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Influence of Angle Ply Orientation of Stacking On Mechanical Properties of Glass-Polyester Composite Laminate

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Abstract- ***This work investigates that the influences of angle ply orientation of stacking on mechanical properties of a E-glass general polyester and Isophthalic polyester composite laminate experimentally and comparing with the results with laminated software. He laminated software is developed based on laminate theory. Laminated Composite materials have characteristics of high modulus/weight and strength/weight ratios [1], excellent fatigue properties, and non-corroding behaviour. These advantages encourage the extensive application of composite materials, for example, in wind turbine blades, boat hulls, automobiles, water tanks, roofing, pipes and cladding, and aerospace. The understanding of the mechanical behaviour of composite materials is essential for their design and application. Although composite materials are often heterogeneous, they are presumed homogeneous from the viewpoint of macro mechanics and only the averaged apparent mechanical properties are considered. The most common method to determine these constants is static testing. In this work ten types of composite laminate specimens with different stacking sequences, i.e., (±0^0, ±10^0, ±30^0, ±40^0, ±45^0, ±55^0, ±65^0, ± 75^0, and ±90^0) are fabricated.***

In this work, the specimens are prepared in the laboratory using compression mould technique E- glass as fiber & with Polyester resin as an adhesive. The specimens are prepared for testing as per ASTM standards to estimate the tensile modulus

Index Term *: compression moulding, Degree of orientation, E-glass, General purpose polyester, Isophthalic polyester, MEKP, stacking sequence, tensile property,*

I. INTRODUCTION

The laminated composite materials usage is increasing in all sorts of engineering applications due to high specific strength and stiffness. Fiber reinforced composite materials are selected for weight critical applications and these materials have good rating as per the fatigue failure is concerned. Present work is aimed to analyze the mechanical behavior of a each laminate under tensile condition. Therefore here different types of composite laminates are selected for test specimens. The present project work mainly is focusing on development of manufacturing process and establishing critical test procedures for the polymer reinforced composite materials to be used in certain engineering applications.

A.FIBER:

Glass fiber also called fiberglass. It is material made from extremely fine fibers of glass Fiberglass is a lightweight, extremely strong, and robust material. Although strength properties are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes. Glass is the oldest, and most familiar, performance fiber. Fibers have been manufactured from glass since the 1930s.

Types of Glass Fiber:

As to the raw material glass used to make glass fibres or nonwovens of glass fibres, the following classification is known:

1. A-glass : With regard to its composition, it is close to window glass. In the Federal Republic of Germany it is mainly used in the manufacture [2] of process equipment.
2. C-glass: This kind of glass shows better resistance to chemical impact.
3. E-glass: This kind of glass combines the characteristics of C-glass with very good insulation to electricity.
4. AE-glass

Alkali resistant glass. Generally, glass consists of quartz sand, soda, sodium sulphate, potash, feldspar and a number of refining and dying additives. The characteristics, with them the classification of the glass fibers' to be made, are defined by the combination of raw materials and their proportions. Textile glass fibres mostly show a circular

B.PROPERTIES OF GLASS FIBER:

Glass fibers are useful because of their high ratio of surface area to weight. However, the increased surface area makes them much more susceptible to chemical attack. By trapping air within them, blocks of glass fiber make good thermal insulation, with a thermal conductivity of the order of 0.05 W/ (mK).

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The strength of glass is usually tested and reported for "virgin" or pristine fibers those which have just been manufactured. The freshest, thinnest fibers are the strongest because the thinner fibers are more ductile. The more the surface is scratched, the less the resulting tenacity. Because glass has an amorphous structure, its properties[3] are the same along the fiber and across the fiber. Humidity is an important factor in the tensile strength. Moisture is easily adsorbed, and can worsen microscopic cracks and surface defects.

C. RESINS:

UNSATURATED POLYESTER (UPE) RESIN is used for a wide variety of industrial and consumer applications. This consumption can be split into two major categories of applications: reinforced and non reinforced. In reinforced applications, resin and reinforcement, such as fiberglass, are used together to produce a composite with improved physical properties. Typical reinforced applications are boats, cars, shower stalls, building panels, and corrosion resistant tanks and pipes. Non fiber reinforced applications generally have a mineral “filler” incorporated into the composite for property modification.

Some typical non fiber reinforced applications are sinks, bowling balls, and coatings. Polyester resin composites are cost effective because they require minimal setup costs and the physical properties can be tailored to specific applications. Another advantage of the polyester resin composites is that they can be cured in a variety of ways without altering the physical properties of the finished part. Consequently polyester resin composites compete favorably in custom markets.

D. GENERAL PURPOSE RESIN:

General-purpose resins are a group of resins generally used because of their low cost. While processing parameters can affect this, the cost of the raw materials tends to limit the type of unsaturated polyesters selected. The resins used in this area are commonly referred to as PET, DCPD, and ortho resins. While PET (polyethylene terephthalic) resin and orthophthalic anhydride and sources of low-cost saturated acids, DCPD (dicyclopentadiene) is typically coupled with maleic anhydride during an initial step, prior to both the isomerization and the condensation polymerization. Dicyclopentadiene improves the solubility of the polyester resin in styrene. As one drives towards the lower cost resins, solubility in styrene is a serious concern. Dicyclopentadiene offers a low cost solution. Due to government regulations aimed at minimizing styrene emissions in open molding, a subset of general purpose resins, “low-styrene” resins, has been developed.

These resins tend to have a higher dependency on DCPD and are cooked to a lower molecular Weight. This allows less styrene to be used to achieve the desired viscosity, and performance generally suffers. It readily impregnates[5] fibrous reinforcing materials such as glass, cloth or mat. It is suitable for the manufacture of general purpose mouldings such as machine guards, machine covers, furniture items, canopy etc. The resin is also used for potting and encapsulation, in decorative applications.

Typical Properties of the Liquid Resin:

Appearance : Clear, colourless to pale yellow

Specific gravity : 1.12

E.ISOPHTHALIC RESIN:

It is a medium viscosity polyester resin based on isophthalic acid. It exhibits good mechanical and electrical properties together with a good chemical resistance compared to general purpose resins It rapidly wets the surface of glass fibre in the form of cloth, mat or chopped fibre to produce laminates [4] and mouldings. Its superior chemical resistance towards most mineral chemical process equipment, storage tanks, tankers, ductings, hoods etc. for handling chemicals at ambient temperature**.**

Typical Properties of the Liquid Resin:

Appearance : Clear, colourless to pale yellow

Specific gravity : 1.11

II. PREPARATION OF COMPOSITE LAMINATE BY COMPRESSION MOULDING TECHNIQUE:

Glass fiber material consisting of extremely thin fibers about 0.005–0.010 mm in diameter. The Uni directional fibers are available in the standard form 600 GSM. Uni Directional fibers are cut to the required size & shape. These are stacked layer by layer of about 4 layers to attain the thickness of 5 mm as per the ASTM D 3039 Standard Specimen. Bonding agent (Polyester) is applied to create bonding between 4 layers of sheet. Polyester is a copolymer; that is, it is formed from two different chemicals. These are referred to as the "resin" and the hardener". The resin consists of monomers or short chain polymers. The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds; the process can take minutes to hours.

In this work the composite laminate is prepared using compression moulding technique. Here Four plies of E-glass fiber are taken in a symmetric manner i.e. ($+90^0$, -90^0, -90^0, + 90^0) one over the other and Polyester resin is used as an adhesive. The size of the mould taken is 30 × 30 cm.

1. Type of resin	:	Polyester
2. No of Laminates	:	4
3. Type of Fiber	:	Uri Directional (UD)
4. Hardener	:	MEKP
5. Nature of Laminate	:	Symmetric type (Ex. $+90^0$, - 90^0, -90^0, $+90^0$)
6. Method of preparation:		Compression mould Technique

Initially the glass fiber is to be cut in required shape of the size 30 × 30 cms of required orientation. Two plies of positive orientation (anti-clockwise) and other two in negative orientation (clockwise) are to be prepared. A thin plastic sheet is used at the top and bottom of the mould in order get good surface finish for the laminate. The mould has to be cleaned well after that PVA (Poly Vinyl Acetate) is applied in order to avoid sticking of the laminate to the mould after curing of the laminate.

Then a ply of positive orientation is taken is placed over the sheet. Sufficient amount of resin which is prepared beforehand (hardener of quantity 10% of the resin is to be mixed with the resin and get stirred well) is poured over the ply.

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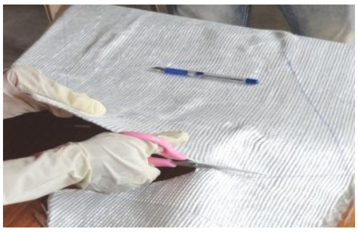
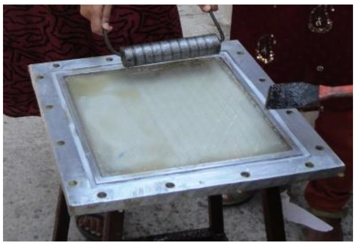
The resin poured in to the mould uniformly and it is rolled in order to get the required bonding using a rolling device. Enough care should be taken to avoid the air bubbles formed during rolling. Then on this ply, other ply of negative orientation (clock wise) is placed, after this, other two plies are placed and rolling is done.

After the rolling of all plies, the covering sheet (plastic sheet) is placed and the mould is closed with the upper plate. The compression is applied on the fiber- resin mixture by tightening the two mould plates uniformly. Enough care should be taken to provide uniform pressure on the laminate while fixing plates. After enough curing time (2-3 hrs) the laminate is removed from the mould plates carefully.





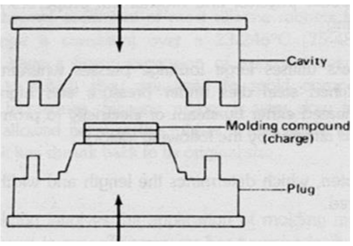


Fig 1: Various steps for preparing a composite laminate

III. PREPARATION OF SPECIMEN FOR THE TENSILE TEST:

After preparing the laminate, in order to find the ultimate tensile strength of the composite laminate conduct the tensile test with UTM, and the specimen is prepared using ASTM standards D3039 The specimen is prepared in dog-bone shape which has a gauge length of 135 mm. The specimens prepared are now tested on the UTM machine and the ultimate tensile strength of the each specimen is determined. As there is a difference in their orientation, each specimen exhibits a definite behaviour during failure

A. General purpose resin:

Fig.2 General polyester tensile test specimens

B. Isophthalic Resin:

Fig.3 Isophthalic Resin tensile test specimens

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IV.VOLUME FRACTION OF GLASS LOADING IN THE LAMINATE (BURN TEST):

Specimens of laminates with specifications (30x31x4.7mm) are cut from the laminates of all orientation sequences are prepared. The volume of the specimen[6] and weight is assessed accurately. Then the laminate test coupon is kept in the electric Furness maintained at 600^0 C to burn the matrix material. The Glass fiber residue is weighed and volume of the glass fibre is assessed from the specific gravity of glass. Calculations were made and the volume fraction of glass loading is given as fallows.

Fig.4 Specimen prepared for Burning Test

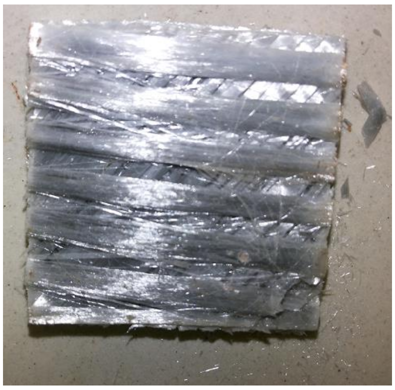

Fig.5 Specimen after Burning Test (GP)

Fig.6 Specimen after Burning Test (ISO)

Volume fraction of glass loading (V_f) = Volume of Glass fibre Volume of the specimen

Volume fraction of matrix material (V_m)	:	1- V_f
Specific weight of glass fiber	:	2.50 Kg/m^3
Specific Gravity General Polyester Resin	:	1.12
Volume of the Fiber	:	2928.76mm^3
Volume of the Resin	:	1378.24
Volume Fraction of Fiber	:	0.68
Volume Fraction of Resin	:	0.32

V. DEVELOPMENT OF SOFTWARE FOR LAMINATE DESIGN FROM CLASSICAL THEORY OF LAMINATES:

A. LAMINATES:

The need for the development of laminate design software arises to save the time in evaluating elastic properties of composite laminate. The development of software is based on classical laminate theory. The details of the laminate theory and development of the software are discussed in detail in the following sections

B .INTRODUCTION TO LAMINATE THEORY:

While working with laminated composite materials, the evaluation of the mechanical properties through theoretical approach is essential before experimenting with laminates. The mechanics of materials deal with the stresses, strains and deformations in engineering structures subjected to mechanical and thermal loads. A common assumption in the mechanics of conventional materials, such as steels and aluminum, is that they are homogeneous and isotropic continua. For a homogeneous material, properties do not depend on the location, and for an isotropic material, properties do not depend on the orientation.

Unless an severely cold worked, grains in metallic materials are randomly oriented so that, on a statistical basis, the assumption of isotropy can be justified. Fibre-reinforced composites are microscopically inhomogeneous and anisotropic (orthotropic) in nature. As a result, the mechanics of fibre reinforced composites[7] are complex than that of conventional materials. The classical theory of laminate based algorithm is developed to design a software program to estimate the mechanical properties of laminated composites with unidirectional reinforcement. Before entering into the experimental work, the following paragraphs will provide information to establish the algorithm.

C. ELASTIC PROPERTIES OF ORTHOTROPIC LAMINA:

The number of independent elastic constraints required to characterize anisotropic and orthotropic materials are 21 and 9 respectively. For an orthotropic material, the 9 independent elastic constants are E_{11}, E_{22}, E_{33}, G_{12}, G_{13}, G_{23}, υ_{12}, υ_{13} and υ_{23}.

Unidirectional oriented fibre composites are a special class of orthotropic materials. If the fibres are in the 1-2 plane, elastic properties are equal in the 2-3 directions so that $E_{22}=E_{33}$, $\upsilon_{12}=\upsilon_{13}$ and $G_{12}=G_{13}$. Thus the numbers of independent elastic constants for a unidirectional oriented fibre [9] composite are reducing to 5, namely, E_{11}, E_{22}, G_{12}, υ_{12} and υ_{23}. Such composites are often called transversely isotropic.

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Elastic properties of unidirectional continuous fibre lamina are calculated from the following equations. Longitudinal modulus referring to figures

$$E_{11}=E_fV_f+E_mV_m$$

And major Poisson's ratio:

$$\upsilon_{12}=V_f\upsilon_f+V_m\upsilon_m$$

The transverse modulus is:

$$E_{22}=(E_f/E_m)/(E_fv_m+E_mV_f)$$

And minor Poisson's ratio:

$$\upsilon_{21}=E_{22}/E_{11}\upsilon_{12}$$

Shear modulus referring to figure 3.1 and 3.2

$$G_{12}=(G_fV_m+G_mV_f)$$

The following properties are to be noted from the above equation.

- The longitudinal modulus (E_{11}) is always greater than the transverse modulus (E_{22}).
- The fibre contributes more to the development of the longitudinal modulus, and the matrix contributes more to the development of transverse modulus.
- The major Poisson's ratio (υ_{12}) is always greater than minor Poisson's ratio (υ_{12}). Since the Poisson's ratio are related by the equation only, can be considered independently.
- As in the case of (E_{22}), the matrix contributes more to the development of (G_{12}) than the fibres.
- Four independent elastic constants namely (E_{11}), (E_{22}), (υ_{12}) and (υ_{12}) are required to describe the in-plane elastic behavior of a lamina. The ratio (E_{11})/ (E_{22}) often considered a measure of orthotropic.

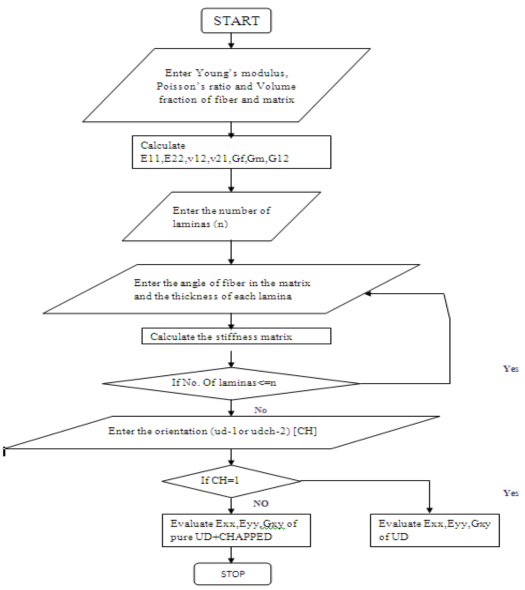

Fig.7: The flow chart of the Laminate design soft ware

Fig.8: Laminate Software

VI. TENSILE TESTING:

Mechanical characterization of composite materials is a complex scenario to deal with, either because of the infinite number of combinations of fiber and matrix that can be used, or because of the enormous variety of spatial arrangements of the fibers and their volume content. The foundation of the testing methods for the measurement of mechanical properties is the classical lamination theory [6]; this theory was developed during the nineteenth century for homogeneous isotropic materials and only later extended to accommodate features enhanced by fiber-reinforced material, such as in homogeneity, anisotropy, and elasticity. Two basic approaches are proposed to determine the mechanical properties of composite materials: constituent testing and composite sample testing The mechanical tests were carried out in an Universal testing machine. The Universal testing machine is a highly accurate instrument.

General purpose resins:

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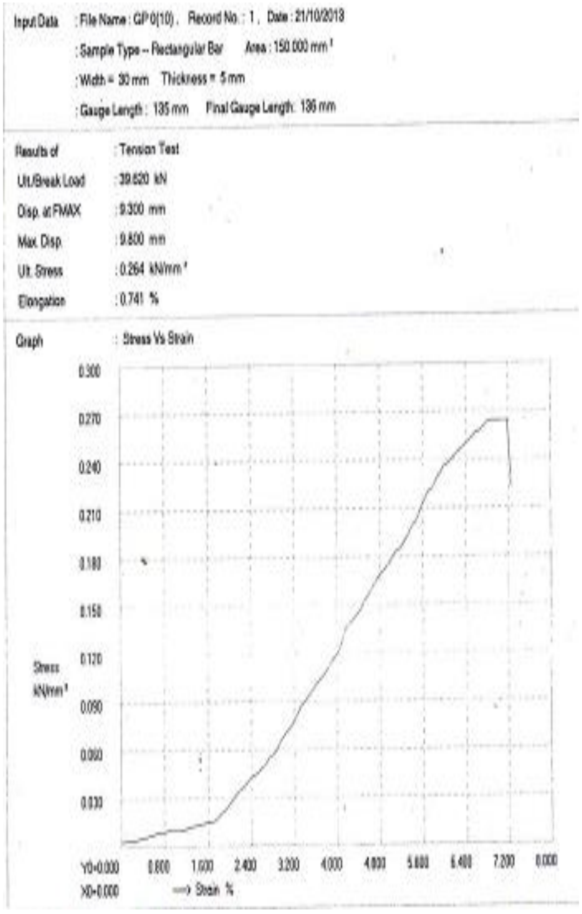

Fig.10 Graph between Stress and Strain for O^0 orientation (GP)

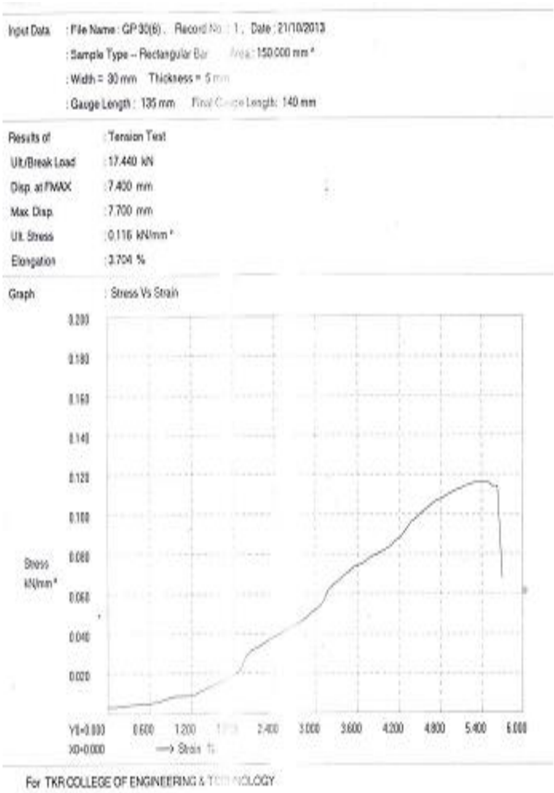

Fig.11 Graph between Stress and Strain for $3O^0$ orientation (GP)

Angle ply orientation	Tensile Modulus by Laminate software	Tensile Modulus by Tensile test
0^0	41.4154	54.11
10^0	39.351	43.54
20^0	33.132	38.234
30^0	24.722	27.5
40^0	18.285	23.54
50^0	15.259	20.02
55^0	14.66	18.98
60^0	14.343	18.2
65^0	14.24	18.12
70^0	14.25	17.86
75^0	14.29	17.42
90^0	14.35	17.2

Table :1 Comparision of Tensile Modulus with Laminate Software

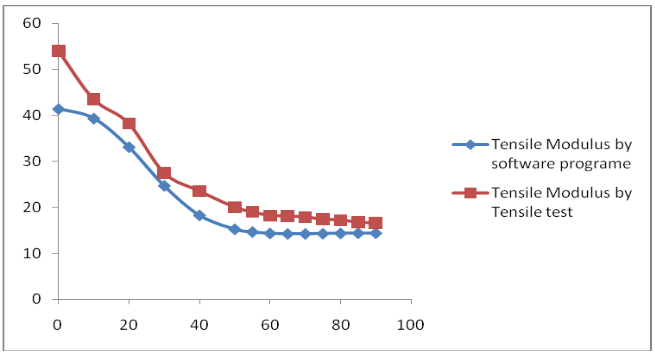

Fig.12: Comparison between Tensile modulus with Experiment and Software Programme

CONCLUSIONS:

Experiments were conducted on Uni Directional Glass fiber and Polyester resin. Laminate composite specimens with varying fiber orientation to evaluate the mechanical behavior.. The values are compared with the prepared Laminate software and the experimental results are coinciding with the software results. Hence software is used to evaluate the tensile modulus of any orientation. And the results of Isophthalic resin are same as of that General purpose resin results because of specific gravity is same. It is observed from the result that glass/Polyester with 0^0 fiber orientation Yields' high strength when compare to other degree of orientations for the same load, size & shape In addition. Hence, it is suggested that fiber orientation with 0^0 is preferred for designing of structures like which is more beneficial for sectors like, wind turbine blades, Aerospace, automotives, marine, space and boat hull etc.

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