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Short Paper

# THE EFFECTS OF FIBER ORIENTATION ON MECHANICAL PROPERTIES OF POLYMER MATRIX COMPOSITES

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## ABSTRACT

This work has studied the effect of fiber orientation on mechanical properties of some polymer matrix composites (PMCs).Composite samples using polypropylene as the polymer matrix and fiber glass as the reinforcement were used. The designation adopted for this experiment was" GFRP – O" which represents glass fiber reinforced plastic while "O" (orientation) represents the direction of laying the glass fiber in the polymer (polypropylene) matrix. Unidirectional, Bidirectional, and Random orientation were used. Un-reinforced plastic (URP), which was the virgin polypropylene served as the control. The melting process was carried out in a muffle furnace using open mould casting process. The results showed that the orientation of the fibers significantly affects the mechanical strength of the reinforced composite as well as the direction of maximum strength.

**Keywords**: *Fibre orientation, glass-fibre reinforced composites, polymer matrix composites, polypropylene.*

## 1. INTRODUCTION

Modern technology requires materials with unusual combination of properties that cannot be met by the conventional metal alloys, ceramics and polymeric materials. This is especially true for materials that are needed for aerospace, underwater and transportation applications (Fukuda.et al, 1997). Material property combinations and ranges are now being extended by the development of novel composite materials (Callister, 1997).

A composite material is a heterogenous solid consisting of two or more different materials that are mechanically or metallurgically bonded together. Each of the various components retains its identity in the composite and maintains its characteristic property and structure. The composite material however generally possesses characteristic properties such as stiffness, strength, weight, high temperature performance, corrosion resistance, hardness or conductivity that are not inherent in the individual components parts. (De Garmo et al, 1997).

Polymeric materials according to Bello (2001) are essentially subjected to some form of applied forces or the other during fabrication or during use of the finished product. The fabrication of an article from a polymeric material for example, the molding of thermoplastics or spinning to a fiber from the melt, all involve deformation of the material by applied forces (Chou et al, 1989). The finished products in providing service must inevitably be subjected to stresses in one form or the other. For these reasons, it is important to understand the effect of such applied forces or stresses on the properties of polymers (Bogdanovich et al,1996).

One of the most popular types of composite materials is the one with fiber-reinforced composite geometry (Wolf et al, 2005). This consists of fibers in a matrix. The fibers may be short or discontinuous and randomly arranged, continuous filaments arranged parallel to each other, in the form of woven rovings (collection of bundles of continuous filaments) or braided (Lubin, 1982). Fiber-reinforced composites are materials of high specific strength or modulus. This is one of the more important type of composite from engineering point of view (Higgins, 1994). Reinforcing fibers can be made of metals, ceramics, glasses, or polymers. The modulus of the resulting composite, matrix and the reinforcement, is governed by the rule of mixture when measured along the length of the fiber as:

$$E_c = E_f V_f + E_m V_m$$

Where $E_c$ = modulus of the entire composites along the length of the fiber;

$E_f$ = modulus of the fiber along the length of the fiber;
Vf = volume percent occupied by the fibers;
$E_m$ = modulus of the matrix (independent of direction);

$V_m$ = volume percent occupied by the matrix $(V_m = 1 - V_f)$

This work attempts to determine the effects of fiber orientation on the mechanical properties of some polymer matrix composites. It also compares the mechanical properties of unreinforced thermoplastics with fibre reinforced thermoplastics.

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## 2. MATERIALS AND METHODS

The materials and equipment used for this experiment were virgin thermoplastic granule; fiber glass, metal mould, melting furnace, weighing balance, vernier caliper, drilling machine, hand file, tensometer and impact tester.

Four sets of specimens A, B, C and D were prepared. Sets A, B, and C (reinforced) were a combination of virgin polypropylene and fiber glass while set D (unreinforced) served as the control.

The samples were produced by laying the orientating fiber in a chosen direction in the matrix of the composites. Weighed virgin polypropylene is first poured into a metal mold forming the first layer, followed by laying of weighed fiber glass. Polypropylene is again poured on the fiber forming a second layer of polypropylene granules. This was followed by a second layer of fiber glass and the process was continued until the fourth layer of fiber was obtained.

Sample sets A contained fibers laid in unidirectional (longitudinal) manner. In samples sets B, the fibres were bidirectional while they are randomly oriented in samples C. The sets of molds were placed into the furnace for melting of the material and heated until they attained the melting temperature which gave a rubbery state ranges from 180 – 230°C. The samples were not allowed to melt beyond the rubbery state to avoid burning off the polypropylene material. After the melting, they were removed from the furnace and allowed to cool and solidify in air. The samples where then removed from the mold and final finishing was done to shape them to standard dimensions for tensile and impact tests. Many sets of the test samples were then subjected to tensile and impact tests using the calibrated Monsato Tensometer and the Standard Izod impact testing machines respectively. The average results obtained for the various loadings are as shown below.

## 3. RESULTS

*Table 1: Tensile Test, Elongation and Toughness Data*

| Sample | Modulus of elasticity ($N/mm^2$) (Average) | Ultimate tensile stress (N/mm2) (Average) | Average Elongation, δ (percent) | Toughness (J) (Average) |
|---|---|---|---|---|
| GFRP-U | 8376.5 | 20.2 | 0.25 | 4.73 |
| GFRP-B | 6107.9 | 17.8 | 0.30 | 5.40 |
| GFRP-R | 5874.5 | 17.1 | 0.31 | 5.36 |
| URP | 3625.24 | 15.225 | 0.45 | 2.43 |

*Where :*

*GFRP-U: The code adopted for composite with unidirectionally laid fibers*

*GFRP-B: The code adopted for composite with bidirectional fibers*

*GFRP-R: The code adopted for composite with randomly oriented fibers*

*URP: The code accepted for unreinforced plastic*

## 4. DISCUSSION OF RESULTS

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the composite and different fibers have different properties and so affect the properties of the composite in different ways. The primary function of the fibers is to carry the loads along longitudinal directions. The results of the analysis of both the reinforced and unreinforced samples are as shown in Table 1 and Figures 1 to 3.

The results of tensile test carried out on the reinforced and unreinforced samples are shown in Table 1. An increase in UTS of the reinforced sample as compared with the unreinforced matrix was observed as graphically shown in Figure1. This can be attributed to increase in modulus of the matrix material due to the presence of fiber. Also the strong covalent bonds along the fiber's length give

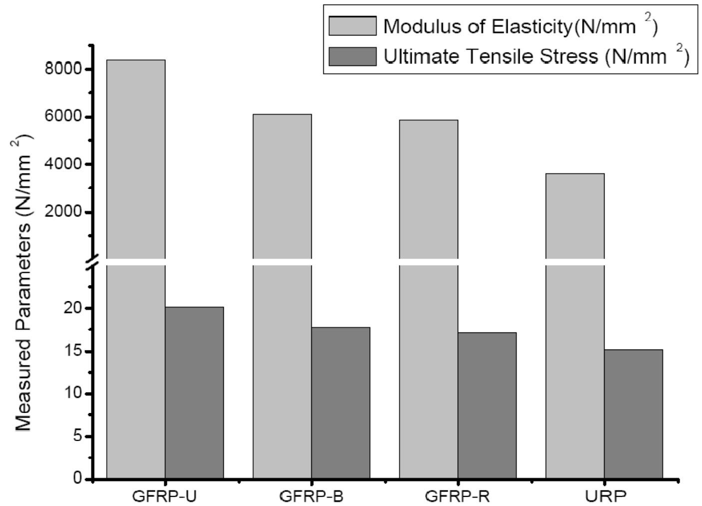


*Fig. 1: Histogram of the tensile test data*

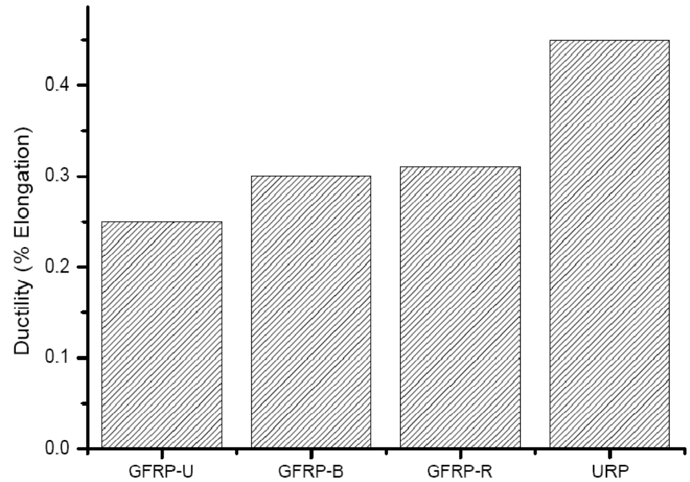


*Fig 2: Histogram of the average ductility*

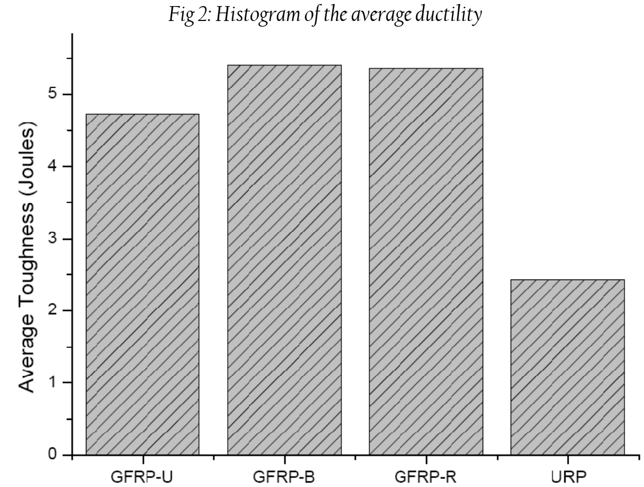


*Fig 3: Histogram of the absorbed impact energy*

them a very high modulus in this direction (as could be seen in figure 1). The addition of fiber (in different orientations) to the ductile polymer matrix has resulted in a stiffer composite. The tensile test results of the unreinforced samples showed a decrease in ultimate tensile as compared with the reinforced samples. The interfacial bond strength plays a pivotal role in determining the properties of the composite. The strong bond between matrix and the fiber produces high stiffness and strength but often a low resistance to fracture (brittle fracture), meaning that crack will propagate though the brittle fibers with little hindrance. As a load is applied to the composite, the matrix and the fiber will experience different tensile strains because of their different moduli and in the regions of fiber ends, the strains in the fiber will be less than in the matrix. As a result of this strain difference, shear stresses are induced around the fibers in direction of fiber axis and the fiber is stressed in tension. The tensile stress is zero at fiber ends and a maximum at the center of the fiber. Conversely, the shear stress is maximum at fiber ends and it falls to almost zero at center of the fiber. It is this variation of shear stresses (shear effect) that is responsible for the build-up of tensile stresses in a fiber. In general terms, as the applied stress increases, the elastic limit of the matrix is passed and it yields in shear at or near the fiber surface. And as the straining continues, the plastics zones (or regions of interface failure) develop at fiber ends and grow inwards towards the middle. Near the centre section of the fiber, the strains in the fiber and matrix are equal and there is no transfer of load in this region (because there is no relative displacement between them), the fiber is approximately constant. As the composite (reinforced and unreinforced) is strained further, the plastic zones grow inward and the stress increases.

The result of percent elongation carried out on the reinforced and unreinforced samples was shown in Figure 2. It was observed that the percent elongation (or ductility) of the reinforced samples was lower (lower ductility) than that of the unreinforced samples. In the ductile matrix (associated with large strain), a strong interfacial bond is important since the fibers usually bear most of the loads in the matrix. The reduction in the ductility of the reinforced samples can be attributed to the addition of fiber. This is because the fibers cannot strain as much as the matrix. The change in percent elongation in the unidirectional, bidirectional and randomly reinforced sample was observed to have some similarities as shown in Figure 2. This observation can be explained to be due to the reinforcement involved where the flow of materials in the mold and changes in fiber orientation throughout molding are inevitable.

The result of the impact test carried out on the reinforced and unreinforced samples is shown in Figure 3. It was observed that the reinforced samples were tougher (higher impact strength) than the unreinforced sample. The higher values in the impact strength possessed by the reinforced sample can be attributed to different orientation of the fibres which seems to pin down movement of dislocations. For instance the samples with bidirectional and the randomly oriented reinforced fibres showed considerable or improved impact strength in contrast with the unreinforced samples which have the lowest values. The impact strength of the unidirectional fibre samples are lower than those of the GFRP-B and GFRP-R samples and this can be attributed to the directional or isotoropic nature of the fibres. In conformity with general trend in properties of materials, the tougher samples were observed to have higher modulus of elasticity and ultimate tensile strengths, however they exhibited low ductility.

## 5. Conclusion

The general mechanical properties of the polymer matrix composite (PMCs) are better in the reinforced than the unreinforced polymer. The addition of high strength low stiffness glass fibers to the ductile polymer matrix plays a significant role in the improvement of the mechanical properties. These properties depend not only on the glass fiber reinforcement used but also on its orientation.

Improved stiffness and strength of the reinforced material was observed compared to the unreinforced material. Unidirectional orientation of the fiberglass was observed to have highest strength and modulus while the random orientation had the lowest. Orientation thus determines the mechanical strength of the composite and the direction in which that strength will be the greatest.

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