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Mechanical Properties of Glass Fiber Reinforced Polyester Composites

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Abstract: Glass fiber reinforced polyester composites have played a dominant role for a long-time in a variety of applications for their high specific strength, stiffness and modulus. In this research work, an E-glass fiber with random oriented reinforced polymer composite was developed by hand lay-up technique with varying fiber percentages (15%, 30%, 45%, and 60% by weight percentage). The influence of glass fiber percentage on the mechanical properties such as tensile strength, bending strength and impact strength was investigated. Hardness of composites was evaluated by using Brinell hardness tester. The results showed remarkable improvement in the mechanical properties of the fabricated composite with an increasing in the glass fiber contents. Tensile strength varies from 28.25 MPa to 78.83 MPa, flexural strength varies from 44.65 MPa to 119.23 MPa and impact energy at room temperature varies from 3.50 Joules to 6.50 Joules, as a function of fiber weight fraction. The hardness value will greatly increase from 31.5 BHN to 47 BHN. The best mechanical properties obtained at 60 wt.% of glass fiber of fabricated composites.

Keywords: Glass fiber; polyester resin; hand lay-up technique and mechanical properties.

1. Introduction

Polymers are particularly attractive as matrix materials because they are easily process able and their density is comparatively low when compared to other materials. They exhibit excellent mechanical properties. High-temperature resins are used as composite materials are currently used in the manufacture of high-speed aircrafts, rockets and other related space and electronics. The reinforcements share the major load especially when a composite consists of fibre reinforcements dispersed in a weak matrix (e.g., carbon/epoxy composite). The strength and stiffness of such composites are, therefore, controlled by the strength and stiffness of constituent fiber [1-4]. The major advantage of fiber reinforced composites is to offer a high strength and modulus those are either comparable to or better than many traditional metallic materials. Because of their low specific gravity, the strength- weight ratio, and modulus - weight ratios, these composite materials are markedly superior to those of metallic materials. In addition, fatigue strength - weight ratio as well as fatigue damage tolerance of many composite laminates is excellent [5, 6].

Mechanical properties of fiber reinforced composites are depending on the properties of the constituent materials (type, quantity, fiber distribution and orientation, void content). Beside those properties, the nature of the interfacial bonds and the mechanisms of load transfer at the interphase

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also play an important role [7]. Flexural properties of random glass-polyester composites by hand-lay up (HLU) moulding are investigated. Flexural parameters derived from the force-deflection data of composites containing 20 wt.% and 30 wt.% continuous random fiber showed mean values of flexural strength and modulus of 84 MPa and 7 GPa and 110 MPa and 10 GPa for the HLU composites [8]. Gonzalez and LLorca [9] studied the compressive strength under transverse loading of fiber-reinforced polymers by means of computational micromechanics. It was found that the composite properties under transverse compression were mainly controlled by interface strength and the matrix yield strength in uniaxial compression. The effects of various environmental conditions on tensile behavior of GFRP plate were investigated. The mechanical behavior of polymeric matrix composites in particular is affected by the environmental conditions.

The experimental results show that the tensile strength of GFRP plates is affected at different levels when subjected to selected environmental conditions [10]. Estabraq [11] study two commercial types of reinforced glass fibers: chopped and 0/90 fiber glass composted with unsaturated polyester resin. It was found that the random composite was notice to have young modulus, maximum stress, and yield strength higher by comparing with the 0/90 composite.

In the present paper, E-glass random fiber reinforcement in polyester resin matrix was produced by hand lay-up technique with varying fiber percentages (15%, 30%, 45%, and 60% by weight percent). The tensile, flexure, impact and Brinell hardness tests were carried out and their performances were evaluated.

2. Experimental Procedure

2.1. Materials

2.1.1. Glass fiber

Glass fiber is a light in weight, extremely strong, and robust. Its bulk strength, stiffness and weight properties are also very favorable when compared to metals. The E-glass fiber with random orientation was used as a reinforcing material in the polyester resin matrix. This kind of glass combines the characteristics of C-glass with very good insulation to electricity. Properties of E-Glass fiber and unsaturated polyester resin are given in the following Table 1 [12].

Table 1. Properties of E glass fiber and unsaturated polyester resin

Property	Tensile strength (MPa)	Compressive strength (MPa)	Elastic modulus (GPa)	Density (g/cm^3)
E-glass	3445	1080	73	2.58
Unsaturated polyester	90	55	3.23	1.35

2.1.2. Polyester resin

Unsaturated Polyester resin is a liquid which will cure into solid when the hardener is added. It has been specially formulated to cure at room temperature. The hardener, MEKP (Methyl Ethyl Ketone Peroxide) is added to cure and also to harden the resin.

2.2. Preparation of Composites

Glass reinforced polymer composites were fabricated by using the hand lay-up (HLU) technique in different weight percentages of glass fiber in polyester such as 15%, 30%, 45%, and 60% step 15%.

Fiber reinforcing fabric was placed in an open mould and then saturated with a wet (resin) by pouring it over the fabric and working it into the fabric and mould. Usually at room temperature, though heat is sometimes used to ensure a proper curing process. Figure 1 illustrates show this might be done simply by placing a woven fabric on a mould constructed from wood or other convenient materials. The polymer resin is then rolled or squeezed into the fabric, and the resin allowed to react chemically (“cure”) to a hard matrix. The mould is then left so that the resin will cure. The prepared E-glass fiber reinforced polyester composite slabs were taken out from the mould and then specimens of suitable dimensions were prepared from the composite frame (30cm x 30cm and plate thickness 5mm for different mechanical tests according to ASTM standards. The test specimens were cut by using the cutter.

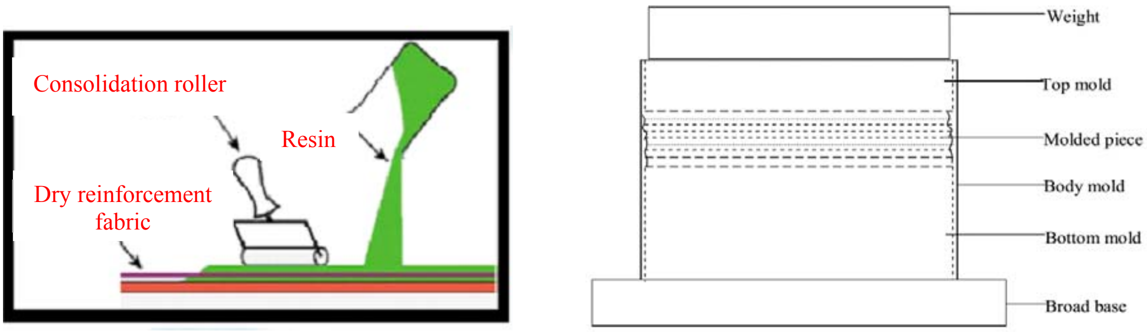


Figure 1. Experimental setup for the hand lay-up technique of GFRP composite production

2.3. Mechanical Testing

2.3.1. Tensile test

The glass fiber reinforced polyester composite material fabricated was cut into required dimension using a saw cutter. For mechanical testing, the edges of this composite are finished by using emery paper. The tensile test was carried out on universal testing machine (UH-F1000kN) with a cross head speed of 5 mm/min as per the ASTM standards.

The test specimens were prepared as Per ASTM D638 (165 x 19) mm; thickness is 5 mm, shown in Figure2. The three specimens were subjected to tensile test and their values were recorded.

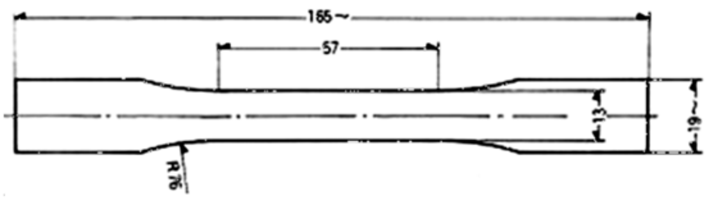


Figure 2. The geometries and dimensions of the specimen

2.3.2. Three point bending test

Three-point Bending tests was used to study the flexural strength of the composite material specimens fabricated and it was carried out by using universal testing machine of 1000 kN full scale load capacity with a cross head speed of 5 mm/min according to ASTM standard D-790 (80 mm x 12.5 mm), thickness is 5 mm. Flexural strength of the composites material was calculated according to equation (1) [8].

$$\sigma_f = \frac{3FL}{2wt^2} \quad (1)$$

where F is applied load (N), L is support span (mm), w and t are width and thickness of the specimen (mm), respectively.

2.3.3. Hardness test

Brinell hardness test was conducted on the specimen using a standard Brinell hardness tester. A load of 300 kgf was applied on the specimen for 30 sec using 5 mm diameter hard metal ball indenter and the indentation diameter was measured using a microscope containing an ocular, usually graduate in tenths of a millimeter, permitting estimates to the nearest 0.05 mm. The surfaces of the specimen should be smooth and free of oil and dirt. The hardness was measured at three different locations of the specimen and the average value was calculated. The indentation was measured and hardness was calculated using equation (2).

$$BHN = \frac{F}{\frac{\pi}{2} D\left(D - \sqrt{\left(D^2 - D_i^2\right)}\right)} \quad (2)$$

where F is applied load used (Kg_f); D is Diameter of ball indenter (mm); and Di is Diameter of impression (mm). It is desirable that the test load is limited to an impression diameter in the range of 2.5 to 4.75 mm.

2.3.4. Impact test

The toughness of the composite specimens was measured by using the Charpy impact tester (PIT Series, U-shaped pendulum of up to 150 J) after determining the impact energy according to the slandered ASTM D-256. The impact energy of the composite fabricated material was calculated by measuring the amount of energy before its fracture, equation (3).

$$\text{Impact strength} = \frac{U_{abs}}{A} \quad (3)$$

where U_{abs} is Energy absorbed (J) and A is Area of cross section of the specimen (m^2). The unit of impact strength is Joule per square meter and the notch depth is 2 mm. For statistical purpose, a total of five samples for each tests were carried out at room temperature.

3. Results and Discussion

3.1. Tensile Behaviour of GFRP Composites

The properties of the composites depend upon the reinforcement materials. The variation in tensile strength of the fabricated composites with 15%, 30%, 45%, and 60% of glass fiber content are shown in Figure 3. The results of tensile strength test with the variation in the glass fiber content of the fabricated composites are listed in Table 2. This table shows the tensile strength of the unsaturated polyester (control sample) before reinforcement reached to 19.76 MPa.

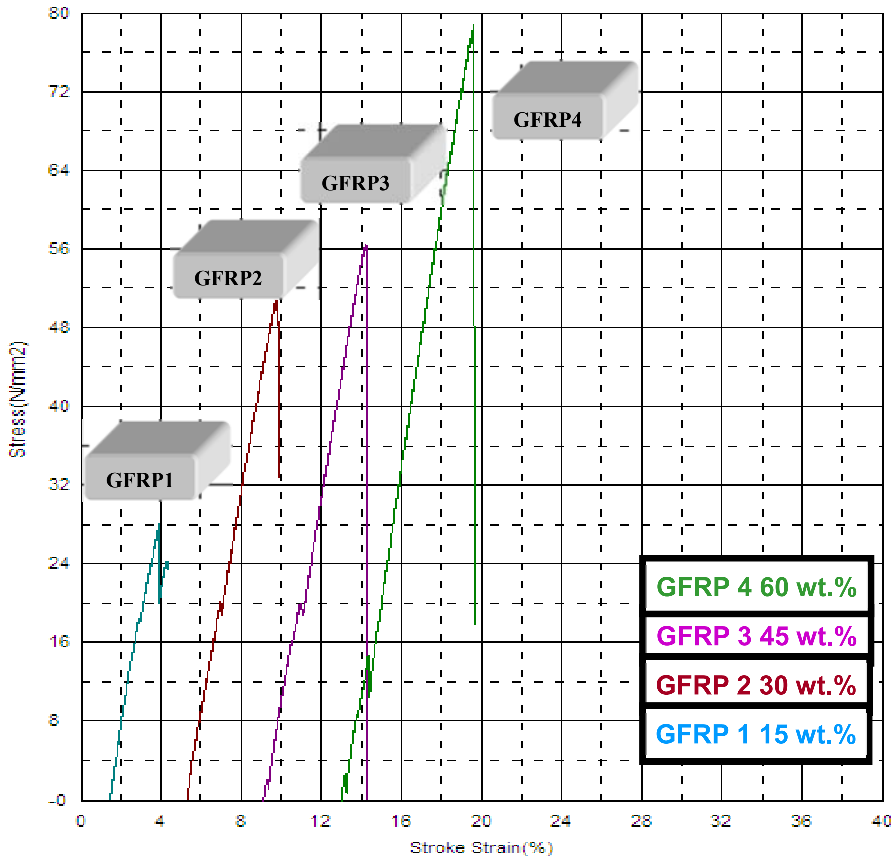


Figure 3. The variation in tensile strength with the glass fiber ratio from 15 wt.% to 60 wt.%

Table 2. Effect of glass fiber contents on tensile strength of fabricated composites

No.	Content (%)	Width (mm)	Thickness (mm)	Max. Load (N)	Yield strength (MPa)	Tensile strength (MPa)
Control sample	0 %	19	5	2707.50	10.29	19.76
GFRP 1	15 %	19	5	3504.30	18.63	28.25
GFRP 2	30 %	19	5	4827.90	20.32	50.82
GFRP 3	45 %	19	5	5370.35	21.08	56.53
GFRP 4	60 %	19	5	7488.85	12.54	78.83

Tensile properties of the composites are mostly affected by the materials, method, specimen condition and preparation and also by percentage of the reinforced. It was found from Figure 3, the tensile strength increased from 28.25 to 78.83 MPa with the maximum tensile strength being for the composite with 60 wt.% glass fiber percentage. The tensile strength of the fabricated composite depends to a large extent on the interfacial bonding strength between the matrix reinforcement and also on the inherent properties of the composite ingredients.

We shows after reinforcing by fibers this property will be improved greatly, where the fibers will withstand the maximum part of loads and by consequence will raise the strength of composite material. The tensile strength will be increased as the fiber percentage addition increased, where these fibers will be distributed on large area in the resin [13]. In the composite reinforced with random fibers the load is concentrated at the end of short fibers Distributed in the matrix which makes the control of transmission of the load from the matrix to the fibers through the interface region is weak. Improvement in tensile composites helps the composite to withstand more tensile forces when they are in service. Also, materials with more strain are likely to fail safe in service. The tensile test specimens before and after test is shown in Figure 4.

(a) Before (b) After

Figure 4. The variation in tensile strength with the glass fiber ratio from 15 wt.% to 60 wt.%

3.2.Bending Strength of GFRP Composites

In this test, the flexural strength behavior of glass fiber reinforced polyester composites in different weight percentages of glass (15%, 30%, 45%, and 60% step 15%) was presented. The results of bending strength test with the variation in the glass fiber content of the fabricated composites are listed in Table 3. It was found from Table 3, the bending strength increased from 35.33 MPa to 119.23 MPa with glass fiber varied from 0 wt. % to 60 wt.% step 15 wt.% and the maximum value of bending strength reached to 119.23 MPa at the glass fiber percentage 60 wt.%.

As mentioned below, the resin is brittle; therefore its flexural strength will be low before reinforcement (35.33 MPa). But after added the fibers to this resin the flexural strength will be raised to the producing material because the high modulus of elasticity of these fibers will helps to carry a large amount of loads and raise this strength, as shown in Figure 5.

Results reveal that type of reinforcements show good stiffness and bending strength. The bending tests specimens before and after test is shown in Figure 6.

Table 3. Effect of glass fiber contents on bending strength of fabricated composites

No.	Content (%)	Width (mm)	Thickness (mm)	Max. Load (kN)	Bending strength (MPa)
Control sample	0 %	12.5	5	0.1142	35.33
GFRP 1	15 %	12.5	5	0.1935	44.65
GFRP 2	30 %	12.5	5	0.2433	83.08
GFRP 3	45 %	12.5	5	0.3845	90.55
GFRP 4	60 %	12.5	5	0.4954	119.23

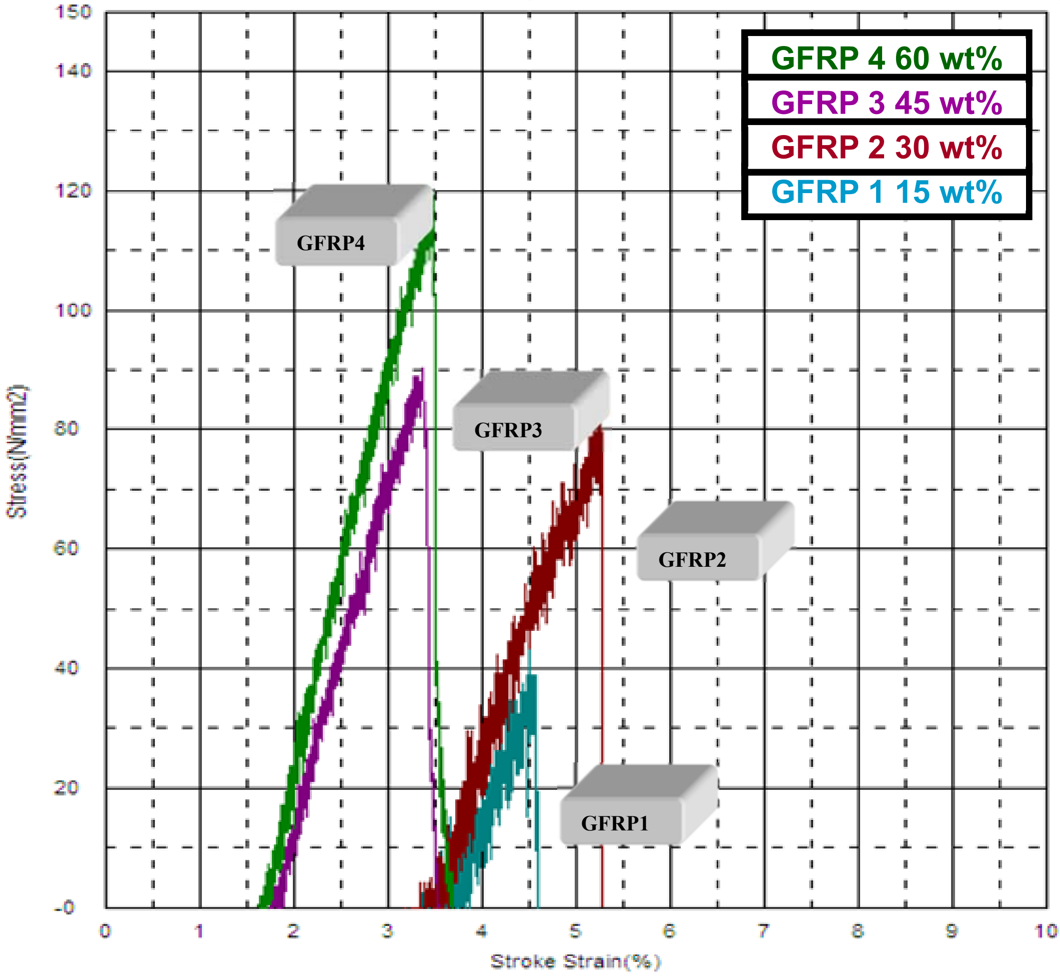
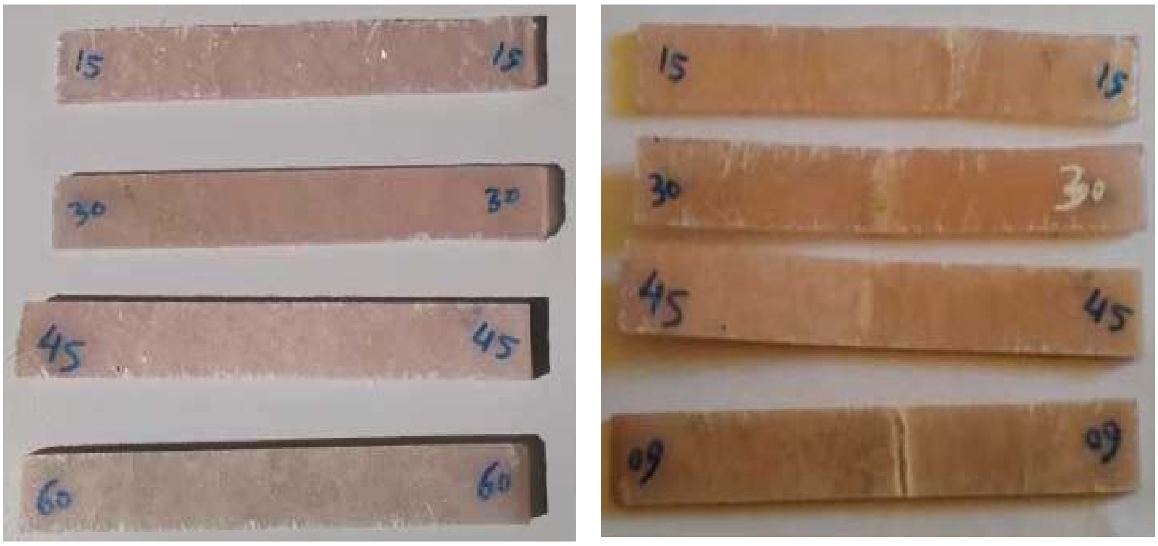


Figure 5. The variation in flexural strength with the glass fiber ratio from 15 wt. % to 60 wt.%



(a) Before (b) After

Figure 6. The bending test specimens (a) before and (b) after test

3.3 Impact Energy of GFRP Composites

The variation of impact strength with the glass fiber content from 15% to 60 % (weight percent), in case of room temperature and nitrogen gas was presented in Figure 7.

It was found from this figure, the impact energy at room temperature and nitrogen gas varies from 3.50 Joules to 6.50 Joules, 4 Joules to 7.10 Joules as a function of fiber weight fraction, respectively.

The impact resistance will continue to increase with increasing the glass fibers reinforcing percentage. The impact resistance considered low to the resins due to brittleness of these materials, but after reinforcing it by glass fibers the impact resistance will be increased because the fibers will carry the maximum part of the impact energy which exposition on the composite material.

Figure 8 (a), (b) and (c) show the impact test specimens of the glass fiber ratio from 15 wt.% to 60 wt.% at before test, after impact test at room temperature, and after impact test at nitrogen gas at -10 °C, respectively.

3.4.Hardness Behaviour of GFRP Composite

The Brinell hardness values for random glass fiber/polyester composite are shown in Figure 9. This figure showed the hardness of the composite increases from 31.5 BHN to 47 BHN with increasing of glass fiber percentages from 15 wt.% to 60 wt%). The maximum Brinell hardness of 47 BHN obtained at 60 wt.% glass fiber content. The hardness plotted with weight fiber fraction in Figure 9, we notices that hardness increase with increasing glass fiber content, Polymers has low hardness, the lowest value for unsaturated polyester resin before reinforcement was 25 BHN.

But this hardness value will greatly increase when the resin reinforced by glass fibers, due to distribution the test load on glass which decrease the penetration of test ball to the surface of fabricated composite material and by consequence raise the hardness of this material [13]. Increased glass fiber content resulted in increase in modulus of the composite, leading to a corresponding increase in the hardness of the composite.

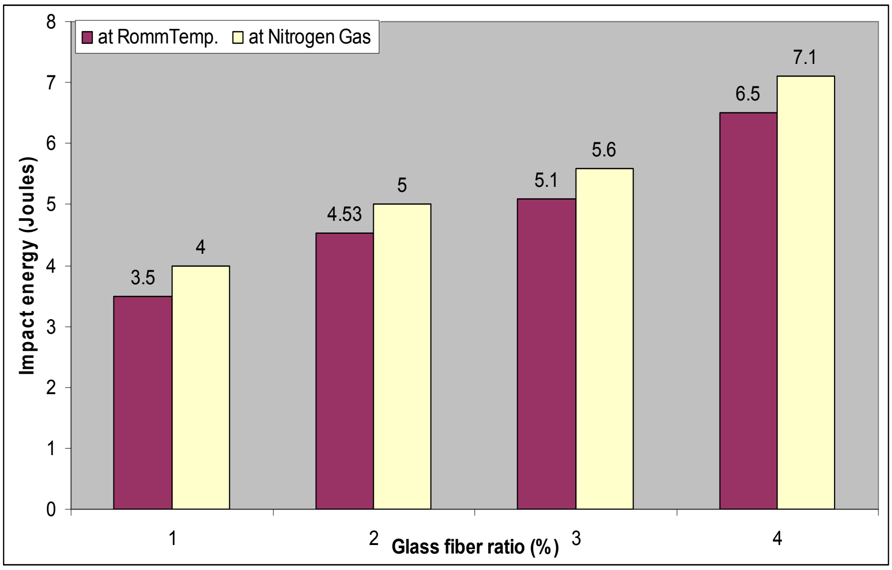


Figure 7. The impact energy chart of the glass fiber ratio from 15 wt.% to 60 wt.% at Room temperature and nitrogen gas at -10 ºC

(a) Before test (b) After impact test at room temp (c) After impact test at nitrogen gas at -10℃

Figure 8. The impact test specimens of the glass fiber ratio from 15 wt % to 60 wt % at (a) before test; (b) after impact test at Room temp; and (c) after impact test at nitrogen gas at -10°C.

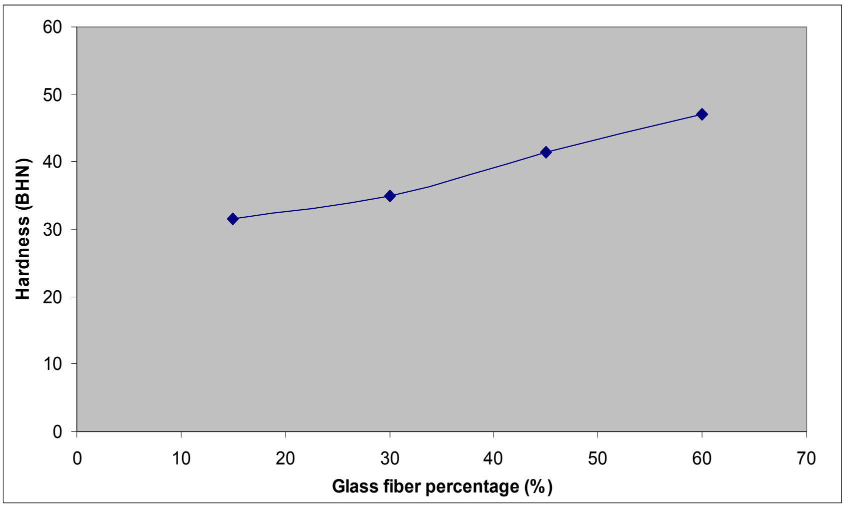


Figure 9. The variation of hardness values with glass fiber content from 15 wt. to 60 wt.%

4. Conclusion

This experimental investigation of mechanical behavior of glass fiber reinforced polyester resin composites leads to the following conclusions:

- This work shows that successful fabrication of glass fiber with random oriented reinforced polyester composites with different fiber contents is possible and very cost effective by simple hand lay-up technique.
- It was found that the tensile strength varies from 28.25 MPa to 78.83 MPa, flexural strength varies from 44.65 MPa to 119.23 MPa and impact energy at room temperature varies from 3.5 Joules to 6.50 Joules with the variation in glass fiber percentage from 15wt.% to 60 wt.%.
- The hardness value will greatly increase from 31.5 BHN to 47 BHN when the resin reinforced by glass fibers from 15 wt.% to 60 wt.%.
- The mechanical property such as tensile strength and flexural bending strength of polyester resin has been improved by a great extent due to the presence of glass fiber reinforcement.

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