EXPERIMENTAL BEHAVIOUR AND STUDY OF LAMINATED COMPOSITES

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ABSTRACT

Carbon fiber reinforced composites are utilized in many design applications where high strength, low weight, and/or high stiffness are required. While composite materials can provide high strength and stiffness-to-weight ratios, they are also more complicated to analyze due to their inhomogeneous nature. One important failure mode of composite structures is delamination. This failure mode is common when composite laminates are subject to impact loading. Various finite element methods for analyzing delamination exist. In this research, a modeling strategy based on contact tiebreak definitions in LS-DYNA® was used. A finite element model of a low-velocity impact event was created to predict delamination in a composite laminate. The resulting delamination relative size and shape was found to partially agree with analytical and experimental results for similar impact events, while the force-time plot agreed well with experimental results. A small difference in contact time in the simulation compared to experimental testing is likely due to the omission of composite failure modes other than delamination. Experimental impact testing and subsequent vibrothermography analysis showed delamination damage in locations shown in previous research. This confirmed the validity of vibrothermography as a nondestructive evaluation technique for analyzing post-impact delamination.

Keyword : - *Carbon fiber, Experimental, Aramid fiber.*

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1. INTRODUCTION

Carbon fiber reinforced composites are utilized in many design applications where high strength, low weight, and/or high stiffness are required. From the aerospace industry to the commercial golf club industry, carbon fiber reinforced composites have become the material of choice for many designs. While composite materials can provide high strength and stiffness-to-weight ratios, they are also more complicated to analyze due to their inhomogeneous nature. In order to use composite material systems safely and efficiently, researchers have studied and developed the underlying theory to explain their structural response and failure mechanisms under loading. Composite structures, or parts, are created by placing layers of material onto one another to create a laminate. The number of individual layers in a laminate, along with their material and orientation, determine the constitutive response of the laminate as a whole.

1.1 NECCESSITY OF COMPOSITES

Composites with improved impact, fatigue and creep resistance were also created. All these improvements were achieved by choosing the Composite materials are being developed and made with two kinds of objectives:
1.To enhance the material properties and performance efficiency.
2.To design materials with combinations of desired properties.

1.2 CLASSIFICATION OF COMPOSITES

Composites can be broadly divided based on the way they came into existence, the level at which they are composed, their structure and the matrix system used.

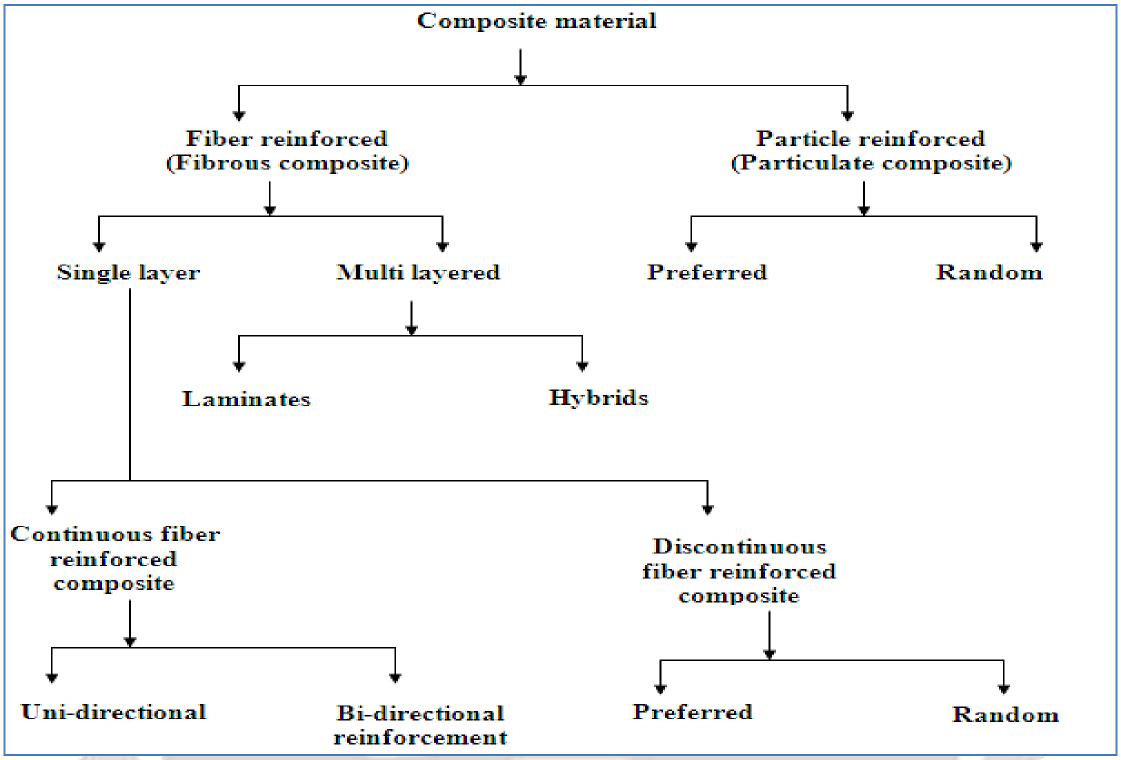

Fig- 1: Classification of Composite Materials

1.3 HYBRID COMPOSITES

Hybrid composites, which combine two or more different fibers in a common matrix, greatly expand the range of properties that can be achieved with advanced composites. They may cost less than materials reinforced only with graphite or boron. Generally,” hybrid” applies to advanced composites and refers to use of various combinations of continuous graphite, boron, Kevlar, or glass filaments (E-GLASS) in either thermoses or thermoplastic matrixes.

1.3.1 FAILURE MODES IN HYBRID COMPOSITE MATERIALS

When hybrid composites are stressed in tension, failure is usually gradual (i.e., does not occur suddenly). The carbon fibers are the first to fail, at which time the load is transferred to the glass fibers. Upon failure of the glass fibers, the matrix phase must sustain the applied load.

1.4 Advantages/ Disadvantages/ Applications

1.4.1 Advantages of composite materials:-

- Weight savings are significant
- Corrosion resistance is outstanding
- Impact and damage tolerance is excellent
- Low thermal expansion
- Tooling is cheaper
- Excellent damping feature
- Improved frictional resistance
- Material waste is reduced

- Design flexibility
- Resistance to crack propagation
- Rigidity enhanced by sandwich
- Easy to repair
- High dimensional stability
- Manufacturing and assembly simplified by part integration
- High torsion stiffness
- Material handling is easy.

1.4.2 Disadvantages of composite materials:-

- Poor non electrical resistance
- Degradation in moisture
- High cost
- Special tooling
- New inspection techniques
- Skilled man power
- Definite shelf life
- Special storage facilities are required.

1.4.3 APPLICATIONS:-

Composite materials have found applications in almost all branches of engineering. A rough estimate indicates that more than 60000 products are being made using these materials. For convenience, the usage of composites can be divided into 9 application areas. This division is based on the design and functional requirements.

- Aerospace applications
- Land transport applications
- Marine vessels and structures
- Building and construction industry
- Chemical plants and corrosion resistant products
- Electrical electronic and communication applications
- Machine elements and energy applications
- Biomedical, rehabilitation and hospital appliances
- Consumer durable products and sports goods

2. OBJECTIVES

The major objectives of the Project work are summarized below:

1. To Fabricate and test adequate models for predicting the mechanical behavior of composite materials.
2. Comparison of obtained experimental results with numerical methods/ FEM Analysis.
3. To study the impact response and damage initiation of composites due to low-velocity impact and high velocity impact.

3. FABRICATION METHOD OF COMPOSITES

3.1 RESIGN TRANSFER MOULDING (RTM):

Fabrics are laid up as a dry stack of materials. These fabrics are sometimes pre-pressed to the mould shape, and held together by a binder. These ‘performs’ are then more easily laid into the mould tool. A second mould tool is then clamped over the first, and resin is injected into the cavity. Vacuum can also be applied to the mould cavity to assist resin in being drawn into the fabrics. This is known as Vacuum Assisted Resin Injection (VARI). Once all the fabric is wet out, the resin inlets are closed, and the laminate is allowed to cure. Both injection and cure can take place at either ambient or elevated temperature.

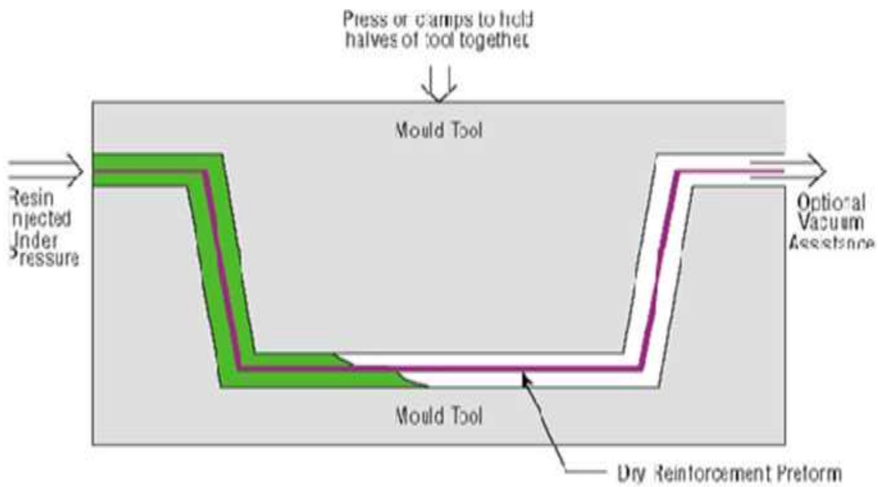

Fig -2: Resign Transfer Moulding

3.2 PRE-PEG MOULDING METHODS:

Like moulding compounds, pre-pegs are, also ready to use combinations of material, but unlike in moulding compounds, the pre-pegs have the reinforcements structured, as they would appear in the finished composites. The resins are also taken to partially cross-linked condition or B-stage. During the moulding operation, the pre-pegs are placed in the mould and the cross-linking is completed.

3.3 FILAMENT WINDING:

This process is primarily used for hollow, generally circular or oval sectioned components, such as pipes and tanks. Fiber tows are passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fiber feeding mechanism, and rate of rotation of the mandrel.

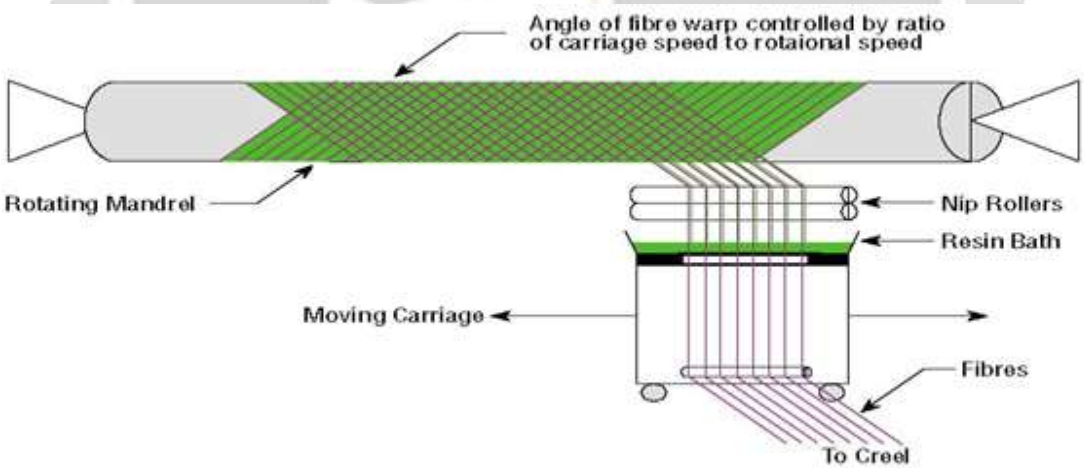

Fig – 3: Filament Winding

3.4 AUTOCLAVE MOULDING:

This process uses a two-sided mould set that forms both surfaces of the panel. One side is a rigid mould and on the other side is flexible polymer film. Reinforcement materials can be placed manually or robotically. They include continuous fiber forms fashioned into textile constructions.

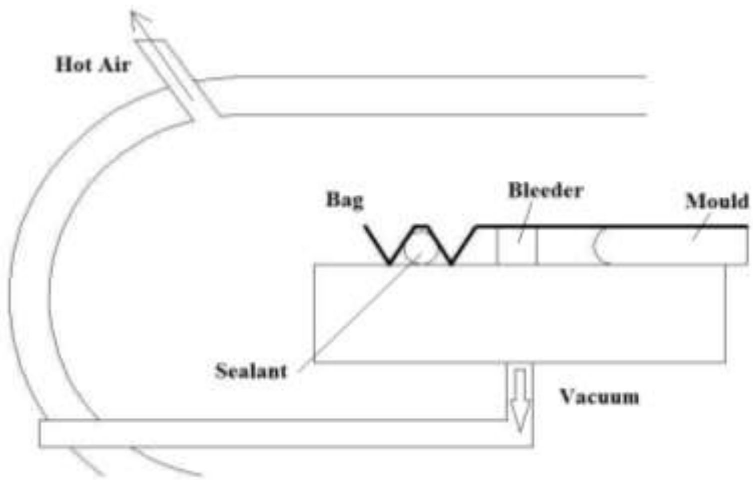

Fig – 4: Autoclave Moulding

3.5 WET RESIN MANUFACTURING SYSTEM OR WET LAY UP:

The resin in this system is available in liquid form, which is the linear polymer stage or a stage without any cross-linking. The fiber to resin proportioning is done either by wetting the resin or by infiltrating the resin, which is then cured into a hard solid (with or without using pressure).

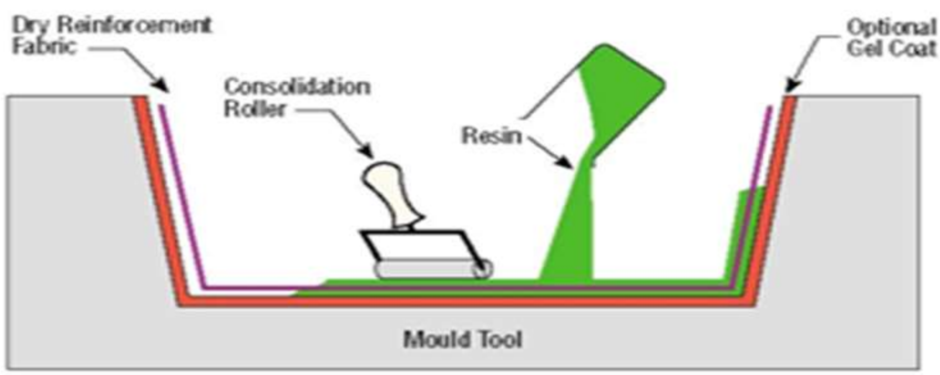

Fig – 5: Wet Resign Manufacturing System

4. EXPERIMENTAL SETUP

4.1 FABRICATION OF COMPOSITE PLATES:

Generally the composite plates are fabricated by hand layup technique. In this first the woven fabric is placed on base plate and epoxy resin is applied uniformly and rolled using a roller to avoid cavities. Then next layer is placed at required orientation and the process is repeated to stack all layers and it is covered with top plate and allowed for curing.

4.2 MATERIAL SELECTION:

Unidirectional glass fiber mat of 300 gsm is used for the fabrication of reinforcement
Epoxy L-12 (AtulLtl Gujarat)
Hardner K-6 (AtulLtl Gujarat)

Fig -6: Epoxy L-12 & Hardener K-6

4.3 HAND LAY-UP PROCESS:

In the early days, the wet lay-up process was the dominant fabrication method for the making of composite parts. It is still widely used in the marine industry as well as for making prototype parts. This process is labour intensive and has concerns for styrene emission because of its open mould nature. In this process, liquid resin is applied to the mold and then reinforcement is placed on top. A roller is used to impregnate the fiber with the resin. Another resin and reinforcement layer is applied until a suitable thickness builds up. It is very flexible process that allows the user to optimize the part by placing different types of fabric and mat materials. Because the reinforcement is placed manually, it is also called as the hand lay-up process. This process requires little capital investment and expertise and is therefore easy to use.

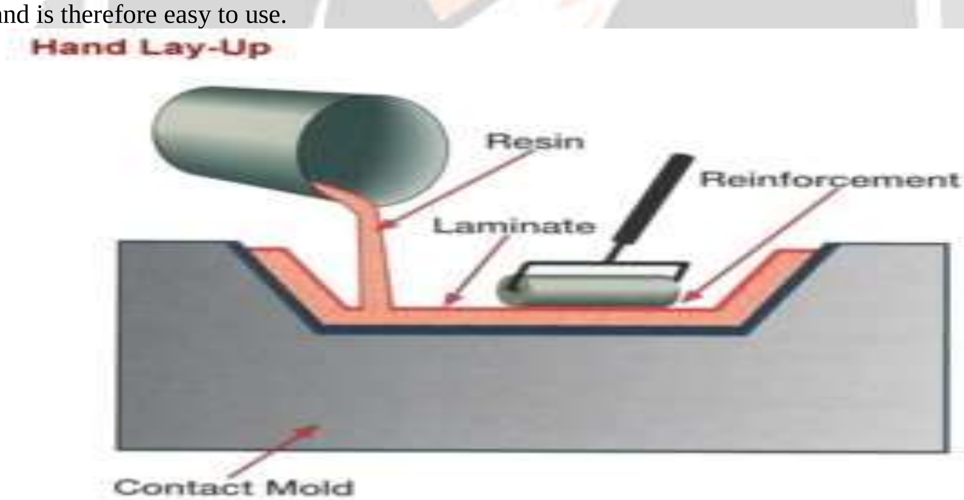

Fig -7: Hand lay-up process

EXPERIMENTAL PROCEDURE:

- Before the fabrication, the fabrics and matrix has to be kept in oven setting the temperature at 60^0C so that the moisture from resin and fabric (if present) will be removed.
- The resin and hardener is mixed together and gently stirred, so that the resin and hardener is properly mixed.
- Applying releasing agent on the work table mounts the releasing layer (Teflon sheet) then again applies the releasing agent.

- Place the first layer of fabric and wet it then apply the next layer and again wet that follow the same procedure for all remaining layers.
- The wetting should be done in such a way that the resin should be distributed equally on the lamina, care should be taken that there should be no starvation or excess of resin on the lamina.
- After the last layer again the resin is applied and covered with Teflon sheet and then the dead weight is applied over the mould.
- The material is cooled at room temperature for 24 hr.
- The specimens are cut as per the standards and the tests are conducted**.**

5. RESULTS AND CALCULATION

5.1 EXPERIMENTAL ANALYSIS

5.1.1 TENSILE TEST

Tensile test is one of the fundamental mechanical tests which is required to evaluate the strength of any material, where a carefully prepared specimen is subjected to tensile load in a controlled manner. Tensile properties can be measured by the relation of load applied on the material to deflection (Strain) experienced against the applied load. Tensile tests are used to determine the modulus of elasticity, elastic limit, percentage of elongation in length and percentage of reduction in area, tensile strength, yield strength, other tensile properties. The Tensile test specimen is prepared according to the ASTM standards; the specimen for tensile test is as shown below;

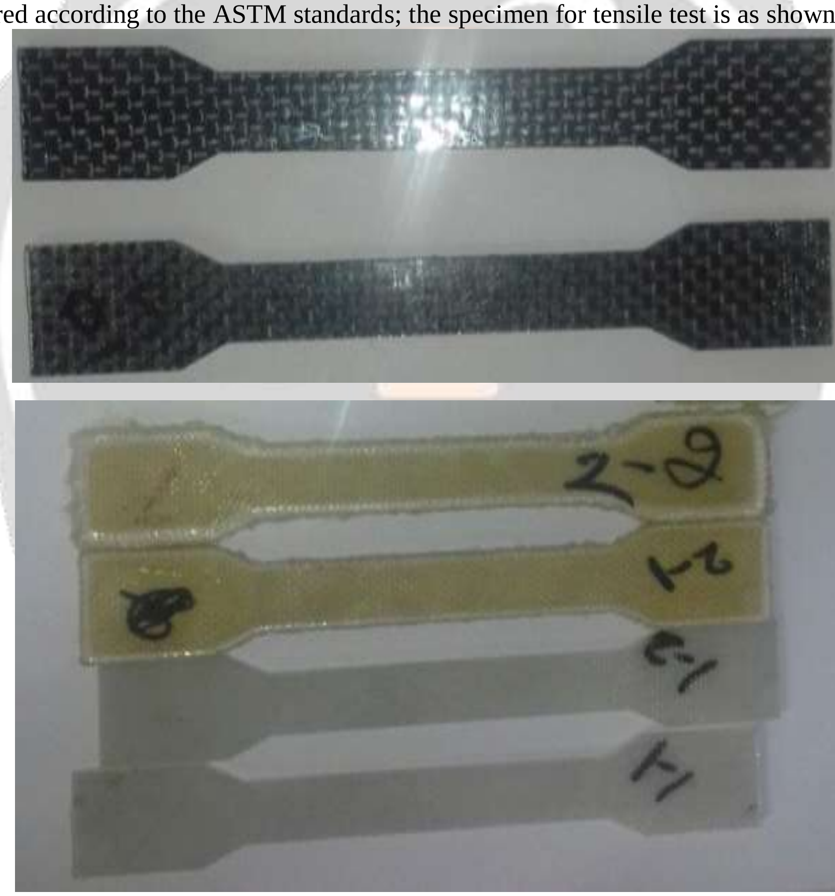

Fig -8: Tensile test specimen of different fibers

Tensile test specimen Tensile test specimen is fixed between the two jaws of fully automated and closed loop computerized Universal Testing Machine (UTM) and tensile load is applied on specimen by pulling the one jaw and fixing the other jaw. The process is recorded and the each pulse values of load applied and deformation in specimen is collected in computer and load *v/s* deflection and stress *v/s* strain graphs are generated and all the data is stored in the computer.

The following figures shows the specimens prepared the test specimen being experiments in the universal testing machine.

Fig -9: Universal Testing Machine

Table -1 Results for Tensile Test Specimens

Sl. No.	Fibers	Yeild Stress (N/mm^2)	Tensile Strength (N/mm^2)
1.	E-Glass Fiber	147.55	179.24
2.	Aramid Fiber	207.60	257.85
3.	Carbon Fiber	303.78	351.96
4.	E-Glass + Aramid fiber	178.15	201.77
5.	E-Glass + carbon Fiber	215.83	247.62

5.1.2 BENDING TEST:

Here the aim is to investigate experimentally the mechanical behavior of composite materials subjected to bending load, at crosshead speed of a 5 mm/min using flexural test system on two types of MMC's, one with aluminum matrix bonded with the interface and the other with a steel matrix interface. The movable carriage of the machine was brought on the loading bar and load was applied gradually in increments of 100N for bending on the specimen under tests, Plot of load verses deflection and yielding were recorded. On the one hand, this study intended to quantify the strain- rate effects on the overall behavior in terms of elastic properties, damage and ultimate characteristics. On the other hand, it contributes to investigate local processes involving damage initiation and growth.

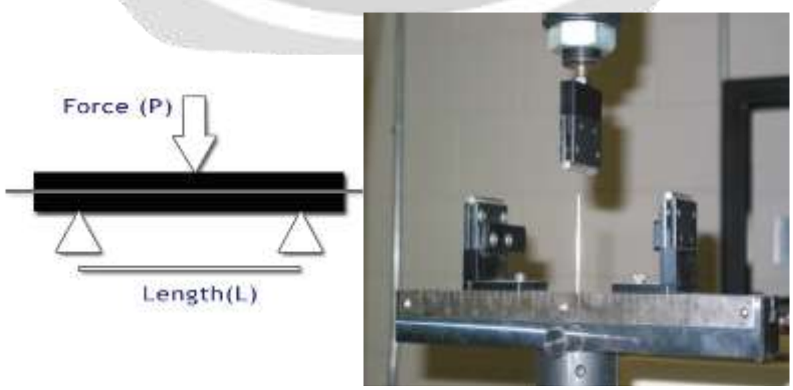

Fig -10: Bending test experiment

Bending test is conducted on each of the specimen with the orientation as mentioned above. The test specimen dimensions and the model done in this project work are shown in the figures below,

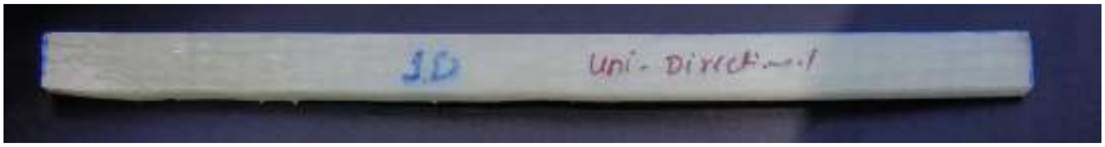

Fig -11: Bending test specimen of different orientation

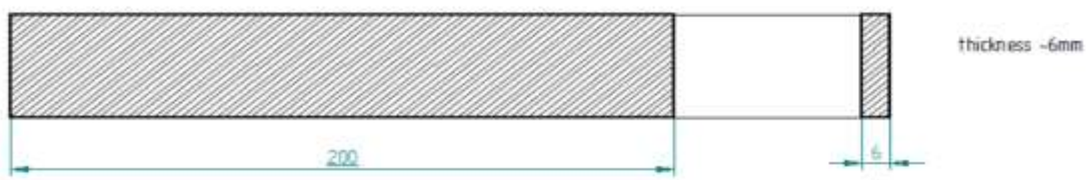

Fig -12: Bending test specimen dimension

Flexural modulus point outs the material's rigidity when bended. The specimen is positioned on a sustain span and load is applied at the midpoint by the loading nose producing bending at a specific rate. The testing was conducted as per the ASTM D790 standard. Flexural strength at particular strain intensity and flexural modulus were estimated. The experiment was frequented thrice and the mean value was considered. The figure-13 shows the flexural strength test. By using the equations (1) and (2), the flexural strength and flexural modulus was calculated. Figure-14 shows experimental set up of flexural strength test and Figure-15 test specimens of 2.5 mm thick 30% GF + 30% CF hybrid composite of the flexural strength test.

$$\textbf{Flexural strength} = \frac{3P_{max}L}{2bh^2} \quad \text{.......... (1)}$$

$$\textbf{Flexural modulus } E_F = \frac{mL^3}{4bh^3} \quad \text{......... (2)}$$

Where,

P_{max}.- Maximum load at failure (N)
L - Distance among supports (m)
b- Width of the specimen (m)
h- Thickness of the specimen (m)
m- Initial slope of the load-deflection curve

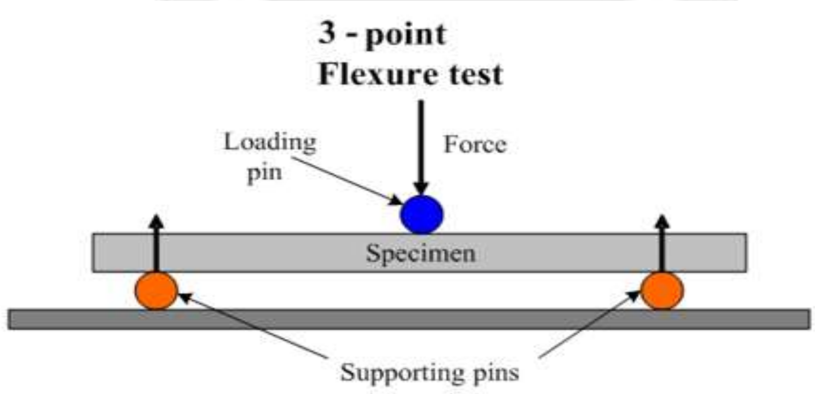

Fig -13: The flexural strength test (3-point bending experiment)

Fig -14: Experimental set up of flexural strength test

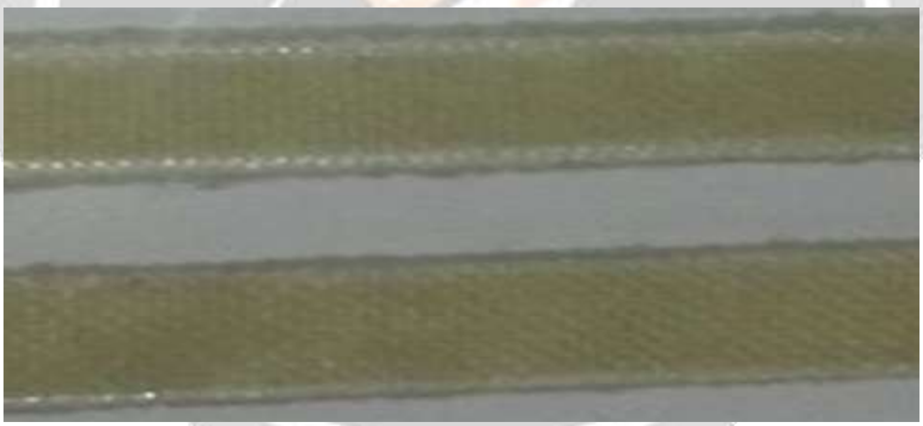

Fig -15: Test specimens of 2.5 mm thick 30% GF + 30% AF hybrid composite for flexural strength test

Table -2 Results For Bending Test Specimen

Sl. No.	**Flexure**	**Bending Strength (σ_u) N/mm^2 or MPa**
	Specimens	Experimental
1.	Glass + Epoxy	150.65
2.	Aramid + Epoxy	210.98
3.	Carbon + Epoxy	284.28

4.	Glass + Epoxy + Aramid	201.84
5.	Glass + Epoxy + Carbon	228.01

6. SCOPE FOR FUTURE WORK

The analysis of hybrid composites have been reviewed for different fibers combination and presented here. During the past decade, there have been many changes in the industry in terms of application would MMC's, PMC and it is estimated that defense/ aerospace applications would account for approximately 60% of the hybrid composite site market by 2020.While the military aerospace market remains an important target for these composites, opportunities have been emerged in other industries. The push for better fuel composites in automobiles and companies in that are working to create new market opportunities for their composites products in industries that, 10 years ago, had never even heard of metal matrix composites.

7. CONCLUSIONS

From the FEM analysis done on the models, it shows that the results obtained is satisfactory and is within the comparable range with respect to Experimental analysis. Using the specimens experimented for their mechanical properties and results are obtained. The following conclusions are made from the obtained results It is evident from the results that the carbon fiber shows a better strength than E-Glass and aramid fibers. Tensile strength, yield strength and ultimate load of the Carbon fiber are superior when compared with others. However the combination of the fibers shows better results as that of in between the two fiber properties for carbon & E-glass combination. This can be attributed to change in the density of the fiber as well as volume fraction of the fibers. However for Aramid+ E-glass fiber its shows intermediate results. The hardness of the test specimen is almost same for all the combination since it is dependent on the matrix volume fraction also tested, which shows that there is no appreciable change in hardness for different fibers.

8. ACKNOWLEDGEMENT

We feel immense pleasure in showing my gratitude to all the people who have made this work possible, by offering help and guidance whenever required. The people whom we list below are deeply acknowledged for their contribution and support. It brings a sense of privilege to associate this work with the name of my guide Associate Professor Dr. Satheesha.V working under whom has been a precious opportunity. We are very grateful to Dr. Ramesh C, Head of Department for providing me this opportunity to work. Special thanks to Dr. Balakrishna Rayanki, Principal Rajarajeswari college of Engineering for lending a helping hand in completion of our project.

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