Experimental Study of Mechanical Properties of Composite Materials

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Abstract— **This paper presents an investigation of E-glass types and polyester. The aim of the work is to compare their mechanical properties, such as; tensile strength, hardness and toughness. Experimental materials were manufactured using lay-up method at the department of Materials Science and Engineering Lab-Misurata University. The prepared samples of woven roving at $[0^o/90^o/\pm 45^o]_s$, $[\pm 30°/\pm 60°]_s$ and chopped mat reinforced with polyester resin. According to the obtained experimental results, all experimental materials showed reasonable mechanical properties. $[0^o/90^o/\pm 45^o]_s$ revealed ideal elastic and plastic behavior in contrast with $[\pm 30°/\pm 60°]_s$ and chopped mat materials. Hardness results of $[0^o/90^o/\pm 45^o]_s$ and chopped mat types were found to be 93 and 80 Rockwell's hardness number respectively. Sharpy impact test for both $[0^o/90^o/\pm 45^o]_s$ and chopped mat types were comparative of $\cong 29.5J$.**

Index Terms: **E-glass fiber, lay-up, quasi-isotropic laminate, composite material, delamination, fiber breakage.**

I. INTRODUCTION

A composite material is a combination of two or more materials (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a macro scale. 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.

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An isotropic materials (for example, aluminum 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 anisotropic 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, 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 for example 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 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 studies have been conducted on the mechanical properties of composite materials such as: A study was conducted in the area of 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/cm^3) which included impact strength, tensile strength, flexural strength and hardness[4]. A chip and powder copper 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[5]. A study of the mechanical properties such as, Yong modulus (E), Impact Strength (I.S), the Hardness and compression Strength (C.S) of polyester reinforced with 20% (v/v) glass fiber woven randomly E-glass was conducted[6]. A study about prepared the composite materials which was consist of polyester as the matrix and BR4RC as additive material with grain size equal to 25 μm with different weight fractions (10%, 20%, 30%, 40%, 50%). This investigation was done in two steps: the first step is to produce the composite material, while the second step is to test the new material which includes tensile test, hardness and microstructure evaluation. Also photomicrographs were taken by ordinary microscope [7].

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

II. EXPERIMENTAL SET-UP

A. Manufacturing of E-glass/polyester Composite Laminate

Figure1 (a&b) 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 fiber orientation and put it on the first layer and wet it again by $\pm 45°$ polyester resin with small roller until all the resin impregnate into the fiber. Repeat this procedure with orientation $[0°/90°/\pm45°]_s$ up to get the required thickness as shown in Figure 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 Figure 3 (a&b).

Figure 1-a. Start Mechanism on Working Table.

Figure 1-b. Prepare the Fiber on Working Table.

Figure 2. Manufacturing Mechanism.

Figure 3-a.Woven Roving Laminate.

Figure 3-b.Chopped Mat Laminate.

B. Models of Specimens

Figure 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 Figure 5 shows the same scenario of the model of chopped strand mat of lay-up method.

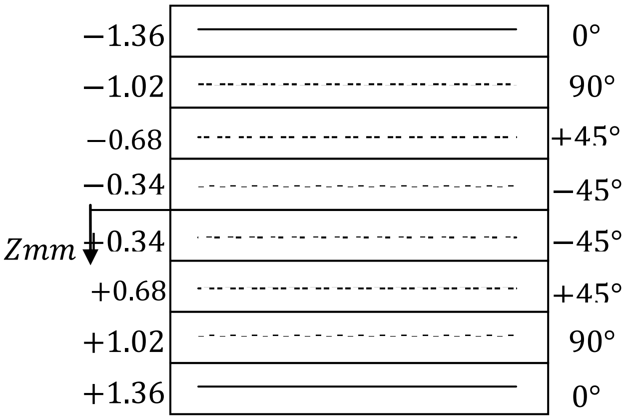

Figure 4-a. Schematic Diagram of Woven Roving Ply Arrangement (Symmetric).

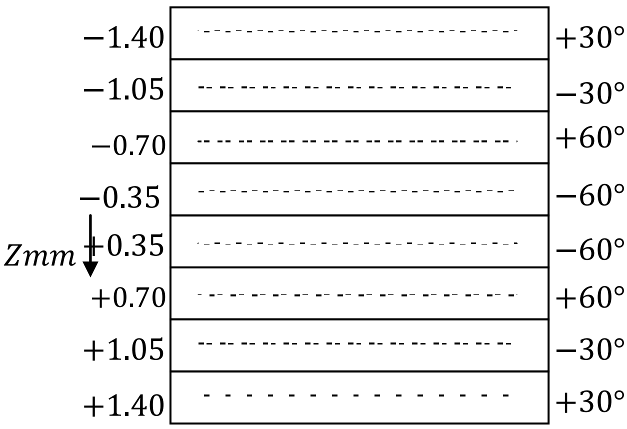

Figure 4-b. Schematic Diagram of Woven Roving Ply Arrangement (Symmetric).

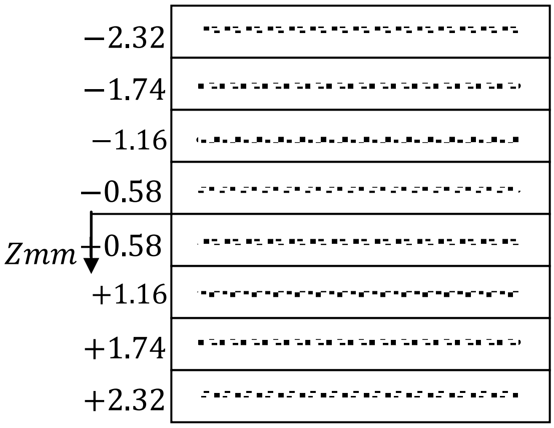

Figure 5. Schematic Diagram of Chopped Mat Ply Arrangement (Symmetric).

C. Tested Methods

C.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 aluminum 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 = 50 mm, w = 26 mm, t = depend on type E-glass fiber) as shown in Figure 6.

Figure 6. Shows the Tensile Test Specimens.

C.2 Determination Hardness for the Composite Laminate.

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 $20mm$ (width) $\times$ $20mm$(length)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 Figure7(a&b).

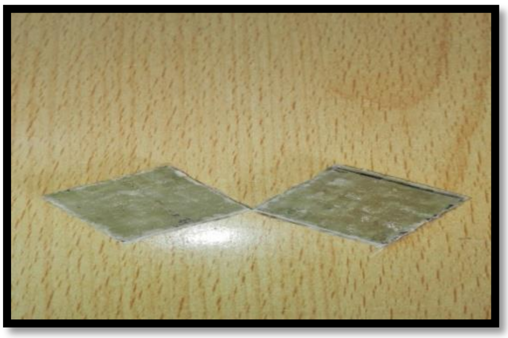

Figure 7- a. Woven Roving Hardness Test Specimens.

Figure 7- b. Chopped Mat Hardness Test Specimens.

C.3 Determination of Toughness for the Composite Laminate.

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 $55\text{mm}(\text{length}) \times 10\text{mm}(\text{width})$ with thickness 7.6 mm. Also, the dimension of the woven roving specimen is $55\text{mm} \times 10\text{mm}$ with thickness 5.8 mm and orientation $[0°/90°/\pm45°]_s$ as shown in the Figure 8(a&b).

Figure 8-a. Chopped Mat Impact Test Specimens.

Figure 8-b. Woven Roving Impact Test Specimens.

III. RESULTS AND DISCUSSION

A. The Stress-Strain Curves

Figure 9 to 11 show the experimental modelled axial stress-strain curves as described in section C.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 follow by a steady continue without failure. The maximum failure stress was 124.363 MPa and the failure stroke was 23.25mm 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.

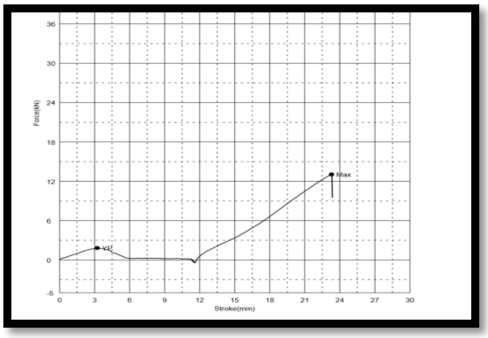

Figure 9. Relationship between the Axial Stress and Axial Strain of the Chopped Mat.

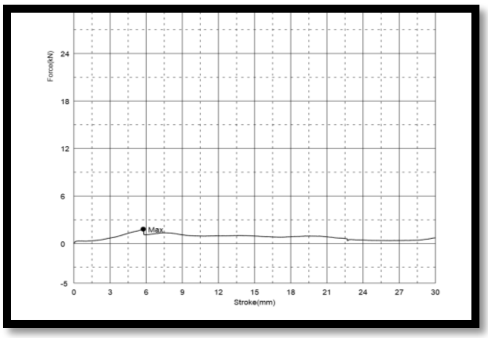

Figure 10. Relationship between the Axial Stress and Axial Strain of the Woven Roving at $[0°/90°/\pm45°]_s$.

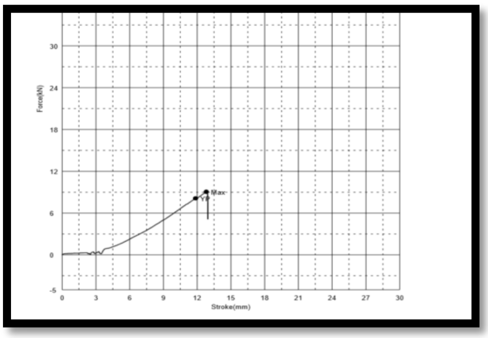

Figure 11. Relationship between the Axial Stress and Axial Strain of the Woven Roving at $[\pm30°/\pm60°]_s$.

B. Experimental Results of Hardness

Table 1 shows the experimental results of hardness as described in section C.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. Hardness Results for Composite Materials.

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

C. Experimental Results of Toughness

Table 2 shows the experimental results of toughness as described in section C.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. Toughness Results for Composite Materials.

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

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. Figure12 shows 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 centre.

The delamination mode is illustrated in Figure13. It was observed that the specimens failed at chopped mat and woven roving$[0°/90°/\pm45°]_s$ due to impact test.

Figure 12. Failed Specimens by the Tensile Test.

Figure 13. Failed Specimens by the Impact Test.

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 arenon-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 help to know properties types fiber and resin.
- The yield stress of woven roving at $[\pm30°/\pm60°]_s$ 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 124.363Mpa.
- The maximum value of hardness was found 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$29.5J.
- The highest of toughness was observed of woven roving at$[0°/90°/\pm 45°]_s$.

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