International Journal of Materials Science
ISSN 0973-4589 Volume 12, Number 4 (2017), pp. 549-559

http://www.ripublication.com

Optimum Orientation of Fibre Direction in Composite Lamina

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Abstract

Composite materials have the potential to replace conventional materials used in various applications. Because of their anisotropic nature their properties can be enhanced in particular direction by ensuring their orientation in plane. This advantage is the main challenge in developing such material for particular application. Because of anisotropy they have n number of elastic constants and their analysis from strength point of view does not remain as simple as that of conventional material analysis. In this study, a composite laminate is designed using MATLAB and LS-Dyna for biaxial tensile loading. This laminate is then tested on biaxial tensile testing machine. The MATLAB code, numerical simulation and experimental results obtained are discussed in this study

Keywords: Optimization; Laminate; orientation; Vacuum Bag; Carbon Fibre; Glass Fibre .

1. INTRODUCTION

Composite materials have shown mechanical behavior that is different from the other conventional engineering materials. Most of the engineering materials are both homogeneous and isotropic. The homogeneous body has uniform properties which are independent of position in the body. The isotropic materials have same properties in every direction. The properties are independent of orientation at point in body. The anisotropic body has directionally dependent properties. Wood and composite are the anisotropic materials. A composite is a type of material which is formed by combination of two or more materials to gain superior properties. The composite materials have high strength to weight ratio hence they are widely used in structural applications (1). Composite materials are good in demand but due to their anisotropic nature their study is not as simple as isotropic materials. The orientation of angles and thickness of laminate affects the mechanical properties of composite lamina. This quest has significantly contributed to the advent of new polymer-matrix composite materials that allowed major design improvements and found extensive application in the manufacture of a variety of products, including automotive and aircraft components, structural components, sporting goods and biomedical devices. As per the requirement of the particular applications the lamina should be designed. Efficient structural analysis and optimisation procedures for size and shape and the orientation of fibres within the material is required to predict the mechanical properties of composite for particulate type of application (2) (3).

Previous studies have shown that composite fibre orientation angles can be optimized by different optimization methods for specific load cases such as longitudinal or in-plane loading (4) (5) (6). Ajith Gopinatha, Senthil Kumar (7)prepared jute fibres of length 5-6 mm. The prepared composites were tested to study the mechanical properties of the composite such as tensile strength, flexural strength, impact strength and hardness. The tensile strength for jute-epoxy and jute-polyester composites was found to be 12.46 N/mm^2 and 9.23N/mm^2. Mustafa Akbulut (6)represented an optimization procedure to minimize thickness (or weight) of laminated composite plates subjected to in-plane loading. Z. A. Mohd. Ishak (8) predicted the Tensile Modulus of Randomly Oriented Non woven Kenaf/Epoxy composite. The results based upon Tsai-Hill failure criterion indicated that the optimum fibre orientation depends upon the stress state and the relative value of the transverse and in-plane shear strengths of the lamina. When the strength of a multi directional composite laminate is to be maximized, more complicated and explicit optimization techniques are needed (9).

In this work a composite laminate of 6 plies were made as shown in Figure 1 and it was tested for bi directional tensile loading. From 750 different cases optimum angles for 6 plies were found out by MATLAB code. Considering classical laminate theory (9) (10)this code was developed. A numerical solution was carried out in LS Dyna. Numerical results were validated by experimental results. A laminate having optimum fiber orientation was fabricated and experimentally tested on bi axial tensile testing machine. With few modifications this code can be used for different material and n number of lamina.

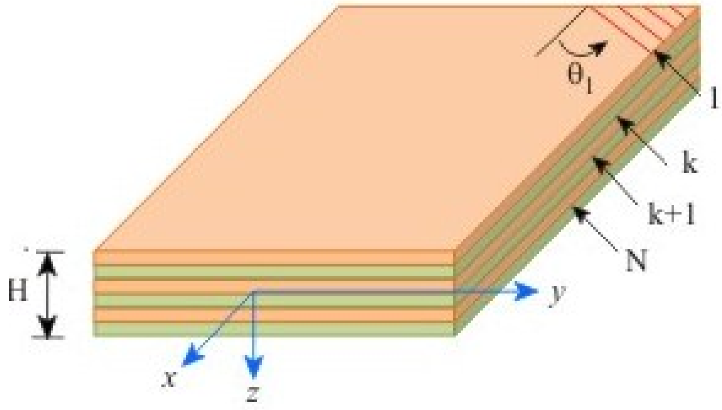

Figure 1: Stacking of lamina in laminate

2. MATERIAL

Unidirectional Carbon fibre and Glass fibre were used in this study. Following properties of Carbon Fibre and Glass Fibre were taken for the numerical simulation.

Table 1: Material properties.

Material	E1(GPa)	E2(GPa)	NU12	G12(GPa)
Carbon fibre	132.0	8.830	0.36	4.76
Glass fibre	43.0	8.90	0.27	4.50

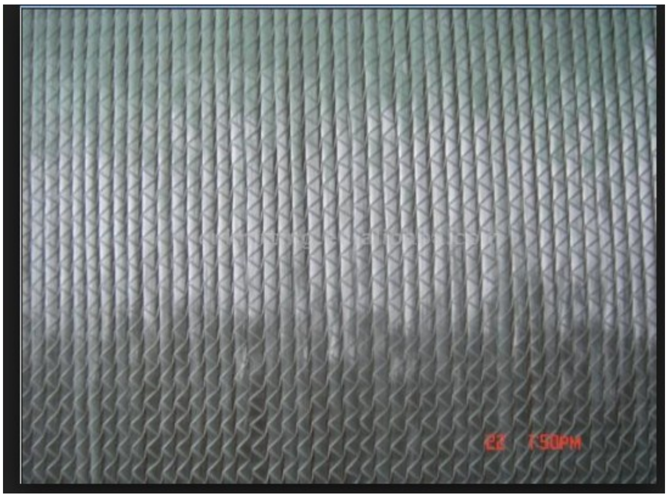

Figure 2: 200 gsm Unidirectional Glass fibre

Figure 3: 200 gsm Unidirectional Carbon Fibre

No chemical treatment was conducted on both carbon fibre and glass fibre prior to this study. Epoxy (Dobeckot 520F) and Hardener 758 was used to make a composite laminate of 6 lamina.

3. MATLAB

As per classical laminate theory code was generated to find out the optimum angle of 6 plies in composite laminate. The MATLAB code is given as bellow. Tsai wu theory *(11)* was applied to calculate the principle stresses in component.

```
clc
clear all;
z1 = -0.660;
z2 = -0.440;
z3 = -0.220;
z4 = 0;
z5 = 0.220;
z6 = 0.440;
z7 = 0.660;
H = 1.32;
Q = ReducedStiffness(43.0, 8.90, 0.27, 4.50);
A = zeros(3,3);
```

```
for a=10:10:80

    A=zeros(3,3);
  c=0;
b=10;
d=10+a;
e=d;
f=b;
g=c;

  Qbar1 = Qbar(Q, c);
  Qbar2 = Qbar(Q, b);
  Qbar3 = Qbar(Q, d);
  Qbar4 = Qbar(Q, e);
  Qbar5 = Qbar(Q, f);
  Qbar6 = Qbar(Q, g) ;

  A = Amatrix(A,Qbar1,z1,z2);
  A = Amatrix(A,Qbar2,z2,z3);
  A = Amatrix(A,Qbar3,z3,z4);
  A = Amatrix(A,Qbar4,z4,z5);
  A = Amatrix(A,Qbar5,z5,z6);
  A = Amatrix(A,Qbar6,z6,z7);

   fprintf('%8.3f %8.3f %8.3f %8.3f %8.3f %8.3f\n',c,b,d,e,f,g);
  fprintf('%8.3f\n',Ebarx(A,H))
  fprintf('%8.3f\n',Ebary(A,H))

 end
```

750 cases of different ply angles were generated by permutation and combination. The angles of plies were varied by 10 degree. As the angle of fibre were varied in each lamina, the final value of modulus E in x and y direction changed for the entire laminate. Simulation in MATLAB was run using above code and the Ex and Ey values for different cases were obtained for carbon and glass fibre. For individual lamina properties mentioned in Table no. 1 were considered.

Figure 4 to 7 shows the values of Ex and Ey (on y axis) for various laminates (on x axis).The laminates have fibres at different angles and different combinations. From figure 4 to 7 it can be concluded that a higher value of modulus Ex in x directions is associated with lower value of Ey in y direction. This is particularly suitable if the loading is in one direction only. Table no. 2 shows the values for such cases.

Table no. 2: High value of Modulus in single direction.

Sr. No	Cases	Carbon Fibre Ex(GPa)	Carbon Fibre Ey(GPa)	Glass Fibre Ex(GPa)	Glass Fibre Ey(GPa)
1	0/0/0/0/0/0	132.0	8.830	43.0	8.90
2	90/90/90/90/90/90	8.830	132.0	8.90	43.0

In unidirectional loading case the particular combination which gives higher value of Ex can be used. Since the objective chosen for this study is Bi axial tensile loading, different combinations were picked up where trade off is obtained between Ex and Ey values. Few of such combinations are mentioned in Table no. 3.

Table no. 3: Few selected combinations for trade off values of modulus in both directions.

Sr no	Ply combination	Carbon Fibre Ex(GPa)	Carbon Fibre Ey(GPa)	Glass Fibre Ex(GPa)	Glass Fibre Ey(GPa)
1	0/10/20/20/10/0	74.632	8.778	31.030	8.551
2	0/10/30/30/10/0	74.273	9.344	28.928	8.723
3	0/10/40/40/10/0	76.658	10.425	28.410	9.274
4	0/10/50/50/10/0	79.073	12.313	28.679	10.304
5	0/10/60/60/10/0	80.465	15.801	29.252	12.034
6	0/10/70/70/10/0	80.235	22.878	29.762	14.794
7	0/10/80/80/10/0	78.324	37.218	29.871	18.405
9	0/10/90/90/10/0	75.658	50.111	29.431	20.272
10	0/20/20/20/20/0	60.789	8.637	26.501	8.338

It can be seen from the above table and the Figures 4 to 7 that 0/10/90/90/10/0 give high values of Ex and Ey respectively.

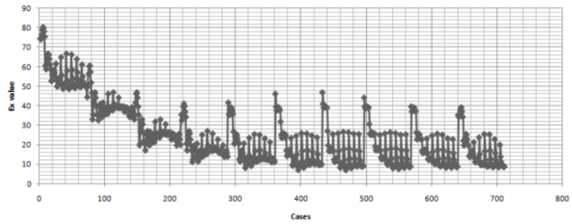

Figure 4. Graph of Ex vs. Cases for carbon fibre

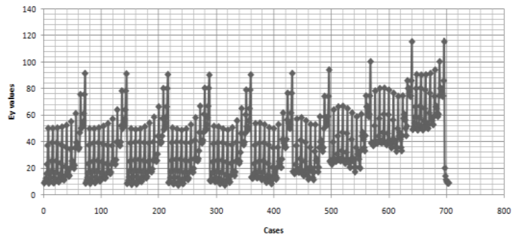

Figure 5. Graph of Ey vs Cases for carbon fibre

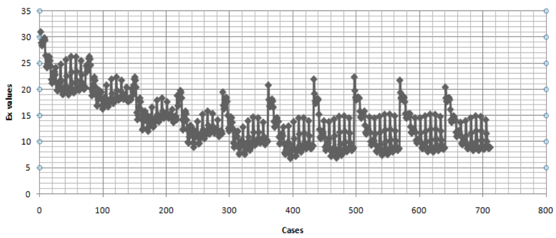

Figure 6. Graph of Ex vs Cases for Glass fibre

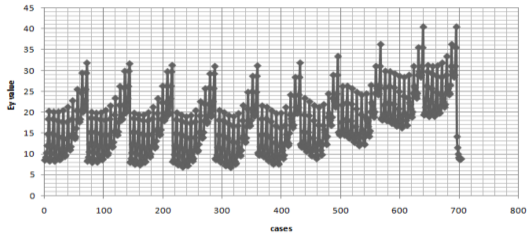

Figure 7. Graph of Ey vs Cases for Glass fibre

4. SIMULATION

The simulation for composite laminate for (0/10/90/90/10/0) and (0/90/90/90/90/0) was done with LS Dyna software whereas meshing was done with Hypermesh 12 software. For meshing shell elements were used. As shown in Figure 8 top and right end of the sample and their respective opposite ends were fixed. Time step of 1 microsec. was taken to apply a load of 2.5 kN on both the sides. Material properties were defined in MAT 54 material card. Figure 9 shows the stress contours for the case (0/10/90/90/10/0) whereas Figure 10 shows the contours for (0/90/90/90/90/0).

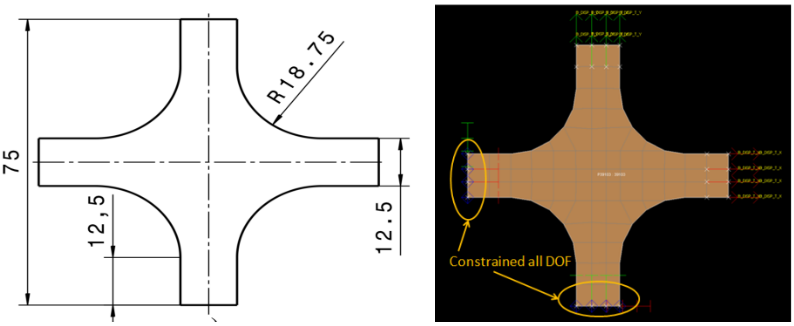

Figure 8. Finite element modeling of specimen

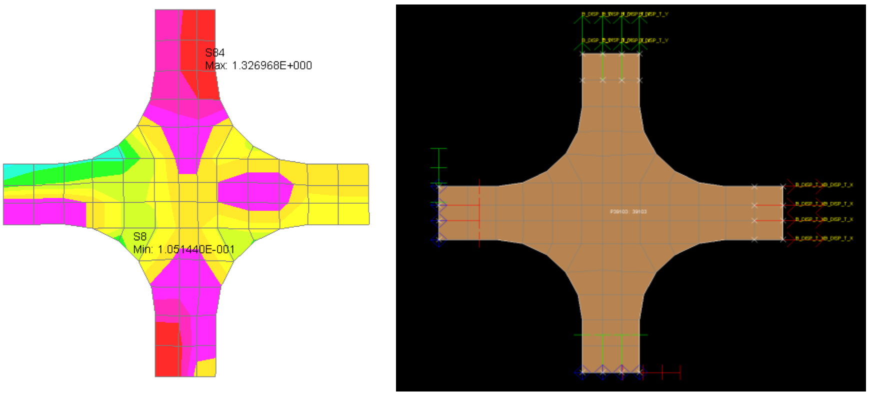

Figure 9. Stress contours for (0/10/90/90/10/0)

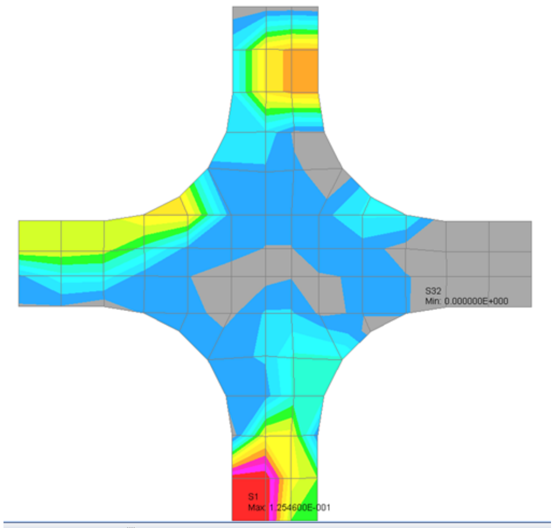

Figure 10. Stress contours for (0/90/90/90/90/0)

Maximum principal stress taken by different laminates is shown in Table No. 4 for (0/10/90/90/10/0) and (0/90/90/90/90/0).

Table No. 4 Maximum Principle stress for cases

Orientation cases	(0/10/90/90/10/0)		(0/90/90/90/90/0)	
Material	Carbon Fibre	Glass Fibre	Carbon Fibre	Glass Fibre
Maximum Principle stress (GPa) (simulation LS Dyna)	1.32696	0.87543	0.125	0.08256
Maximum Principle stress (GPa) (Calculations MATLAB)	1.21019	0.7865	0.1123	0.07234

5. Bi-AXIAL TENSILE TEST EXPERIMENT

For this test the specimen were prepared as per ASTM D6856 standard. The dimensions of the specimen are given in Figure 11.

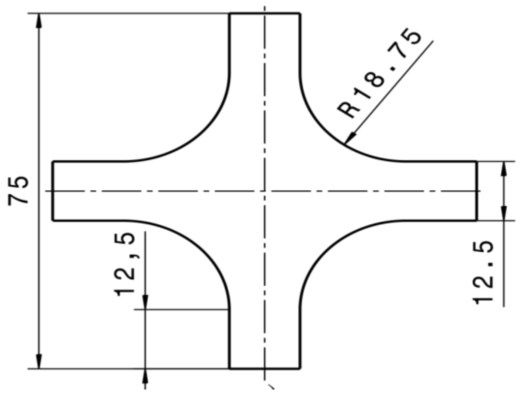

Figure 11. Tensile test specimen for biaxial tensile test

Two specimens of carbon fiber for 90/90/10/10/90/90 and 0/10/90/90/10/0 configuration and two specimens for glass fiber 90/90/10/10/90/90 and 0/10/90/90/10/0 were prepared from vacuum bagging technique.

Vacuum bag technique is used for making composite laminate of composite fiber. As previously discussed epoxy resin and hardener was used. The proper mixture of hardener and epoxy is required for effective functioning. For 10ml of epoxy 6ml of hardener is required. In order to develop the pressure in between the lamina the vacuum was created.

Figure 12. Vacuum Bag technique

From the bi-axial testing of above four specimens first ply failure was observed as given in the following Table No. 5

Table No. 5 First ply failure stresses

Configuration	Carbon fiber(stresses GPa)	Glass Fiber(stresses GPa)
0/0/10/10/0/0	0.822122	0.541212
0/10/10/10/10/0	0.72143	0.433312
90/90/10/10/90/90	0.891321	0.311154

From the above values it can be concluded that the optimum configuration given by MATLAB code is validated in LS Dyna where more stresses were observed in another configuration. The same thing was observed in actual mechanical testing also. Wherein optimum configuration took more load than the other configurations. The code gave similar results for glass fiber also. From the observations it had been concluded that for bi axial tensile test best orientation is 0/10/90/90/10/0.

6. CONCLUSION

The outcome of the present work is the effect of orientation of angles on mechanical properties of composite lamina. The effect of bi axial tensile force was investigated on carbon fibre and Glass fibre. The optimum angles configuration was 0/10/90/90/10/0 for both the materials for a good bi axial strength. Experimental study confirmed the outcome of MATLAB code.

As a future scope of study optimum fiber orientation can be found out for a bi-axial loading wherein the loading directions are not perpendicular to each other.

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