Experimental Study of Mechanical Properties of Composite Materials

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Abstract- This paper presents an experimental study of a composite material for comparative some mechanical properties of types the E-glass. The experimental study based on manufacturing techniques by lay-up was develop to evaluate strength stress, hardness, toughness, and stress-strain characteristic for composite material. The composite manufacturing material was fiber E-glass of woven roving at [(0°)/((90°)/(±45°))]_s , [±30°/±60°]_s and chopped mat reinforced with polyester resin. All the manufacturing specimens were conducted to mechanical tests such as tensile test, Reckwell's hardness test and impact test.

Two types of fiber were used to study mechanical properties and its comparative during the tests of the specimens. Stress-strain curves were evaluated from data base computer.

It has been found that a good mechanical properties of experimental results in tests. Also, it has been found that the manufacturing techniques by lay-up apparel to describe the microstructure well.

Keywords—E-glass fiber, lay-up, quasi-isotropic laminate, composite material, delamination, fiber breakage.

I. I. INTRODUCTION

A combination of two or more materials (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a macroscale. The constituents retain their identities, that is, they do not dissolve or merge completely into one another although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another. Examples are cermets and metal-matrix composites [1].

The physical properties of composite materials are generally not isotropic in nature, but rather are typically orthotropic. For instance, the stiffness of a composite panel will often depend upon the directional orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel. For instance, the fiber reinforcement and matrix used, the method of panel build, thermosetting versus thermoplastic, type of weave, and orientation of fiber axis to the primary force.

An isotropic materials (for example, aluminium or steel), in standard wrought forms, typically have the same stiffness regardless of the directional orientation of the forces / moments. The relationship between forces/moments and strains/curvatures for an isotropic material can be described with the following material properties: young's modulus, the shear modulus and the Poisson's ratio, in relatively simple mathematical relationships. For an isotropic material, it requires the mathematics of a second order tensor and can require up to 21 material property constants. For the special case of orthogonal isotropy, there are three different material property constants for each of young's modulus, shear modulus and poisson's ratio for a total of 9 material property constants to describe the relationship between forces/moments and strains/curvatures [1].

Fiber reinforced composite materials can be divided into two main categories normally referred to as short fiber reinforced materials and continuous fiber reinforced materials. Continuous reinforced materials will often constitute a layered or laminated structure. The woven and continuous fiber styles are typically available in a variety of forms, being pre-impregnated with the given matrix (resin), dry, uni-directional tapes of various widths, plain weave, harness satins, braided, and stitched.

The short and long fibers are typically employed in compression molding and sheet molding operations. These come in the form of flakes, chips, and random mate (which can also be made from a continuous fiber laid in random fashion until the desired thickness of the ply / laminate is achieved) [1].

Shock, impact, or repeated cyclic stresses can cause the laminate to separate at the interface between two layers, a condition known as delamination. Individual fibers can separate from the matrix e.g. fiber pull-out. Composites can fail on the microscopic or macroscopic scale. Compression failures can occur at both the macro scale or at each individual reinforcing fiber in compression buckling. Tension failures can be net section failures of the part or degradation of the composite at a microscopic scale where one or more of the layers in the composite fail in tension of the matrix or failure the bond between the matrix and fibers. Some composites are brittle and have little reserve strength beyond the initial onset of failure while others may have large deformations and have reserve energy absorbing capacity past the onset of damage. The variations in fibers and matrices that are available and the mixtures that can be made with blends leave a very broad range of properties that can be designed into a composite structure [1].

The use of glass fiber reinforced plastic (GRP) tubes has spread in the chemical, oil, gas and other energy-related industries because of their lightness, corrosion resistance, durability, ease of installation and low through life cost [2,3].

There are many literature view took about this point such as: [4], was studied the effect of changing the reinforcement percentage by fibers on Mechanical properties, for composite material consists of conbextra epoxy (EP-10) resin reinforced by biaxial woven roving kevlar fibers) $[0° - 45°]$ with density (340 g/cm3) which included impact strength , tensile strength , flexural strength and hardness. [5] were applied chip and powder copper which are used as reinforcing phase in polyester matrix to form composites. Mechanical properties such as flexural strength and impact test of polymer reinforcement copper (powder and chip) were done. [6], was studied the mechanical properties such as, Yong modulus (E),Impact Strength(I.S),the Brinell hardness(B.H) and compression Strength (C.S) of polyester reinforced with 20% (v/v) glass fiber woven randomly E-glass . [7], were presented studying about prepared the composite materials which was consist of polyester as the matrix and BR4RC as additive material with grain size equal to25μm with different weight fractions (10%,20%,30%,40%,50%). This investigation was done into two stages: the first stage is to produce the composite material, while the second stage is to test the new material which includes tensile test, hardness and microstructure evaluation. Also photomicrographs were taken by ordinary microscope.

In this paper, manufacturing techniques using composite material will be presented including experimental investigation to evaluate, stress-strain curves, toughness and hardness, also failure modes.

II. II. EXPERIMENTAL SET-UP

A. Manufacturing of E-glass/polyester Composite Laminate

Fig.1 shows the hand lay- up method which is started by cutting the E-glass fiber to limited dimension with fiber orientation of $[0°/90°]$ and putting a first layer on a smooth working table then wetting it by a polyester resin using a small roller. Cut the second layer with $\pm 45^o$ fiber orientation and put it on the first layer and wet it again by polyester resin with small roller until all the resin impregnate in to the fiber. Repeat this procedure with orientation $[0°/90°/\pm45°]_s$ up to get the required thickness as shown in *Fig.2*. In the last layer make sure all the air voids are removed. Put a smooth sheet on the last layer and weight it by using a suitable balance. Leave the wetted laminate to cure at room temperature for 24 hours. Otherwise, the same scenario of manufacturing uses for $[\pm30°/\pm60°]_s$, and chopped mat as shown in *Fig.3*.

Fig.1-a. photograph to start mechanism on working table

Fig.1-b.photogragh to prepare the fiber on working table

Fig.2-a. photograph of preparing resin.

Fig.2-b. photograph of mechanism the manufacturing.

Fig.3-a.photograph the woven roving laminate.

Fig.3-b.photograph the chopped mat laminate.

B. Models of specimens.

Fig.4(a-b) shows a schematic diagram of fiber configurations of manufacturing laminate composite material of woven roving by using arrangement of lay-up method while *Fig.5* shows the same scenario of the model of chopped strand mat of lay-up method.

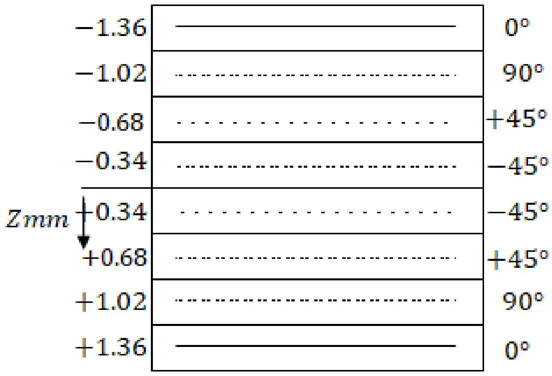

Figure.4- schematic diagram of woven roving ply arrangement (symmetric).

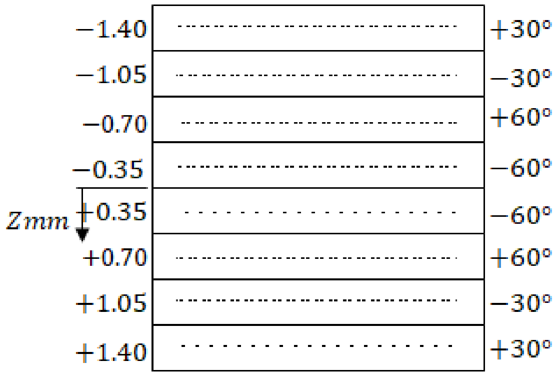

Figure.4-b. schematic diagram of woven roving ply arrangement (symmetric).

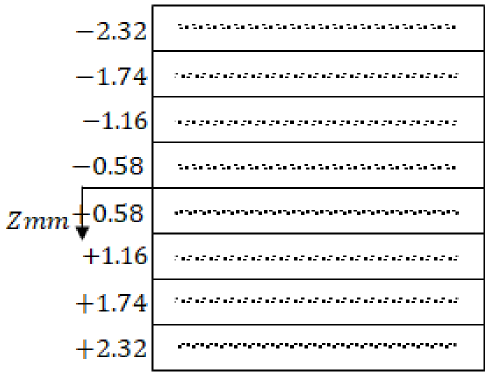

Fig.5. schematic diagram of chopped mat ply (symmetric).

C. Tested Method

1. Determination of the Tensile Strength for the Composite Laminate.

In order to determine the tensile strength of the composite laminate, three samples were cut from the previous laminate according to the test method of composite laminate by [8] as illustrated in section A. Each specimen was equipped by small rectangular aluminium sheets at its ends for machine grips. The samples must be carefully aligned in test machine jaws to avoid induced sample bending. All samples geometrically similar (L=150mm, e=50mm, w=26mm, t=depend on type E-glass fiber) as shown in *Fig.6*.

Fig.6-a. photograph of mechanism fixed the aluminium sheets on specimens.

Fig.6-b. photograph of specimens the tensile test.

1) 2. Determination of the Hardness for the Composite Laminate.

In order to determine the hardness of the composite laminate, two samples were cut from the previous laminate according to the test method of composite laminate by [8] as illustrated in section A. The dimension of the chopped mat specimen is $20mm \times 20mm$ with thickness $7mm$. Also, the dimension of the woven roving specimen is $20mm \times 20mm$ with thickness $5mm$,and orientation $[0°/90°/\pm45°]_s$ as shown in the *Fig.7*.

Fig.7-a. photograph the woven roving specimen.

Fig7-b. photograph the chopped mat specimen.

2) 3. Determination of Toughness for the Composite Laminate.

In order to determine the toughness of the composite laminate, three samples were cut from the previous laminate according to the test method of composite laminate by [8] as illustrated in section A. The dimension of the chopped mat specimen is $55mm \times 10mm$ with thickness $7.6mm$. Also, the dimension of the woven roving specimen is $55mm \times 10mm$ with thickness $5.8\ mm$ and orientation $[0°/90°/\pm45°]_s$ as shown in the *Fig.8*.

Fig.8-a. photograph the chopped mat specimen.

Fig.8-b. photograph the woven roving specimen.

III. III. RESULTS AND DISCUSSION.

A. A. The stress-strain curves.

Fig. 9-11 show the experimental modelled axial stress-strain curves as described in section 1 for the quasi-isotropic composite laminate which was used to the manufacturing . It can be demonstrated the experimental curves in the early stages are linear then exhibited non linear behaviour and then became linear up to failure. In addition, it can be observed at $[0°/90°/\pm45°]_s$ that after linearity behavior to followed by a steady continue without failure. The maximum failure stress was 124.363Mpa and the failure stroke was 23.25 mm of chopped mat while woven roving of $[0°/90°/\pm45°]_s$ was about 28.856 Mpa and the failure stroke was infinite, also woven roving of $[\pm30°/\pm60°]_s$ was 118.586 Mpa and also the failure stroke was 12.8 mm. The non-linearity of the experimental curve is probably related to the matrix cracking through the thickness of the composite laminate. The non-linearity due to matrix cracks is well documented in the literature [9-11]. The immediate effect of micro cracks is to cause degradation of the stiffness due to redistribution of stresses and variation of strain in cracked laminate[12]. The matrix cracks can induce delamination which leads to fibre breakage and may lead to laminate failure. The experimental curves can be seen at high strain until failure. This is probably due to further damage such as delamination matrix macro-cracks.

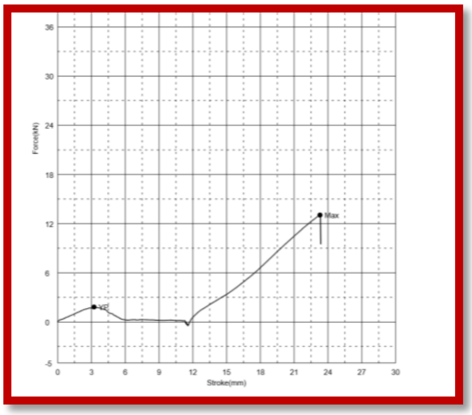

Fig. 9. relationship between axial stress and axial strain of chopped mat.

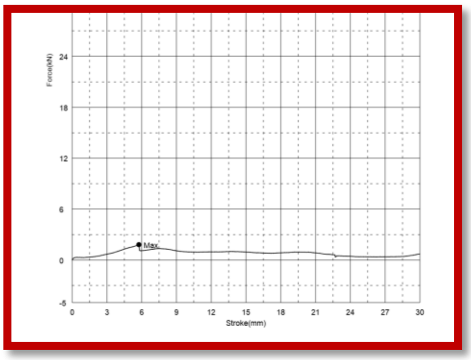

Fig.10. relationship between axial stress and axial strain of woven roving at $[0°/90°/\pm45°]_s$

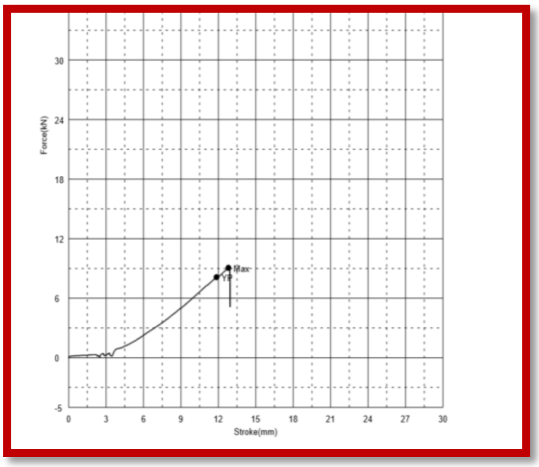

Fig. 11. relationship between axial stress and axial strain of woven roving at $[\pm30°/\pm60°]_s$.

B. B. The experimental results of hardness.

Table 1 shows the experimental results of hardness as described in section 2. It can be observed that increase of hardness value is 93 with increased the volume of fiber fraction,, also the length of fiber which it was compared with chopped mat.

Table.1. Results of Rockwell's Hardness for composite material.

Composite material (E-glass)	***Hardness H.R.C***
woven roving $[0°/90°/\pm45°]_s$	93
chopped mat	80

C. C. The experimental results of Toughness.

Table2. shows the experimental results of toughness as described in section 3. It can be observed that there is no clearly different between woven roving, chopped mat by the same type of fiber (E-glass) which it is used during the manufacturing.

Table.2. Results of Toughness for composite materials.

Composite material(E-glass)	***Energy of Fracture (J)***
woven roving $[0°/90°/\pm45°]_s$	29.7
chopped mat	29.5

D. D. Failure Modes

Two modes of failure were observed namely; the fiber breakage mode and delamination mode. The fiber breakage mode was exhibited by most of tensile specimens. *Fig.12* show photograph of three tested specimens. Tensile test was carried out on manufacturing specimens with chopped mat, woven roving $[0°/90°/\pm45°]_s$ and woven roving $[\pm30°/\pm60°]_s$. It was observed that the entire specimens failed by fiber breakage mode near its ends and also one specimen in its center.

The delamination mode is illustrated in *Fig.13*. It was observed that the specimens failed at chopped mat and woven roving $[0°/90°/\pm45°]_s$ due to impact test.

Fig. 12 photograph of failed specimens by tensile test.

Fig. 13 photograph of failed specimens by impact test.

IV. IV. CONCLUSIONS

- The study showed that, composite materials have good mechanical properties usefully to repair defected metal pipes which are used in oil and gas industry with minimum effective cost.
- The experimental stress-strain curves of tested specimens is non linear. This non-linearity is probably related to the matrix cracking and delamination between the plies.
- Fiber breakage and delamination were observed in failed specimens.
- Manufacturing of composite material by lay-up can be to know properties types fiber and resin.
- The yield stress of woven roving at $[\pm 30°/\pm 60°]_s$ was highest $52.5323 Mpa$.
- The non- linearity behaviour of woven roving at $[0°/90°/\pm 45°]_s$ continuous without failure.
- The maximum ultimate stress was observed at chopped mat $124.363 Mpa$.
- The maximum value of hardness was observed at $[0°/90°/\pm 45°]_s$ H.R.C 93
- The energy of fracture value was about corresponding of chopped mat and woven roving at $[0°/90°/\pm 45°]_s$ $29.5 J$.
- The highest of toughness was observed of woven roving at $[0°/90°/\pm 45°]_s$.

V. V. FUTURE WORK

The Experimental work is continuing on specimens with different fibers. Also the study will be focused on the improving the failure mode of the laminate by using different techniques.

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LIST OF SYMBOLS

e: Length of end tabs.
L : Free length.
t: Measured thickness of specimen.
w: Measured width of specimen.
Z: Direction of thickness the composite laminate.

VI. VI. REFERENCE

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