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Synthesis and Characterization of Woven Roving Glass Mat for Epoxy Composites, Structural Composites

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Abstract: In current years composites have concerned considerable importance as a potential operational materials by replacing the traditional materials, because of their superior properties such as high tensile strength, low thermal expansion, high strength to weight ratio ,low cost, light weights, high specific modulus, renewability and biodegradability. they consists of mainly matrix and fiber. In this work, woven roving mats (e-glass fiber orientation (-45^0/45^0, 0^0/90^0, - 45^0/45^0),ud450gsm)were cut in measured dimensions and a mixture of epoxy resin (epofine-556, density-1.15gm/cm3), hardener (fine hard^{tm} 951, density- 0.94 gm/cm3) and acetone [(ch3)2co, m= 38.08g/mol] was used to manufacture the glass fiber reinforced epoxy composite by hand lay-up method. mechanical properties such as tensile strength, sem analysis, hardness test, density tests are evaluated.

I. INTRODUCTION

Mankind has been aware of composites materials since several hundred years before Christ and has been applied innovations to improve the quality of life. Composites are a combination of two or more materials yielding properties superior to those of the individual ingredients. One material is in the form of a particulate or fiber, called the reinforcement or discrete phase. The other is a formable solid, called the matrix or continuous phase. The region where the reinforcement and matrix meet is called the interface. Contemporary composites resulting from research and innovation from the past few decades have progressed from glass fiber for automobile bodies to particulate composites for aerospace and a range of other applications. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche (hollow in a wall or statues) applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. Composites that form heterogeneous structures which meet the requirements of specific design and function with desired properties limit the scope for classification. Over, this lapse is made up for, by the fact that new types of composites are being innovated all the time, each with their own specific purpose like flake, particulate and laminar composites. Composite materials (or composites for short) are engineering materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. Composite properties are determined by chemical and mechanical interaction of the combined materials. This work focus on a class of composites called Fiber Reinforced Polymer (FRP) that combine fibers of glass or other materials (the reinforcement) with thermo set and/or thermoplastic resins (the matrix). A typical composite material is a system of materials composing of two or more materials (mixed and bonded) on a macroscopic scale. For example, concrete is made up of cement, sand, stones, and water. If the composition occurs on a microscopic scale (molecular level), the new material is then called an alloy for metals or a polymer for plastics. Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals or ceramics). The matrix holds the reinforcement to form the desired shape; while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material possesses. Fiber glass reinforced plastic, commonly known as fiber glass, was developed commercially after World War II. Since that time, the use of fiber glass has grown rapidly. The term 'fiber glasses, can be described as a thermo set plastic resin that is reinforced with glass fibers. In this manual, the more general terms Fiber Reinforced Polymer/Composites or FRP/Composites will be used to describe these extremely useful material systems.

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A Composite Material consists of two phases:

A. Matrix phase
B. Reinforcement

Matrix phase The primary phase having a continuous character is called matrix. Matrix is usually more ductile and less hard. It consists of any of three basic material types polymers, ceramics or metals. The matrix forms the bulk part. Reinforcement The secondary phase is embedded in the matrix in a discontinuous form. The dispersed phase is usually harder and stronger than the continuous phase and is called reinforcement. It serves to strengthen the composites and improves the overall mechanical properties of the matrix. Much of the strength of FRP/Composites is due to the type, amount and arrangement of the fiber reinforcement. While over 90% of the reinforcements in use are glass fibers, other reinforcements have established a critical niche. E-glass is the most commonly used fiber reinforcement. It is strong, has good heat resistance, and high electrical properties. For more critical needs, S-Glass offers higher heat resistance and about one-third higher tensile strength (at a higher cost) than that of E-glass. Carbon Fibers (graphite) are available in a wide range of properties and costs. These fibers combine light weight with very high strength and modulus of elasticity. The modulus of elasticity is a measure of the stiffness or rigidity in a material. For high stiffness applications these reinforcements are hard to beat, with a modulus of elasticity that can equal steel. FRP/ Composites with carbon fiber reinforcement also have excellent fatigue properties. The primary use of carbon fibers is in aircraft and aerospace, in which weight savings are a major objective. While its cost limits carbon's use in commercial applications, it is used extensively where material content is low, such as sporting equipment. Aramid or aromatic polyamide fibers (Kevlar or Twaron) provide high strength and low density (40% lower than glass) as well as high modulus. These fibers can be incorporated in many polymers and are extensively used in high impact applications, including ballistic resistance. Natural Fibers such as Sisal, Hemp and Flax have been used for many applications with low strength requirements. They are limited to applications not requiring resistance to moisture or high humidity. Arrangement of the glass fibers -how the individual strands are positioned -determines both direction and level of strength achieved in a moulded FRP/Composite. The three basic arrangements of glass fiber reinforcement are unidirectional, bidirectional and multidirectional. Unidirectional arrangements provide the greatest strength in the direction of the fibers. Unidirectional fibers can be continuous or intermittent, depending on specific needs determined by part shape and process used. This arrangement permits very high reinforcement loading for maximum strengths. The fibers in a bidirectional arrangement are in two directions – usually at 900 to each other, thus providing the highest strength in those directions. The same number of fibers need not necessarily be used in both directions. High fiber loading can be obtained in woven bidirectional reinforcements. Multidirectional or random arrangements provide essentially equal strength in all directions of the finished part.

Reinforcements are supplied in several basic forms to provide flexibility in cost, strength, compatibility with the resin system, and process requirements. Regardless of the final form, all fiber reinforcements originate as single filaments. A large number of filaments are formed simultaneously and gathered into a strand. A surface treatment is then applied to facilitate subsequent processing, maintain fiber integrity, and provide compatibility with specific resin systems. After this treatment, the strands are further processed into various forms of reinforcements for use in moulding FRP/Composites. Continuous strand roving this basic form of reinforcement is supplied as untwisted strands wound into a cylindrical package for further processing. Continuous roving is typically chopped for spray-up, sheet moulding compounds. In the continuous form, it is used in pultrusion and filament-winding processes. Woven roving Woven from continuous roving, this is a heavy, droppable fabric available in various widths, thicknesses and weights. Woven roving costs less than conventional woven fabric and is used to provide high strength in large structural components such as tanks and boat hulls. Woven roving is used primarily in hand lay-up processing. Woven fabrics made from fiber yarns, woven fabrics are of a finer texture than woven roving. They are available in a broad range of sizes and in weights. Various strength orientations are also available. Reinforcing mat Made from either continuous strands laid down in a swirl pattern or from chopped strands, reinforcing mat is held together with a resinous binder or mechanically stitched. These mats are used for medium strength FRP/Composites. Combination mat, consisting of woven roving and chopped strand mat bonded together, is used to save time in hand lay-up operations. Hybrid mats of glass and carbon and aramid fibers are also available for higher strength reinforced products. Surfacing mat Surfacing mat or veil is a thin fiber mat made of monofilament and is not considered a reinforcing material. Rather, its purpose is to provide a good surface finish because of its effectiveness in blocking out the fiber pattern of the underlying mat or fabric. Surfacing mat is also used on the inside layer of corrosion-resistant FRP/Composite products to produce a smooth, resin-rich surface. Chopped fibers Chopped strands or fibers are available in lengths from 1/8" to 2"for blending with resins and additives to prepare moulding compounds for compression or injection moulding and other processes. Various surface treatments

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are applied to ensure optimum compatibility with different resin systems. The matrix or resin is the other major component of an FRP/Composite. Resin systems are selected for their chemical, electrical and thermal properties. The two major classes of resins are thermo set and thermoplastics. Thermo set resins thermosetting polymers are usually liquid or low melting point solids that can easily combine with fibers or fillers prior to curing. Thermo set feature cross-linked polymer chains that become solid during a chemical reaction or “cure” with the application of a catalyst and heat. The high level of cross-linking provides for reduced creep compared to thermoplastics. The thermo set reaction is essentially irreversible. Among the thermo set resins for FRP/Composites, the family of unsaturated polyesters is by far the most widely used. These resins are suitable for practically every moulding process available for thermo set. Polyesters offer ease of handling, low cost, dimensional stability, and a balance of good mechanical, chemical, and electrical properties. They can be formulated for high resistance to acids, weak alkalis and organic solvents. They are not recommended for use with strong alkalis. Other formulations are designed for low or high temperature processing, for room temperature or high-temperature cure, or for flexible or rigid end products. Vinyl esters provide excellent resistance to water, organic solvents and alkalis, but less resistance to acids than polyesters. Vinyl esters are stronger than polyesters and more resilient than epoxies. Moulding conditions for Vinyl esters are similar to those for polyesters. Epoxies are another family of thermo set resins used in FRP/ Composites. They have excellent adhesion properties and are suited for service at higher temperatures – some as high as 500o F. Epoxy-matrix FRP/Composites are processed by any of the thermo set methods. Epoxies are more expensive than polyesters, and cure times are longer, but their extended range of properties can make them the cost/performance choice for critical applications. Epoxy/fiber structures have generally higher fatigue properties than polyesters. Polyurethanes are a family of resins that offer very high toughness, high elongation, faster cure times and good coupling to a variety of reinforcements. Polyurethanes are easily foamed in a controlled process to produce a wide range of densities. Additives are easily incorporated into resin systems to provide pigmentation, flame retardance, weather resistance, superior surface finish, low shrinkage and other desirable properties. Gel coats consisting of a special resin formulation provide an extremely smooth next-to-mould surface finish on FRP/Composites. They are commonly applied in hand lay-up and spray-up processes to produce a tough, resilient, weather-resistant surface. Gel coats, which may be pigmented, are sprayed onto the mould before the reinforcement and resin are introduced. Other thermosetting resin systems, generally formulated with chopped strand or milled fiber reinforcement for compression or transfer moulding are: Phenolics: Good acid resistance, good fire/smoke, and thermal properties. Silicones: Highest heat resistance, low water absorption, excellent dielectric properties. Melamine’s: Good heat resistance, high impact strength. Diallyl phthalates: Good electrical insulation, low water absorption. Thermoplastic resins Thermoplastic polymers can soften and become viscous liquids when heated for processing and then become solid when cooled. The process is reversible allowing a reasonable level of process waste and recycled material to be reused without significant effect on the end product. Thermoplastic resins allow for faster moulding cycle times because there is no 17 chemical reactions in the curing process. Parts may be formed as fast as heat can be transferred into and out of the moulding compound. Polypropylene and polyethylene are the most common thermoplastic resins used in FRP/Composites. They have excellent resistance to acids and alkalis and have good resistance to organic solvents. Their relatively low melting points allow for rapid processing at lower cost. Nylon and Acetyl are highly resistant to organic solvents and may also be used where increased mechanical properties are required

II. EXPERIMENTAL PROCEDURE

A. Hand lay-up

Hand lay-up is carried out by manually applying loose plies onto a mould, and then wetting them with a roller or brush. This is a labour-intensive process, requiring measures to prevent the plies from shifting**.**

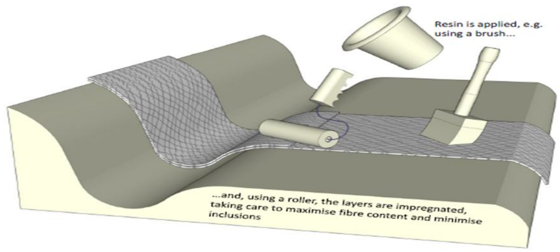

Fig.1.Hand lay-up

It is a cost-effective process since it requires only simple tools and a small number of consumables.

B. Specimen Specifications

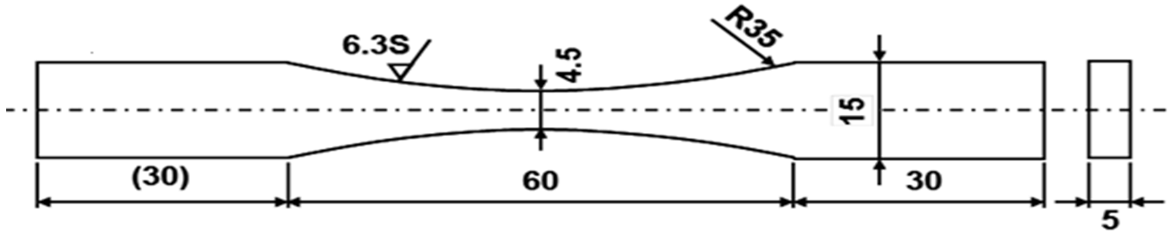

Fig.2.Dimensions of smooth Plate test specimen

C. Materials Used

Fig.3

Fig.4

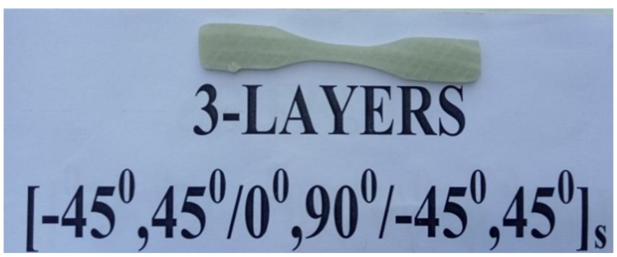

Fig.5

Fig.6

1) *Principle Involved:* The addition of glass Fiber mat in epoxy composite, mechanical properties gets enhanced to some extent when compared with the only epoxy. After a certain amount of addition of glass fiber mat these properties do not get enhanced and in some cases on further addition of fillers the properties get decreased.

Chemical ingredients used:

a) Epoxy Resin (EPOFIN-556)
b) Hardener (HY-951)
c) Silicon Spray
d) Glass Woven Roving Mats
e) Dilute HCl for cleaning of waste glass beaker

2) *Apparatus Used*

a) Weighing machine
b) Wooden board
c) Transparent plastic Sheet
d) Plastic glass (Use and throw)
e) Wooden bit
f) Cleaning brush
g) Hammer
h) Hack saw
i) File
j) Amery papers for polishing
k) UTM

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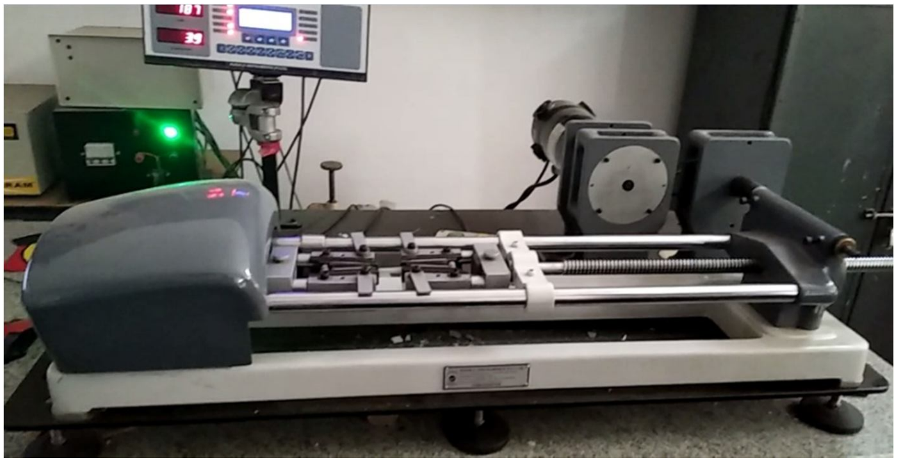

Fig.7

Specimen preparation woven roving mats of glass fibres[-45^0/45^0],unidirectional glass fiber mats are reinforced in epoxy resin to prepare the composite. The composite slabs with fiber mat orientation [-45^0/45^0,0^0/90^0,-45^0/45^0] are made by conventional hand-lay-up technique. The low temperature curing epoxy resin (EPOFIN 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Epoxy EPOFIN 556 resin is chemically belonging to the 'epoxide' family. The epoxy resin and the hardener are supplied by fine finish organics pvt. Ltd. Composites of three different compositions (0 wt%, 10 wt% and 20 wt% alumina filling) are made and the fiber loading (weight fraction of glass fiber in the composite) is kept at 50% for all the samples. The castings are put under load for about 24 hours for proper curing at room temperature. The mix is stirred manually to disperse the fibres in the matrix. The cast of each composite is cured under a load of about 50 kg for 24 hours before it removed from the mould. Then this cast is post cured in the air for another 24hours after removing out of the mould. Specimens of suitable dimension are cut using a CNC milling machine for mechanical testing. APPLICATIONEPOFINE® – 556 / FINEHARD™ - 951
EPOFINE® – 556 / FINEHARD™ - 951 system is recommended for room temperature or low bake composite manufacture. This system when required for casting or encapsulating applications, it can be used along with dried fillers such as silica, talc,
dolomite, mica etc. The fillers are dried at 150 – 200oC for 3 – 4 hours and then cooled to 40 – 50oC in dry atmosphere. Typically, 1Kg of silica filler can be mixed with 1 Kg of Epofine – 556. The mould used for casting should be coated with Fine release – QZ13. After mixing resin and hardener, it must be used within 30 minutes. Larger quantities will have lesser pot life. 100g of Epofine – 556 and 12g of Fine hard – 951 can produce exothermic of over 200°C.

3) Special Features

The following advantages make it ideal for industrial use.

Simple mixing ratio (Resin: Hardener = 100: 10 - 12 by weight)

a) Tolerant mixing ratio (± 2 %).
b) Medium viscosity resin/hardener mix.
c) Typical mix viscosity is about 1,500 mPas at 25°C
d) Excellent water resistance.
e) Very Good chemical resistance and electrical insulation

III. PROPERTIES

Table.1 Characteristics EPOFINE® – 556

Characteristic	Test Method	Unit	Specification
Viscosity at 25^{o}C	ASTM-D 2196	mPas	9,000 – 12,000
Epoxy Content	ASTM-D 1652	g/eq	180 - 190
Density at 25^{o}C	ASTM-D 4052	g/cc	1.15 - 1.20
Flash Point	ASTM-D 93	°C	> 200
Storage life		Years	3

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Table.2 Mechanical and Physical Properties
(Determined on standard test specimens at 27°C)

Property	Test Method	Unit	Value
Tensile strength	ASTM:D638	N/mm^2	70 – 80
Elongation at break	ASTM:D638	%	2.0 – 2.2
Flexural strength	ASTM:D790	N/mm^2	90 – 100
Glass transition temperature (DSC)	IEC 1006	°C	70 – 80

Table.3 Electrical Properties

Property	Test Method	Unit	Value
Dielectric strength	IEC 60243-1	KV/mm	23 – 25
Dielectric dissipation factor	ISO 178	%	1.2 – 1.3
Dielectric Constant	IEC 60250		4 – 4.2
Volume Resistivity	IEC 60093	Ohm cm	> 10^{15}

Storage, Handling And Disposal

Storage : Store in a cool, dry place.

Shelf life : As given above, when stored in original sealed Containers at 2 - 40°C.

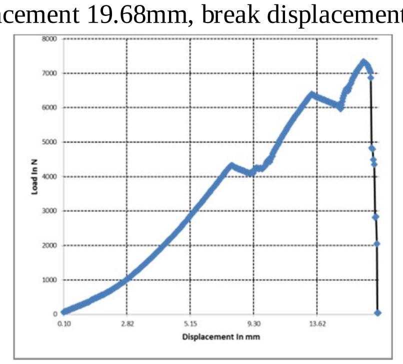
Handling : Use hand gloves and protective glasses.

Disposal : Dispose by incineration or as per local regulations.

IV. RESULTS

A. *Mechanical Testing*

After fabrication the test specimens were subjected to mechanical test as per ASTM standards. The tensile test of composite was carried out using KIPL-PC2000. The tensile test is generally performed on flat specimens. A uniaxial load is applied through both the ends. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. In the present study, the test was conducted on KIPL-PC200 machine using flat composite with rectangular section with the combination of 3 layers, by using woven roving mats with different orientations like unidirectional and $-45^0/45^0$ used. Its layer orientation is[-45^0/-45^0,$0^0/90^0$,-$45^0/45^0$]. The specimen area is 42.8 mm2 pre-set values are high limit as 20020N,low limit as 0.1N.mode of test is breaking of specimen, test speed is 10mm/min, displacement increment is 0.01mm and proof stress is fixed to 0.2%.after conducting the test we got peak load as 7335.6N and peak displacement as 19.16mm, peak displacement percentage 85,break load is 2049.7N, break displacement 19.68mm, break displacement 88.the test results are given below.



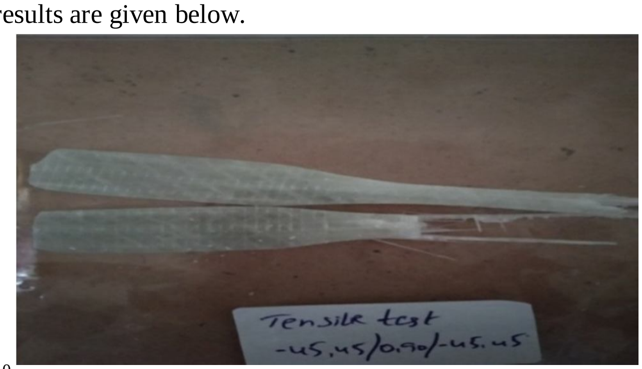


Fig. 8. [-$45^0/45^0$, $0^0/90^0$,-$45^0/45^0$] composite load Vs displacement plot

B. *SEM Analysis*

1) *X-Ray Diffraction (XRD) of Glass Fiber:* As we know the glass is an amorphous material, so the XRD analysis showed the broad peak as compared to the crystalline material having sharp peak. The reason of the coming broad peak is that the atoms of the glass powder have short range order and the atoms are randomly oriented. The XRD peak has been given below.

C. *Hardness Test:* Micro-hardness Leitz micro-hardness tester was used to measure the micro-hardness of composite specimens. Figure 3.3 shows the experimental set up for the micro-hardness test. A diamond intender with an apical angle of 136° was intended over the surface of the specimen under a load of 2.94 N.

After the removal of load the two diagonals D1 and D2 of the indentation were measured. The Hardness value was calculated using the below Equation.

$H\ v=0.1889F/L^2$

$L= (D_1 +D_2)/2$

1) 29.91HV,2) 30.33HV,3) 30.63HV, Average: 30.29HV

To convert HV to MPa multiply by 9.807. =297.1MPa=0.2971GPa

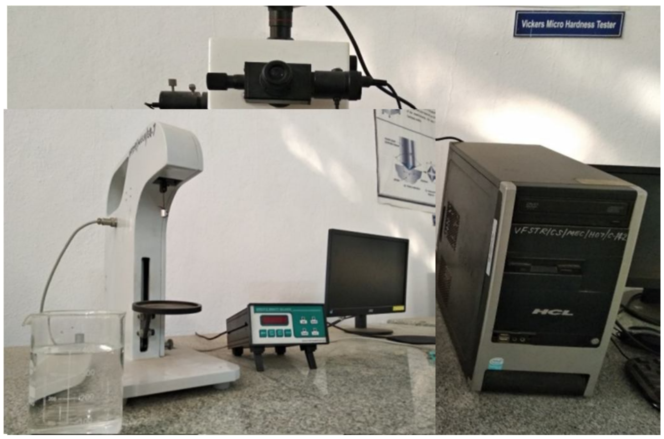


Fig.9. Fig.10. Experimental set up for density test

D. *Density Measurement of Glass fiber by Psychometry*

The density of the glass fiber was found to be

Specific gravity in air = 1.6582Specific gravity in water =1

V. CONCLUSIONS

This experimental investigation on epoxy composites filled with woven roving composite mat has led to the following specific conclusions:

A. The polymer matrix composite based on the woven roving glass mat with epoxy resin and hardener [$-45^0/45^0, 0^0/90^0, -45^0/45^0$]. With three layers were successfully prepared by using hand lay-up technique and cured process under room temperature.

B. After making laminated plate, we have cut the laminates into Standard Test specimen using ASTM (American society of Testing Materials) table. Totally twenty eight test specimens are drawn from that Glass fiber laminate, After that test specimens are tested in the Universal Testing Machine (UTM), Each test specimen tested separately, and found out Ultimate tensile load of specimen each Specimen

C. Binder content is also increasing with increment of fiber reinforcement, which ultimately increasing the porosity or decreasing the bulk density.

D. Micro hardness also exhibits the similar character as that of tensile and strength. It increases with fiber loading and surface treatment. Maximum hardness obtained on 15%fiber loaded treated composite.

E. In all above cases the SEM observations agree well with the mechanical properties

F. Impact Strength, Flexural Strength, hardness value were decreased with the increase in the content of the reinforcement (i.e., glass fiber).

G. Glass fiber was found to be effective reinforcement in case of application involving tensile load.

H. GF was an effective reinforcement for EPOFINE 556. The mechanical properties of EPOFINE 556 were enhanced by the addition of GF which bore the main load between the contact surfaces and protected the matrix from further serve abrasion of the counterpart. The wear performance of GF-reinforced GF/EPOFINE 556 composite was mainly governed by the process of matrix removal, fiber thinning, interfacial deboning and detachment of broken fibers from the EPOFINE556 matrix.

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