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Effect of Glass Fibers Stacking Sequence on the Mechanical Properties of Glass Fiber/Polyester Composites

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Abstract

The objective of this work is to compare the mechanical properties including tensile, bending and impact properties between different glass fiber architecture reinforced polyester composites which are fabricated by a hand lay-up technique. The effects of stacking sequences of glass fibers consists of five layers which mainly are plain woven, short fiber, and sandwich layer glass composites on the mechanical properties of composites have been studied. The results showed that the tensile and bending properties of all different composite laminates are significantly higher compared to the neat resin. The plain woven glass reinforced polyester composites showed the highest values compared with other composite laminates. As the glass fiber mats a core are tightly packed and absorbs the impact stresses and distributes them evenly in the composites sandwich layer, the glass composites showed the highest value of impact strength compared with other composite laminates. Moreover, from SEM investigations, in these composites, there is an inverse relationship between the amount of delamination and the amount of hackles, and as the hackles increase the mechanical properties including tensile and bending of these composites are enhanced.

Keywords: Glass fiber; Polyester; Sandwich layer composites; Mechanical properties; SEM fracture surface; Delamination; Hackles

Introduction

The mechanical properties of a material including tensile, bending and different impact properties are a good indication mark of its durability, sustainability, and performance in proposed uses. Fiber-Reinforced Polymer (FRP) consists of high-strength fibers (glass, carbon, aramid, Natural fibers, etc.) embedded in a polymer resin matrix (polyester, epoxy, etc.). Recently, FRP has gained reputed reliability and performance in civil Engineering construction applications, including FRP bridge decks, internal FRP reinforcement for concrete and, strengthening of reinforced concrete [1-3].

Glass fiber reinforced polymer (GFRP) is a good alternative selection for the wood in boat building and in any purpose has a direct contact to the water or moisture due to the hydrophobicity of glass fiber with the water or moisture [4-6]. Moreover, glass fibers are actually used as short strand or longitudinal plain woven fibers to polymer matrix composites. This enables the fibers to be used in many applications and products such as hot pipes, water tanks, wind turbine blade and in the field of aerospace due to their good mechanical and impact properties [7-9].

Most of the recent research studies focused on the mechanical and impact properties of the continuous plain woven glass fiber reinforced polymer composites [7-10]. Moreover, the effect of the impactor shape and water immersion aging on the drop-weight impact responses of carbon reinforced epoxy and hybrid glass-graphite fibers/toughened epoxy composites has been investigated [11-13]. Seltzer et al. [14] find the energy absorption capability of hybrid glass/carbon composites was primarily influenced by the presence of z-yarns. This leads to the 3D composites dissipated over twice the energy than the 2D laminates, regardless of their individual characteristics such as fiber type, compaction degree, and porosity.

Some research articles focused on the investigation of the mechanical and impact properties of short glass fiber reinforced composites as reported [15,16]. Recently the authors [17] have studied the notch sensitivity of short and 2D plain-woven glass fibres reinforced with unsaturated polyester and epoxy matrix composites. However, there is a lack of published data on a comparison between the mechanical properties of different glass fiber architecture reinforced polymer composites. Therefore, the objective of this work is to compare the mechanical properties including tensile, bending and impact properties between different glass fiber architecture reinforced polyester composites which include plain woven, short fiber strand, and sandwich layer glass composites.

Experimental Procedures

Materials

Glass chopped mats and plain woven glass fiber with a density of 330 g/m^2 and 430 g/m^2 respectively were used as reinforcement and unsaturated polyester resin was used as a polymer matrix. Polyester resin was used along with the accelerator (Cobalt Octoate) with 0.3 wt.% and catalyst MEKP (Methyl Ethyl Ketone Peroxide) with 0.5 wt.%. All of these materials were obtained from Al Ahram Company, Export and Commercial Agencies, Egypt.

Preparation of the composites

Glass fiber reinforced unsaturated matrix was fabricated using traditional hand lay-up method. In this method, the polymer resin after mixing with the accelerator and the catalyst was poured on the mold plate and the first layer of glass mat was impregnated with the resin. The second layer of resin was then poured to impregnate the second layer of

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the glass using a roller or brush to achieve a thorough wet out of the fibres with resin. These steps were repeated to the desired number of layers and finally the bubbles were removed by using a compression roller to compress the mat and squeeze air bubbles and excess resin from the laminates. The fiber volume fraction of the composites was determined according to the ignition loss method according to ASTM D2548-68. Five layers of plain woven glass composites with a thickness of 2.7 mm were laminated with 32.1 vol.% and was abbreviated as PWGC and five layers of chopped glass mats with a thickness of 4.2 mm were laminated with 14.3 vol.% and was abbreviated as STGC. Moreover, the sandwich layer composites material of a 3 mm thickness were fabricated with 18.3 vol.% total volume content and was abbreviated as SLGC. Plates of neat resin with a 2.3 mm thickness were fabricated for comparing the different mechanical properties of different composites with those of neat resin. After curing at room temperature for 24 hours under compression weight, the composites were post cured at 100°C (for 2 hours) and were left to cool in the oven. Specimens for all the tests were cut from the cured composite plates by water jet cutting technique.

Mechanical characterization

Tension test: Tension tests were carried out according to ASTM D 3093/ D3039 M standard with sample dimensions of 250 × 25 × t mm using emery cloth to prevent gripping damage. The measurements were done using a universal testing machine at room temperature.

Flexural test: Three-point bending tests were also conducted using the same machine according to ASTM D 790-03 with sample dimensions of 220 × 25 × t mm and the span to depth ratio was 60:1. Three specimens were prepared and tested for each type of composites.

The flexural strength (σf) was calculated using:

$$\sigma f = \frac{3PL}{2bd^2} \quad (1)$$

Where, P is the load (N), L is the length of support span (mm), b is the specimen width (mm), and d is the specimen thickness (mm). The flexural modulus (Ef) was calculated using:

$$Ef = \frac{L^3 m}{4bd^3} \quad (2)$$

Where, m is the slope of the initial straight line portion of the load-deflection curve.

Izod impact test: Izod impact tests on unnotched specimens with dimensions of 62 × 12.7 × t mm were done according to ASTM D 256-05 using a pendulum impact tester.

Results and Discussions

Tension test

The tensile strength of the composite is influenced by the strength and modulus of the fibers [18]. The variations of the tensile strength for different composite stacking sequences are shown in Figure 1. It is clearly indicated that the tensile strength of all different composite laminates are significantly higher compared to the neat resin. The tensile strength of PWGC, SLGC and STGC laminates is about 28.7, 12.2, 10 times, respectively higher compared to that of the neat resin. Moreover, it was found that there is a sharp increase in the tensile strength of PWGC laminate compared to STGC, SLGC. The increase in the tensile strength of PWGC composite is attributed to that the 2D plain woven glass fibers are stronger and stiffer than the short fibers due to the greater extensibility of glass fibers during the tension test. The tensile fracture surface of different laminates is shown in Figure 2 which indicates

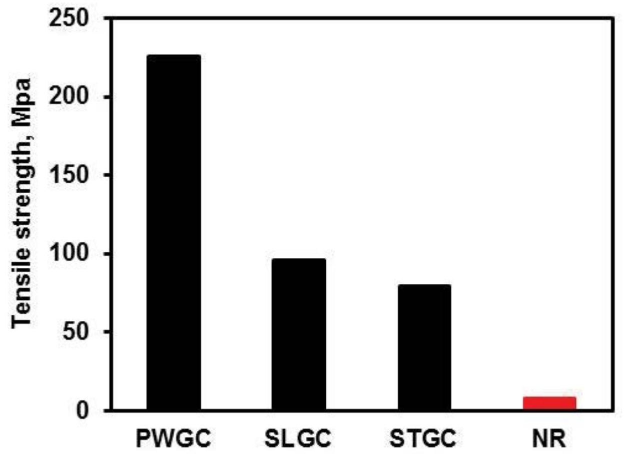

Figure 1: Tensile strength of different laminates.

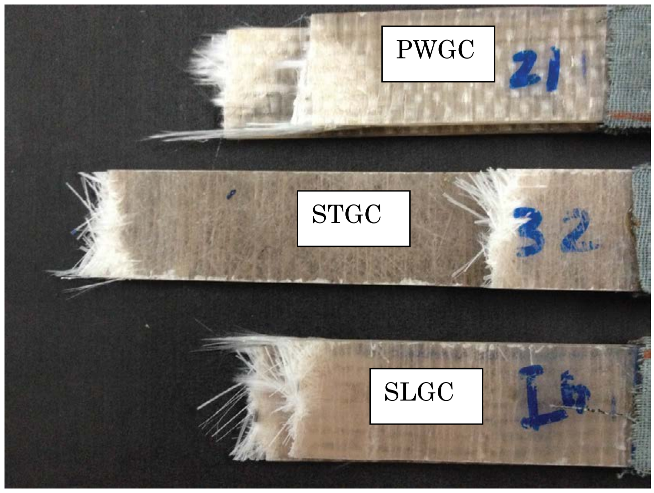

Figure 2: Tensile fracture surface of different laminates.

that failure in PWGC laminate is governed by extensive fiber pull out and delamination, whereas in STGC laminates, the failure shows a pull out of fibers and little delamination as shown in the white areas in Figure 2. On the other hand, SLGC hybrid laminate shows mixed failure modes where extensive fiber pull out with little delamination is observed in the plain woven skin layers and little fibers pull out in the short glass composite in the core of the laminate as also shown in white area in Figure 2. Hybrid laminate of jute and glass typically delaminate at the interface when loaded in tension as reported [17].

Figure 3a1, 3b1 and 3c1 illustrates SEM of failed specimen under tensile loading for different types of composites. It can be observed that the hackles which are the pullout fibers bonded to the matrix which is an indicator of the strength of the bonding of the surface of fibers to the matrix. These hackles are significantly clear in PWGC composites and the hackles is higher than that of SLGC and STGC composites and the hackles is the least in STGC as shown in Figure 3a1, 3b1 and 3c1. As a result of that the tensile strength of PWGC is higher than that of SLGC and STGC composites, respectively as shown in Figure 1. From these results, the delamination of matrix is more severe in STGC than SLGC composites and the delamination in SLGC is higher than that of PWGC composites as shown in Figure 3a2, 3b2 and 3c2.

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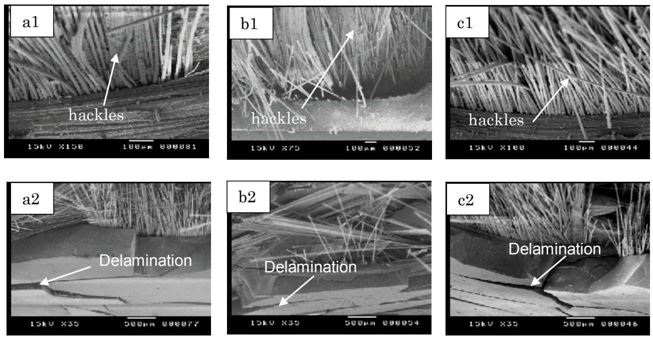

Figure 3: SEM micrographs of tensile test specimens for different stacking sequences (a1, a2) PWGC, (b1, b2) SLGC, and (c1, c2) STGC.

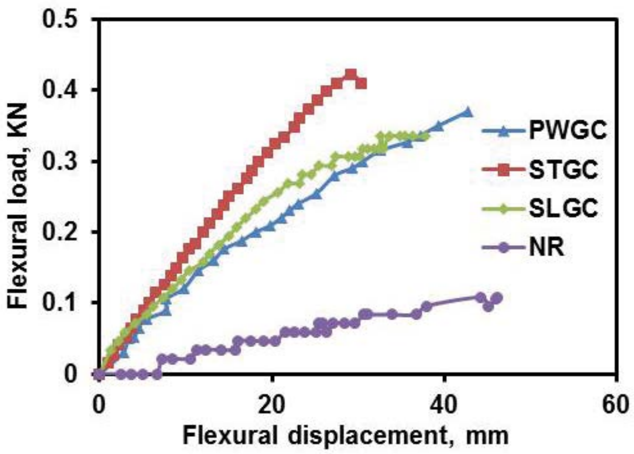

Figure 4: Load-displacement curves of different laminates.

Flexural test

The flexural load-deflection diagrams for various composites with different laminate stacking sequences are shown in Figure 4. Non-linear behavior is shown in all curves and the point of deviation from linearity is the indication of failure initiation due to development of crack on the tension side on the back side of the flexural loading. Figure 4 indicates the flexural strength and modulus variations of the composites with different stacking sequences. It is observed that the flexural strength and modulus of all different composite laminates are significantly higher compared to the neat resin as shown in Figure 5a. The flexural strength of PWGC, SLGC and STGC laminates was around 3.6, 2.4, 1.7 times higher, respectively, compared to that of the neat resin as shown in Figure 5a. The flexural modulus variations of PWGC, SLGC, STGC was also around 2.9, 1.9, 1.1 times higher, respectively, compared to that of the neat resin as shown in Figure 5b. Moreover, it can be seen that the flexural strength and modulus variations are comparatively higher than those of STGC and SLGC laminates as also shown in Figure 5. The cracks in the flexural tests always initiate at the tension side of the specimen (opposite side of loading) and slowly propagates in an upward direction through the whole thickness towards the loading (compressive) side until the failure of the composites occurs. Therefore, the bending properties depend on the strength of the tension surface which is the main loaded bearing component. As a result of that the flexural strength and modulus of PWGC and SLGC is always higher than those of STGC.

Similar results in jute sandwich composites were reported [19] where the flexural properties of short jute-polyester composites with plain woven jute fibers as skin layers are higher than those without skin layers. Figure 6 shows the flexural fracture of different composites through the whole thickness. The fracture surface of PWGC and SLGC at the tension side was not fully fractured at the skin layers due to the high strength of the glass cloth skin layers however; the crack is clear at the tension side of STGC as shown in Figure 6. This result reflects the major role of the skin layers to improve the flexural properties of the composites.

In summary, in these composites the tensile properties are indicator of the bending properties and in these composite materials it can be stated that there is inverse relationship between the amount of delamination and the amount of hackles, and as the hackles increase the mechanical properties including tensile and bending of these composites are enhanced.

Impact test

Figure 7 shows the impact strength of the composites with different stacking sequences. It is can be seen that the impact strength of all different composite laminates are significantly higher compared to the neat resin as has been shown in Figure 7. The impact strength of SLGC, PWGC and STGC is around 55.9, 52.6, 34.4 times higher, respectively compared to that of the neat resin as shown in Figure 7. Moreover, it is interesting to observe that the impact strength of SLGC laminate is higher than that of STGC and PWGC laminates as shown in Figure 7 and this trend is different trend to the tension and bending results as has been shown in Figures 1 and 5. This phenomenon based on the glass fiber stacking sequence of SLGC which consists of two layers of plain woven glass fibers as skin layers and three short glass fiber mats as

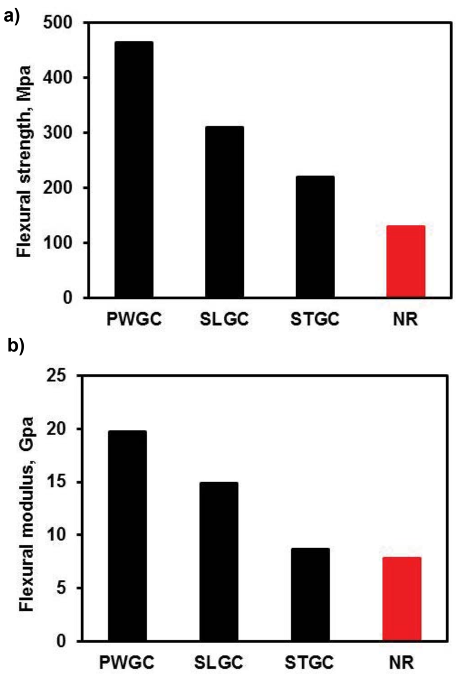

Figure 5: Flexural properties of different laminates (a) flexural strength (b) flexural modulus.

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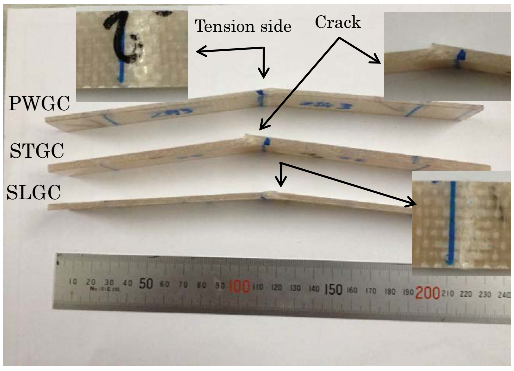

Figure 6: Flexural fracture surface of different laminates.

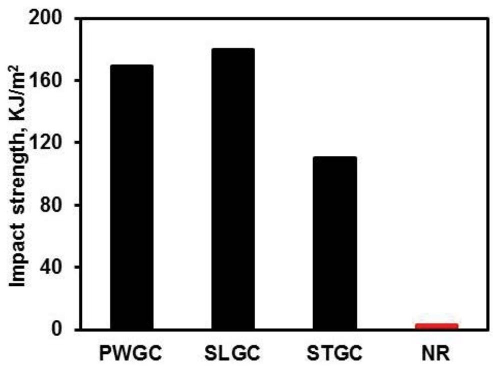

Figure 7: Impact strength of different laminates.

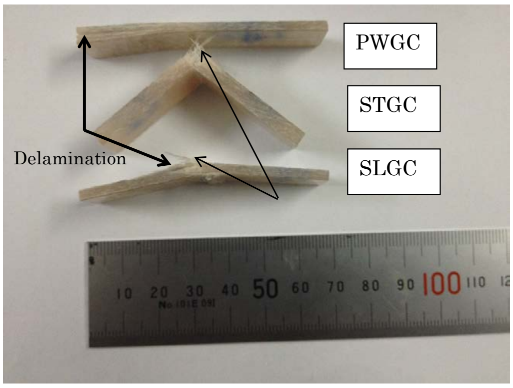

Figure 8: Impact fracture surface of different laminates.

a core as has been explained and reported for jute and palm sandwich composites [20]. This structure gives high chance to absorb more energy than the other structures (PWGC and STGC). Glass fiber mats in the core are tightly packed and the high strength glass fibers in the outer layers are able to withstand the tensile stress while the glass fiber mats core absorbs the impact stresses and distributes them consistently in the composites. As a result of that the impact strength of SLGC laminate is higher than that of STGC and SLGC laminates. Figure 8 displays the impact fracture surface of the different laminates which indicates that the failure in SLGC laminate is governed by extensive delamination with fiber pull out from the glass core which consumes the impact energy and therefore SLGC laminate displayed the highest impact strength compared to those of the other laminates.

However, PWGC composite laminates showed extensive delamination without fiber pull out and therefore PWGC laminate displayed less impact strength than that of SLGC laminate. On the other hand, the failure in STGC laminates is almost complete with fiber pull out and delamination due to the absence of glass skin layers as shown in Figure 8. Consequently, SLGC laminate displayed the least comparable impact strength compared to those of the other composite laminates.

Conclusion

The effect of glass fiber stacking sequence on the tensile, flexural and impact properties of glass fiber reinforced polyester composites, have been experimentally studied and evaluated. From the results of this study, the following conclusions can be summarized as the following:

1. The mechanical properties including the tensile and bending properties of all different composite laminates are significantly higher compared to the neat resin and the PWGC laminate showed the highest tensile and bending properties compared to STGC and SLGC laminates.

2. The tensile fracture surface of different laminates indicates that failure in the PWGC laminate is governed by extensive fiber pull out and delamination, whereas in the STGC laminates, the failure shows pull out of fibers and little delamination.

3. SLGC hybrid laminate shows mixed tensile failure mode where extensive fiber pull out with a little delamination is observed in the skin layers and little fiber pull out in short glass fibers in the core of the laminate.

4. The impact strength of all different composite laminates is significantly higher compared to the neat resin.

5. The impact failure of the SLGC laminate is governed by extensive delamination with fibers pull out from the glass core which consumes the impact energy. Consequently, the SLGC laminate displayed the highest impact strength compared to those of other laminates.

6. The hackles are significantly clear in PWGC composites and the hackles is higher than that of SLGC and STGC composites and the hackles is the least in STGC.

7. In these composites, there is an inverse relationship between the amount of delamination and the amount of hackles, and as the hackles increase the mechanical properties including tensile and bending of these composites are enhanced.

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