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CHARACTERIZATION AND MECHANICAL BEHAVIOR OF COMPOSITE MATERIAL USING FEA

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Abstract: Composites have been used extensively in applications such as pipes and pressure vessels. Therefore there is need for further studies on the physical and mechanical properties of these materials. In the present work composite laminates made of glass fiber and epoxy resin are tested to find the strength of the laminate and also its mechanical properties. By using FEA (Ansys 11.0) the optimum helix angle is determined for the composite material
Key words: Fiber Reinforced Polymers, Finite Element Analysis, Glass Fiber, Epoxy Resin.

1. INTRODUCTION

Mankind has been aware composite materials since several hundred years and applied innovation to improve the quality of life. Although it is not clear has to how Man understood the fact that mud bricks made sturdier houses if lined with straw, he used them to make buildings that lasted. Ancient Pharaohs made their slaves use bricks with to straw to enhance the structural integrity of their buildings, some of which testify to wisdom of the dead civilization even today.

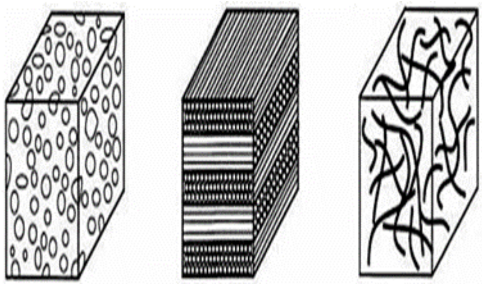

Figure 1.1 classifies layers and fibers in composite materials.

Particulate composite Laminated composite Fiber reinforced composite

1.1 Manufacturing Method - Hand Lay-Up And Spray-Up

Hand lay-up is a simple method for composite production. A mold must be used for hand lay-up parts unless the composite is to be joined directly to another structure. The mold can be as simple as a flat sheet or have infinite curves and edges. For some shapes,molds must be joined in sections so they can be taken apart for part removal after curing. Before lay-up, the mold is prepared with a release agent to insure that the part will not adhere to the mold. Reinforcement fibers can be cut and laid in the mold. It is up to the designer to organize the type, amount and direction of the fibers being used. Resin must then be catalyzed and added to the fibers. A brush, roller or squeegee can be used to impregnate the fibers with the resin. The lay-up technician is responsible for controlling the amount of resin and the quality of saturation. The basic process of hand lay-up is shown in fig 2.1. Other fabrication processes such as vacuum resin transfer molding and compression molding can be used with hand lay-up to improve the quality of the finished part or save.

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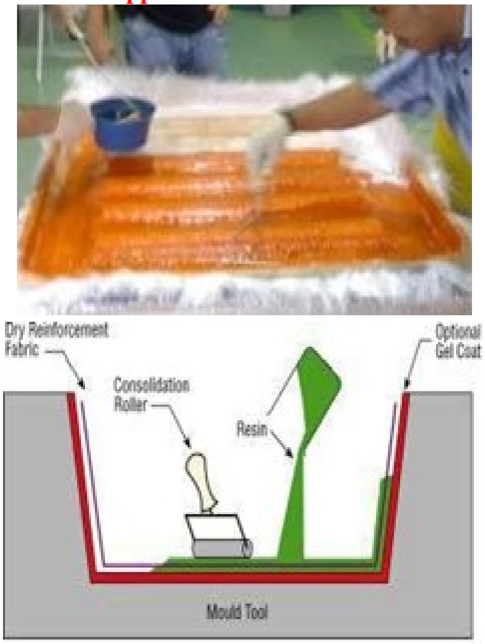

Fig. 1.2 Hand Lay Up Method

2. Material Selection

The materials tested consisted of glass fiber reinforced composites with epoxy resin matrix reinforced composites with epoxy matrix. The types of fiber used are E-glass fiber from PPG. Ind., Inc., USA. Table 1 shows the mechanical properties of the fibers [1]. The matrix used in this study is epoxy resin and hardener types of MW 215 TA and MW 215 TB respectively. The properties of the fibers were supplied by the manufacturers.

Table 2.1: Material properties of Glass fibers

Type of fiber	Ef (Gpa)	Vf	Gf (Gpa)	ρ (g/cc)	Ultimate Tensile stress(MPa)
Glass fiber	72.52	0.33	29.721	2.0	350

Table 2.2: Material properties of Matrix (Epoxy Resin)

Em	Vm	Gm	ρ (g/cc)	Ultimate Tensile stress(MPa)
3.2	0.28	1.25	1.1	26

2.3 Procedure for Preparation of Laminate:

The set up consists of a mild steel plate, of dimensions length 300mm and width 300mm.Three sides of this mild steel plate is welded with hollow metal rods to prevent the leakage of resins. The fourth side is kept unwelded for easy removal of the composite laminate. The metal setup is kept on an even flat surface and wax is applied to the metal plate, then a transparent thin film is placed on the metal plate on which glass fiber woven cloth mats are placed layer by layer to get a thickness of 12mm,since, the thickness of mat is 1mm.

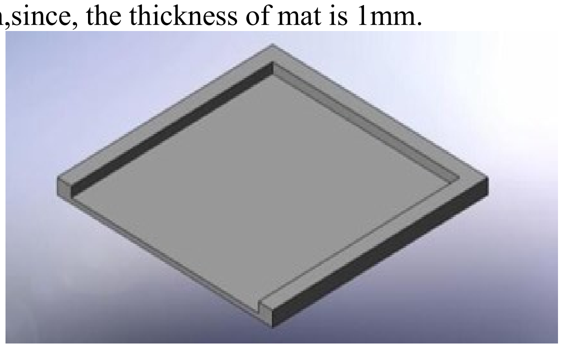

Figure 2.2: Solid Model of laminate Plate

The mixture of an epoxy resin is gently poured in between woven cloth mats. Then a transparent thin film is placed above and below the mats. A metal plate is placed and 10kg of weight is placed on the specimen so that the resin

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spreads uniformly between the mats. Allow it to harden for 12hrs. Now remove the laminate. And cut the laminates as per the dimension of universal test bench.

Fig 2.1 Composite Laminate

2.4. Volume Fraction:

The volume fraction of the composite (Vc) is equal to the sum of, the volume fraction of the fiber (Vf) and the volume fraction of the matrix (Vm). i,e.

Vc = Vf + Vm

The sum of the volume fraction of the fiber (Vf) and the volume fraction of the matrix is considered as one(1).

Vf + Vm =1 Vm = 1 - Vf

The value for volume fraction of the fiber (Vf) is 0.46.

Vm = 1 - 0.46

Vm = 0.54

Therefore, the volume fraction of the matrix (Vm) is 0.54.

2.5. Test Procedure

The universal testing machine set-up chosen has maximum loading capacity of 100kN. The machine has two crossheads one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. The test process involves placing the test specimen i.e. lamina plate in the testing machine. Initial loading of 5 tons is applied. Then tension is applied gradually until the specimen breaks. During the application of tension, the elongation of the gauge section is recorded against the applied force. The maximum ultimate load is 4150 kgf and breaking point is 4000 kgf.

Fig 2.3 Composite Laminate on Universal Testing Machine

2.6 Tensile strength of the composite (Tsc): Tensile strength of laminate is sum of strength and volume fraction of fiber and matrix

i.e. Tsc = σf Vf +σm Vm

We know that, the value for the volume fraction of the fiber (Vf) is 0.46 and the value for the volume fraction of the matrix (Vm) is 0.54.

Considering the values for σf and σm as 350 MPa and 26 MPa, respectively, we get

Tsc = 175MPa

Fig 2.4 Laminate after Applying Tensile Strength

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3. MATERIAL PROPERTIES

Design of Fiber Reinforced polymer composite components require extensive study of material properties before selecting the material to be used to make the product. Design approach used for metallic materials could not be utilized for polymer composite materials, since these materials are orthotropic in nature. Design of composite materials is based on the classical laminate theory. The cumbersome mathematical solutions may be performed to estimate the tailored material properties to be

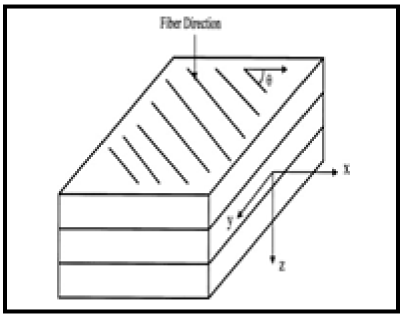

Figure 3.2: - Loading directions along x,y and z directions

Elastic Properties of Orthotropic Lamina:

The number of independent elastic constraints required to characterize anisotropic and orthotropic materials are 21 and 9 respectively. For an orthotropic material, the 9 independent elastic constants are E11, E22, E33, G12, G13, G23 12, 13 and 23.Unidirectional oriented fiber composites are a special class of orthotropic

stimated by software tools.

The design of the FRP components requires a definite approach with consensus of discussion depending on the functional requirements. The complex nature of failure behavior of fiber- reinforced composites makes the design approach complex. In view of developing user-friendly approaches for design of commercial FRP products the preset work provides a pathway towards establishing simple methods for required class of products.

Notations:

The angle between the positive x-axis and the 1 axis is called the fiber orientation angle and is represented as shown in Fig 3.1.by. If the second axis is vertically upward to the plane of the lamina, is positive when direction of measurement is counter clock wise from positive x-axis. On the other hand, if second axis is vertically downward, is positive when direction of measurement is clock wise from the positive x-axis.

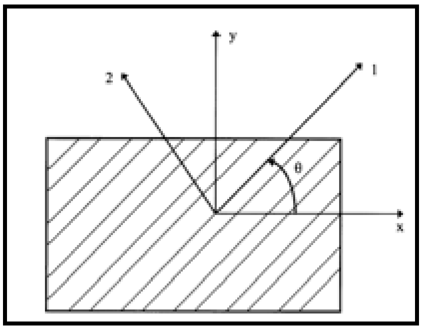

Figure 3.1: - Thin lamina showing fiber orientation angle-1

materials. If the fibers are in the 1-2 plane, elastic

properties are equal in the 2-3 directions so that E22=E33,

12=13 and G12=G13. Thus the number of independent elastic constants for a unidirectional oriented fiber composite reduces to 5, namely, E11, E22, G12, 12 and

23. Such composites are often called transversely isotropic.

Elastic properties of unidirectional continuous fiber lamina are calculated from the following equations.

Longitudinal modulus referring to Fig.3.1and 3.2

E11=Ef Vf +EmVm

And major Poisson's ratio:

12=Vf f +Vmm

The transverse modulus is:

E22= (Ef / Em)/ (Ef vm +EmVf) And minor Poisson's ratio:

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21=E22 / E11 12
Shear modulus referring to Fig.3.1and 3.2 G12 = (Gf Vm + Gm Vf).
The following properties are to be noted from the above equation.
• The longitudinal modulus (E11) is always greater than the transverse modulus (E22).
• The fiber contributes more to the development of the longitudinal modulus, and the matrix contributes more to the development of transverse modulus.
• The major Poisson's ratio (12) is always greater than

Elements In The Stiffness Matrix:

The elements in [A],[B],[D] the stress-strain matrix can be caliculated from the equations given below,
Amn = (Qmn)(hj-hj-1)
minor Poisson's ratio ( ). Since the Poisson's ratio
Bmn = 1/2n z=1 (Qmn)j (hz2-h 2)
12
are related by the equation only, can be considered independently.
• As in the case of (E22), the matrix contributes more to the development of (G12) than the fibers.
• Four independent elastic constants namely (E11), (E22), (12) and (12) are required to describe the in-
z-1
Dmn = 1/3n z=1 (Qmn)j (hz3-hz- 3)
Where, n = Total number of laminas in the laminate (Qc)z= Elements in the [Q] matrix of the zth lamina
Hz-1 = Distance from the midplane to the top of the zth lamina
plane elastic behavior of a lamina. The ratio (E11)/ (E22) is often considered a measure of orthotropic.
• The above equations are derived using the simple mechanics of the material approach along with the following assumption:

1. Both fibers and matrix are linearly elastic isotropic materials.
2. Fibers are uniformly distributed in the matrix.
3. Fibers are perfectly aligned.
4. There is perfect bonding between fibers and matrix.
5. The composite lamina is free of voids.

Since, in practice, none of these assumptions are completely valid, these equations provide only approximate values for the elastic properties of a continuous fiber of 0o lamina.
Elastic Isotropic Lamina:
From the Mechanics of Materials the cartesian strains resulting from a state of plane stress is represented by the following equations.
$\sigma z = \tau x\ z = \tau yz = 0$ $\varepsilon x=1 /E (\sigma x - \nu \sigma y)$ $\varepsilon y =1 / E(\sigma y - \nu \sigma x)$ $\gamma xy =1 /G (\tau xy)$
In an isotropic material, considering plane stress,there is a strain also in z direction due to Poission effect: $\varepsilon z = -\nu(\sigma x+\sigma y)$. This strain component will be ignored. In this relatlion there are three elastic components These are Young's modulus E, Poission's ratio ν and Shear modulus G ($\sigma z = \tau xz=\tau yz=0$).
The stiffness matrix [Q] can be formulated as follows.
[S] represents the Compliance matrix relating strains to known stresses. The inverse of the compliance matrix is called stiffness matrix, which is used in relating stresses to strains
Hz= Distance from the midplane to the bottom
of the zth lamina
Based on the above-mentioned theory the material properties of the laminated composites are found.

3.1 Material Properties

The values: Young's modulus, Poisson's ratio and Volume fraction of fiber and matrix are determined [1]. By using these values, mechanical properties of fiber and matrix are obtained through a composite material program.

Program for material properties

1) Enter the total no. of laminas in a laminate
2) Enter the Young's modulus of fiber and matrix
3) Enter the Poisson's ratio of fiber and matrix
4) Enter the volume fraction of fiber in lamina
5) Enter the thickness of single lamina

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6) Enter the angle ply in lamina 1

3.2 Dimension of the laminate Length of Laminate = 200 mm Width of the laminate = 30 mm
No. of laminas in laminates = 6 layers Layer thickness = 2 mm
Total thickness of laminate = 12 mm

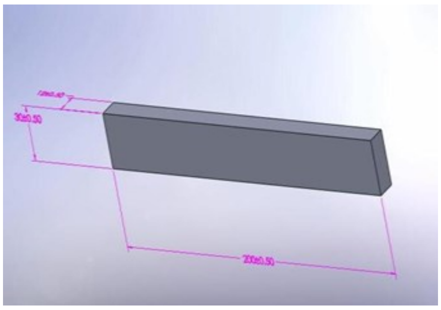

Figure 3.4: Solid Model of the laminate

3.3. Finite Element Method

The finite element method represents and extension of the methods for the analysis of framed structures to the analysis of the continuum structures. The basic philosophy of the method is to replace the structure of the continuum having an unlimited or infinite number of unknowns at certain chose discrete points. The method is extremely powerful as it helps to accurately analyze structures with complex geometrical properties and loading conditions. In the infinite method, a structure or continuum is discretized and idealized by using a mathematical model, which is an assembly of subdivisions, or discrete elements, known as finite element are assumed to be interconnected only at the joints called nodes. Simple functions such as polynomials are chosen in terms of unknown displacements at the nodes to approximate the variation of the actual displacements over each finite element. The external loading is also transformed into equivalent forces applied at the nodes. Next the behavior of each element independently and later as an assembly of these elements is obtained is relating their response to that of the nodes in such a way that the following basic conditions are satisfied at each node.

4. FE Analysis:

Ansys 11 package is used to solve the present problem. The element type selected is solid layered 191. Both the ends of the laminate are fixed in all degrees of freedom. The material selected is glass fiber and epoxy resin. And the pressure applied is 0.049033 N/mm2. The geometric and meshed model is shown in fig. 4.1 The deformation, stresses and strains of the laminates is shown in the figure 4.2 to 4.7 and all results are tabulated in table 4.1(a,b)

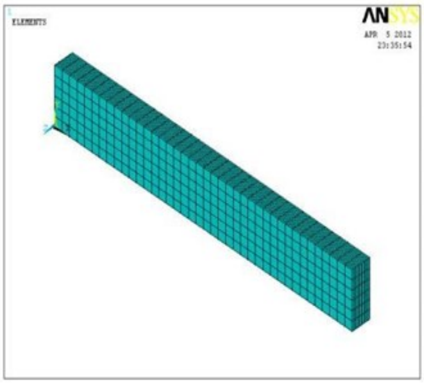

Fig: 4.1 Geometric and Meshed model

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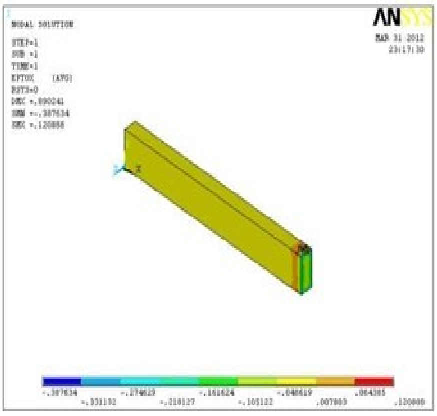

Fig: 4.2 Deformation and strain in X-direction

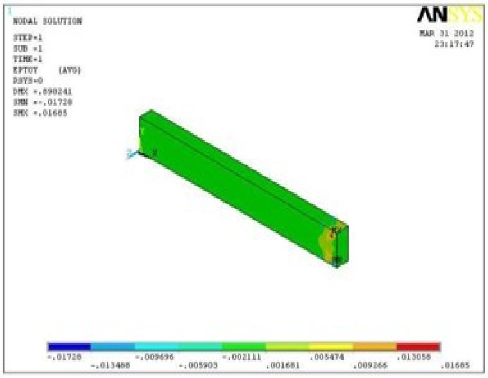

Fig: 4.3 Strain in Y-direction

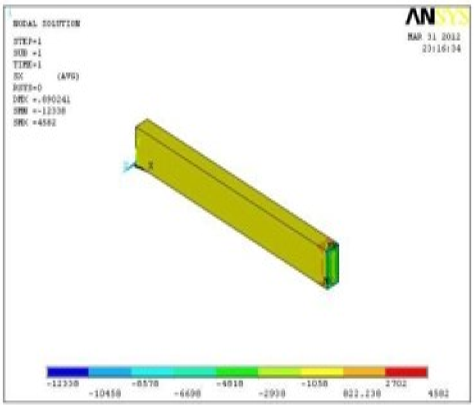

Fig: 4.4 Stress in X-direction

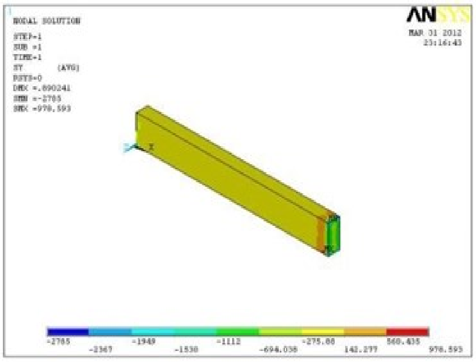

Fig: 4.5 Stress in Y-direction

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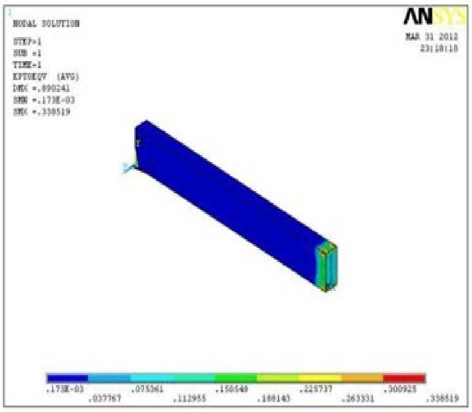

Fig: 4.6 Total mechanical strain

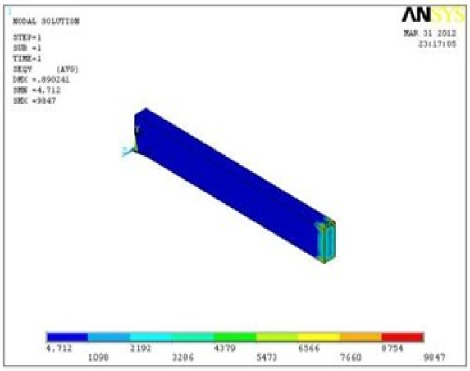

Fig: 4.7Von mises Stress

Table 4.1(a): E-glass fiber- Deflection and Stresses

Fiber angle s	Deflectio n	Stress in directions		Shear stress in xy directio n	Von mises Stresse s
		x	Y		
$[0]_6$	1.915	3481	692.023	3663	8530
$[\pm30]_6$	1.156	4494	2979	3249	9100
$[\pm45]_6$	0.942483	4976	1748	3149	9443
$[\pm60]_6$	0.890241	4582	978.593	3288	9847
$[90]_6$	0.91605	3670	683.853	3560	9319

Table 4.1(b): E-glass fiber – Strains

Fiber angles	Strain in directions			Von mises Strain
	X	y	Shear Strain	
$[0]_6$	0.278093	0.008668	0.70395	0.857976
$[\pm30]_6$	0.18824	0.031467	0.346497	0.560699
$[\pm45]_6$	0.139515	0.021457	0.313421	0.403451
$[\pm60]_6$	0.120888	0.01685	0.321896	0.338519
$[90]_6$	0.123988	0.013862	0.334991	0.327722

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5. Results and Discussion

Composite laminates of Glass fiber having dimensions of 200mm long, 30mm width and 12mm thick is analyzed with pressure of 0.049033 N/mm2 and compared with each other. The table 5.1 to 5.3 shows the comparison of deflection, Vonmisses stress and strain for different helix angle and their graph is shown in fig 5.1 to 5.3, and the stress strain for 600 winding angle are as shown in fig 5.4

Table 5.1: Comparison of deflections

Composite materials Helix angle	Deformation
$[0]_6$	1.915
$[\pm30]_6$	1.156
$[\pm45]_6$	0.942483
$[\pm60]_6$	0.890241
$[90]_6$	0.91605

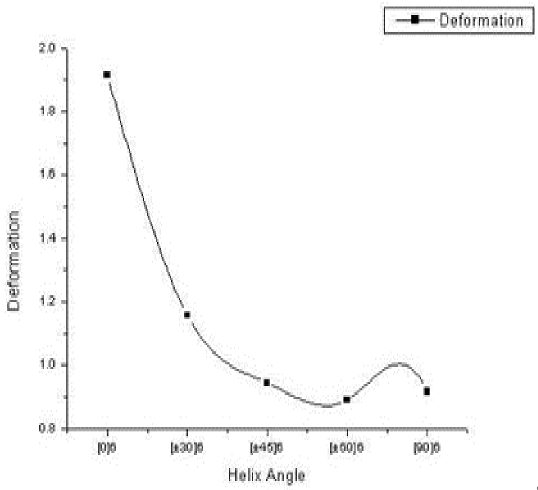

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Fig: 5.1 Graphs show the deflection for different helix angles

Table 5.2: Comparison of Vonmisses Stress Composite materials

Composite materials Helix angle	Von Mises Stress
$[0]_6$	8530
$[\pm30]_6$	9100
$[\pm45]_6$	9443
$[\pm60]_6$	9847
$[90]_6$	9319

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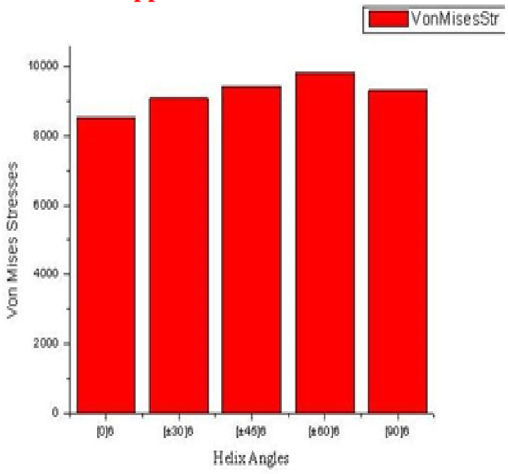

Fig: 5.2 Graphs show the comparison of Vonmisses stress for different helix angles

Table 5.3: Comparison of Strain in X-direction

Composite materials Helix angle	Von Mises Strain
$[0]_6$	0.857976
$[\pm30]_6$	0.560699
$[\pm45]_6$	0.403451
$[\pm60]_6$	0.338519
$[90]_6$	0.327722

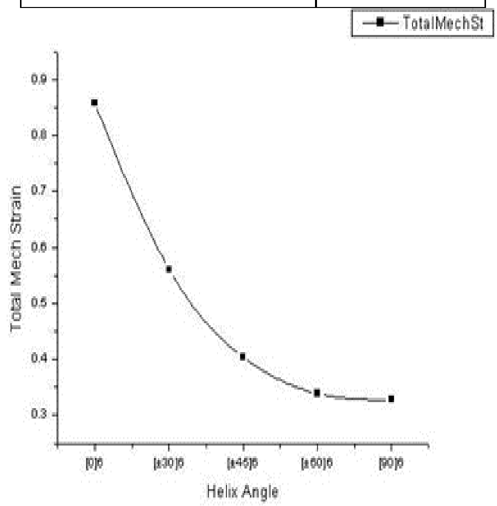

Fig: 5.3 Graphs shows the comparison of Strain for different helix angles

From the above results it is shown that deflection in 600 helix angle is less compare to other helix angle and there of the stresses also

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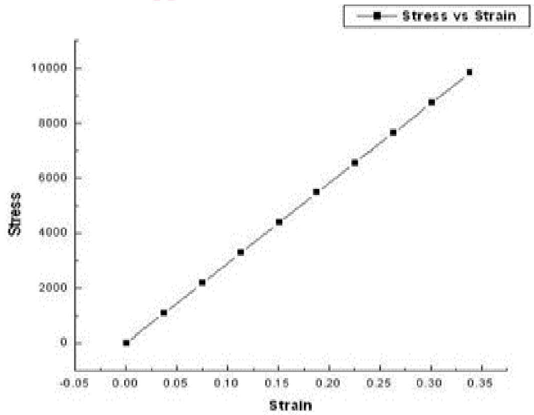

Fig 5.4: Stress Strain Curve for 600 winding angle

6. CONCLUSION

From the results it is concluded that composite materials with 600 fiber angle is having less deformation and 900 is having minimum strain. Therefore both 600 and 900 helix angle is considered to be the optimum winding angles when working with composite materials

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