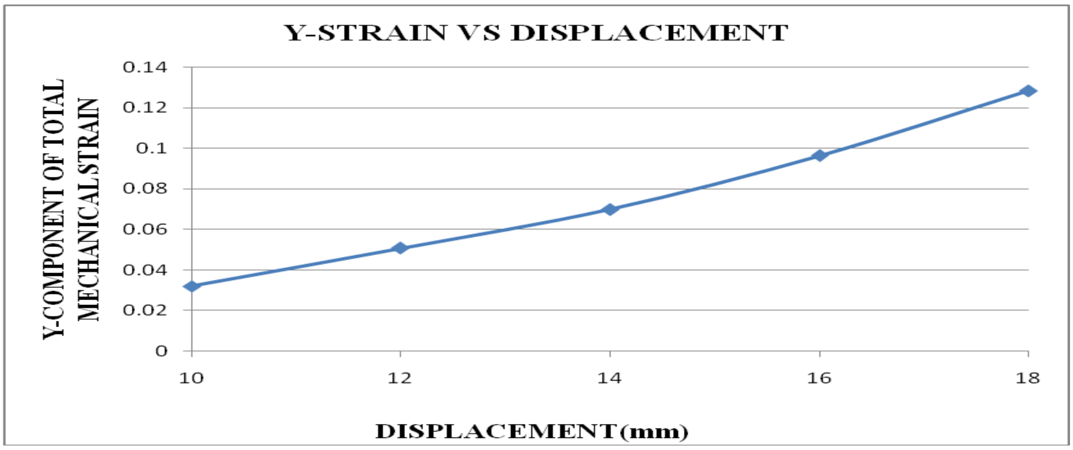

Figure4.12. *Variation of Y-component of total mechanical strain to Displacement*

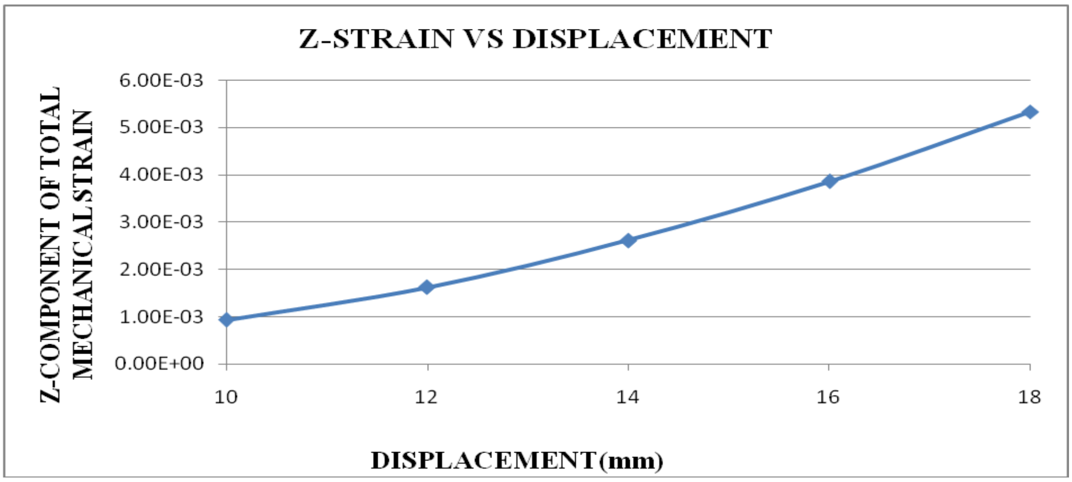

Figure4.13. *Variation of Z-component of total mechanical strain to Displacement*

Shear Strains

The shear strain in XY plane is increasing up to 16mm and falling later as shown in figure- 4.14. The maximum shear strain value is 0.17. The shear strains in YZ and XZ planes are less and the variation is as shown in Figures 4.15 and 4.16 respectively. Similarly, the load versus displacement is linear and is shown in figure-4.17.

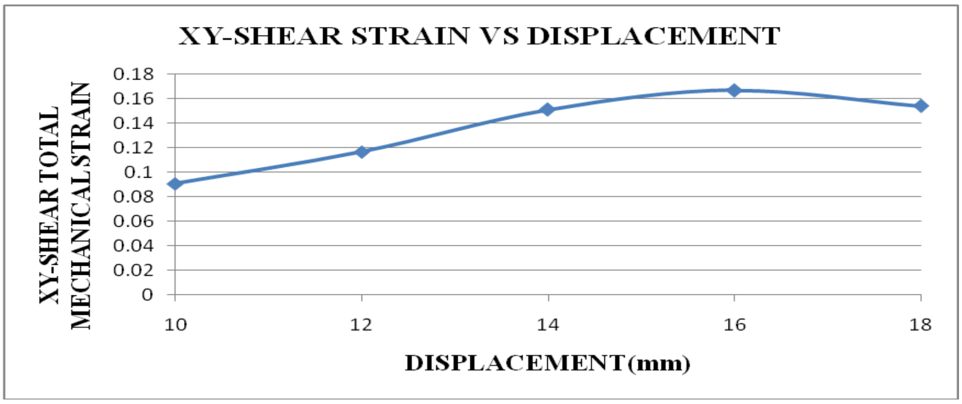

Figure4.14. *Variation of XY-shear total mechanical strain to Displacement*

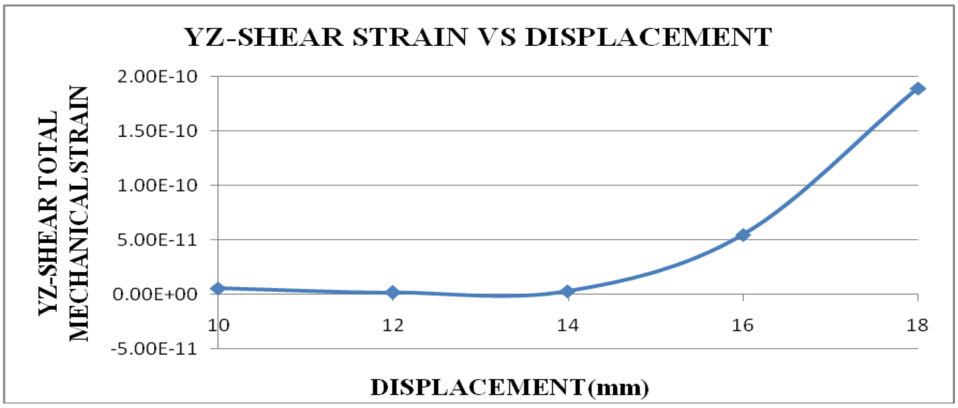

Figure4.15. *Variation of YZ-shear total mechanical strain to Displacement*

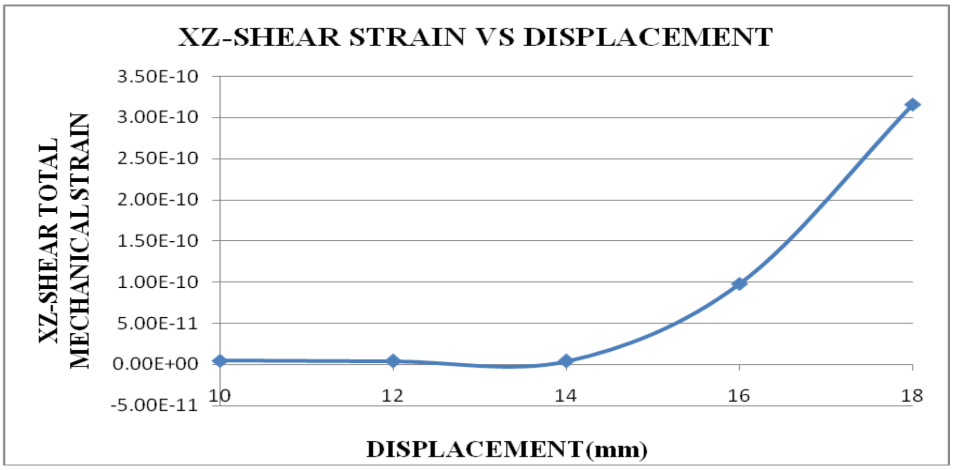

Figure4.16. *Variation of XZ-shear total mechanical strain to Displacement*

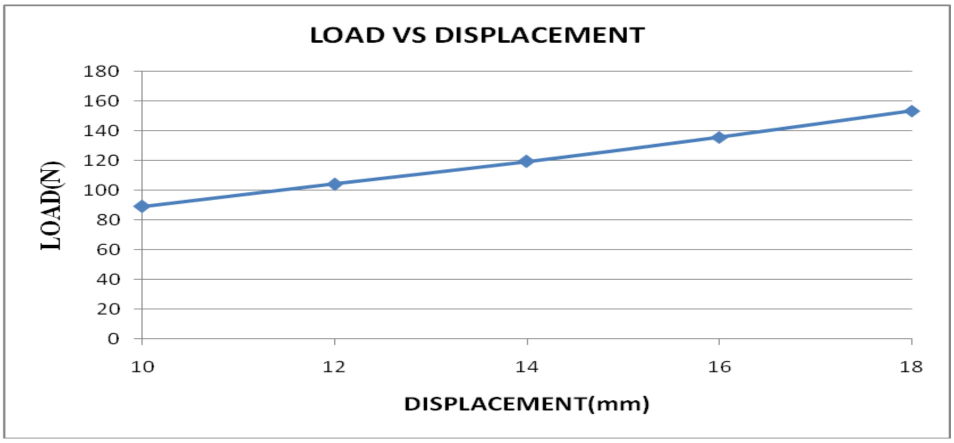

Figure4.17. *Variation of YZ-shear total mechanical strain to Displacement*

CONCLUSION

Delamination is one of the failure modes of laminated composites. The numerical technique, Finite element method has been used for the simulation of delamination process in laminated composites. The stresses and strains developed in four layered Carbon epoxy laminated composite has been studied in detail. The results are in good agreement with theoretical results. The deformation in width direction is negligible due to cracking of layers in Y-direction.

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