Study of Distortion in Composite Plate Using Different Boundary Conditions

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Major Project

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology in Mechanical Engineering

(CAD/CAM)

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Master of Technology at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

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Undertaking for originality of work

I, **Vivek S Patel, Roll No. 12MMCC24**, give undertaking that the Major Project entitled **"Study of Distortion in Composite Plate Using Different Boundary Conditions"** submitted by me, towards the partial fulfillment of the requirements for the degree of **Master of Technology** in **Mechanical Engineering (CAD/CAM)** of **Institute of Technology, Nirma University**, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will results in severe disciplinary action.

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This is to certify that the Major Project Report entitled **"Study of Distortion in Composite Plate Using Different Boundary Conditions"** submitted by **Mr.Vivek Patel (Roll No: 12MMCC24)** towards the partial fulfillment of the requirements for semester-IV of Master of Technology (Mechanical Engineering) in the field of CAD/CAM of Nirma University is the record of work carried out by him under our supervision and guidance.The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

Use of the composite material is increased in past few year as it gives improved characteristics of material which is not possible in conventional material. Many different industries wants to use this material for their product as it proves better than regular material. There are many scopes ahead in this field as it is still a developing area for research.

Here, as attempt has been made to determine distortion of simply supported symmetrically 4-ply laminated composite plate subject to uniformly distributed load. The classical lamination theory has been used for calculating the deflection of the plate and a code has been generated using SCILAB. The finite element had been carried out using ANSYS 14.5 to determine deflection for the same and results were compared.

The effects of fiber orientation of 4-ply composite pate on deflection have been investigated using FE analysis for same boundary condition. The effects of fiber orientation for boundary condition clamped on all sides have also been studied. All these analysis have also been carried out using another FE software HyperWorks and results are compared with analytical as well as ANSYS solution.

The experimental set up has been prepared and composite plates have been made by using manual lay-up method. For fiberglass composite plate, deformation has been found for simply supported boundary condition with uniformly distributed loading condition by experiment. The results for the same have been compared with FE analysis results.

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Chapter 1

Introduction

1.1 General

Fiber-reinforced polymer (FRP), also fiber-reinforced plastic, is a composite material formed of a polymer matrix reinforced with fibers. The Fibers are usually glass, carbon, etc., although other fibers such as paper, wood or asbestos also used sometimes. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde resins are still in employment. FRPs are commonly practiced in the aerospace, automotive, and building industries. Composites are material formed in layers or matrix with the two or more different materials, such that it can obtain the different physical and chemical properties for the particular application. Fiber reinforced composites have high strength to weight ratio due to this aerospace and automotive industries are taking interest in these type of material. As it improves the strength, but the weight is very less compared to conventional material, sports-industries are also getting interested in using this for sports equipment.

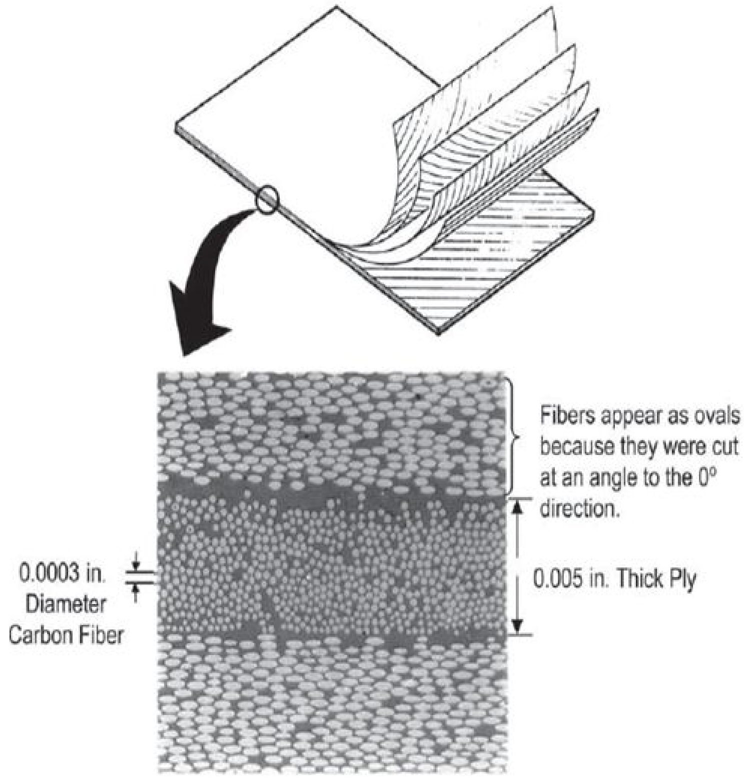

Figure 1.1: Cross-Ply Laminates

The composite material component can have multiple properties like higher strength, lighter weight, higher performance, rehabilitating existing structures and drawing out their lifespan. These fabrics are not generally usable as fibers alone, typically infused by a matrix material that act to transfer loads to the fibers. The matrix also protects the fibers from abrasion and environmental approach. The matrix dilutes the properties to some degree, but even so very high specific (weight-adjusted) properties are available from these fabrics.

The composite plate has multiple layers as shown in figure 1.1. They called as laminates. Laminates are multi-layered stacks of composite plies. Laminate stacks are defined by the fiber direction in a sequence. So as the number of ply increase the length of laminate increase. Fiber directions are given by angles from 0° to 90°. As shown in figure 1.2, layer stacking sequence written as [(20/-30)2/0]s. "2" outside of the bracket shows that the same kind of sequence is used twice. Here "s" stays for symmetrical from the mid-ply. There may be another type of layer sequence are possible like unsymmetrical in figure 1.3 sequence [45 -45 45]. For longer stack sequence, these nomenclature make understanding of layers less complicated..

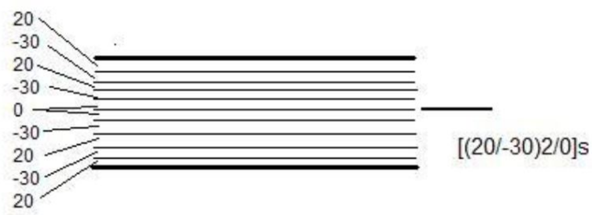

Figure 1.2: Example Of Laminate Stacking Sequence

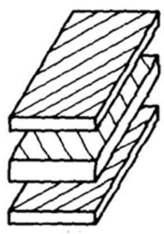

Figure 1.3: A multi-ply laminate composed of individual laminae, each possibly of a different material and oriented in different directions

Composites are popular for producing prototype parts because a extensive change of bodies can be produced rapidly and inexpensively. It is commanded solely to configure a bed of fibers in the desired form, and then saturate them with a curable thermosetting polymer. Figure 4 illustrates how this might be done simply by placing a woven fabric on a mold constructed from wood or other convenient material. The polymer resin is then rolled or crushed into the framework, and the resin allowed to react chemically ("cure") to a hard matrix. The application of an uncured resin to a dry fabric of fiber perform is called wet hand lay-up. Figure 1.4 shows simple wet hand lay-up method. The curing reaction may require elevated temperature, but resins capable of curing at room temperature are widely useable. This technique can create a large and complete article, such as a canoe or auto body panel, or also make repairs as filling in a rusted-out portion of a car body.

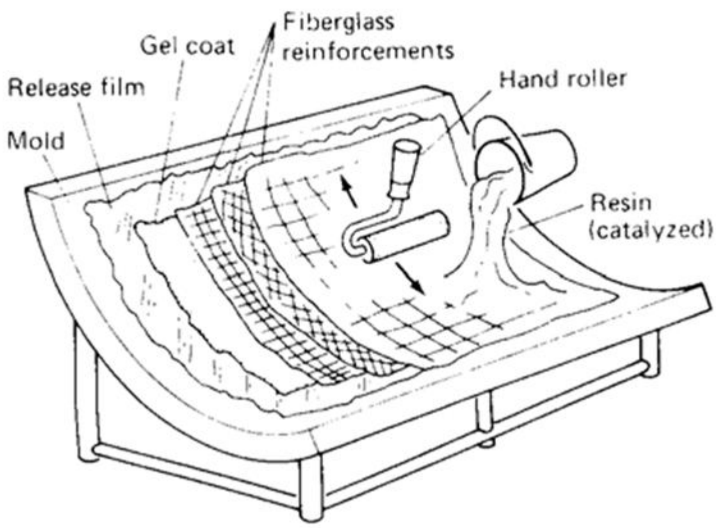

Figure 1.4: Wet Hand Lay-up Process

1.2 Fiber-Glass

Fiberglass refers to a group of products developed from individual glass fibers combined into a variety of forms. Glass fibers can be divided into two major groups according to their geometric (i) continuous fibers used in yarns and textiles, and (ii) the discontinuous (short) fibers used as baits, blankets, or boards for insulation and filtration. Fiberglass can be formed into yarn much like wool or cotton and woven into fabric which is sometimes used for draperies. The fiberglass tex material is commonly used as a reinforcement material for mold and laminated plastics. Fiberglass wool, a thick, fluffy material made from discontinuous fibers, is used for thermal insulation and sound absorption. It is commonly found in ship and submarine, bulkheads and hulls, automobile engine compartments and body panel lines, furnaces and air conditioning units, acoustical wall and ceiling panels and architectural partitions.

1.3 Mechanical Behavior of Composite Material

Composite materials are orthotropic/anisotropic in nature as they are made from more than two materials, generally is anisotropic. When composite material component is under loading due to different fiber orientation, stress distribution is in the different fiber direction. While designing the composite material for an application, there are different variables that have to take into consideration as fiber orientation, fiber and matrix material, the layer stacking sequence will affect the distortion in the material while applying loads. They are to be changed as per the flexibility needed in composite material. In this dissertation composite plates in different loading and boundary condition have been looked into.

1.4 Objective

The primary objective of this dissertation to determine the deflection of the plate made from composite material. For different layer orientation and boundary condition analytical, numerical and experimental methods have been developed to determine deflection in the composite plate.

1.5 Outline

- **Chapter 2** - Literature Review - In this chapter the summary of research papers are there. From these boundary condition and material properties have been adapted for current work.

- **Chapter 3** - Analytical Method - In this chapter classical lamination theory is explained. This theory is used for calculating the deflection for composite plate. SCILAB code is generated for this theory and results have been obtained.

- **Chapter 4** - Numerical Method - In this chapter whole plate modeling is explained. Properties of plate material, meshed model in ANSYS and HyperWorks and plate dimension are mentioned in this chapter. Results of ANSYS and HyperWorks are shown with graph of change in deflection - layer orientation and analysis results.

- **Chapter 5** - Comparison of results - ANSYS and HyperWorks results are compared in this chapter and the difference is analyzed.

- **Chapter 6** - Experimental on deflection measurement - In this chapter the detail of the experiment is given. Starting with manufacturing of plate, then preparing experimental set up and getting results of experiment. These results are compared with the HyperWorks results. Good similarity have been obtained.

- **Chapter 7** - Conclusion and Future scope - In this chapter the results obtained from SCILAB, ANSYS and HyperWorks are discussed. Conclusion about maximum and minimum distortion in the composite plate for different boundary conditions are made. Also the future scope to do research in the same field have been pointed out.

Chapter 2

Literature Review

The composite material is applied in different application from last decade. Many different patterns of analysis have been done since and still there is further scope of research in this country because there are many aspects that are still to be determined. Many researchers had been worked on composite material analysis. Rao and Venkateswarlu [1] were working on bending problems in composite material. Different shape had been assessed in their research.

Zhange and Yang [3] discussed about the recent development in the FEA analysis using different theories of lamination with the focus on vibration, buckling, deformation, damage and failure. Different theories for the buckling effect were their primary focus. On this topic different future study that can be done as failure and impairment analysis under different loading condition. Analysis of the damage evolution in composite laminates, multistage modeling of crack initiation, propagation and overall structural failure.

Khalili et al. [4] discussed the new method to analyze composite material which uses the double Fourier series for the analytical method. The different boundary condition had been talked about. From that different conditions have been adopt for current dissertation. By Them different boundary conditions were used like SSSS, CCCC, SCSC, SSSF, where S, C and F stand for Simply supported, Clamped and Free edge of a rectangular plate accordingly. A 10 layer carbon/epoxy plate had been taken. For different fiber orientation these have been matched and compared with FE method results which are previously available. The same thing had been matched for other fabric and quite similar results were obtained as FE models. This model is less complex than the FE model that are available. An overview of influence of fiber orientation on boundary condition being discussed.

Khashaba and Seif [5] discussed the different loading condition as in tension, bending and combined tension/bending of woven material. Material properties were obtained by testing and used it for research. The effect of load-displacement for some conditions were taken into consideration and tested it. Material failure points had been obtained from that. 3-point and 4-point bending tests had been done and its results being analyzed. Failure stress in this material was higher in bending than tension, been concluded. 4-point bending gives good results. As other material, these results may change.

Albuquerque et al. [6] discussed the composite plate that follows the Kirchhoff's hypothesis that assumes that normal of the plate will remain same even when the plate in under some loading. The radical transformation in boundary elements was used for analysis. Results with this method were obtained and compared with conventional methods.

MerArnel Manahan [7] discussed about the deflection in a composite plate under distributed loading condition. Classical lamination theories had been used which is also used in current dissertation. Discussed about how the change in fiber orientation is affect the deflection of composite material under distributed loading condition. MatLab for analytical results and ANSYS for FEA analysis were used. Obtained results were different as it compares because some of the variable changes the governing differential equation. The effect of change in number plies on the deflection and other properties. As their number of ply increase the deflection is decreasing and the variation in the results of the Matlab and ANSYS also decreases. There are some of the variables that are needed to take into consideration while design a composite material for a particular application. VM82 is an ANSYS used as its preloaded module for the given condition.

Hashin [10] concluded a survey of different methods and theories that had been used for analysis of the composite material. Learned an overview of methods that are used in current days for analysis of the composite material. The material properties of composite with a different failure mode discussed. Like delamination of layers, fracture etc. Little overview of the different composite material used in the recent era has been discussed.

Whitney and Leissa [11] discussed the formation of governing equations of a laminated anisotropic plate. Governing equations have been obtained by integrating the equations of nonlinear elasticity. Governing equations than reduce to use for orthotropic plate by giving symmetrical from middle plane of the plate and neglecting shear part. Concluded with reduction of effective stiffness of plate depends on the layer orientation and number of total plies in laminate.

Reddy [12] discussed generation of shear deformation theory for laminated composite plate. In which started with discussion of classical lamination theory which is direct extension of classical plate theory. With based of CLT, extended it to shear deformation theory. By given some approximation in displacement u, v and w , three dimensional problem converted to two dimension and governing equations has been obtained. From this single layer shear deformation theory has been obtained.

Lui and Li [13] discussed displacement hypothesis and theories based on that hypothesis. This includes the Kirchhoff'hypothesis. Reddy and Robbins [14] discussed different theories for deformation in composite laminates. Based on these theories computational model have been developed and analysis done. With these different results have been concluded. Gorgi [15] discussed an overview how symmetric composite plate's deflection has been affected under static loading condition.

Chapter 3

Analytical Method

Classical lamination theory has been used in this analytical method. For generation of the classical lamination code, SCILAB software is used.The deflection of the simply supported composite plate under boundary condition has been determined using SCILAB code.

3.1 Classical Lamination Theory

Assumption

1 Lamina are perfectly bonded.

2 Thickness of plate is much smaller than length of plate.

3 Transverse shear strain are negligible.

4 Plate follows Kirchhoff's Hypothesis

5 Each ply obeys' Hooke's Law

6 Displacement in u, v and w are smaller than thickness t.

Steps of calculation

1 Calculate reduced stiffness matrix Q_{ij} for each material used in the laminate The stiffness matrix describes the elastic behavior of the ply in plane loading

$$Q_{ij} = \begin{pmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{pmatrix} \tag{3.1}$$

Where, $Q_{11} = (E_{11}^2)/(E_{11} - \nu_{12}E_{22})$
$Q_{12} = (E_{11}\nu_{11}E_{22})/(E_{11} - \nu_{12}^2 E_{22})$
$Q_{22} = (E_{11}E_{22})/(E_{11} - \nu_{12}^2 E_{22})$
$Q_{66} = G_{12}$

2 Calculate the transformed reduced stiffness matrix ABD for each ply based on the reduced stiffness matrix and fiber angle

$$Q_{ij} = Q_{11}Q_{12}Q_{16}Q_{12}Q_{22}Q_{26}Q_{16}Q_{26}Q_{66} \tag{3.2}$$

3 Calculate the A_{ij}, B_{ij}, D_{ij} matrices using the equations 3.3 where z represents the vertical position in the ply from the midplane measured in meters:

$$A_{ij} = Q_{ij} \times (z_k - z_{k-1}) B_{ij} = \frac{1}{2} Q_{ij} \times (z_k^2 - z_{k-1}^2) D_{ij} = \frac{1}{3} Q_{ij} \times (z_k^3 - z_{k-1}^3) \tag{3.3}$$

4 Assemble ABD:As the temperature and moisture are neglected its matrix from ABD formulation will eliminate and the remaining ABD matrix will be as 3.4:

$$\begin{pmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{pmatrix} \tag{3.4}$$

3.2 Governing Equation

The governing equations consist of the behavior of the plate internally as well as the behavior of the boundary conditions. The governing equations will be derived using the Newtonian approach where summing the forces and moments on the plate is used to develop the differential equations. Figure 3.1 shows a composite plate in the x-y-z orientations, a loading of q(x,y) and a width 'a' and a length 'b' with the reference point at the center of the plate.

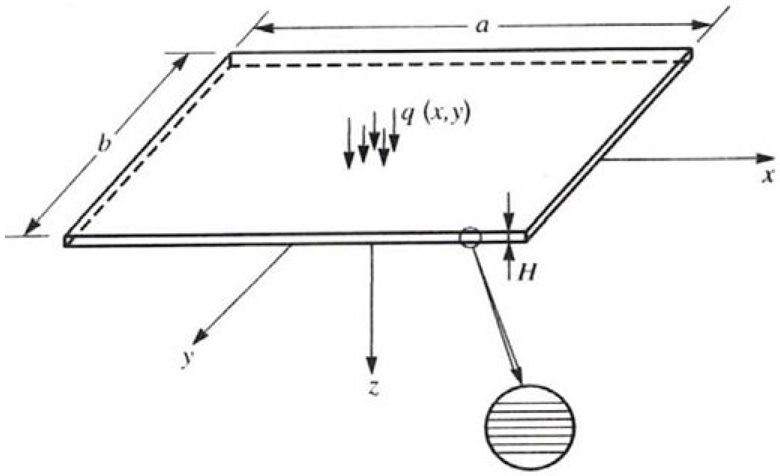

Figure 3.1: Nomenclature of plate and loading

Resultant forces(N) and moments(M) acting upon plate are shown in fig 3.2 and gives the two governing equation as given in equations 3.5 and 3.6:

$$\frac{\partial N_x}{\partial x} + \frac{\partial N_{xy}}{\partial y} = 0 \tag{3.5}$$

$$\frac{\partial N_{xy}}{\partial x} + \frac{\partial N_y}{\partial y} = 0 \tag{3.6}$$

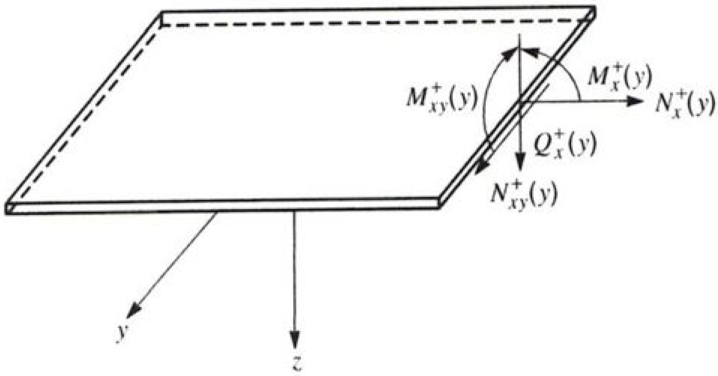

Figure 3.2: Resultant on plate

The third governing equation is found by summation of shear force resultants acting on inner side of the plate figure 3.2 shows the resultant forces and similarly figure 3.3 the summation of the moments acting on the plate. By substituting the moment resultant for x-axis and y-axis in equation of force resultant, the third governing equation has been obtained(equation 3.7):

$$(\frac{\partial^2 M_x}{\partial x^2}) + (2\frac{\partial^2 M_{xy}}{\partial x \partial y}) + (\frac{\partial^2 M_y}{\partial y^2}) = 0 \tag{3.7}$$

As in this dissertation, deflection of the plate is taken so it is better to represent the governing equation in terms of the displacement. It is expressed in matrix 3.8.

$$\begin{pmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{pmatrix} * \begin{pmatrix} e_x^{\circ} \\ e_y^{\circ} \\ \gamma_{xy}^{\circ} \\ k_x^{\circ} \\ k_y^{\circ} \\ k_{xy}^{\circ} \end{pmatrix} \tag{3.8}$$

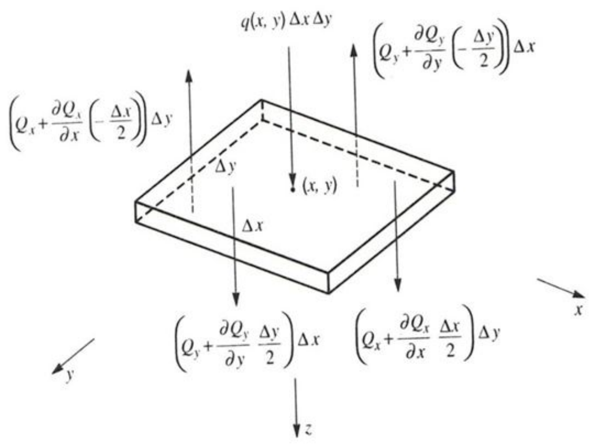

Figure 3.3: Force in Z direction

Here, terms $e_x^\circ, e_y^\circ, \gamma_{xy}^\circ, k_x^\circ, k_y^\circ, k_x y^\circ$expressed in terms of displacement function. This gives the relation between force/moment and displacement. By substituting this equation in the 3.7, three equilibrium equation that governs this laminated plates in terms of displacement[8] has been obtained.

3.3 SCILAB results

The SCILAB code starts off by putting forward the material properties for each ply. In this example, each ply has the same material properties listed in Table 3.1. SCILAB needs only five properties as $E_x, E_y, \upsilon_{xy}, G_{xy}$, t (thickness). The code then computes the values of the stiffness matrix $[Q_{ij}]$ for each ply. The code first computes the compliance matrix $[S_{ij}]$ for each ply. This matrix is then transformed and inverted to acquire the values of $[Q_{ij}]$. Next, the code calculates the z distances of each plate from the mid-plane, which will provide the distances to calculate the bending stiffness matrix [D]. This bending stiffness matrix is applied to calculate the deflection of the plate. SCILAB results are shown in table 3.2

Table 3.1: Material Properties used in SCILAB

Material Properties	Value	Unit
Young's Modulus in x-direction(E_x)	25×10^6	N/m^2
Young's Modulus in y-direction(E_x)	1×10^6	N/m^2
Shear Modulus in xy-plane(G_{xy})	5×10^5	N/m^2
Major Poisson's Ratio(υ)	0.25	-

Table 3.2: SCILAB results

Layer Orientation	Deflection of composite plate(m)
[0 90]s	0.00108
[0 90]s	0.00102

APPENDIX A shows the SCILAB code.

Chapter 4

Numerical Methods

4.1 Plate Modeling

For plate modeling ANSYS and HyperWorks software are used and also in the analysis same package is used. For two different boundary conditions SSSS and CCCC [4] and uniformly distributed load these software have been used and results are obtained. SHELL181 module (element plastic 4 node 181) is used as it has the capacity to analyze up to 255 layers of the composite material. SHELL181 geometry is shown in the fig.4.1 [7]. It is 4 nodes with 6-degree of freedom at each node.

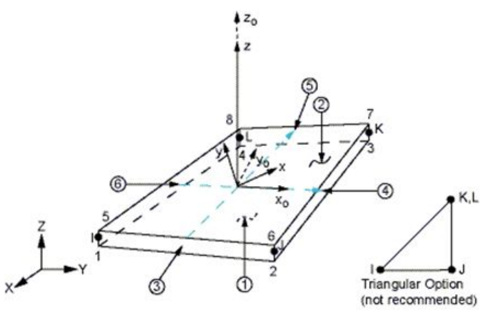

Figure 4.1: SHELL181 Geometry

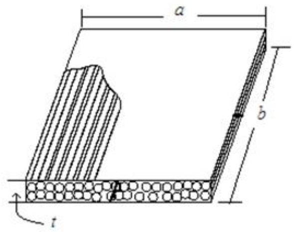

Figure 4.2: Plate Dimention

The plate dimension as shown in figure 4.2 is about 100 mm by 100 mm with thickness of 2.5 mm each ply. Composite plate of glass/epoxy which have the properties shown in table. 4.1. In figure 4.3 and 4.4 properties inserted in ANSYS and HyperWorks are shown

Table 4.1: Material Properties used in ANSYS and HyperWorks

Material Properties	Value	Unit
Young's Modulus in x-direction(E_x)	25×10^6	N/m^2
Young's Modulus in y-direction(E_x)	1×10^6	N/m^2
Shear Modulus in xy-plane(G_{xy})	5×10^5	N/m^2
Shear Modulus in yz-plane(G_{yz})	2×10^5	N/m^2
Major Poisson's Ratio(υ)	0.25	-

For analytical work only 5 properties have been given. These all properties are needed for input in the ANSYS and HyperWorks as they required. It is shown in the fig 4.3 and 4.4. To fulfil this $E_y = E_z, G_{xy} = G_{xz}, and \nu_{xy} = \nu_{xz}$. This is because of the plane stress assumption.

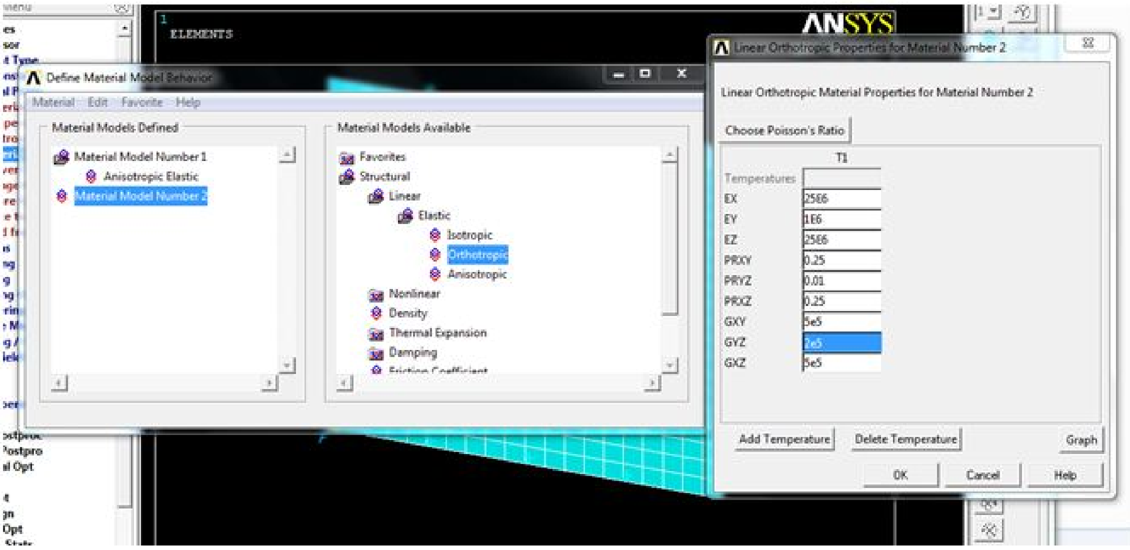

Figure 4.3: Material Properties for Orthotropic plate in ANSYS

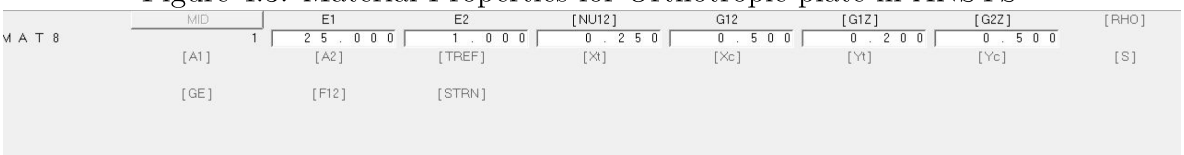

Figure 4.4: Material Properties for Orthotropic plate in HyperWorks

In figure 4.5 and 4.6 respectively shows the ANSYS and HyperWorks model of plate with dimention 100 x 100 mm that makes a 20 x 20 element mesh.

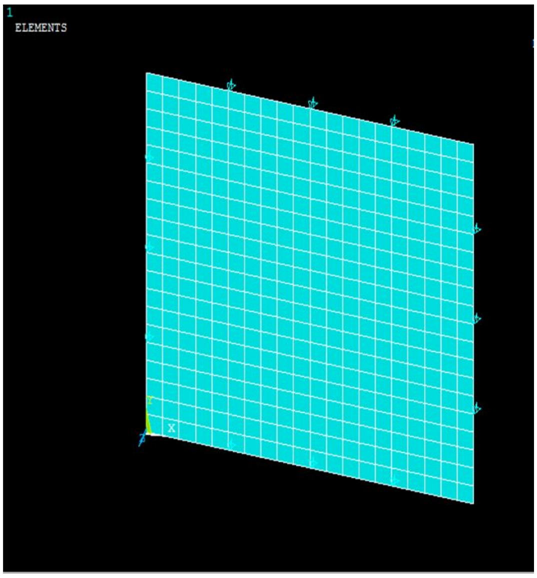

Figure 4.5: Meshed Model of [0 90]s in ANSYS

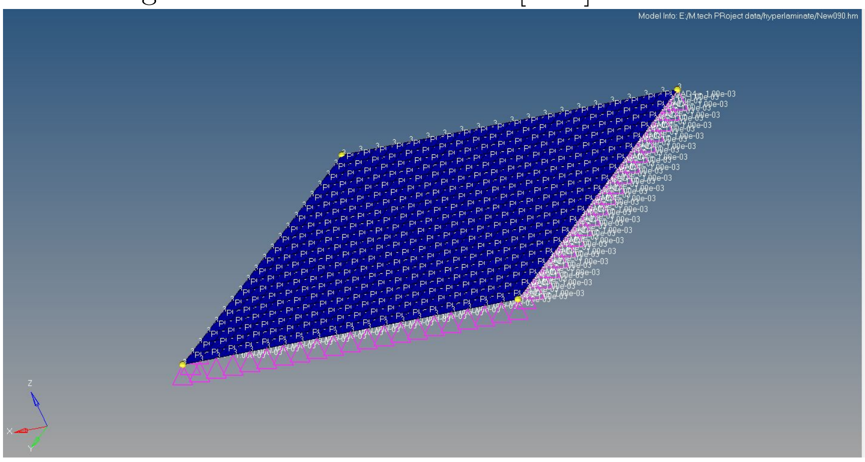

Figure 4.6: Meshed Model of [0 90]s in HyperWorks

4.2 Boundary Conditions

In this dissertation results for different boundary conditions have been obtained. Mainly 2 boundary conditions (BC) had taken (i) simply supported and (ii) clamped. Simply supported is written as "S" and clamped as "C". Now analysis done on plate and plate have 4 sides so boundary conditions are as follows:

a. SSSS - Simply supported on all four sides

b. CCCC - Clamped on all four sides

c. SFSF - Simply supported on two opposite sides and the other two sides are free ("F")

d. CFCF - Clamped on two opposite sides and the other two sides are free ("F")

SSSS and CCCC were analyzed with UDL-uniformly distributed load condition. Other two BC also checked in UDL loading. For all BC 4-ply composite plate with [0 90]s to [90 90]s have been analyzed and results have been obtained.

4.3 ANSYS results

a. SSSS-UDL: The response of a symmetric 4-ply plate with a lay-up of [0 90]s has been performed using ANSYS to validate the SCILAB code. The plate is under uniformly distributed load (UDL). The effect of change in fiber orientation on distortion of plate have been investigated. These results are shown in table 4.2. Figure 4.7 shows the effect of change in fiber orientation. Figure 4.8 shows the ANSYS results of [0 90]s plate.

Table 4.2: Results of SSSS condition with Uniformly distributed loading in ANSYS

SR.No	Layer orientation	Displacement in Ansys(m)
1	[0 90]s	0.00116
2	[10 90]s	0.00124
3	[20 90]s	0.00129
4	[30 90]s	0.00135
5	[40 90]s	0.00153
6	[50 90]s	0.00159
7	[60 90]s	0.00168
8	[70 90]s	0.00125
9	[80 90]s	0.0012
10	[90 90]s	0.000956

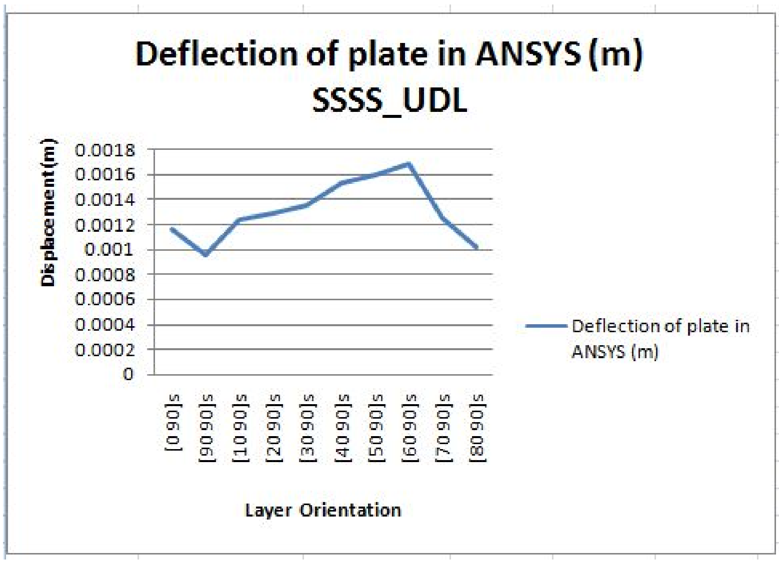

Figure 4.7: Graph of Layerorientation - deflection (m)

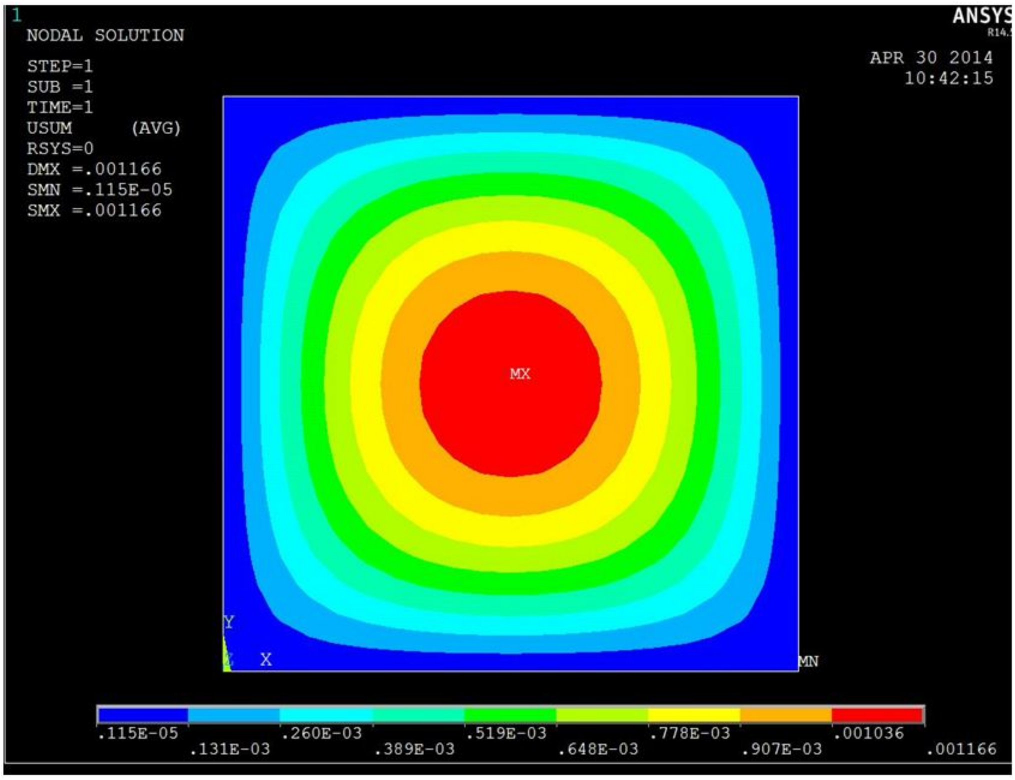

Figure 4.8: ANSYS [0 90]s plate, SSSS-UVL

b. CCCC-UDL: The response of a symmetric 4-ply plate with a lay-up of [0 90]s has been performed using ANSYS . The effect of change in fiber orientation on distortion of plate have been investigated. These results are shown in table 4.3. Figure 4.9 shows the effect of change in fiber orientation. Figure 4.10 shows the ANSYS results of [0 90]s plate.

Table 4.3: Results of CCCC condition with Uniformly distributed loading in ANSYS

SR.No	Layer orientation	Displacement in Ansys(m)
1	[0 90]s	0.000563
2	[10 90]s	0.000572
3	[20 90]s	0.00059
4	[30 90]s	0.000635
5	[40 90]s	0.000654
6	[50 90]s	0.000726
7	[60 90]s	0.000758
8	[70 90]s	0.000791
9	[80 90]s	0.000546
10	[90 90]s	0.000436

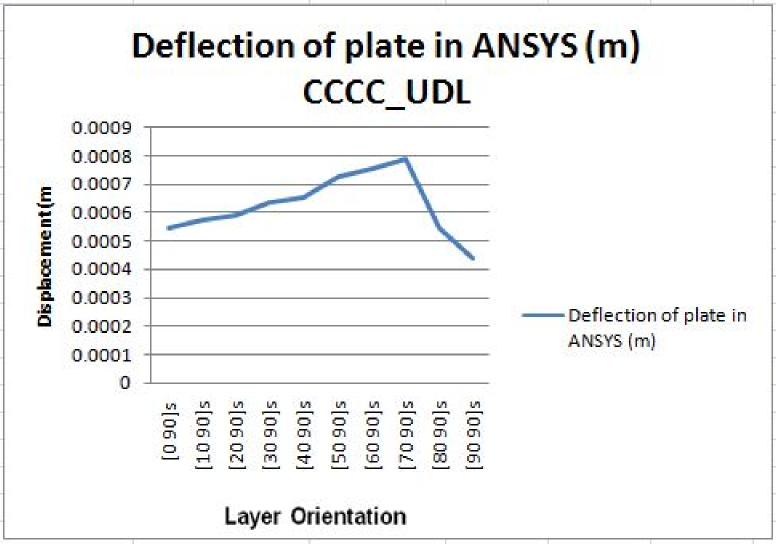

Figure 4.9: Graph of Layerorientation - deflection (m)

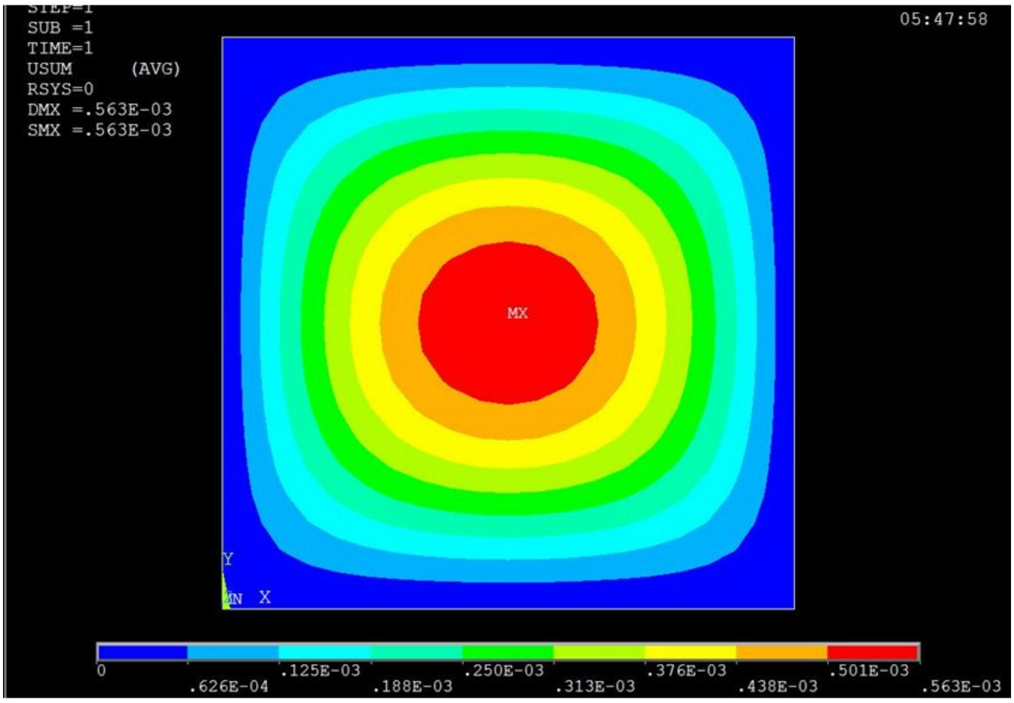

Figure 4.10: ANSYS [0 90]s plate, CCCC-UVL

4.4 HyperWorks results

a. SSSS-UDL: The response of a symmetric 4-ply plate with a lay-up of [0 90]s has been performed using HyperWorks to validate the SCILAB code and ANSYS. The plate is under uniformly distributed load (UDL). The effect of change in fiber orientation on distortion of plate have been investigated. These results are shown in table 4.4. Figure 4.11 shows the effect of change in fiber orientation. Figure 4.12 shows the ANSYS results of [0 90]s plate.

Table 4.4: Results of SSSS condition with Uniformly distributed loading in HyperWorks

SR.No	Layer orientation	Displacement in HyperWorks(m)
1	[0 90]s	0.00105
2	[10 90]s	0.00121
3	[20 90]s	0.0013
4	[30 90]s	0.00136
5	[40 90]s	0.00158
6	[50 90]s	0.0016
7	[60 90]s	0.00169
8	[70 90]s	0.00135
9	[80 90]s	0.00104
10	[90 90]s	0.000103

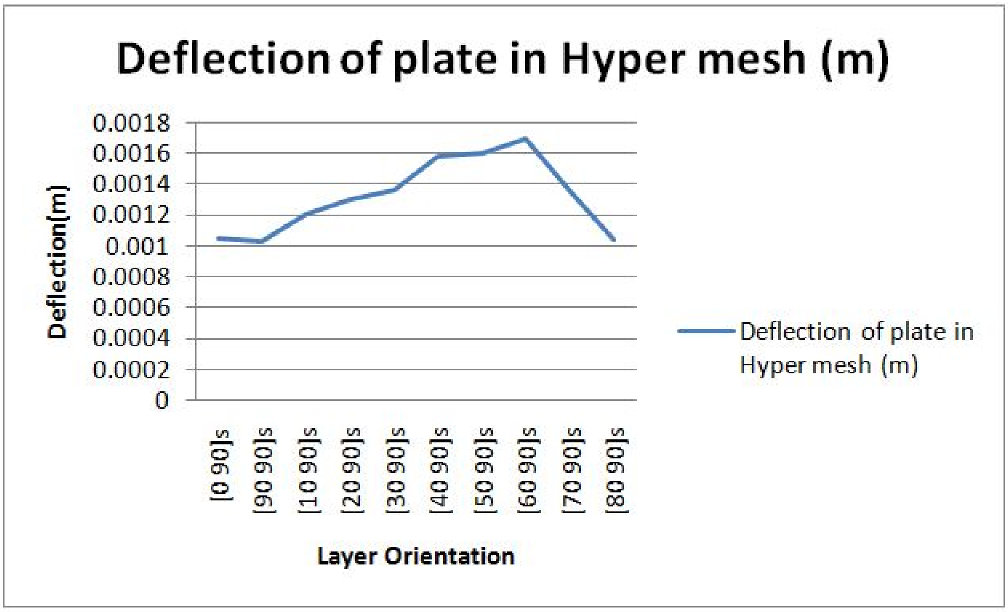

Figure 4.11: Graph of Layerorientation - deflection (m)

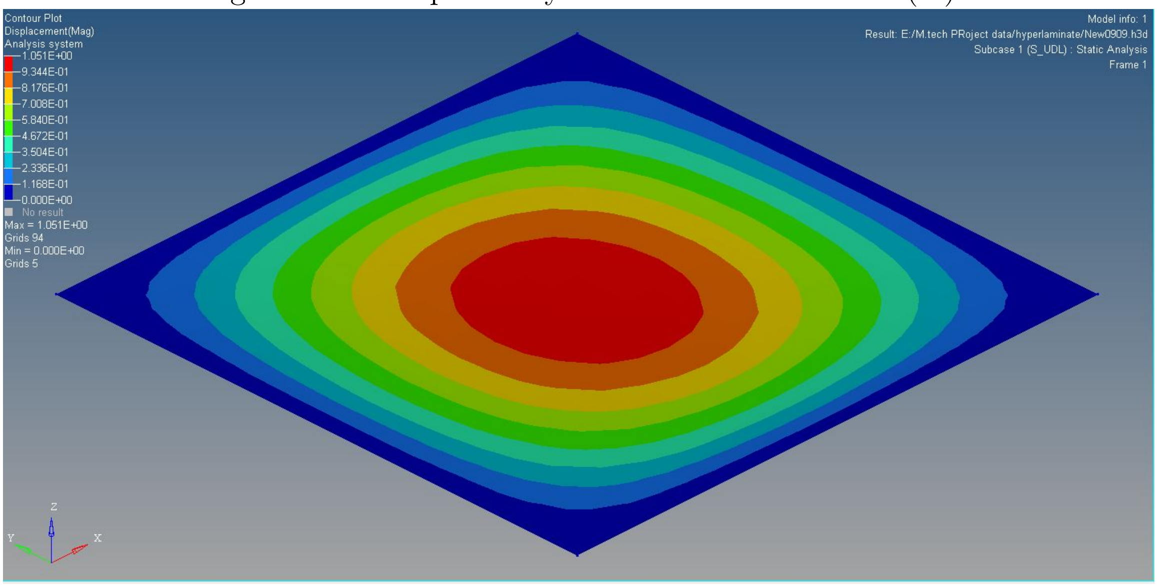

Figure 4.12: HyperWorks [0 90]s plate, SSSS-UVL

b. CCCC-UDL: The response of a symmetric 4-ply plate with a lay-up of [0 90]s has been performed using HyperWorks . The effect of change in fiber orientation on distortion of plate have been investigated. These results are shown in table 4.5. Figure 4.13 shows the effect of change in fiber orientation. Figure 4.14 shows the ANSYS results of [0 90]s plate.

Table 4.5: Results of CCCC condition with Uniformly distributed loading in HyperWorks

SR.No	Layer orientation	Displacement in HyperWorks(m)
1	[0 90]s	0.000504
2	[10 90]s	0.000527
3	[20 90]s	0.000567
4	[30 90]s	0.000632
5	[40 90]s	0.000715
6	[50 90]s	0.000749
7	[60 90]s	0.000785
8	[70 90]s	0.000805
9	[80 90]s	0.000601
10	[90 90]s	0.00042

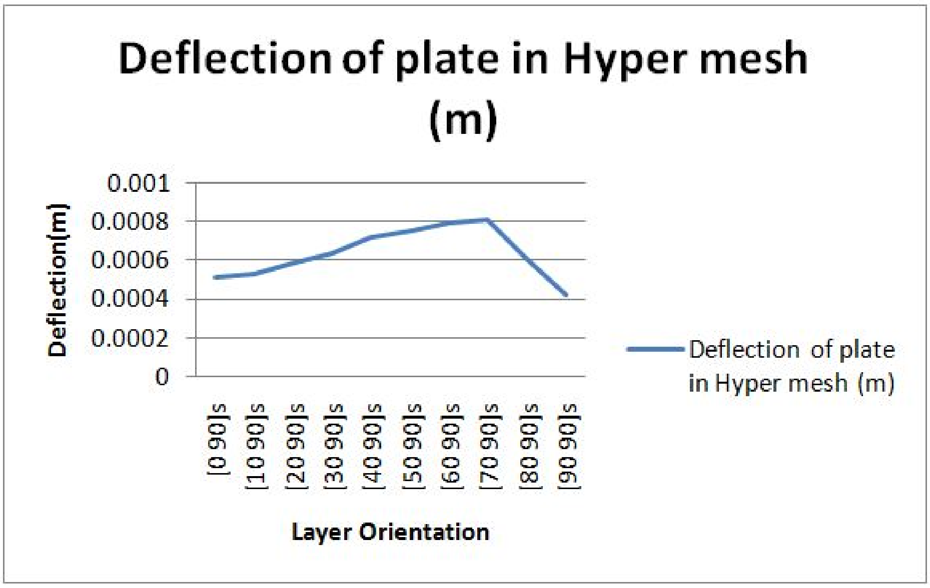

Figure 4.13: Graph of Layerorientation - deflection (m)

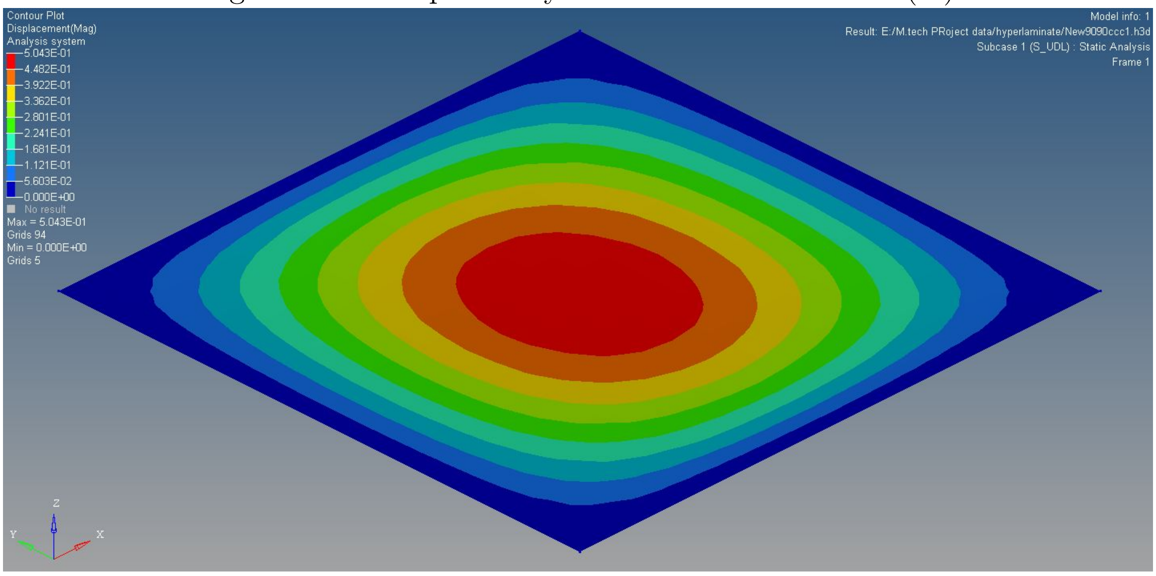

Figure 4.14: ANSYS [0 90]s plate, CCCC-UVL

Chapter 5

Comparison of results

5.1 Comparison of results of SSSS boundary condition

Results obtained for SSSS condition have been compered in table 5.1 and figure 5.1

Table 5.1: Results of SSSS condition with Uniformly distributed loading

SR.No	Layer orientation	Displacement in ANSYS	Displacement in HyperWorks	SCILAB(m)
1	[0 90]s	0.00116	0.00108	0.00105
2	[90 90]s	0.000956	0.00103	0.00102
3	[10 90]s	0.00124	0.00121	-
4	[20 90]s	0.00129	0.0013	-
5	[30 90]s	0.00135	0.00136	-
6	[40 90]s	0.00153	0.00158	-
7	[50 90]s	0.00159	0.0016	-
8	[60 90]s	0.00168	0.00169	-
9	[70 90]s	0.00125	0.00135	-
10	[80 90]s	0.00102	0.00104	-

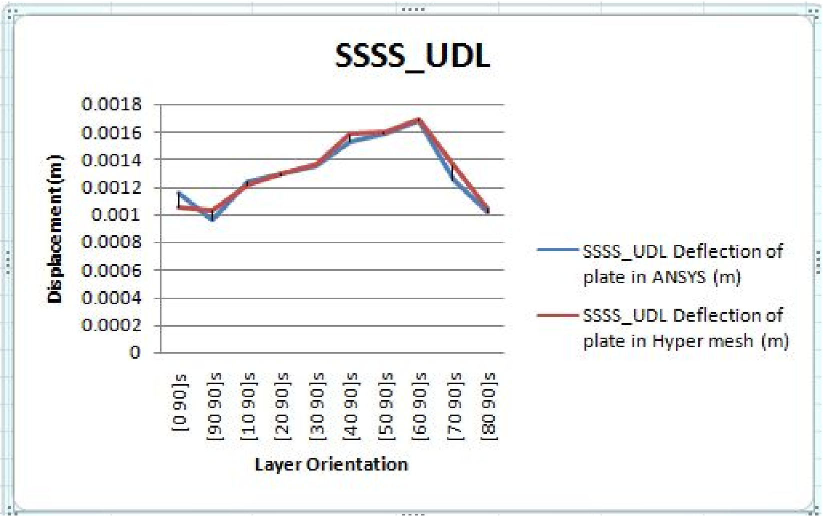

Figure 5.1: SSSS comparison

5.2 Comparison of results of CCCC boundary condition

Results obtained for CCCC condition have been compered in table 5.2 and figure 5.2

Table 5.2: Results of CCCC condition with Uniformly distributed loading

SR.No	Layer orientation	Displacement in ANSYS	Displacement in HyperWorks)
1	[0 90]s	0.000543	0.000504
2	[10 90]s	0.000572	0.000527
3	[20 90]s	0.00059	0.00058
4	[30 90]s	0.000634	0.000632
5	[40 90]s	0.000653	0.000684
6	[50 90]s	0.000726	0.000749
7	[60 90]s	0.000754	0.000785
8	[70 90]s	0.00079	0.000805
9	[80 90]s	0.000546	0.000601
10	[90 90]s	0.000436	0.00042

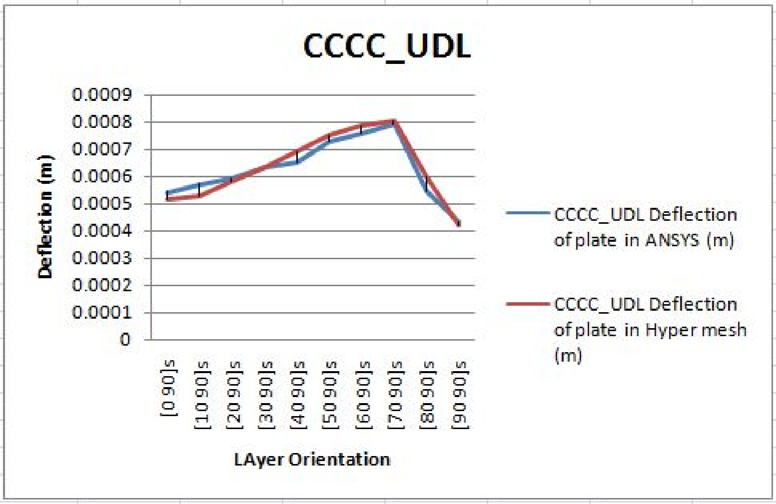

Figure 5.2: CCCC comparison

5.3 Comparison of results of SFSF and CFCF boundary conditions

Results obtained for SFSF and CFCF condition have been compered in table 5.2. Figure 5.3, 5.4, 5.5 and 5.6 shows boundary condition, loading condition, SFSF [0 90]s analysis and CFCF[0 90]s analysis accordingly.

Table 5.3: Results of SFSF and CFCF condition with Uniformly distributed loading

SR.No	Layer orientation	SFSF condition Displacement (mm)	CFCF condition Displacement (mm)
1	[0 90]s	1.134	0.552
2	[10 90]s	1.346	0.614
3	[20 90]s	1.929	0.78
4	[30 90]s	2.969	1.084
5	[40 90]s	4.869	1.43
6	[50 90]s	8.34	1.98
7	[60 90]s	12.98	2.673
8	[70 90]s	15.84	3.362
9	[80 90]s	16.84	3.457
10	[90 90]s	15.99	3.437

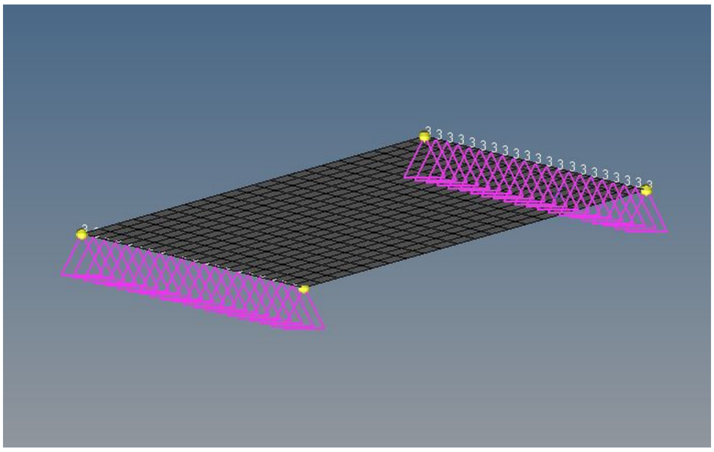

Figure 5.3: Plate model with Boundary Condition

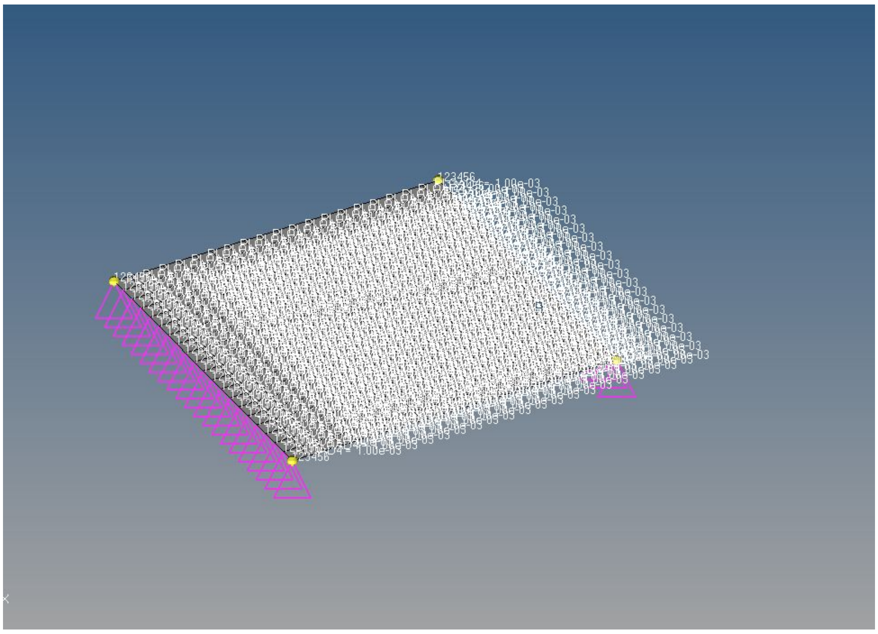

Figure 5.4: plate model with Loading Condition

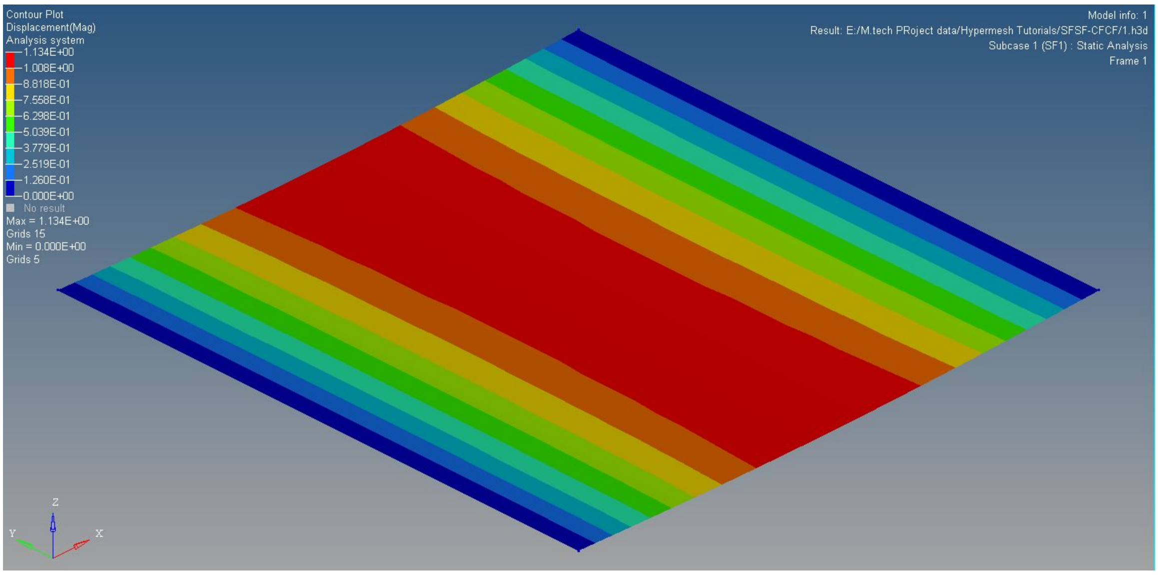

Figure 5.5: HyperWorks results of SFSF [0 90]s plate

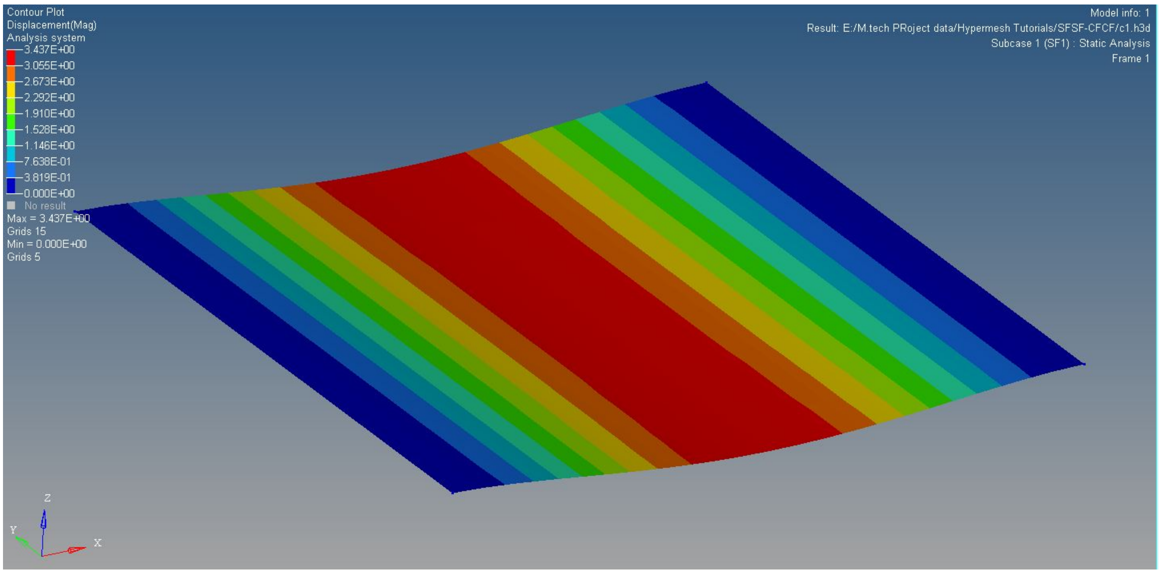

Figure 5.6: HyperWorks results of CFCF [0 90]s plate

Chapter 6

Experiment Method

6.1 Methodology

6.1.1 Manufacturing of composite plate

Manufacturing of any composite component can be done by different method. As the geometry, layers and other physical properties changes manufacturing method changes. Some of the manufacturing method for composite plate are (i) Manual Lay-up method (ii) Pultrusion method (iii) Wire wounding method. For experimental purpose composite plate is made by manual lay-up method. Manual lay-up method is quite time-consuming method but also the least costly method than any other.

In this method following items are used to make Fiberglass/epoxy composite plate: (i)Fiberglass 2400 tex (ii) Epoxy resin and its harder (iii)Plastic cups (iv)Syringe (v)Wooden Plate (vi) Gum tape (vii) Grease (viii) Brush and roller (ix) Surgical Gloves and (x) Nose protection

Steps of manufacturing

- Cover the wooden plate (which act as mould in this case) with Gum tape (cello-tape).
- Spread grease on it but make it very small thickness layer otherwise it got mix up with the resin/hardener mixture
- Make the mixture of Epoxy resin to hardener ratio 10:1. Let it mix for 3-5 min before use it to make 1st layer of it.
- Make the 2nd layer of fiberglass string as per needed angle of that layer. Fiber-glass strings are pre-cut before procedure started. It comes in the roving so can be cut as per the needed length.
- Now repeat the steps III and IV till the requirement of plate and then let the plate become dry in normal temperature. It can take different time to become solid as per the resin/harder ratio, resin type, surrounding temperature, etc. In this case it take 4-5 hrs. to become solid.

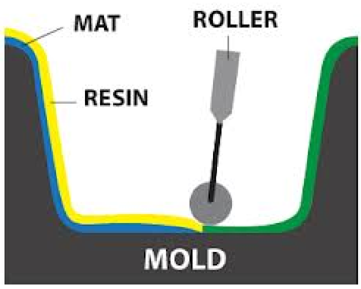

Figure 6.1: Manual Lay-up method

6.1.2 Errors/difficulties While manufacturing

- Not considered proper ratio of Resin to hardener
- Grease is not used at 1st trial of making plate.
- Need to do experiment for make proper ratio to 10:1 of Resin/Hardener.

6.1.3 Manufactured Plate

Configuration and properties Figure 6.2 and 6.3 shows the plates [0 90]s and [90 90]s accordingly. Material properties are obtained from vendor of fiberglass.

- 200 x 200 x 1.6 mm plate of fiberglass/epoxiresin.
- Two plates (I.)[0 90]s and (II.) [90 90]s
- $(E_x) = 25200\ N/mm^2$
- $(E_y) = 12500\ N/mm^2$
- $(\upsilon) = 0.65$
- $(G_{xy}) = 12500\ N/mm^2$

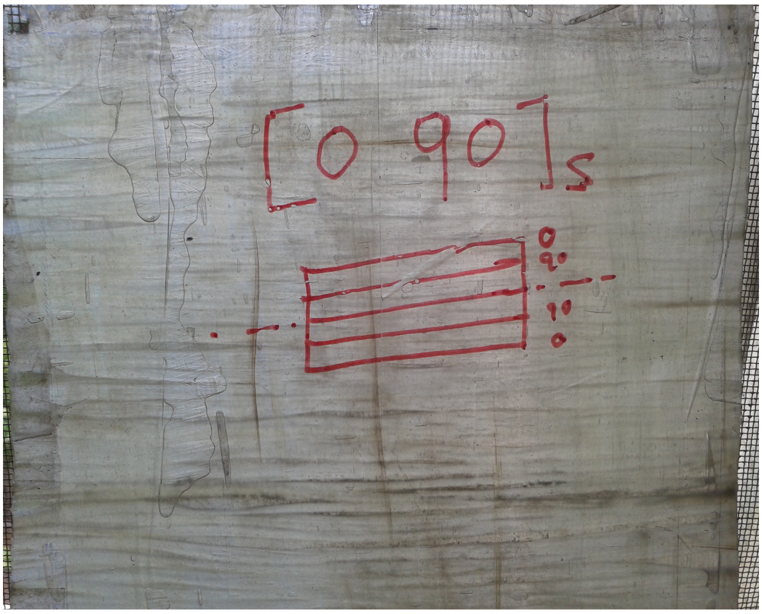

Figure 6.2: [0 90]s plate

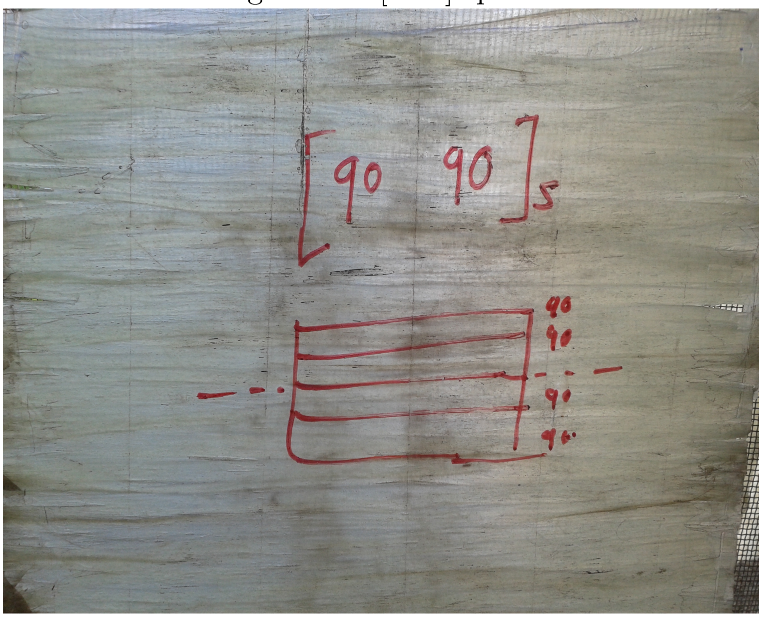

Figure 6.3: [90 90]s plate

6.2 Experimental Setup

1.For experiment, plate was simply supported from all sides and under boundary condition. Figure 6.4 and 6.5 shows side view of setup and top view of the experimental setup without loading.

Figure 6.4: Side view without loading

Figure 6.5: Top view without loading

2.Here in figure 6.6 and 6.7 shows the experimental setup with loads.

Figure 6.6: Side view with loading

Figure 6.7: Top view with loading

3. Figure 6.8 shows use of digital vernier for measuring the deflection in plate.

Figure 6.8: Measuring with vernier

6.3 Experiment results

- Table 6.1 shows the experimental results.

Table 6.1: Experiment results

Plate	Initial Reading of Vernier (mm)	After loading Reading of Vernier (mm)	Difference (mm)
[0 90]s	70.01	66.87	3.14
[90 90]s	69.98	66.48	3.21

- Table 6.2 shows the comparison of the Experimental and FE results

Table 6.2: Comparison with FE results

Plate	Experimental results (mm)	FE results (mm)	% deference (mm)
[0 90]s	3.14	2.98	5
[90 90]s	3.21	2.97	7

Chapter 7

Conclusions and Future scope

7.1 Conclusions

Four play fiberglass composite plate has been taken to determine distortion with different fiber orientation and different boundary condition in this dissertation.

- The plate with SSSS boundary condition under uniformly distributed loading minimum deflection occurs at layer sequence [90 90]s, where as maximum deflection occurs when outer layer at 60°.The plate with CCCC boundary condition under uniformly distributed loading minimum deflection occurs at layer sequence [90 90]s, where as maximum deflection occurs when outer layer at 70°.

- The plate with SFSF and CFCF boundary conditions under uniformly distributed loading minimum deflection occurs at layer sequence [0 90]s, where as maximum deflection occurs when outer layer at 80°. Here, for SFSF boundary condition have more value for deflection compared to CFCF boundary condition.

- To verify the results for deflection under different condition, analytical method using SCILAB programming, numerical method using FE softwares like ANSYS and HyperWorks and experimental methods have been used. Comparison for all these three methods have been carried out to validate results and difference between them have been found up to 5-10%.

7.2 Future Scope

- The similar kind of work can be implemented for different shape of the plate or beam.
- The accuracy level can be improved for experimental work using strain-gauge.
- The same work can be extended for different loading condition other than uniformly distributed loading.

References

[1] Venkateswarlu M., Rao S. Rama, "Bending of composite material", Def Science J, Vol31 1981, pp 293-297

[2] Madhujit Mukhopadhyay, "Mechanics of Composite materials and Structure", Universities Press, copyright 2004

[3] Zhange Y., X ,Yang C. H,"Recent developments in finite element analysis for laminated composite plates", Composite Structure. Vol. 88, 2009, pp. 147-157.

[4] M.R. Khalili a, K. Malekzadeh b, R.K. Mittal c," A new approach to static and dynamic analysis of composite plates with different boundary conditions ", Composite Structures, Vol. 69 (2005), pp 149-155.

[5] Khashaba U A ,Seif M. A, "Effect of different loading conditions on the mechanical behavior of [0/45/90]s woven composites" ,Composite structure, Vol. 74, 2006, pp 440-448.

[6] E.L. Albuquerque a, P. Sollero a, W.S. Venturini b, M.H. Aliabadi c, "Boundry element analysis of Kirchhoff's Plate", International Journal of Solids and Structures , vol.43 (2006), pp. 4029-4046.

[7] Mer Arnel Manahan, "A Finite Element Study of the Deflection of Simply Supported Composite Plates Subject to Uniform Load", Dec 2011.

[8] Gibson F Ronald,"Principles of Composite material Mechanics", Second Edition. CRC Press, Copyright 2007

[9] Timoshemko P., Stephen, S. Woinowsky-Kreiger, "Theory of plates and shells". Second Edition, Mc-Grow Hill, Inc, Copyright 1959

[10] Z. Hashin ," Analysis of composite material-A survey"

[11] J.M. Whitney and A. W. Leissa "Analysis of heterogeneous Anisotropic plates", Journal of applied mechanics, june 1969, pp. 261-266

[12] J.N. Reddy,"A generation of two-dimention theories 0f laminated composite plates", Applied numarical methods, vol. 3, pp.173-180(1987)

[13] D.S. Liu, X.Y. Li,"An overall view of laminate theories based on displacement hypothesis", J Compos Mater, 30 (1996), pp. 1539-1561

[14] J.N. Reddy, D.H. Robbins Jr."Theories and computational models for composite laminates" ApplMech Rev, 47 (1994), pp. 147-169

[15] M. Gorgi,"On large deflection of symmetric composite plates under static loading",ProfInstMechEngrs, 200 (C1) (1986), pp. 13-19