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# REVIEW ON METHODS TO REDUCE DELAMINATION IN COMPOSITE LAMINATE

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## ABSTRACT

Composite material has much more advantage and application than metal. This is mainly because of their excellent mechanical properties with low density and ease of manufacturing, but failure mechanism of composite is unpredictable, testing of composite is very costly. The main reason for damages in composite materials are inter-laminar de-bonding, delamination, micro-cracks, micro-buckling and inclusions among these damages delamination is one of the major defects observed in composite structure. In this paper, we are reviewing the methods to reduce occurrence of delamination in composite laminate by understanding the effect of number of ply and effect of stiffener on delamination in composite laminate.

**KEYWORDS**: Composite laminated plate, Delamination, Finite Element Analysis, Number of ply, Stiffener.

## INTRODUCTION

The composite materials are in use for the aerospace industries and mechanical industries because of their good material & mechanical properties. The laminated composite plate is made up of multilayer lamina. And due to this multilayer structure their inter laminar stresses can significantly con- tribute to delamination even when they are much lower than the failure strength of the classical lamination theory [1]. Under repeated or impact load significant shear stresses develop in between two adjacent ply due to the tendency of each layer to deform independently. These stresses are maximum at edge of a laminate and may cause de-lamination at such locations [2]. The cause of fiber pull-out and de-lamination is weak bonding. Thus de-lamination is an insidious kind of failure as it develops inside of the material without being obvious on the surface much like metal fatigue [4].

## COMPOSITE LAMINATE

Composite laminates are assemblies of layers of fibrous composite materials which can be joined to provide required engineering properties including in-plane stiffness, bending stiffness, strength and coefficient of thermal expansion. Typical fiber used includes graphite, glass, boron and silicon carbide. Some matrix materials are epoxies, polyamides, aluminum, titanium and alumina[6]. In some case layers of different materials may be used, resulting in a hybrid laminate. The individual layers generally are orthotropic (that is with principal properties in orthogonal directions) or transversely isotropic (with isotropic properties in the transverse plane) with the laminate then exhibiting anisotropic (with variable direction of principal properties), orthotropic or quasi-isotropic properties. Quasi-isotropic laminates exhibit isotropic (that is independent of direction) in plane response but are not restricted to isotropic out-of-plane (bending) response. Depending upon the stacking sequence of the individual layers, the laminate may exhibit coupling between in plane and out-of-plane response. An example of bending-stretching coupling is the presence of curvature developing as a result of in-plane loading. [7]

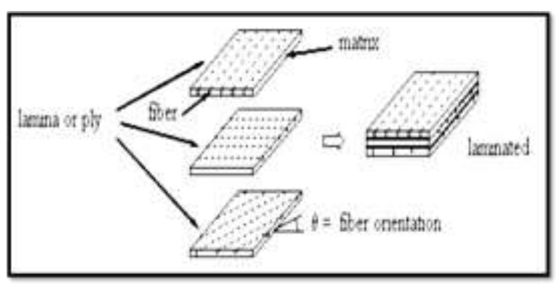


*Fig. Composite Laminate*

Though composite material has much more advantage and application than metal but up to this date composite is not able to replace metal from different industrial fields and reasons behind is data available about composite is much more less, failure mechanism of composite is unpredictable, testing of composite is very costly, for analysis of composite very much more power full tool will be required and last but not the least composite is very difficult to model both by analytically and with computer.

Finite element method is especially versatile and efficient for the analysis of complex structural behavior of the composite laminated structures. Most of the composite laminate fails due to de-lamination [3]. De-lamination failure may be detected in the material by its sound, solid composite has bright sound while delaminated part sounds dull and reinforced concrete sounds solid, where as delaminated concrete will have a light drum-like sound when exposed to a dragged chain pulled across its surface. Bridge decks in cold climate countries which use de-icing salts and chemicals are commonly subject to de-lamination and as such are typically scheduled for annual inspection by chain-dragging as well as subsequent patch repairs of the surface. Other non-destructive testing methods are used including testing with ultrasound, radiographic imagining. Causes of De-laminations are impact damage, matrix micro cracking, overload or fatigue, inadequate bonding between layers, environment condition [5]. In this paper stiffened composite laminate panel is analyzed for de-lamination for different methods to reduce occurrence of de-lamination in composite laminate.

## ANALYSIS OF COMPOSITE LAMINATE Vs SINGLE COMPOSITE LAMINA

Theoretically we know that use of composite laminate is always beneficial over use of single composite lamina because thickness of ply in laminate is small due to that defect intensity is also very low and higher will be the strength. As in laminate more than one composite lamina is present made up of same or different composite material, due to presence of more than one composite material in laminate its strength will be higher than single composite lamina consist of single composite material. Failure of composite laminate is mostly occurs with de-lamination but in case of single composite lamina with higher thickness failure can be occurs with separation of fiber and matrix, crack propagation in matrix, breaking of fiber and many more. So that strength of composite laminate is higher than single composite laminate. Now we prove it by both analytically and by FEA method.

For this analysis we are considering three plates one is composite laminate and other two are single composite lamina. This analysis we will conduct with two methods Firstly we try to find out analytical solution for those cases & then we solve the same with the use of Ansys. After analysis deformation and stress plot of all the three plates are taken and that result obtain after the analysis is compare with the result obtain from mathematical solution.

Following tables shows Comparison of Result for Deformation & Stress Analysis

| **Plate** | **1st Plate**<br>**[Composite Laminate]** |
|---|---|
| **Deformation** | 0.02548mm(FEA)<br>0.02597mm(Analytically) |
| **Stress** | By FEA<br>[CFRP 50/50] 21.656Mpa<br>[CFRP 70/30] 78.339Mpa<br>By Analytically<br>[CFRP 50/50] 21.64Mpa<br>[CFRP 70/30] 78.35Mpa |

| **Plate** | **2nd Plate**<br>**[CFRP 50/50] E=50GPa** |
|---|---|
| **Deformation** | 0.05978mm(FEA)<br>0.06mm(Analytically) |
| **Stress** | 67.95Mpa(FEA)<br>67.07Mpa(Analytically) |

| **Plate** | **3rd Plate**<br>**[CFRP 70/30] E=181GPa** |
|---|---|
| **Deformation** | 0.01642mm(FEA)<br>0.016mm(Analytically) |
| **Stress** | 78.27Mpa(FEA)<br>77.99Mpa(Analytically) |

Here we compare composite laminate plate (i.e. 1st plate) with CFRP [50/50] plate (i.e. 2nd plate) and form the result we can see that deformation of composite laminate plate is much more less than CFRP [50/50] plate.

As 3rd plate i.e. CFRP [70/30] is made up of 70% of fiber and 30% of matrix but as we know function of matrix is to support or held the fiber together in structure but in this case percentage of matrix is very less and with such combination of matrix and fiber it is easy to manufacture composite plate of thickness up to 3mm to 5mm and such plate in laminate form

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gives very good result. But with such combination of matrix and fiber it is very difficult to manufacture such composite plate with 10mm thickness and such plate fail very fast due fiber pull out type of failure.[9] So that such composite plate is practically rarely used. Due to this reason comparison with 3rd plate is not done. But we perform analysis on 3rd plate because if any one find out best way to manufacture such composite plate which having maximum strength so that at that time for comparison analysis of 3rd plate is done. In this case we also find out the Avg. deformation of 2nd & 3rd plate is 0.0381mm, which is also higher than deformation in composite laminate plate (i.e. 1st plate). From all this analysis we find out that composite laminate plate is always beneficial then same thickness single composite plate.

## MEHODS TO REDUCE DELAMINATION IN COMPOSITE LAMINATE

As seen from above results composite laminates are very use full instead of single lamina but its failure due to delamination is very insidious kind of failure here to reduce the same we are reviewing different methods to reduce this kind of failure in composite laminates

### A. INCREESING NUMBER OF PLY OVER COMPOSITE LAMINATE

To find out effect of number of ply over composite laminate here we are considering a simply supported square plate Ax = Ay = 2000mm, thickness t=10mm laminated with AS4D/9310. The plate is loaded in compression with and edge load Nx=-1 N/mm and Ny = Nxy = Mx = My = Mxy = 0. We have to find the centre deflection perpendicular to the plate surface when the number of layer is n=1, 5, 10, 15 and 20 so that we can find behavior of composite laminate as no. of ply increase. For this we can use symmetry to model ¼ of the plate and with the use of A, B, D and H matrices we try to find out effect of number of ply over composite laminate.

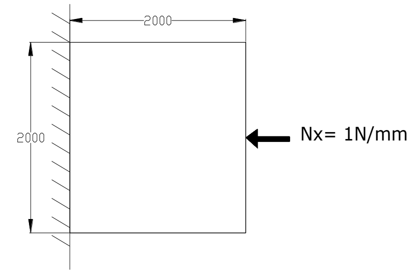


*Fig. Simply Supported Composite Laminate Square Plate*

Here let us consider N= no. of ply over composite laminate, so start by taking N=1 & after by increasing no. of ply as 5, 10, 15, 20 we get results as below.

| Plate with No. of Ply | Delamination in mm |
|---|---|
| N=1 | 0.219144mm |
| N=5 | 0.021061mm |
| N=10 | 0.010362mm |
| N=15 | 0.00688mm |
| N=20 | 0.00516mm |

Form result we can say that as number of plate in laminate increase strength of laminate structure increases. Therefore as no. plate in laminate increase center deflection perpendicular to the plate surface decreases. So that it is always beneficial to use composite in the form of laminate with maximum number of ply. [8]

### B. APPLYING STIFFENER ON COMPOSITE LAMINATE

The stiffened panel consists of three components the skin, the stringer web, and the stringer flange. The construction of stiffeners (stringer web and flange) repeats at a fixed interval, as shown in the figure below. All three components are made of layered composite materials. An in-plane buckle and the bond between the skin and the flange to be damaged. The representative section shown below contains a 600 mm x 160 mm portion of the panel skin and one stiffener assembly.

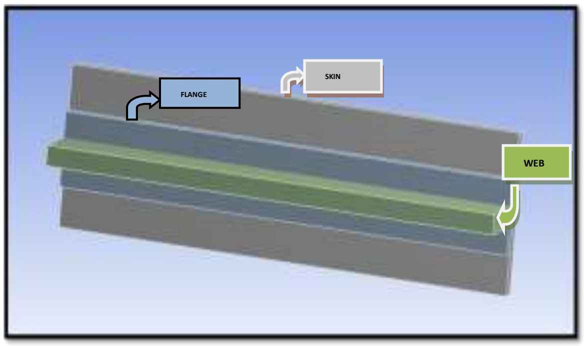


*Fig 9.1: Stiffened Composite Panel*

The stiffened panel may undergo various local and global failure modes when subjected to a service load. This example focuses primarily on the global buckling of the panel and the progressive failure of the bonding material between different structural components. To simulate this highly nonlinear and unstable phenomenon, the nonlinear stabilization method and bonded contact with a cohesive zone model are used.

One end of the panel is completely constrained, as shown in the figure below. The other end is assumed rigid and allowed only uniform displacement in the longitudinal (global X) direction. To simulate these conditions, a pilot node is created and the CP command is used to couple the X displacement of the pilot node and the X displacement of all other nodes at this end. The periodic symmetry requires that any node on one cut boundary of the representative model moves in the same way as the corresponding node at the other cut boundary. An in-plane compressive force of 76666 N in the negative X direction is applied at the pilot node to induce buckling and de-lamination.

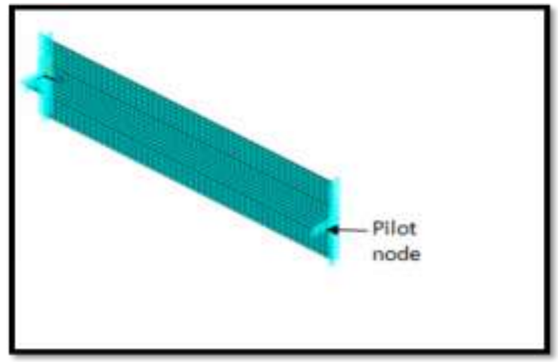


*Fig 9.2: Stiffen Composite Laminate Panel under Boundary Condition*

In this step we try to find out effect of stiffener on composite laminate for that we are considering two composite laminate structures having same dimension and made up of same composition. Force of 7666N is acting on both plate at one end and another end of both plates is fixed. Both plates are made up of 14 layer of composite material. Property of composite material is shown in table.

Property of Carbon- Fiber -Reinforced Polymer:

| | |
|---|---|
| Young's modulus in X direction (Mpa) | 130000 |
| Young's modulus in Y direction (Mpa) | 8000 |
| Young's modulus in Z direction (Mpa) | 8000 |
| Poisson's ratio (PRXY, PRYZ, PRXZ) | 0.3 |
| Shear modulus GXY (Mpa) | 5000 |
| Shear modulus GYZ (Mpa) | 2500 |
| Shear modulus GXZ (Mpa) | 5000 |

*Table 8.1: Property of CFRP*

First composite laminate plate is show in fig. It is simple composite laminate plate with dimension 180x600mm without composite stiffener.

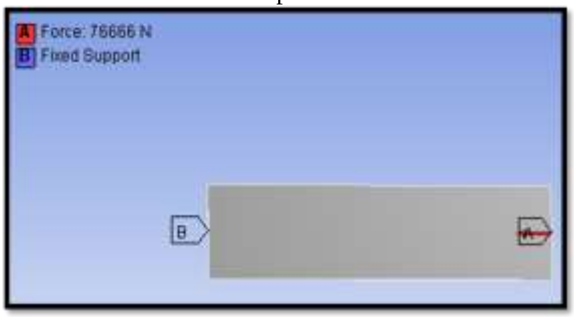


*Fig 8.1: Single Composite Laminate Plate*

Second composite laminate plate is shown in fig. It is also 180x600mm in dimension. But one T shape composite laminate stiffener is attached to it. We can use any shape of composite laminate stiffener [I, T, L] but here we consider T shape of stiffener.

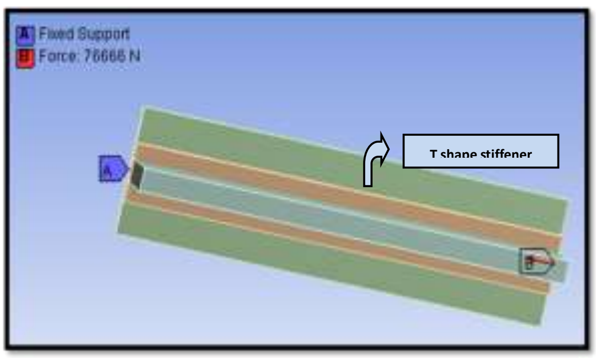


*Fig 8.2: Composite Laminate Plate with T Shape Stiffener*

## CONCLUSION

**ANALYSIS RESULT FOR BOTH THE PLATE**

When we analyse both the plate we find out that single composite laminate plate get totally distorted that is it deforms up to 682.14mm. But second composite laminate plate with T shape stiffener deforms only 3.29mm. From this analysis result we can say that due to use of stiffener we can increase the strength of composite laminate.

So, these are the two methods which we have used to reduce mode of failure in composite laminate & made analysis for both in CAD environment. From this work we understand few more thing i.e.

- Strength of composite laminate is higher than single composite lamina.
- As number of ply in composite laminate goes on increasing its strength also goes on increasing.
- Stiffener increases the strength of composite laminate.
- How to analyze any composite laminate structure for de-lamination.

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## REFERENCES

[1]. Chuijin Yang, Jubing Chen, Shexu Zhao "The Interlaminar Stress of Laminated Composite under Uniform Axial Deformation" Published Online April 2013 (http://www.scirp.org/journal/mnsms)
[2]. Voyiadjis GZ., "Damage in composite materials."Amsterdam, New York: Elsevier; 1993.
[3]. E. J. Barbero, Finite Element Analysis of Composite Materials : using ANSYS (Second Edition)
[4]. Reddy JN, Arciniega RA. Shear deformation plate and shell theories: from Stavsky to present. Mech Adv Mater Struct 2004;11:535–82 .
[5]. Gurdal Z, Haftka RT, Hajela P, "Laminated composite materials", USA, John Wiley & Sons; 1999.
[6]. Ghugal YM, Shimpi RP. A review of refined shear deformation theories of isotropic and anisotropic laminated plates. J Reinf Plast Compos 2001;20:255–72.
[7]. Kant T, Swaminathan K. Estimation of transverse/ interlaminar stresses in laminated composites – a selective review and survey of current developments. Compos Struct 2000;49:65–75.
[8]. Recent developments in finite element analysis for laminated composite plates Composite Structures 88 (2009) 147–157