

Fabrication of Fiber Reinforced Composite

K. Shiva Shankar¹, Ch Harish², B. Praharshini³, Amulya⁴, Rahul⁵

Assistant Professor, Department of Aeronautical Engineering, MLR institute of Technology, Hyderabad, India¹

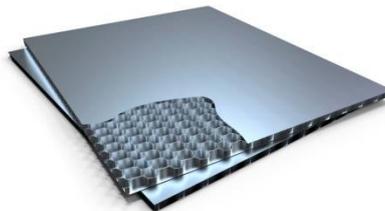
Student, Department of Aeronautical Engineering, MLR institute of Technology, Hyderabad, India^{2, 3, 4, 5}

ABSTRACT: In the present day scenario, use of glass fiber composites has been extended to a large number of aircraft components which includes structural and non-structural components such as wings, helicopter rotor blades, engine ducts etc. Glass fiber reinforced polymer (GFRP) is a composite material which consists of laminates having reinforcing fibers (GLASS) of significant strength embedded in a matrix material and has a relatively low elastic modulus and the high strength-to-weight ratio the wing of a subsonic aircraft will be designed in CATIA software and analysis in the ANSYS software. The performance of wing under the application of loads will be studied by varying the orientation of fiber layers. From the study, it was observed that the variation in stress occurs with variation in orientation of fiber layers of GFRP composites.

KEYWORDS: Glass fiber reinforced polymer (GFRP), reinforcing fibers, and high strength-to-weight ratio.

I. INTRODUCTION

This project deals with the fabrication of the sandwich panel i.e. by using aluminium and composite. Sandwich panel is a structure made of three layers: one is core and two are thin skin. These panels are used in applications where high structural rigidity and low weight are required. In this we are considering the core as e-glass fiber (composite) and skin as aluminium and testing it by taking the standard specimen size.(as per Indian Standards)
The testing that is carried in the sandwich panel is: Tensile, Compression and shear.



Composite Materials:

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components.

MATRIX + REINFORCEMENT = COMPOSITES

The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties.

Properties:

- High strength to weight ratio
- Corrosion resistance
- Greater fatigue life
- Inherent durability
- High Di-electric strength

High Strength to Weight Ratio:

- Strength to weight ratio is defined as a material's strength divided by its density. It is also known as specific strength.

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- The materials with the highest specific strengths are typically fibers such as carbon fiber, glass fiber and various polymers, and these are frequently used to make composite materials. Tenacity is a customary measure of strength of a fiber or yarn. Tenacity is the usual measure of specific strength.

Corrosion Resistance:

- Corrosion resistance refers to the resistance a material offers against the reaction with adverse elements which can corrode the material. Various materials have this property intrinsically, depending upon their corrosion resistance rate. Some other methods can also be used to resist corrosion such as painting, hot dip galvanizing and the combination of these methods with coating.
- FRP composites do not rust or corrode. There are various resin systems available to the fabricator which provides long-term resistance to almost every chemical and temperature environment. Properly designed FRP composites parts have long service life and minimum maintenance as compared to most competitive materials.

Greater Fatigue Life

- Fatigue is the weakening of a material caused by repeatedly applied loads. It occurs when a material is subjected to repeat loading and unloading.
 - The number of applications of a given stress to which a sample of metal can be subjected before failing. (as per ASTM)
 - The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.
 - Fatigue life is represented by S-N curve. (Stress vs. No. of cycles)
- S-N Curve:**
- In high-cycle fatigue situations, materials performance is commonly characterized by an S-N curve, also known as a Wohler curve. This is a graph of the magnitude of a cyclic stress (S) against the logarithmic scale of cycles to failure (N).

APPLICATIONS OF COMPOSITES:

Composite materials have found applications in a wide range of industries.

- Aerospace
- Automobile
- Civil
- Marine
- Electrical and Electronic systems

CLASSIFICATION OF COMPOSITES:

Composites are classified mainly into two types;

- Based on REINFORCEMENT
- Based on MATRIX
- Based on REINFORCEMENT:

Depending on the form of the reinforcing the material with the matrix, they are classified into three types

Particulate

- Fiber
- Structural
- Based on MATRIX

Generally matrix is a resin, which is used for the protection of reinforcement. They are three types

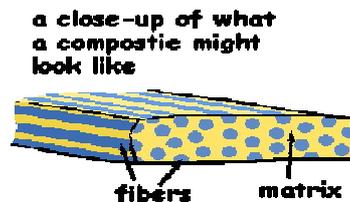
- Polymer Matrix
- Metal Matrix
- Ceramic Matrix

MATRIX + REINFORCEMENT = COMPOSITE; by combining in this way with different combinations of matrix and reinforcement we form different types of composites are formed

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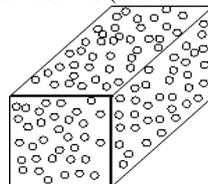
Particulate Reinforced Composites (PRC)

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 is greater than 28%. In particulate composites, the particles strengthen the system by the hydrostatic coercion of fillers in matrices and by their hardness relative to the matrix. Imparts least anisotropic property to composite Particles are used to increase the modulus of the matrix, to decrease the permeability of matrix, to decrease the ductility of matrix. The composite's strength usually depends on the diameter of the particles, the inter-particle spacing, and the volume fraction of the reinforcement. The matrix properties influence the behavior of particulate composite.

- There are generally two types of PRC:
 1. Large particle
 2. Dispersion-strengthened

1. Large particle:

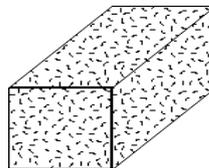
A type of particle reinforced composite wherein particle-matrix interactions cannot be treated on a atomic level. The degree reinforcement or improvement of mechanical behaviour depends on strong bonding at the matrix-particle interface. EXAMPLES: Concrete (Matrix), Sand and Gravel (Particulates).



2. Dispersion Strengthened:

Dispersion-strengthened means strengthening of materials where in very small particles of a hard yet inert phase are uniformly dispersed with in load bearing matrix phase.

The dispersed phase may be metallic or non-metallic, oxide materials are often used.



PROPERTIES:

- High strength
- Low cost
- High dielectric constant
- Low density

Fiber Reinforced Composites/Fiber Reinforced Polymer (FRP): Composites

Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. The performance of a fibre composite is judged by its length, shape, orientation, and composition of the fibres and the mechanical properties of the matrix. The orientation of the fibre in the matrix is an indication of the strength of the composite and the strength is greatest along

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the longitudinal directional of fibre. By using multi-directional orientation for bearing the heaviest loads gives the best result. Monolayer tapes consisting of continuous or discontinuous fibres can be oriented unidirectional stacked into plies containing layers of filaments also oriented in the same direction. Organic and inorganic fibres are used to reinforce composite materials. Almost all organic fibres have low density, flexibility, and elasticity. Inorganic fibers are of high modulus, high thermal stability and possess greater rigidity than organic fibres and notwithstanding the diverse advantages of organic fibres which render the composites in which they are used. Mainly, we have different types of fibres namely:

- glass fibres
- carbon fibre
- silicon carbide fibres
- high silica
- quartz fibres
- metal fibres and wires
- graphite fibres
- boron fibres
- aramid fibres

Types of fiber reinforcing:

- Continuous and Aligned
- Discontinuous and Aligned
- Discontinuous and Randomly oriented



PROPERTIES:

- High specific strength
- High specific stiffness
- Strength- weight ratio
- Modulus - weight ratios
- Fatigue tolerances
- Creep
- High strength and modulus
- low specific gravity

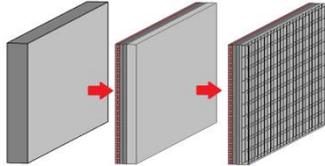
STRUCTURAL REINFORCED COMPOSITES:

A structural composites consists of both homogenous and composite materials, their properties depends upon the characteristics properties of the constituent materials as well as geometric design. Laminate Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category. These may be of several layers of two or more metal materials occurring alternately or in a determined order more than once, and in as many numbers as required for a specific purpose. Sandwich laminates have many areas as it ought to be, although they are known to follow the rule of mixtures from the modulus and strength point of view. It is not possible to achieve high strength materials unlike the fiber version. But sheets and foils can be made isotropic in two dimensions more easily than fibers. The main functional types of metal-metal laminates that do not posses high strength or stiffness are single layered ones that endow the composites with special properties, apart from being cost-effective. There are many combinations of sheet and foil which function as adhesives at low temperatures. Such materials, plastics or metals, may be clubbed together with a third constituent. Pre-painted or pre-finished metal whose primary advantage is elimination of final finishing by the user is the best known metal-organic laminate. Several combinations of metal-plastic, vinyl-metal laminates, organic films and metals, account for up to 95% of metal-plastic laminates known. They are made by adhesive bonding processes.

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PROPERTIES

- High bending stiffness
- low density
- better strength

Polymer matrix composites (PMC):

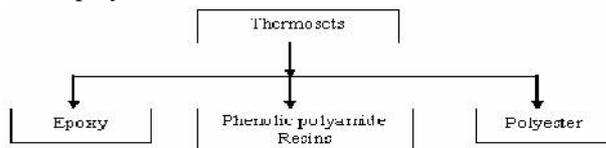
- ❖ A polymer is defined as a long-chain molecule containing one or more repeating units of atoms joined together by strong covalent bonds.
- ❖ Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties.
- ❖ Two main kinds of polymers:
 - Thermo sets
 - Thermoplastics.

Thermo sets:

- ❖ Thermo sets are very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites.
- ❖ Thermo sets find wide ranging applications in the chopped fiber composites form

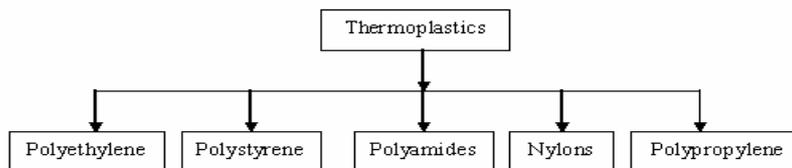
Most used thermo sets are

- Epoxy
- Polymer
- Phenolic polyamide resins.



Thermoplastic

- ❖ Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point.
- ❖ Fiber reinforcement is apt for these resins.
- ❖ Aerospace components, automobile parts, defense systems etc., use a great deal of this type of fiber composites



Metal Matrix Composites (MMC):

Material having metal as a matrix material in composites is called Metal Matrix. Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature

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and non-reactive too. Titanium, Aluminium and magnesium are the popular matrix metals which are currently used in aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to-weight ratios of resulting composites can be higher than most alloys. The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging, or rolling. Continuous reinforcement uses monofilament wires or fibres such as carbon fibre or silicon carbide. Because the fibres are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. Discontinuous reinforcement uses whiskers, short fibres, or particles. The most common reinforcing materials in this category are alumina and silicon carbide

PROPERTIES:

- High tensile strength
- High creep resistance
- High toughness

Ceramic Matrix Materials (CMM):

Material having a ceramic as a matrix material in a composite is called ceramic matrix. Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favorite for applications requiring a structural material that doesn't give way at temperatures above 1500°C. Naturally, ceramic matrices are the obvious choice for high temperature applications. High modulus of elasticity and low tensile strain, which most ceramics possess, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. When ceramics have a higher thermal expansion coefficient than reinforcement materials, the resultant composite is unlikely to have a superior level of strength. In that case, the composite will develop strength within ceramic at the time of cooling resulting in micro cracks extending from fibre to fibre within the matrix. Micro cracking can result in a composite with tensile strength lower than that of the matrix. Generally, CMC names include a combination of type of fibre/type of matrix. CMC consists of ceramic fibres embedded in a ceramic matrix material. Now a day's CMC are used in hot sections of the sections. CMCs can operate at temperatures exceeding the capability of current alloys typically used in high-pressure turbines. CMCs can operate with little or no cooling. CMCs are less in weight compared to alloys.

PROPERTIES:

- High Fracture toughness or crack resistance.
- Anisotropic or orthotropic
- Good insulators
- High porosity
- Good Electrical conductivity
- Very stable to corrosion
- No macroscopic damage, even if the matrix has cracked locally.

GLASS FIBERS:

Glass fibres are the most common of all reinforcing fibres for polymeric matrix composites (PMC). An individual structural glass fibre is both stiff and strong in tension and compression along its axis. The principal advantages of glass fibers are low cost, high tensile strength, high chemical resistance, and excellent insulating properties. The disadvantages are relatively low tensile modulus and high density (among the commercial fibers), sensitivity to abrasion during handling (which frequently decreases its tensile strength), relatively low fatigue resistance, and high hardness (which causes excessive wear on moulding dies and cutting tools)

- ❖ The two types of glass fibers commonly used in the fiber-reinforced plastics:
 - E-glass
 - S-glass.

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- ❖ Another type are:
 - A-glass
 - E-CR-glass
 - C-glass
 - D-glass
 - R-glass

The basic commercial form of continuous glass fibers:

- ❖ Strand, which is a collection of parallel filaments numbering 204 or more
- ❖ Other forms of glass fibers are:
 - Roving
 - Chopped Strands
 - Woven roving or woven cloth



Chopped strand (discontinuous)



Chopped strand mat (continuous)



Woven Roving



Woven mat

MATERIALS:

- ❖ For the fabrication of the sandwich panel we require two materials mainly:
 1. Aluminium
 2. Glass fiber

Aluminium (Al 6063 –T6):

- ❖ Aluminium is used as the skin for the sandwich panel
- ❖ Aluminium 6063 is an Al alloy, with magnesium and silicon as the alloying elements. It has good mechanical properties and is heat treatable and weld able. It is typically produced with smooth surfaces fit for anodizing.

Chemical Composition: The composition is only of alloy excluding aluminium:

Chemical	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others
Percent (w%)	0.2-0.6	0-0.35	0-0.10	0-0.10	0.45-0.9	0-0.10	0-0.10	0-0.10	0.15

Physical properties: Density – 2.7 g/cc (Metric)

Mechanical Properties:

Ultimate Tensile Strength	241 MPa
Tensile Yield Strength	214 MPa
Modulus Of Elasticity	68.9 MPa
Poisson's Ratio	0.33
Shear Modulus	25.8 GPa
Shear Strength	152 Mpa
Bearing Yield Strength	434 MPa

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Applications:

- Extrusions
- Doors
- Irrigation tubing
- Hydro formed Tubes
- Road and rail transportation

Glass Fiber:

- ❖ Glass Fiber is used as the core of the sandwich panel which is covered by aluminium both sides as skin. By this the core of the panel can withstand high strength when it's under loading conditions.

E-Glass Fiber :(Electrical)

- ❖ E-glass is Alumino-borosilicate glass.
- ❖ E-glass has the lowest cost of all commercially available reinforcing fibers, which is the reason for its widespread use in the FRP industry.
- ❖ These have better properties than the remaining type of glasses.

Typical Compositions of Glass Fibers (in wt %)

Type	SiO ₂	Al ₂ O ₃	CaO	MgO	B ₂ O ₃	Na ₂ O
E-glass	54.5	14.5	17	4.5	8.5	0.5

Key Properties of E-glass:

Mechanical Properties:

Material	$E, \text{GPa } \sigma$	b, GPa	$\rho \text{ kg/m}^3$	$E/\rho \text{ MJ/kg}$	$\sigma b/\rho \text{ MJ/kg}$
E-glass	72.4	2.4 2	540	28.5	0.95

Properties that make E-glass so popular in Fiber glass include:

- Low cost
- High Production
- High Strength and stiffness
- Non-flammable
- Resistant to heat
- Good chemical corrosion
- Good electrical insulation

Applications:

- Aircraft doors, skins
- Wing bracket fairings
- Hulls
- Boats
- Bridge

II. FABRICATION PROCESS

The fabrication of sandwich panel is made by using two materials i.e. glass fiber and aluminium in a standard specimen form.(as per Indian Standards)

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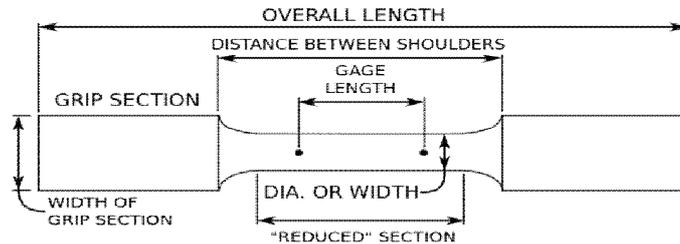
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Standard Specimen:

A standard specimen is prepared in a round or a square section along the gauge length, depending on the standard used. Both ends of the specimens should have sufficient length and a surface condition such that they are firmly gripped during testing. Different standard sizes are considered for different tests.

The standards are considered either as per ISO or ASTM.



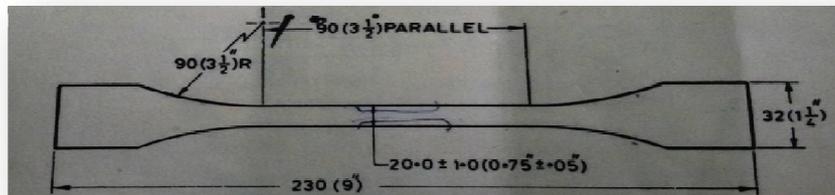
Gauge length:

Gauge length is the original length of the sample of which extension calculations are made. Normally less than the full specimen length and is user defined. The gauge length is sometimes taken as the distance between the grips.

Standard Tensile test Specimen:

A tensile specimen is a standardized sample cross-section. It has two shoulders and a gage section in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in the area.

For our requirement we are considering a flat grip specimen for tensile specimen.



Standard Dimensions:

- As per ISO standards.

Fabrication of specimen:

For fabricating the sandwich panel we need to lay up the aluminium with glass fiber.

The things required for the fabrication are:

- Aluminium
- Glass fiber i.e. of forms
 - i. Glass
 - ii. Roven
 - iii. UD (uni directional)
 - iv. CSM (Chopped Strand Mat)
- Resin-Epoxy-LY556=L12
- Hardner-HY951

Aluminium:

Aluminium 6063 t6 is used as the skin panels of the specimen. Its layed-up by with glass fiber by using resin

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- ii. Cutting the material according to required dimensions
- iii. Mixing up the resin and hardener
- iv. Laying up the layers
- v. Curing
- vi. Marking and Cutting the specimen

Finally, after removing the excess material the final standard specimen is obtained.



Standard tensile test specimen



Cross Breaking specimen

Testing of specimen:

- ❖ Testing reveals the properties of a material when force is applied dynamically or statically.
- ❖ Testing shows whether the material suitable for its application by measuring properties such as elasticity, tensile strength etc.,
- ❖ Composite specimen is tested in three methods to achieve the result, They are;
 - Tensile Test
 - Cross Breaking Test
 - Shear Test

Tensile Test:

- ❖ Tensile testing, also known as tension testing.
- ❖ The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces.
- ❖ The machine must have the proper capabilities for the test specimen being tested. There are four main parameters: force capacity, speed, precision and accuracy.
- ❖ A tensile specimen is a standardized sample cross-section. It has two shoulders and a gage (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area.

Testing Process

- ❖ Place the specimen on the
- ❖ A graph has been plotted simultaneously when the loads are being applied.



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- ❖ The main components of Tensile machine are;
 - Load Frame
 - Load Cell
 - Cross Head
 - Output Device
 - Test Fixtures.



- ❖ The main components of cross breaking test are;
 - Load Frame
 - Load Cell
 - Cross Head
 - Output Device
 - Test Fixtures.

III. RESULTS AND DISCUSSIONS:

The tests performed on the panel are: Tensile, cross-breaking and shear. We will discuss the results of those tests.

Tensile Test:

Equipment Required: Universal testing machine

Orientation Used: 90 deg

To perform the tensile test of the specimen we require the basic input data:

Input Data:

Specimen Type : Flat
Specimen Width : 21.07 mm
Specimen Thickness : 10.8 mm
C/S Area : 227.556 mm³

The result obtained for

Tensile Testing:	Al 6063 t6	fabricated panel
Ultimate Tensile load -	241Mpa	245.2MPa

From this we observe that the tensile strength of sandwich is more compare to that of aluminium. The strength of the fiber reinforced material has improved by combining the glass fiber and aluminium material compared to the original aluminium material.

Cross-Breaking test:

Equipment Required: Universal testing machine

Orientation Used: 90 deg

Input Data:

Width, mm : 16.83
Thickness, mm : 10.21
Area, mm² :171.83

Cross Breaking:	Al 6063 t6	Fabricated panel
Cross -Breaking strength-	434MPa	179.1MPa

The cross breaking strength of the panel is less than compared to the aluminium. This is because of the lamination and orientation of panel. In this test we find out the fracture or the bending strength of the material. By changing the laminating process or by changing the layers in the panel may obtain a better result compared to the present.

Shear test:

Equipment Required: Universal testing machine

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Orientation Used: 90 deg

Input Data:

Width, mm : 7.84

Thickness, mm : 3.9

Area, mm² : 30.105

Shear Test:	Al 6063 t6	Fabricated panel
Shear Strength -	152MPa	108.95MPa

Shear strength of the panel is less compared to the aluminium. Shear is deformation of material in which parallel internal surface slide past one another. As, the shear deals especially with the internal surfaces orientation of the panel have a vital role. If we take different orientation for the layup of the panel, that withstands different strength and have different properties. If we consider a layer at 45 deg, that produces different strength. Depending on the requirement we need consider different orientations as 0deg, 45deg, etc to have a better shear strength.

IV. CONCLUSION

Finally, we conclude that the strength of the fiber reinforced material has improved by combining the glass fiber and aluminum material compared to the original aluminum material. The use of FRP materials improves with development of additional design standards and increased demand in the field applications, FRP will continue to grow in popularity as a retrofit material.

REFERENCES

- [1] Hogg, P. J., Multiaxial non-crimp fabrics: the future of composite reinforcement? Mater. Technol., 1993,8, 51-56.
- [2] Tjong SC, Meng YZ. Properties and morphology of polyamide 6 hybrid composites containing potassium titanate whisker and liquid crystalline copolyester. Polymer 1999;40:1109-17.
- [3] Tjong SC, Meng YZ. Microstructural and mechanical characteristics of compatibilized polypropylene hybrid composites containing potassium titanate whisker and liquid crystalline copolyester. Polymer 1999;40:7275-83.
- [4] Shumsky VF, Getmanchuk IP, Lipatov YS. Effect of a filler on the rheological and mechanical properties of the liquid crystalline polyester-poly(methyl methacrylate) blends. JAppl Polym Sci 2000;76:993-9.
- [5] Lee MW, Hu X. Development and structure-property characterization of LCP/PP/SiO₂ in-situ hybrid composites. Polym Mat Sci Eng 2001;84:982-3.
- [6] Lee MW, Hu X, Yue CY, Li L, Tam KC. Effect of fillers on the structure and mechanical properties of LCP/PP/SiO₂ in-situ hybrid nanocomposites. Comp Sci Tech 2003;63:339-46.
- [7] Kulichikhin VF, Parsamyan IL, Lipatov YS, Shumsky VF, Getmanchuk IP, Babich VF, Postema AR. Rheological, mechanical, and adhesive properties of thermoplastic-LCP blends filled by glass fibers. Polym Eng Sci 1997;37:1314-21.
- [8] Kitano T, Haghani E, Tanegashima T, Saha P. Mechanical properties of glass fiber/organic fiber mixed-mat reinforced thermoplastic composites. Polym Comp 2000;21:493-505.
- [9] Hashmi SAR, Kitano T, Chand N. Dynamic mechanical behavior of LCP fiber/glass fiber-reinforced LLDPE composites. Polym Comp 2001;22:213-20.