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Effect of the Glass Fiber Diameter and Position Angle in the Mechanical Properties of Fiberglass Composite Materials

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ABSTRACT: In the present study, the fiberglass is widely used in many applications as manufacturing tools and automotive. Due to its chemical resistivity and good mechanical properties compared with metals; the fiberglass is extensively used in automobile industry in components and body kits. Development of fiber glass containments as fiber diameter and position angle is essentially in order to enhance the mechanical properties and to have a long life time. The tensile strength, impact strength, density, and hardness were found affected by the fiber position and fiber diameter in the epoxy matrix. As increasing the fiber diameter; the hardness and the impact strength will be increased, however; the tensile strength will be decreased.
Key words: glass fiber, epoxy resin, fiber glass, fiber position, fiber diameter, composite material, mechanical properties, automotive, manufacturing tools.

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I. INTRODUCTION

A composite is composed of two (or more) individual materials, which come from metals, ceramics, and polymers as in figure 1. The design goal of a composite is to achieve a combination of properties that is not displayed by any single material, and to incorporate the best characteristics of each of the component materials. One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material (normally an epoxy or polyester). The glass fibers are relatively strong and stiff (but also brittle), The glass fibers are relatively strong and stiff (but also brittle), whereas the polymer is more flexible. The fibers (filler) are materials that are strong with low densities. The matrix is material component that surrounds the fiber and serves to hold the fiber (filler) in a favorable position. Designed to display a combination of the best characteristics of each material (i.e. fiberglass acquires strength from glass and flexibility from the polymer). Matrix and filler bonded together (adhesive) or mechanically locked together. Thus, fiberglass is relatively stiff, strong and flexible in addition, it has a low density. Generally, the fiberglass has high strength to weight ratio (low density - high tensile strength), high tensile strength, high toughness, and corrosion resistance.

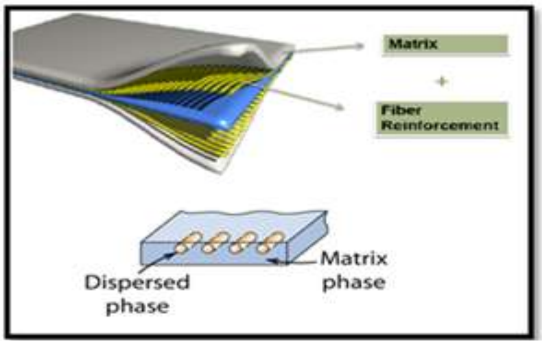

Figure 1. Composite material construction

These mechanical properties are varying with the fiber diameter and position angle in the matrix phase. There are three types of fiber position; continuous aligned, discontinuous aligned, and discontinuous randomly positioned as in figure 2.

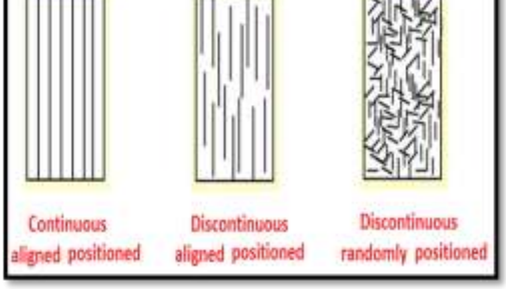

Figure 2 Fiber position

The objective is to change the fiber position angle and diameter in discontinues fiber in the composite material to enhance the mechanical properties as tensile strength, hardness, and impact strength. High mechanical properties and low density are required in some manufacturing tools automotive parts.

II. MATERIAL AND METHOD

2.1. Selection of the Material

The Synthetic fiber is manufactured from E-glass which is alumina-borosilicate glass with less than 1% w/w alkali oxides. Three fiber diameters are used 17µm, 30µm, and 50µm. The position angle of fiber will be changed from 0°, 30°, 60°, and 90° in the resin matrix.

The resin was selected to be manufactured from epoxy. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homo-polymerization, or with a wide range of co-reactants including acids, phenols, and alcohols as a curing agents.

Both of epoxy and glass fiber was purchased from local market in Egypt.
Different fiberglass samples were prepared with different dimensions and fiber positions. The fiber to resin composition ratio was kept at 30/70 by weight percentage for all samples.

2.2. Fiberglass Fabrication

To prepare different samples as mentioned; silicon rubber mold shall be fabricated to fabricate the samples. So, wooden box of required size 20 × 20 × 10 cm was made and coated with wax polish, which acts as a releasing agent.

A proper metallic tensile specimen with a suitable dimension was put inside the wooden box as in figure 3. Then, the silicone rubber was poured above.

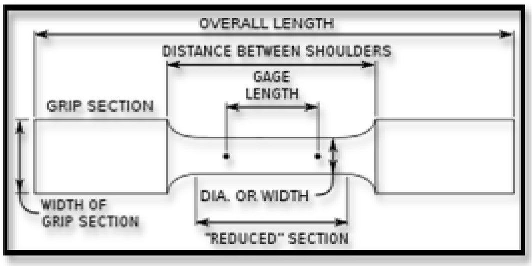

Figure 3. Specimen with a proper shape put inside the box

The silicon rubber was put on a shaker and let to cure as in figure 4. The final silicon rubber samples mold was as in figure 5.

Figure 4. Silicon rubber mold during curing

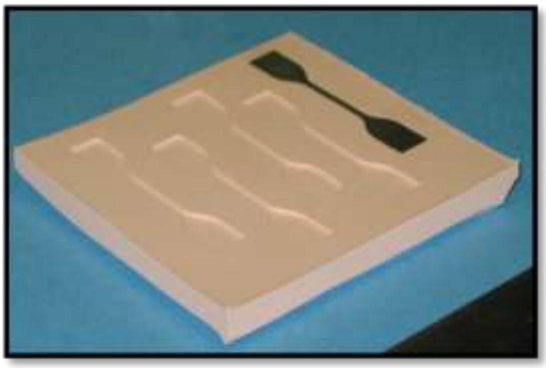

Figure 5. Final Specimen silicon rubber mold

2.3. Fiberglass and Epoxy resin Fabrication

The epoxy resin was put in cup with its curing agent and mixed by hand as in figure 6.

Figure 6. Epoxy with curing agent mixing

The glass fiber was put on the mold; then, the epoxy was poured above. Using hand lay out technique to ensure more epoxy to fiber dispersion.

Figure 7. Putting different fiber diameters in the mold with different position angles

Seven samples were prepared for different positions and fiber diameter as in table 1 and 2. Each sample shall be tested according to tensile strength, impact strength, and hardness.
The direction of discontinuous fibers at angle 0, 30°, 60°, and 90° are indicated in figure 8.

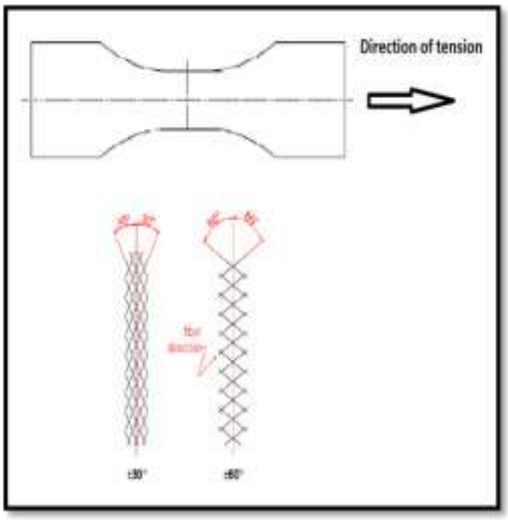

Figure 8. Fiber position angle

Table 1. Samples with different fiber diameter at 0° position angle

Sample	Fiber Position Angle	Fiber diameter
D-1	**0°**	17 µm
D-2		30 µm
D-3		50 µm

Table 2. Samples with different fiber position angle at 24 µm fiber diameter

Sample	Fiber diameter	Fiber position angle
P-1	**30 µm**	0°
P-2		30°
P-3		60°
P-4		90°

2.4. Instrument Used
1. Universal Testing machine
A universal testing machine (UTM) is used to test the tensile and compressive strength for materials as in figure 9.

Figure 9. Used universal testing machine

An earlier name for a tensile testing machine is a tensiometer. The samples were prepared as 30 Cm length X 2.5 Cm width X 0.5 Cm thickness. The specimen gauge length was 20 cm.
The UTS specifications are as in table 3

Table 3. UTS specifications

Model	TZ-TTM
Measurement Range	5-200Kg
Outer Size	500*450*1050mm
Test Force Range	0.4%-100% FS
Display Value Accuracy	Plus or minus 1 %
Extension Range	0 ~ 360 mm
Measurement Accuracy	±0.1mm
Test Speed Adjustment	(1 ~ 200) mm / min
Return Speed	100mm/min
Test Speed Error	(5.5 ~ 10) mm / min: ± 1mm / min
Test Length	180mm
Spacing Positioning Error	±0.5mm
Data Output	Computer software
Machine	About 80Kg

Quality	

2. Rockwell Hardness Tester

Rockwell hardness tester used to measure the hardness of the samples using ASTM D 785 as shown in figure 10.

Figure 10. Rockwell Tester

3. Impact IZOD Tester

Impact strength testing was performed by Charpy impact tester according to ASTM D-5371 as in figure 11.

Figure 11. Impact Charpy Tester

4. High Precision Lab Digital Balance

An analytical balance (often called a "lab balance") is a class of balance designed to measure small mass in the sub-milligram range as in figure 12. The measuring pan of an analytical balance (0.1 mg or better) is inside a transparent enclosure with doors so that dust does not collect and so any air currents in the room do not affect the balance's operation.

Also, the sample must be at room temperature to prevent natural convection from forming air currents inside the enclosure from causing an error in reading. The digital balances specifications are indicated in table 4.

Figure 12. Digital Balance

Table 4 Digital balance specifications

Manufacturer	SARTORIUS AG GOETTINGEN
Model No.	BP 2215
Serial No.	90403533
Max Weight	220 Grams
Precision	0.01rams

III. RESULTS AND DISCUSSIONS

1. Tensile strength

Samples were prepared for tensile test as in figure 13.

Figure 13 Samples for tension testing

Regarding to samples D1, D2, and D3; the tensile strength was found increasing with decreasing the fiber diameter as shown in figure 14.

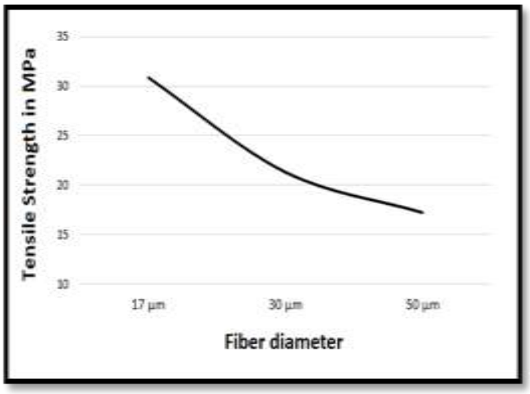

Figure 14.11 Fiber diameter effect in tensile strength

Regarding to samples P1, P2, P3, and P4; the tensile strength was found increasing while the fiber is positioned in the same direction of tensile load as shown in figure 15.

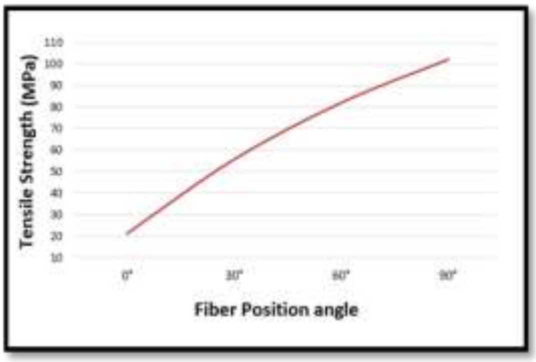

Figure 1512. Effect of fiber position angle in tensile strength

2. Hardness

Samples were prepared for hardness test as in figure 16.

Figure 16. Samples for hardness testing

Regarding to samples D1, D2, and D3; the hardness was found increasing with increasing the fiber diameter as shown in figure 17.

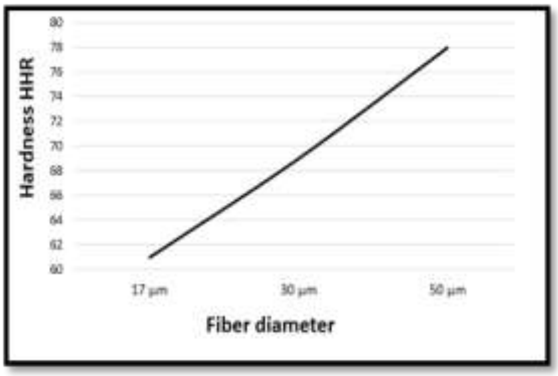

Figure 17 Fiber diameter effect in hardness

Regarding to samples P1, P2, P3, and P4; the hardness was found almost constant for each fiber position as shown in figure 18. So, there is no effect of fiber position in fiberglass hardness.

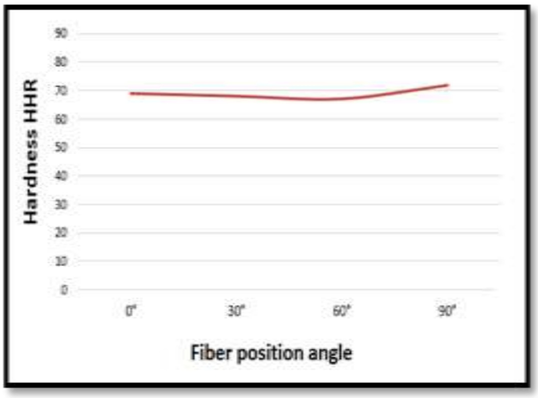

Figure 18. Effect of fiber position angle in hardness

3. Impact strength

Samples were prepared for impact test as in figure 19.

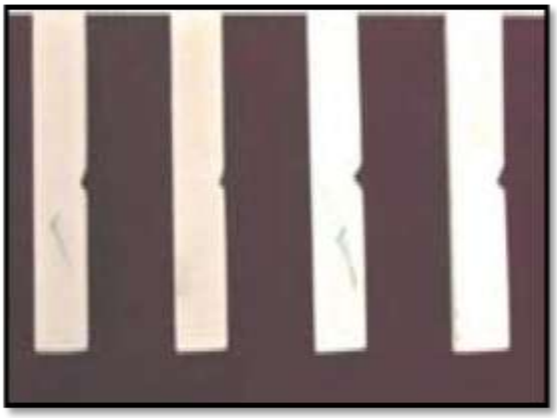

Figure 19. Samples for impact testing

Regarding to samples D1, D2, and D3; the impact strength was found increasing with increasing the fiber diameter as shown in figure 20.

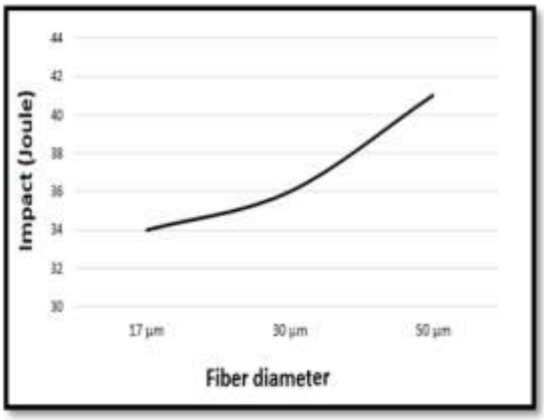

Figure 20. Fiber diameter effect in impact strength

Regarding to samples P1, P2, P3, and P4; the impact strength was almost constant for each fiber position as shown in figure 21. So, there is no effect of fiber position in fiber glass impact strength.

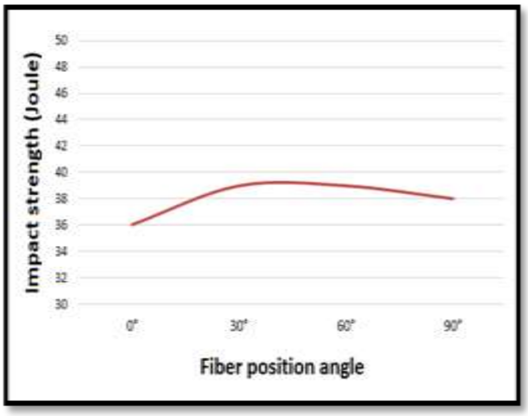

Figure 21. Effect of fiber position angle in impact strength

4. Density

Samples were weighted using the digital balance. Each sample volume was calculated. So, the density was calculated from the following equation:-

$$\text{Density } \rho = \frac{\text{Mass (gm)}}{\text{Volume (cm3)}}$$

Regarding to samples D1, D2, and D3; the density was found decreased with increasing the fiber diameter as shown in figure 22. It makes sense where; as increasing the diameter, the volume will be increased. For the same weight percentage between fiber and resin; the density is inverse proportional with fiber volume.

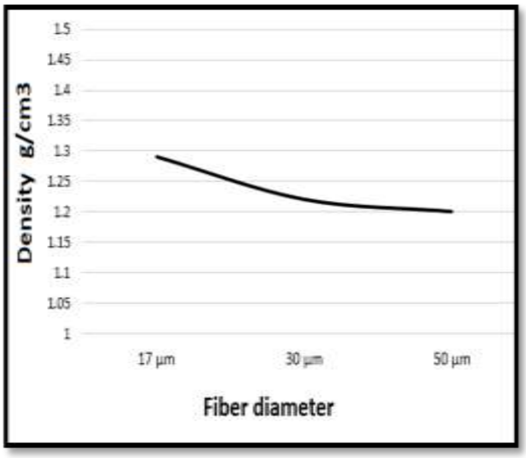

Figure 22. Fiber diameter effect in density

Regarding to samples P1, P2, P3, and P4; the density was found decreased with increasing the position angle as in figure 23. This is due to less fiber volume in high values of position angle.

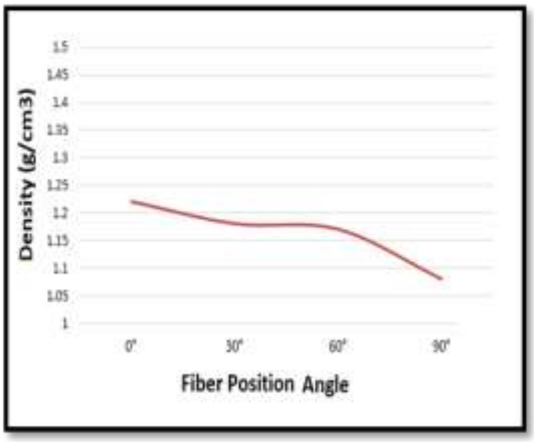

Figure 23. Effect of fiber position angle in density

IV. CONCLUSIONS AND RECOMMENDATIONS

For parts of manufacturing tools and automotive applications; it is much recommended to have high tensile strength, hardness, and impact strength with less density.

It is concluded that as increasing the fiber diameter; the hardness, impact strength, and density will be increased. But the tensile strength will be decrease. To increase the tensile strength; the fiber position angle shall be positioned in 90°.

So, it is recommended that it is much better to use fiberglass with discontinues aligned short glass fiber that is positioned in 90° to increase the tensile strength. Moreover; increasing the glass fiber diameter (as 50μm) is much recommended to increase the hardness, impact strength, and low density.

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