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IMPACT ANALYSIS of A COMPOSITE LAMINATE using ANSYS

John Brightlin T[1] & Vanishree Beloor[2]

[1] PG Scholar, [2] Assistant Professor
Department of Industrial Engineering & Management
JSS Academy of Technical Education
Bangalore, Karnataka
India

ABSTRACT

In today's scenario composite materials are extensively used to safeguard a person from impact loading therefore the behaviour of the composite laminate is studied for impact loading. Composite material exhibit complex failure behaviour under impact loading. Possible modes of failure in composite may include matrix cracking, fibre breakage, fibre matrix de bonding or de lamination between composite plies. Carbon fibre reinforced composite and Boron fiber reinforced composite is chosen as a test material. Initially uniaxial and biaxial loading conditions are given to find the behaviour of composite laminate. ANSYS is used as a tool for the analysis. Both analytical and experimental results are compared.

Key Words: *Composites, Impact, MATLAB, ANSYS.*

1. INTRODUCTION

Composites are defined as the combination of two or more material differing in composition both physical and chemical resulting in the formation of third material of different composition. The constituents of the combining materials are, they do not completely merge or dissolve into each other. Examples of naturally occurring composite materials are: Wood is a fibrous natural composite so are the bones. Early days composites were made by mixing straw and clay to make clay stones. Reinforcement being the straw and matrix material the clay. The glass fibre was first developed in 1940's. Extensive work on composites began since 1965. Composite's reaction to loads depends on its direction and this is one of the differences between laminated composites and conventional materials. Properties of composite materials are: high specific modulus and high specific strength which leads to reduction in the components weight, in turn increases efficiency and saves energy.

The desired strength and stiffness in the required direction can be achieved which is one of the main advantage of composite materials. For high strength and high modulus application carbon fibres are generally used.

The measured strength value obtained for most of the material is different from their theoretical values because of the presence of flaws and imperfections in the material. The cracks which lie at an angle to the load direction leads to decrease in strength. Along the length non polymeric materials have strength higher because of their cross sectional fibres being small.

1.1 COMPOSITE TYPES:

1. Fibrous Composites: They are composed of fibres wherein one material is the fiber that is the reinforcement and the other material the matrix

2. Particulate Composites: They are composed of particles wherein one material is the particle that is the reinforcement and the other material the matrix

3. Laminated Composites: In this type of composites the fibres and matrix are made of different material and they are in the form of layers.

2. PROBLEM STATEMENT:

- When the composite laminate is subjected to different loading conditions like uniaxial, biaxial and impact loading it tends to fail at certain point. To find out the ballistic range of the multilayered laminate by keeping the number of layers constant and changing the orientation of the laminate.
- Validate the analytical data with the theoretical value.

3. OBJECTIVE:

- To find the multilayered composite material composition which can withstand large impact loading.

4. MATHEMATICAL MODELLING

4.1 Law of Elasticity:

Generalized Law of Elasticity for Orthotropic Material is:

$$\{\sigma\} = [Q]\{\epsilon\} \quad (1)$$

[Q] is material Stiffness Matrix

$$[Q] = \begin{bmatrix} Q11 & Q12 & 0 \\ Q12 & Q22 & 0 \\ 0 & 0 & Q66 \end{bmatrix} \quad (2)$$

Where:

$Q11 = \frac{E1}{1-\gamma12\gamma21}$, $Q12 = \frac{\gamma12E2}{1-\gamma12\gamma21}$, $Q22 = \frac{E2}{1-\gamma12\gamma21}$, Q66 = G12

where,

E1, E2, G12, $\gamma12$ are engineering constants of n^{th} layer. The transformed lamina stiffness matrix for every lamina:

$$\begin{Bmatrix} \sigma x \\ \sigma y \\ \tau xy \end{Bmatrix} = \begin{bmatrix} \overline{Q11} & \overline{Q12} & \overline{Q16} \\ \overline{Q12} & \overline{Q22} & \overline{Q26} \\ \overline{Q16} & \overline{Q26} & \overline{Q66} \end{bmatrix} \begin{Bmatrix} \epsilon x \\ \varepsilon y \\ \varepsilon xy \end{Bmatrix} \quad (3)$$

Transformed reduced stiffness terms:

$[\overline{Q}] = [T]^{-1} [Q] [T]^{-1}$

$$[T] = \begin{bmatrix} m^2 & n^2 & 2mn \\ n^2 & m^2 & -2mn \\ -mn & mn & m^2 - n^2 \end{bmatrix}$$ with m = cos(theta) & n = sin(theta).

'theta' is fiber orientation angle for k^{th} lamina.

4.2 Strain and Stress variation in a Laminate:

Total Strain in each layer is given by: $\begin{bmatrix} \varepsilon x \\ \varepsilon y \\ \gamma xy \end{bmatrix} = \begin{bmatrix} \varepsilon x^0 \\ \varepsilon y^0 \\ \gamma xy^0 \end{bmatrix} + Z \begin{bmatrix} Kx \\ Ky \\ Kxy \end{bmatrix}$ (4)

where, The middle surface strains is $\begin{bmatrix} \varepsilon x^0 \\ \varepsilon y^0 \\ \gamma xy^0 \end{bmatrix}$ & The middle surface curvature is $\begin{bmatrix} Kx \\ Ky \\ Kxy \end{bmatrix}$

The stresses in the kth layer can be expressed in terms of the laminate middle surface strains and curvatures as:

$$\begin{Bmatrix} \sigma x \\ \sigma y \\ \tau xy \end{Bmatrix} = \begin{bmatrix} \overline{Q11} & \overline{Q12} & \overline{Q16} \\ \overline{Q12} & \overline{Q22} & \overline{Q26} \\ \overline{Q16} & \overline{Q26} & \overline{Q66} \end{bmatrix} \left[\begin{bmatrix} \varepsilon x^0 \\ \varepsilon y^0 \\ \gamma xy^0 \end{bmatrix} + Z \begin{bmatrix} Kx \\ Ky \\ Kxy \end{bmatrix} \right] \tag{5}$$

4.3 Resultant Laminate Forces and Moments:

The force resultants Nx, Ny and Nxy can be related to the mid plane strains ε^0 and curvatures K^0 at the surface by the following equation:

$$\begin{Bmatrix} Nx \\ Ny \\ Nxy \end{Bmatrix} = \begin{bmatrix} A11 & A12 & A16 \\ A12 & A22 & A26 \\ A16 & A26 & A66 \end{bmatrix} \begin{Bmatrix} \varepsilon x^0 \\ \varepsilon y^0 \\ \gamma xy^0 \end{Bmatrix} + \begin{bmatrix} B11 & B12 & B16 \\ B12 & B22 & B26 \\ B16 & B26 & B66 \end{bmatrix} \begin{Bmatrix} Kx \\ Ky \\ Kxy \end{Bmatrix} \tag{6}$$

Similarly, the moment resultants Mx, My and Mxy can also be related to the strains and curvatures at the surface by the following equation:

$$\begin{Bmatrix} Mx \\ My \\ Mxy \end{Bmatrix} = \begin{bmatrix} B11 & B12 & B16 \\ B12 & B22 & B26 \\ B16 & B26 & B66 \end{bmatrix} \begin{Bmatrix} \varepsilon x^0 \\ \varepsilon y^0 \\ \gamma xy^0 \end{Bmatrix} + \begin{bmatrix} D11 & D12 & D16 \\ D12 & D22 & D26 \\ D16 & D26 & D66 \end{bmatrix} \begin{Bmatrix} Kx \\ Ky \\ Kxy \end{Bmatrix} \tag{7}$$

Where,

$$A_{ij} = \sum_{k=1}^{N} (\overline{Qij})_k (Z_k - Z_{k-1}) \tag{8}$$

$$B_{ij} = 1/2 \sum_{k=1}^{N} (\overline{Qij})_k (Z_k^2 - Z_{k-1}^2) \tag{9}$$

$$D_{ij} = 1/3 \sum_{k=1}^{N} (\overline{Qij})_k (Z_k^3 - Z_{k-1}^3) \tag{10}$$

Combining the above equations:

$$\begin{Bmatrix} Nx \\ Ny \\ Nxy \\ Mx \\ My \\ Mxy \end{Bmatrix} = \begin{bmatrix} [A] & [B] \\ [B] & [D] \end{bmatrix} \begin{Bmatrix} \varepsilon x^0 \\ \varepsilon y^0 \\ \gamma xy^0 \\ Kx \\ Ky \\ Kxy \end{Bmatrix} \tag{11}$$

When forces and moments are given as an input, middle surface strains and curvatures are found using the equation 11
From middle surface strain and curvature values the total stain of each is found using equation 4
From the value of total strains in each layer total stresses are found using the equation 5.

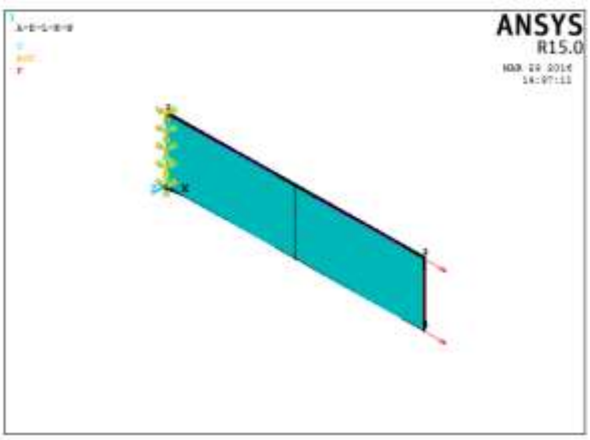
5. METHODOLOGY

Methodology to carry out the above objectives:

- A MATLAB code is written to find the overall laminate properties of the composite for uniaxial, biaxial and impact loading conditions and the stress and strain in each and every layer (both top and bottom) is found.
- Using ANSYS (LS-DYNA) the entire material properties are analysed and validated with Classical Lamination Theory (CLT).
- Failure point of the material is found

5.2 Different Loading Conditions:

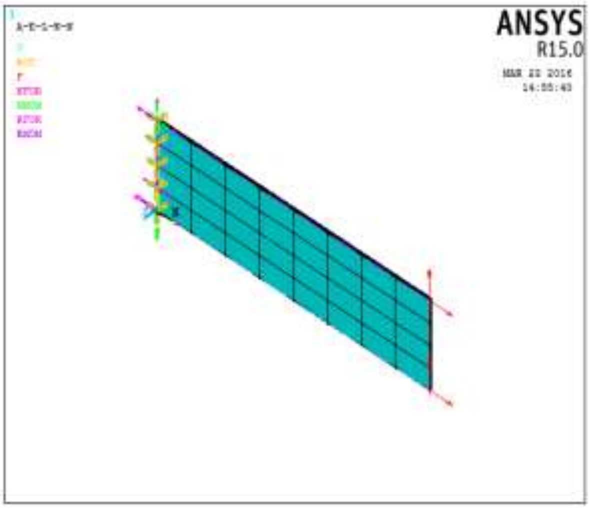
Uniaxial Loading: In order to find the stress in the longitudinal direction, the composite laminate structure is given load in axial direction i.e, x axis by applying small load on one side and fixing the other side. The displacement, stress and strain is found and plotted.



Dimension of the laminate considered for Analysis:

Height	-	25 mm
Width	-	100 mm
Force	-	1250 N

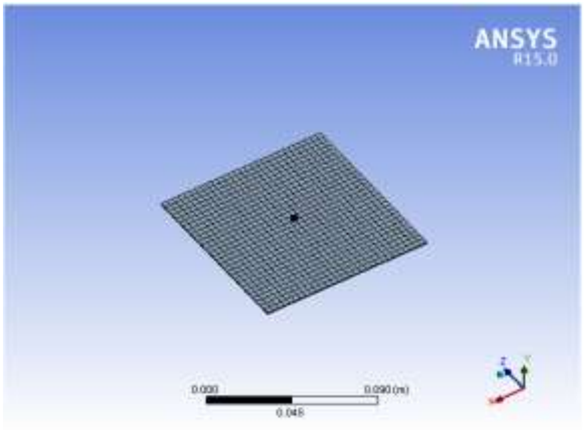
Biaxial loading: In order to find the stress in the longitudinal direction, the laminated structure is loaded in axial direction and longitudinal direction i.e, x axis and y axis by applying small load on one side in both x and y direction and fully constraining the other side. The displacement, stress and strain is found and plotted.



Dimension of the laminate considered for Analysis:

Height	-	25 mm
Width	-	100 mm
Force in x direction	-	1250 N
Force in y direction	-	1250 N

Impact Loading: When the composite laminate is subjected to impact loading if tends to fail at certain point. To find the velocity of the impact object which causes the laminate to fail is the main parameter to be considered here.



Diameter of the ball	-	2 mm
Dimension of the laminate	-	100 * 100 mm
Number of layers	-	4 layers
Thickness of each lamina	-	0.25 mm
Total thickness of the laminate	-	1 mm

For the above dimension of the ball and the plate, the stress and deformation is found and plotted for different velocities of the ball.

Comparison is done between the conventional material and the composite material and the results are tabulated.

6. RESULTS & COMPARISON:

6.1 MATLAB Code functionality

In order to implement the methodology,

Carbon-epoxy with 4 layers having fiber orientation of [-45, 45, -45, 45] antisymmetric is considered.

Both these are compared with Boron fiber.

6.2 CASE 1: CARBON FIBER

6.2.1 UNIAXIAL LOADING:

Table 1 - Theoretical Values:

4 Layers - Antisymmetric (-45, 45, -45, 45) - Uniaxial				
		SigmaX	**SigmaY**	**SigmaXY**
Layer 4	Top	35.27	-14.73	-4.54
	Bottom	45.09	-4.91	-11.34
Layer 3	Top	64.73	14.73	24.95
	Bottom	54.91	4.91	18.15
Layer 2	Top	54.91	4.91	-18.15
	Bottom	64.73	14.73	-24.95
Layer 1	Top	45.09	-4.91	11.34
	Bottom	35.27	-14.73	4.54

Table 2- Analysis Values:

4 Layers - Antisymmetric (-45, 45, -45, 45) - Uniaxial				
		SigmaX	**SigmaY**	**SigmaXY**
Layer 4	Top	34.22	-13.58	-5.01
	Bottom	46.23	-5.11	-10.56
Layer 3	Top	65.99	13.58	23.95
	Bottom	55.3	5.11	18.69
Layer 2	Top	55.3	5.11	-18.69
	Bottom	65.99	13.58	23.95
Layer 1	Top	46.23	-5.11	10.56
	Bottom	34.22	-13.58	5.01

6.2.2 BIAXIAL LOADING:

Table 3 - Theoretical Values:

4 layers - Antisymmetric (-45, 45, -45, 45) – Biaxial				
		SigmaX	**SigmaY**	**SigmaXY**
Layer 4	Top	20.55	20.55	-9.07
	Bottom	40.18	40.18	-22.68
Layer3	Top	79.45	79.45	49.90
	Bottom	59.82	59.82	36.29
Layer 2	Top	59.82	59.82	-36.29
	Bottom	79.45	79.45	-49.90
Layer 1	Top	40.18	40.18	22.68
	Bottom	20.55	20.55	9.07

Table 4 - Analysis Values:

4 layers - Antisymmetric (-45, 45, -45, 45) – Biaxial				
		SigmaX	**SigmaY**	**SigmaXY**
Layer 4	Top	24.88	24.88	-11.64
	Bottom	46.78	46.78	-21.57
Layer3	Top	83.18	83.18	45.22
	Bottom	62.61	62.61	38.29
Layer 2	Top	62.61	62.61	-38.29
	Bottom	83.18	83.18	-45.22
Layer 1	Top	46.78	46.78	21.57
	Bottom	24.88	24.88	11.64

6.3 CASE 1: BORON FIBER

6.3.1 UNIAXIAL LOADING:

Table 5 - Theoretical Values:

Table 6 - Analysis Values:

4 Layers - Antisymmetric (-45, 45, -45, 45) - Uniaxial				
		SigmaX	**SigmaY**	**SigmaXY**
Layer 4	Top	36.55	-15.27	-3.6

4 Layers - Antisymmetric (-45, 45, -45, 45) - Uniaxial				
		SigmaX	SigmaY	SigmaXY
Layer 4	Top	35.87	-14.13	-4.36
	Bottom	45.29	-4.71	-10.89
Layer3	Top	64.13	14.13	23.95
	Bottom	54.71	4.71	17.42
Layer 2	Top	54.71	4.71	-17.42
	Bottom	64.13	14.13	-23.95
Layer 1	Top	45.29	-4.71	10.89
	Bottom	35.87	-14.13	4.36

6.3.2 BIAXIAL LOADING

Table 7 - Theoretical Values:

4 Layers - Antisymmetric (-45, 45, -45, 45) - Biaxial				
		SigmaX	SigmaY	SigmaXY
Layer 4	Top	21.74	21.74	-8.71
	Bottom	40.58	40.58	-21.78
Layer3	Top	78.26	78.26	47.91
	Bottom	59.42	59.42	34.84
Layer 2	Top	59.42	59.42	-34.84
	Bottom	78.26	78.26	-47.91
Layer 1	Top	40.58	40.58	21.78
	Bottom	21.74	21.74	8.71

Table 8 - Analysis Values:

4 Layers - Antisymmetric (-45, 45, -45, 45) - Biaxial				
		SigmaX	SigmaY	SigmaXY
Layer 4	Top	19.65	19.65	-7.23
	Bottom	44.53	44.53	-25.75
Layer3	Top	82.75	82.75	46.11
	Bottom	62.37	62.37	36.58
Layer 2	Top	62.37	62.37	-36.58
	Bottom	82.75	82.75	-46.11
Layer 1	Top	44.53	44.53	25.75
	Bottom	19.65	19.65	7.23

- Table 1, 2, 3& 4 gives the Uniaxially Loaded and Biaxially Loaded Carbon Epoxy Laminate subjected to Force of 1250N.
- Table 5, 6, 7& 8 gives the Uniaxially Loaded and Biaxially Loaded Boron Epoxy Laminate subjected to Force of 1250N.
- Comparing Tables 1 to 8 it is found that Carbon Epoxy can withstand more Load when compared to Boron Fiber as the stress values are less
- So Carbon Fiber Laminate is taken for further work.
- The Theoretical and analysis values are found to match.

6.4 IMPACT ANALYSIS RESULTS:

When the velocity of the impact object is kept on increasing for the below mentioned plate dimension keeping the diameter of the ball constant, the plate fails at certain point and point at which it fails is considered as the failure point.

6.4.1 COMPOSITE LAMINATE

In case of composites five different fiber orientation combinations are considered i.e, + 30, + 45, + 60, + 75, (0,90) and the results are tabulated and the configuration which can withstand highest load is found.

Diameter of the ball	-	2 mm
Dimension of the plate	-	100 * 100 mm
Ball material	-	Stainless Steel
Plate Material	-	Composite Laminate
Number of Layers	-	4 Layers
Thickness of the Lamina	-	0.25 mm
Thickness of the Laminate	-	1 mm

Table 9 – $\pm$ 30^o Fiber Orientation

Velocity(m/s)	Directional	Normal

Table 10 - $\pm$ 45^o Fiber Orientation

Velocity(m/s)	Directional Deformation (m)	Normal Stress (Pa)
1.5E5	0.158	4.963E9
1.55E5	0.204	5.551E9

	Deformation (m)	Stress (Pa)
1.5E5	0.158	1.0501E10
1.65E5	0.295	1.223E10
1.675E5	0.318	7.96E9
1.677E5	0.320	6.298E9
1.68E5	Fails	Fails

Table 11 – ± 60° Fiber Orientation

Velocity(m/s)	Directional Deformation (m)	Normal Stress (Pa)
1E5	0.190	1.41E9
1.1E5	0.136	3.218E9
1.2E5	0.157	3.938E9
1.202E5	0.158	4.289E9
1.204E5	Fails	Fails

Table 12 – ± 75° Fiber Orientation

Velocity(m/s)	Directional Deformation (m)	Normal Stress (Pa)
1E5	0.249	1.51E9
1.25E5	0.106	2.541E9
1.45E5	0.113	8.827E9
1.455E5	0.117	9.303E9
1.465E5	Fails	Fails

Table 13 – (0,90)° Fiber Orientation

Velocity(m/s)	Directional Deformation (m)	Normal Stress (Pa)
1E5	0.203	1.903E9
1.25E5	0.043	4.749E9
1.275E5	0.056	5.051E9
1.285E5	0.0569	5.859E9
1.29E5	0.054	5.26E9
1.295E5	Fails	Fails

From the above tables 9, 10, 11, 12 & 13 it is clear that the ± 45° fiber orientation can withstand more impact loading and the value is **1.7125E5 m/s**.

Table 14 : Failure Velocity

Orientation	Failure Velocity (m/s)
+-30	1.68E5

+-45	**1.7125E5**
+-60	1.204E5
+-75	1.465E5
(0,90,0,90)	1.295E5

7. CONCLUSION & FUTURE SCOPE

- General Classical Lamination Theory (CLT) has been implented to predict the stress and shear stress in all the three mutual direction for a laminate.
- A MATLAB code has been written which employs all the classical lamination relations to find the stress values.
- First, for the Carbon fiber, uniaxial loading and biaxial loading is given and the properties are found for an antisymmetric four layered laminate
- Second, for the Boron fiber, uniaxial and biaxial loading conditions are given and the properties are found for the same antisymmetric laminate
- From the above comparison it is found that Carbon Fiber is able to withstand more load since the stress values obtained is less.
- The theoretical values are validated with ANSYS software and the values are in good agreement.
- Comparison is made between conventional material and composite material for the impact analysis.
- Within the composite laminate, for four layered antisymmetric laminate, comparison is made by changing the orientation of each lamina. It is found that $\pm$ 45^{o} laminate is able to withstand more impact i.e, 1.7125 x 10^5 m/s by keeping the diameter of the impact (ball) constant (2mm)
- Future work can be to change the impact object from ball to any other irregular shaped object and find the failure.
- Change the diameter of the impact (ball) to get an idea about what velocity the object fails.

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RamazanKarakuzu[a], EmreErbil[a]& Mehmet Aktas[b]
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[b]Dept of Mechanical Engg, Usak University, 64300, Usak, Turkey

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Rakesh Vishwakarma[1], C.M. Mishra[2] and Dr. D.K. Patil[3]
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[2]Asst. Professor, MANIT, Bhopal, M.P
[3]Prof. RGPV, Bhopal, M.P

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