Designate: Study on Fatigue Possessions of Glass Epoxy Composite Laminate

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Abstract-- Polymer matrix composites are heterogeneous in nature, it is composed of matrix material and reinforcing materials. The properties of both reinforcing and matrix materials lead improved mechanical properties than metals. These material have high strength to weight ratio, corrosion resistance and high stiffness, because of which these materials are being used as structural materials in the applications like aerospace, naval, automobiles and civil engineering fields. Even though these materials provide good mechanical properties the most life limiting failure modes of these materials is delamination due to the fact that they composed of laminated layers.Because of which lot of researchers are striving for increasing the strength between the plies. Many parameters have identified for mechanical properties of these materials like strength of the fibers, orientation of the fibers, thickness of the laminates, glass transitiontemperature(TG) of the matrix material etc. Depending on the properties requirement of the materials for specific application these materials are designed. One of the most significant behavior of the material to be studied in any applications is the fatigue life of the material. So, in this Research the fatigue behavior of pure glass/epoxy composite laminates will be studied.

Research Objective-- Based on the literature review there is less number of studies on fatigue behavior of glass fiber reinforced in epoxy composite materials. So, the objective of the present research is to study the fatigue behavior of glass fiber/ epoxy composite material.

The sequences of actions undertaken for accomplishing the objectives are

- Selected the levels for facesheet thickness as 1,2 and 3 mm and GSM 300,400 and 600.
- The laminates are fabricated using hand layup technique.
- As per ASTM standard D3039 the laminates are cut in standard size.
- The samples were subjected to flexural testing in IISc Bangalore to get the peak load.
- For fatigue test the specimens are subjected to 80% of load.

Keywords-- *composite materials, fatigue behavior, glass fiber, mechanical properties*

I. INTRODUCTION

Polymer matrix composites are heterogeneous in nature, it is composed of matrix material and reinforcing materials. The properties of both reinforcing and matrix materials lead improved mechanical properties than metals. These material have high strength to weight ratio, corrosion resistance and high stiffness, because of which these materials are being used as structural materials in the applications like aerospace, naval, automobiles and civil engineering fields. Even though these materials provide good mechanical properties the most life limiting failure modes of these materials is delamination due to the fact that they composed of laminated layers [1]. Because of which lot of researchers are striving for increasing the strength between the plies. Many parameters have identified for mechanical properties of these materials like strength of the fibers, orientation of the fibers, thickness of the laminates, glass transition temperature (TG) of the matrix material etc. Depending on the properties requirement of the materials for specific application these materials are designed. One of the most significant behavior of the material to be studied in any applications is the fatigue life of the material. So, in this project the fatigue behavior of pure glass/epoxy composite laminates will be studied.

II. COMPOSITE MATERIALS

Composites can be defined as materials that consist of two or more chemically and physically different phases separated by a distinct interface. The different systems are combined judiciously to achieve a system with more useful structural or functional properties non attainable by any of the constituent alone. Composites, the wonder materials are becoming an essential part of today's materials due to the advantages such as low weight, corrosion resistance, high fatigue strength, and faster assembly. They are extensively used as materials in making aircraft structures, electronic packaging to medical equipment, and space vehicle to home building. The difference between blends and composites is that the two main constituents in the composites remain recognizable while these may not be recognizable in blends. The predominant useful materials used in our day-to-day life are wood, concrete, ceramics, and so on. Surprisingly, the most important polymeric composites are found in nature and these are known as natural composites. The connective tissues in mammals belong to the most advanced polymer composites known to mankind where the fibrous protein, collagen is the reinforcement. It functions both as soft and connective tissue. Composites are combinations of materials differing in composition, where the individual constituents retain their separate identities. These separate constituents act together to give the necessary mechanical strength or stiffness to the composite part. Composite material is a material composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different from those of any of the constituents. Matrix phase is the primary phase having a continuous character. Matrix is usually more ductile and less hard phase. It holds the persed phase and shares a load with it. Dispersed (reinforcing) phase is embedded in the matrix in a discontinuous form. This secondary phase is called the dispersed phase. Dispersed phase is usually stronger than the matrix, therefore, it is sometimes called reinforcing phase.

III. CLASSIFICATION OF COMPOSITES

Classification of composite is done based on the both matrix material and reinforcing material.

- ✓ The classification of composite is on the basis of matrix phase, composites can be classified into polymer matrix composites (PMCs), ceramic matrix composites (CMCs), and metal matrix composites (MMCs).
- ✓ The classifications according to types of reinforcement are particulate composite, fibrous composites and laminate composites.

IV. POLYMER MATRIX COMPOSITES

Polymer matrix composites are very widely used due to their low cost and simple fabrication process. These are ideal matrix material as they can be processed easily, possess light weight and have good mechanical properties. The structure of the polymer matrix composites are more complex then ceramics or metals. The high temperature resins are extensively used in aeronautical applications. They get degraded on prolonged exposure to ultra-violet rays. Unlike ceramics and metals which have fixed melting point, polymers do not have fixed melting point. The temperature at which crystallinity is destroyed is called glass transition temperature. The polymer liquid is cooled it contracts or shrinks. There are two main kinds of polymers, thermosets and thermoplastics.

- ➢ Thermosets has qualities such as a well-bonded three-dimensional molecular structure after curing. When they are heated they get permanently get hardened, on further heating they decompose. Before failure they accommodate only low strains. They having the definite shell life. Once they are prepared they cannot be reprocessed.it has the long curing cycles. In the fabrication process the temperature required is low.
- ➢ Thermoplastics does not involve chemical reactions. Thermoplastics before failure they can accommodate high strains and has the indefinite shell life. They can reprocessed and has short curing cycles. Thermoplastics have higher viscosity at higher temperature and hence difficult to process.

The different thermoplastics materials are shown in the figure 1.4, and the different thermosets are shown in the figure 1.5.

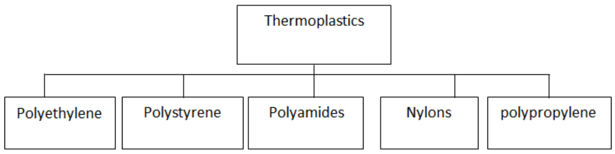


Figure 1: Different thermoplastics materials.

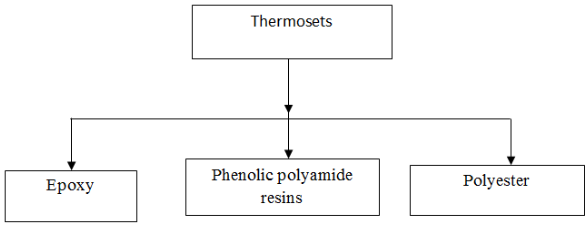


Figure 2: Different thermosets materials

V. CERAMIC MATRIX MATERIALS (CMM)

Ceramic matrix composites are used in the environment where the temperature is very high. It has a very strong ionic bonding and in some cases covalent bonding. It has a very high melting point, stability at high temperature and high compressive strength, good corrosion resistance. It includes crystalline ceramics, glass ceramics, inorganic silica-based glasses, intermetallics and carbon. It has the low tensile strain and high modulus of elasticity. In ceramic matrix it has a wide variety of inorganic materials, they are generally nonmetallic and are processed at high temperature. The reinforcements includes oxides carbides and borides.

Figure 3

VI. METAL MATRIX COMPOSITE (MMC)

The metal matrix composite is strong and tough and can be deformed easily. Now days it has a wide interest in research. They withstand higher temperature in corrosive environment than polymer matrix composites. Most alloys and metals can be used as matrices and require reinforcement materials which need to be stable over a range of temperature. Metal matrix material has to offer high strength and they require high modulus reinforcements. The strength-to-weight ratios of composites can be higher than most alloys. The melting point, physical and mechanical properties of the composite for various temperatures determine the service temperature of composites. Many metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements has more stunted with increase in the melting temperature of matrix materials. The metal matrix composite component is shown in the figure 1.3.

Figure 4: Metal matrix composite component

VII. FIBER REINFORCED COMPOSITE MATERIALS

The important class of reinforcements are fibers, because they satisfy the desired conditions and transfer strength for matrix constituent influencing and enhancing their properties. Glass fibers were the earliest known fibers used in reinforce materials. Ceramic and metal fibers are subsequently found out and put to extensive use, to render composites stiffer more resistant to heat. Fibers have short of ideal performance due to several factors. The performance of the fiber composite is judged by its length, shape, orientation, and composition of the fibers and the mechanical properties of the matrix. The orientation of the fiber in matrix is indication of the strength of composite and strength is greatest along the longitudinal directional of fiber. This doesn't mean the longitudinal fibers can take the same quantum of load irrespective of the direction on which it is applied. Optimum performance from longitudinal fibers can be obtained if the load is applied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite.

VIII. PARTICULATE REINFORCED COMPOSITE MATERIALS

Microstructures of metal and ceramics composites, which show particles of one phase strewn in the other, are known as particle reinforced composites. Square, triangular and round shapes of reinforcement are known, but the dimensions of all their sides are observed to be more or less equal. The dispersed size in particulate composites is of the order of a few microns and volume concentration has greater than 28%.. The mechanism put to strengthen each of them is also different. The dispersed in the dispersion-strengthen materials reinforces the matrix alloy by arresting motion of dislocations and needs large amount of forces to fracture the restriction created by dispersion. In particulate composites, the particles strengthen the system by the hydrostatic coercion of fillers in matrices and by their hardness relative to the matrix. Three-dimensional reinforcement in composites offers isotropic properties, due to the three systematical orthogonal planes. Since it is not homogeneous, the material properties are sensitivity to the constituent properties, as well as the interfacial properties and geometric shapes of the array.

IX. FABRICATION OF COMPOSITES

A. HAND LAY-UP

For the manufacturing of small and large reinforced products the hand lay-up technique is the simplest, oldest and most commonly used method. The hand lay-up is shown in the fig. 1.3

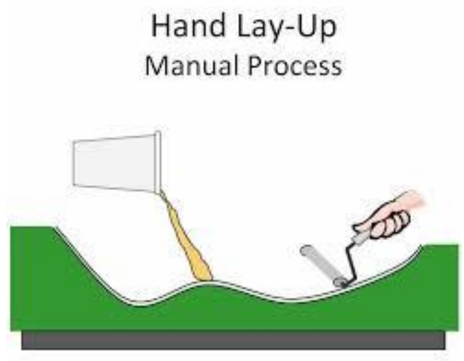


Figure 5

X. FATIGUE IN COMPOSITE MATERIALS

The wide application of composite materials is mainly due to their high strength and stiffness, coupled with low density compared with steel. The fatigue load involves the formation of cracks on matrix and then on fibres. Composite materials has different combinations (fibre orientation) and forms, so the fatigue study is particularly complex and demanding. In brittle materials the fatigue failure occurs first and characterized by low values of strain, so the matrix is damaged before the formation of cracks. The fatigue failure can take various forms on composite materials: broken fibres, fibre-matrix interface failure, delamination, presence of cracks in the matrix. Cracks decrease stiffness and strength of the composite materials. The formation and numbers of cracks depends on fibres orientation. In composite materials with different fibre orientation cracks arise first in the weaker plans and then in other plans until the stronger. The laminates offer a lower stiffness and static strength due to the distortion of fibreglass. Another possible reason is the percentage of fibres that is less than 60-65%.

XI. ADVANTAGES

The advantage of composite are,

- Strength
- Corrosion resistance
- Stiffness
- Wear resistance
- Attractiveness
- Weight

XII. CHAPTER 2: LITERATURE REVIEW

S. Helmy et al. [1] investigated the tensile fatigue behavior of tapered glass/epoxy laminates and the effect of nanoclay addition into the epoxy resin. The parameters considered were, ply drop laminate thickness, ply drop location, number of plies dropped at one location, fabric type, loading condition, fiber content and spacing between ply drops. Authors have found that, the presence of nanoclay in the matrix increases the ultimate strength and decreases the strain to failure. The nanoclay suppresses the fatigue damage in terms of damage index and crack growth rate over the whole fatigue life except the early stage of loading.

Mehmet Karahan et al. [2] Studied the fatigue tensile behavior of carbon/epoxy composite reinforced with non-crimp 3D orthogonal woven fibric. Authors found that, The average fatigue life for the warp-directional loading case is about three times longer than that for the fill-directional loading case.

P.Coronado et al. [3] deliberate the influence of temperature on a carbon-fiber epoxy composite subjected to static and fatigue loading under mode-1 delamination. In this paper, interlaminar crack initiation and propagation under mode-1 with static and fatigue loading of a composite materials are experimentally assessed for different test temperature. The material under study is made of a 3501-6 epoxy matrix reinforced with AS4unidirectional carbon fibers with a symmetric laminate configuration. Author have found that, the material exhibits better mechanical behavior in the test performed at 9 ^{0}C in the static initiation phase, where obtained the highest values of G_{IC} due to a slight increase in ductility in the matrix. When the test temperature decreases, less fracture energy is required to initiate the delamination.

Andrew makeev. [4] studied, interlaminar shear fatigue behavior of glass/epoxy and carbon/epoxy composites. This work addresses a strong need in accurate fatigue properties of glass and carbon fiber reinforced polymer-matrix composites. This work provided the engineering community with material properties essential for understanding fatigue delamination onset in glass/epoxy and carbon/epoxy composite systems.

Ermias Gebrekidan Koricho et al. [5] Intentional, The bending fatigue behavior of twill fabric E-glass/epoxy composite. The amount of stiffness reduction was observed to be a function of the magnitude of applied fatigue loading on the specimen. Author have found that, the static tensile and flexural tests revealed that bending strength is higher than that of tensile strength. When the fatigue load level increases, the fatigue life decreases is short and the extent of damaged zone prior to catastrophic failure becomes smaller.

S.Liang et al. [6] Calculated, a comparative study of fatigue behavior of flax/epoxy and glass/epoxy composites. A slight increase of the hysteresis slope, which suggests an increase on fibre's young's modulus has been observed. The total loss of modulus of 15-20% and 50-70%, respectively, is found on FFRE and GFRE specimens. The flax fibre reinforced composites offered a more stable cyclic performance than the glass fibre composite. The stiffness degradation of both composites exhibits no dependence on the loading level.

Ali movaghghar, [7] did theoretical and experimental study of fatigue strength of plain woven glass/epoxy composite. In this paper an energy-based model for predicting fatigue life and evalvation of progressive damage in composite materials is proposed. Tests were performed on a special machine type DP-5/3 which is used to determine the bending fatigue resistance of sheet fibrous woven specimens. It has been shown that the theoretical fatigue strength curves obtained by means of this model were in good agreement with experimental data.

N.H.Tai et al. [8] Considered, Effects of thickness on the Fatigue-behavior of quasi-isotropic carbon/epoxy composite before and after low energy impacts. The fatigue tests were performed in an MTS 810.22 servo-hydraulic test machine under load control mode. A desktop ultrasonic system (AIT-5112)was employed to inspect the damage area of the specimen. Author have found that the residual tensile strengths of the composites after low-energy impact loading show that low-energy impact has a more significant influence on tensile strength for thinner than for thicker laminates.

Monotonic and fatigue tests were carried out in four-point bending on a glass fabric/epoxy composites, using two different stress ratios by G.Carino et al.[9]. Authors found that, ultimate failure both in monotonic tests and in fatigue was precipitated by microbuckling phenomena happening at the compression side of the specimen.

D.Pitchaiah et al. [10] Did experimental study on the fatigue strength of glass fiber epoxy and chapstan E-Glass epoxy laminates. The research was aimed to understand the flexural fatigue behavior under high cycle fatigue conditions of glass fiber epoxy, chapsten E-glass epoxy and glass fiber polyester epoxy laminates. Author have found that, the residual bending load is also maximum and the stiffness retention after pivoting state is 72.5% of the vergin specimen. He states that the glass fiber polyester epoxy laminate is good for flexural fatigue critical applications such as wind turbine blades, air craft wing and automotive leaf spring constructions.

Pizhong Qiaoet al. [11] intended the effect of stress ratio, frequency and mean stress on fatigue life of E-glass/polyurethane composites. An improved model for fatigue life prediction is proposed for the parameters and is in good agreement with the predictions of existing available data and present testing data.

XIII. CHAPTER 3: RESEARCH OBJECTIVE AND METHODOLOGY

A. RESEARCH OBJECTIVE

Based on the literature review [1-11] there is less number of studies on fatigue behavior of glass fiber reinforced in epoxy composite materials. So, the objective of the present research is to study the fatigue behavior of glass fiber/ epoxy composite material.

B. RESEARCH METHODOLOGY

The preferred methodology for the study is presented by a flow diagram in figure 3.1.

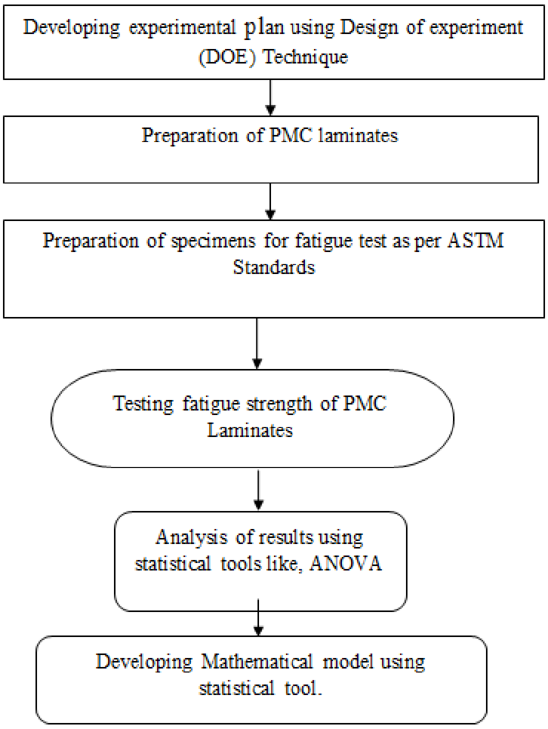


Figure 6: Methodology

The sequences of actions undertaken for accomplishing the objectives of the project are

- Selected the levels for facesheet thickness as 1, 2 and 3 mm and GSM 300,400 and 600.
- The laminates are fabricated using hand layup technique.
- As per ASTM standard D3039 the laminates are cut in standard size.
- The samples were subjected to flexural testing in IISE Bangalore to get the peak load.
- For fatigue test the specimens are subjected to 80% of load.

XIV. CHAPTER 4: MATERIAL AND EXPERIMENTAL METHODS

A. MATERIAL SELECTION

The material and their properties selected for making the laminates are shown in Table No.4.1

Table 1: Properties of material

Reinforcement	**Matrix material**	**Hardener**
E-glass of 300 GSM bidirectional woven roving	Epoxy resin (LY556)[Araldite]	Hardener (HY 951)[Aradur]

a. GLASS FIBER REINFORCEMENT

It I the most common fiber is used in the PMC's. The color of the fiber is white and is dry fabric as shown in the Fig 4. The advantage include high strength, low cost, good insulation property and high chemical resistance. The drawbacks includes poor adhesion to polymers, higher density, low elastic modulus. Types of glass, E Glass, S Glass,C glass. Bi-directional E-glass fiber Most fabric constructions has more flexibility for making of complex shapes than straight unidirectional offer. Fabrics has the option for resin impregnation by solution or the hot melt process. For aerospace structures, tightly woven fabrics are usually used to save weight, minimizing resin void size, and maintaining Fiber orientation during the fabrication process.

Figure 7: Bidirectional E-glass fiber

b. EPOXY RESIN

Matrix resins bind glass reinforcing fibers together, protecting them from impact and environment. The increased complexity of the epoxy polymer chain and the potential for a greater degree of control of the cross linking process gives a much improved matrix in terms of strength and ductility. Epoxies require the resin and hardener to be mixed in equal proportional and more strength required heating to complete the curing process. This can be advantageous as the resin can be applied directly to the fibres and curing need only take place at the time of manufacture. The epoxy is cured by adding a hardener in equal amounts and being heated to about 120°C. The hardeners are usually short chain diamines such as ethylene diamine. Heat is usually required since the cross linking involves the condensation of water which must be removed in the vapour phase.

Figure 8: Epoxy resin (LY556)

c. HARDENER

A substance or mixture added to plastic composition to promote or control the curing action by taking part in it. Also a substance added to control the degree of hardness of the cured film.

Figure 9: Hardener (HY 951)

B. DEVELOPMENT OF EXPERIMENTAL PLAN

In this project the parameters selected for the study are facesheet thickness, orientation of the fiber and GSM .The parameters and levels considered for the study are shown in table no. 2.

Table 2: Parameters and levels

Parameters	Levels		
	1	2	3
Facesheet Thikness, mm	1	2	3
Orientation of the fibers	30^0	60^0	90^0
GSM	300	400	600

For the above parameters and levels the minimum number of experiments to be conducted is 7. Hence the nearest orthogonal array is L9.The L9 orthogonal array is shown in the table no. 3.

Table 3: L9 orthogonal array

Experiment Number	Column 1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Experimental plan:

Using design of experiment (DOE) approach, the minimum number of experiments to be conducted are 7. For this the nearest orthogonal array is L9. The experimental plan according to L9 array is shown in table 4.4.

Table 4: Experimental plan

Experiment no.	Facesheet thickness	Orientation	GSM
1	1	30^0	300
2	1	60^0	400
3	1	90^0	600
4	2	30^0	600
5	2	60^0	300
6	2	90^0	400
7	3	30^0	400
8	3	60^0	600
9	3	90^0	300

C. CALCULATION FOR LAMINATE PREPARATION

To prepare face sheet bidirectional E-glass of 300 GSM and epoxy resin (LY556) are used.

a. GLASS/EPOXY LAMINATE OF 1MM THICKNESS

Number of plies of glass fiber to be combined with matrix material

$\rho f = 2.54 g/cc$ $\rho_{resin} = 1.15 g/cc$

$w_{ff} = 65\%$ $w_{fr} = 35\%$

Density of laminate= $(\rho_f * W_{ff}) + (\rho_{resin} * W_{fr})$

= (2.54*0.65) + (1.15*0.35)

= 2.053 g/cc.

Weight of laminate= $\rho_{laminate}$* $V_{laminate}$

= (2.053*0.1*30*30)

= 184.77 g

Weight of resin = w_{fr}*$W_{laminate}$

= 0.35*184.77

=64.66 g

Weight of fiber = w_{ff}*$W_{laminate}$

= 0.65*184.77

= 120.10 g

Weight of hardner = W_{resin}*11/111

= 64.66*11/111

= 6.40 g

Weight of one ply = 25,38,61 gms

No. of layers required= w_{fiber}/ w_{fiber} one ply

300=120.10/25=4.804=5layers

400=120.10/38=3.160=4layers

600=120.10/61=1.96=2layers

b. Glass\epoxy laminate of 2mm thickness:

Number of plies of glass fiber to be combined with matrix material

ṗf =2.54g/cc ṗresin =1.15g/cc

Wff= 65% Wfr= 35%

Density of laminate = (ṗf × Wff) + (ṗresin × Wfr)

= (2.54×0.65) + (1.15×0.35)

= 2.053 g/cc

Weight of laminate = $ṗ_{laminate}$ × $V_{laminate}$

=2.053×0.2×30×30

= 369.54 g

Weight of resin = W_{fr} × $W_{laminate}$

= 0.35 × 369.54

= 129.339 g

Weight of fiber = W_{ff} × $W_{laminate}$

= 0.65× 369.54

= 240.20 g

Weight of hardner = Wresin × 11/111

= 129.339 × 11/111

= 12.81 g

Weight of one ply =25,38,61

No. Of layers required = Wfiber / Wfiber one ply

300GSM = 240.20/25=9.60=10 layers

400GSM = 240.20/38=6.32= 7 layers

600GSM = 240.20/61=3.93=4 layers

c. Glass\epoxy laminate of 3mm thickness:

Number of plies of glass fiber to be combined with matrix material

ṗf =2.54g/cc ṗresin =1.15g/cc

Wff= 65% Wfr= 35%

Density of laminate = (ṗf × Wff) + (ṗresin × Wff)

=(2.54×0.65) + (1.15×0.35)

= 2.053 g/cc

Weight of laminate = $ṗ_{laminate}$ × $V_{laminate}$

=2.053×0.3×30×30

= 554.31g

Weight of resin = W_{fr} × $W_{laminate}$

= 0.35 × 554.31

= 194.00 g

Weight of fiber = W_{ff} × $W_{laminate}$

= 0.65× 554.31

= 360.30 g

Weight of hardner = W_{resin} × 11/111

= 194 × 11/111

= 19.22 g

Weight of one ply = 25,38,61

No. Of layers required = Wfiber / Wfiber one ply

300GSM = 360.30/25=14.41= 15 layers

400GSM = 360.30/38=9.48 = 10 layers

600GSM = 360.30/61=5.90 = 6 layers

D. LAMINATE PREPARATION

The PMC laminate were fabricated using hand layup process.

The laminates of thickness 1, 2 and 3 mm are prepared with the help of hand layup technique.

1. The Bidirectional fiber layers are cut to the size of 30X 30 cm as shown in the figure.
2. Weight of one ply is measured using electronic weighing machine.
3. The number of ply required for laminate preparation is calculated.
4. The hardener and resin are taken in a flask as per calculation and mixed.
5. A layer of resin is applied on the surface of the releasing paper and then the fiber layer are placed on the applied resin. Then again a layer of resin is applied on the surface of the fiber and then next layer is placed on the previous layer. The procedure is continued till the laminate structure is built as shown in figure
6. The laminate structures are cut to the size 250*25*2 mm as per ASTM standard D 3039.
7. The prepared samples of different thickness are shown in the figure 4.4.

Figure 10: Measuring of resin and hardener &Mixing of resin and hardner hand lay up

E. SAMPLES

The prepared samples of laminate of different sizes are shown in figure 4.5

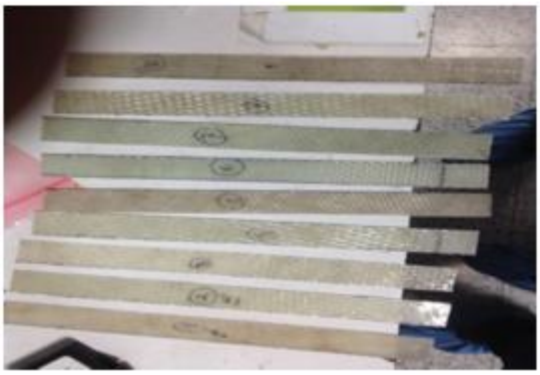


Figure 11: prepared laminate of 1mm 2mm 3mm thickness

XV. CHAPTER 5: TESTING OF LAMINATE STRUCTURE

A. FLEXURAL TESTING OF LAMINATE

ASTM D 3039: Standard test method for flexural properties of polymer matrix composite laminates.

The samples are cut to the dimensions as per ASTM standard for flexural and fatigue testing. The test specimen geometry as specified in the above standard is 250mm*25mm*2mm. The details of test specimen are given in the figure 5.1 and the test setup is shown in the figure 5.2. Flexural test was done using a three point bend setup on a 10kn capacity computer control UTM. The distance between the two supports was maintained at 200mm. The results of the flexural tests of polymer composite laminates are discussed in detail in chapter 6

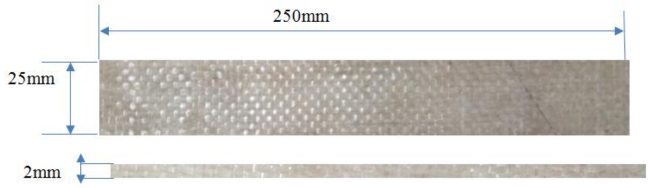


Figure 12: Flexural test specimen

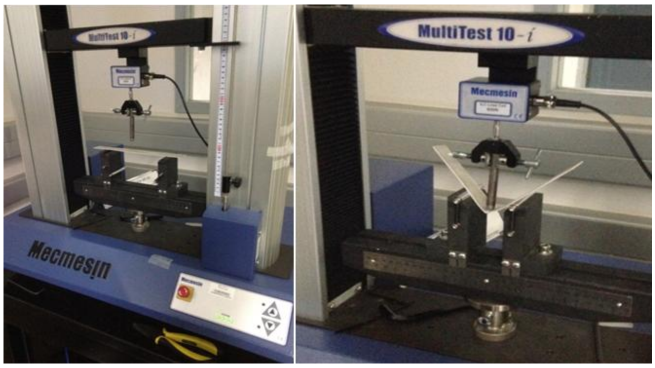


Figure 13: Flexural test setup for laminate

B. FATIGUE TESTING OF LAMINATE

Fatigue test is done as per ASTM standard D3039. The test specimen of the standard has a length 250mm, width25mm and thickness 2mm. The Fatigue test is conducted at constant frequency of 5Hz and at 80% of peak load. The fatigue test was done using a three point bend setup with a 10kn capacity fatigue machine in IISE Bangalore. Span length is kept constant. The details of the test setup are shown in the figure 14.

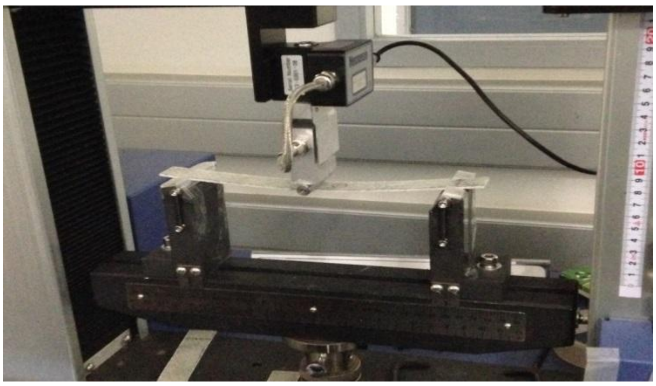


Figure 14: Fatigue test setup for laminate

XVI. CHAPTER 6: RESULTS AND DISCUSSION

A. FLEXURAL AND FATIGUE BEHAVIOR OF LAMINATE

Flexural strength of laminate is tested as per the ASTM standard D3039. The calculated values of flexural strength and endurance limit are given in Table no. 5.

Table 5: Flexural strength and endurance limit of laminate structure

Material	Peak load in N	Flexural strength In N/mm²	Endurance limit
Laminate specimen (1mm thickness)	1.1	13.2	7.5
Laminate specimen (1mm thickness)	1.2	14.4	7.1
Laminate specimen (1mm thickness)	1.80	21.6	8.1
Laminate specimen (2mm thickness)	2.0	12	6.7
Laminate specimen (2mm thickness)	1.4	8.4	6.8
Laminate specimen (2mm thickness)	1.6	9.6	6.3
Laminate specimen (3mm thickness)	1.7	6.8	3.6
Laminate specimen (3mm thickness)	1.8	7.2	3.2
Laminate specimen (3mm thickness)	1.2	4.8	2.3

B. EFFECT OF FLEXURAL STRENGTH ON FATIGUE BEHAVIOR OF LAMINATE STRUCTURE

The fatigue behavior is studied in 80% loading condition. The flexural strength verses number of cycles are plotted for all the nine specimens and is shown in the figure 6.1 to 6.9. From the graph, the fatigue life of the sandwich structure is more than 25000 cycles. The flexural strength and endurance limit for all the specimens is shown in the table 6.1. From the table the maximum endurance limit is 8.1 for 1mm laminate thickness.

1) Fatigue of specimen 1

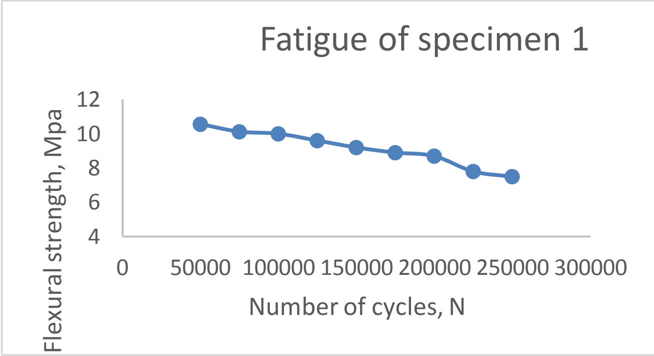


Figure 15: Fatigue life of 1mm laminate thickness

2) Fatigue of specimen 2

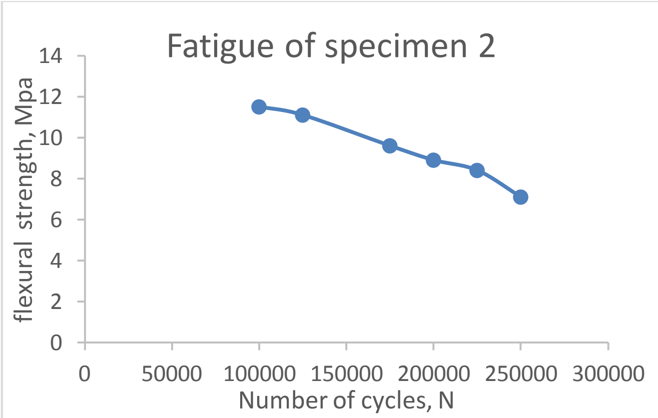


Figure 16: fatigue life of 1mm laminate thickness

3) Fatigue of specimen 3

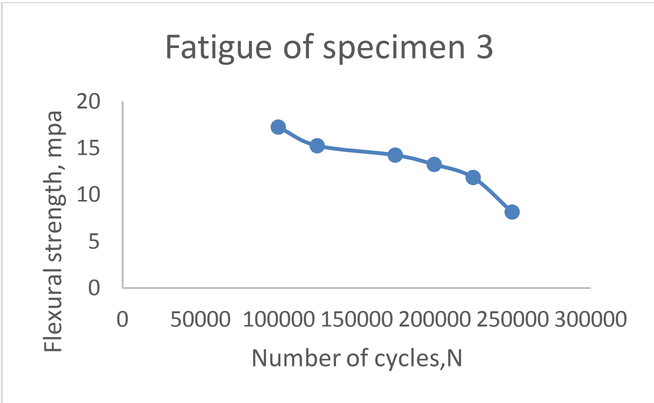


Figure 17: Fatigue life of 1mm laminate thickness

4) Fatigue of specimen 4

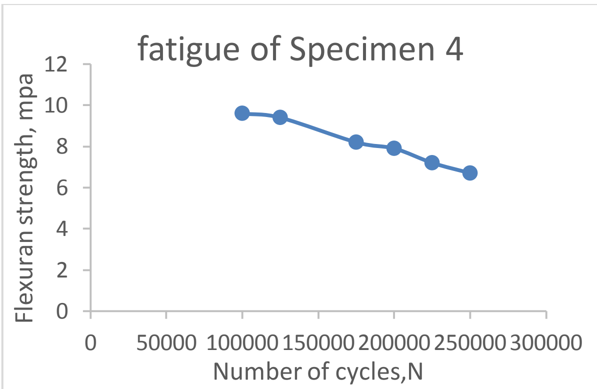


Figure 18: Fatigue life of 2mm laminate thickness

5) Fatigue of specimen 5

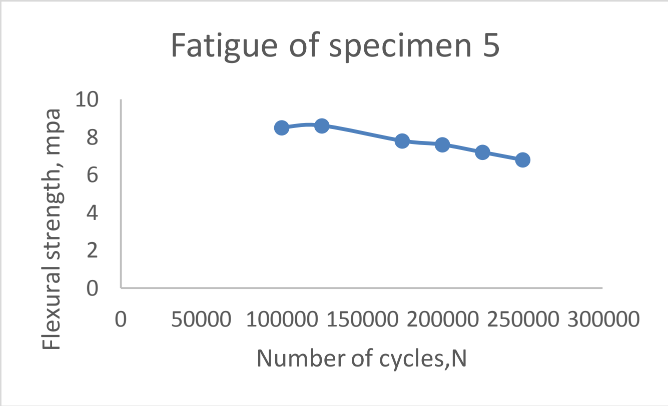


Figure 19: Fatigue life of 2mm laminate thickness

6) Fatigue of specimen 6

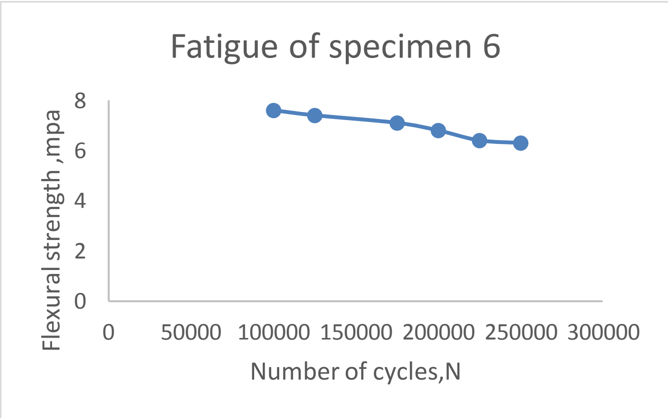


Figure 20: Fatigue life of 2mm laminate thickness

7) Fatigue of specimen 7

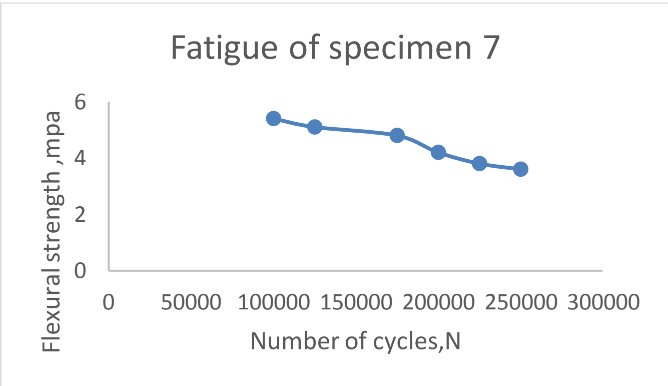


Figure 21: Fatigue life of 3mm laminate thickness

8) Fatigue of specimen 8

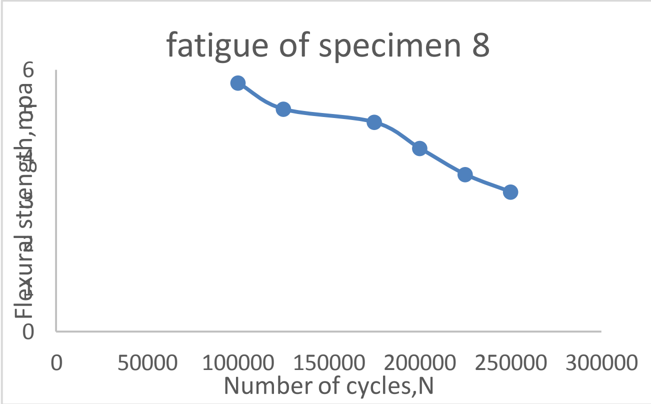


Figure 22: Fatigue life of 3mm laminate thickness

9) Fatigue of specimen 9

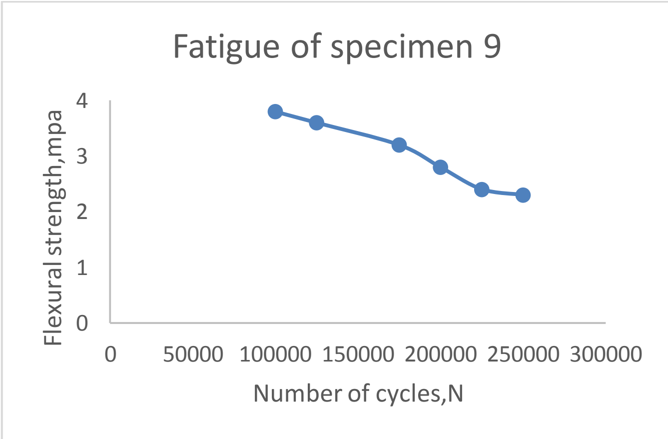


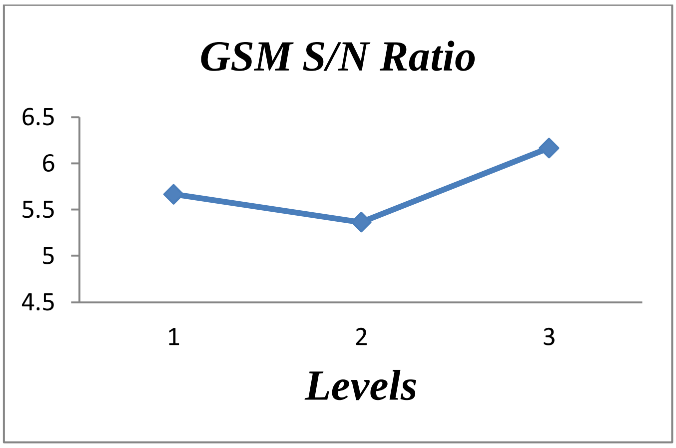
Figure 23: Fatigue life of 3mm laminate thickness

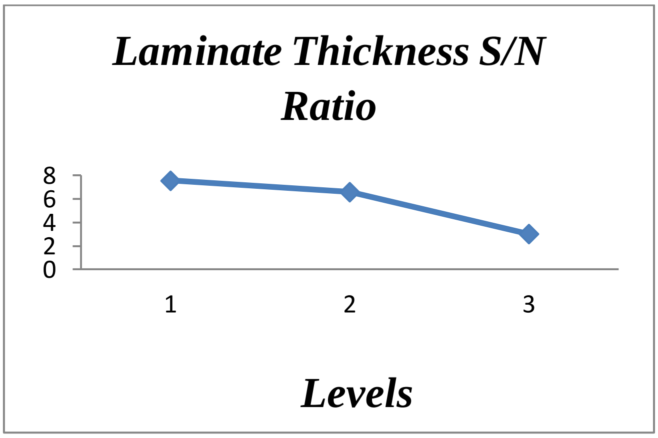
C. ANOVA FOR ENDURANCE LIMIT

The analysis of variance is performed for the endurance limit of all the laminate structures to find the most significant material parameter which corresponds to the fatigue life. The results of ANOVA are shown in table 6.2 and response plots in figure 6.10. From the results of ANOVA it is found that the most significant parameter for endurance limit is laminate thickness contributing 96.02 % followed by fiber orientation of 0.58 % and GSM of 2.75%. The Table No.6.2 shows the results of ANOVA for endurance limit.

Table 6: ANOVA tabe for endurance limit

S.No	Parameters	DOF	SS Factor	MS Factor	F	% Influence
1	Laminate thickness	2	34.206667	17.103333	148.00962	96.020211
2	Fiber orientation	2	0.2066667	0.1033333	0.8942308	0.580126
3	GSM	2	0.98	0.49	4.2403846	2.7509201
4	Error	3	0.3466667	0.1155556	1	0.6487431
5	Total	9	35.74		154.14423	100





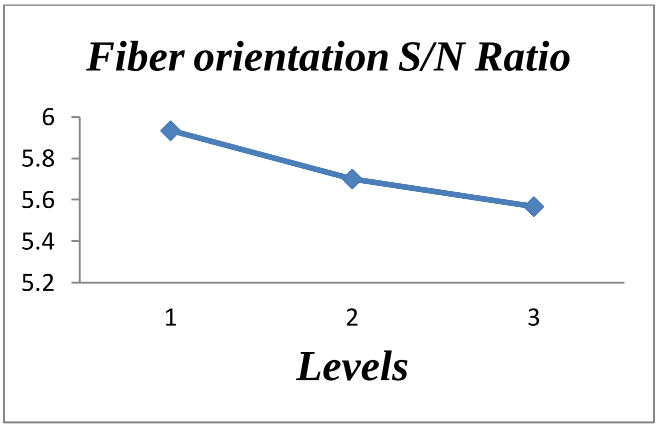


Figure 24: Response plots

CHAPTER 7: CONCLUSION AND FUTURE SCOPE OF WORK

A. CONCLUSION

Now a days carbon fiber and glass fiber reinforced composites are being increasingly used in different fields of engineering by replacing conventional materials. Advantages of these composite materials over conventional materials include higher stiffness, higher strength, better fatigue behavior, corrosion resistance, and tailored properties. Conversely, delamination, discontinuous stress, reparability, and interchangeability are the disadvantages of polymer composites. Fatigue behavior of composite materials is different from that of the metals. Composites are inhomogeneous and anisotropic as compared to metals which are homogenous in nature and isotropic in behavior. In fatigue, composite materials undergo a series of changes, that is, matrix cracking, fiber-matrix debonding, fiber breaking and finally the failure. Thus, matrix, fiber and interface between fibers and materials play an important role in deciding the fatigue behavior of a laminate.

The objective of the Research work is to estimate the fatigue life of the composite laminate by varying the thickness, One of the most attractive candidates to composite materials is the automotive industry. As continuous fibrereinforced composites provide good mechanical properties, they have been increasingly used in many lightweight structures such as structural automotive parts which were subjected in service to fatigue loadings. Therefore, a good prediction of fatigue life is required. Hence it can be recommended that the Glass Fiber Polyester Epoxy laminate is good for flexural fatigue critical applications such as wind turbine blades, Air craft wing and auto motive leaf spring constructions.

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