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Polycarbonate/Short Glass Fiber Reinforced Composites – Physico-mechanical, Morphological and FEM Analysis

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ABSTRACT: A series of polycarbonate (PC), reinforced with short glass fiber (SGF) in different weight ratios viz., 10, 20 and 30%, has been fabricated by melt mixing with the aid of a twin screw extruder, in order to study the influence of glass fiber reinforcement on PC. The test specimens were fabricated as per ASTM standards and evaluated for their physico-mechanical properties. Incorporation of short glass fiber to PC enhances the tensile behavior of the composites significantly. The morphological behavior of PC composites has been performed using a scanning electron microscope (SEM). The experimentally measured tensile results were used to estimate the stress distribution in the bearing component, made of glass fiber reinforced polycarbonate (GFR-PC) composite, using three-dimensional finite element analysis (FEA).

KEY WORDS: Polycarbonate, short glass fiber, composites, mechanical properties, morphology, finite element analysis.

INTRODUCTION

THE DEMANDS OF today's larger, faster and light weight automotives have led to new requirements for metals, plastics and honeycomb structures apart from the structural units [1]. The transmission and supporting units play a significant role in performance,

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durability and weight reduction. Polymer composites and engineering polymers play a major role in the automotive sector due to their light weight, high strength to weight ratio and easy fabrication [2]. For the industry, the latest possibilities afforded by the use of glass fiber reinforced polymer (GFRP) composites in place of traditional materials means considerable savings in mass and money can be achieved [3].

The most widely known and recognized reinforcing fiber in use today is glass fiber. However, carbon and polyaramid fibers are also finding ever increasing usage. The presence of reinforcing glass fibers lends added strength and stiffness to the final composite [3], permitting applications not normally associated with resinous plastics. The applications of any new class of polymer composite depend mainly upon the characteristics of that composite. These include behavior at high temperature, maximum stress the composite can withstand, fatigue characteristics, impact strength, wear resistance, corrosion behavior, load bearing, moldability and other machinability parameters [4].

Polycarbonate (PC) is considered one of the most important classes of polymers and is extensively used in automobile, structural and many engineering applications [5,6]. Fillers are added to PC to improve handling, molding, dimensional stability and to reduce the overall cost of the system [5,6]. Wood [7] estimated that PC is likely to pass nylon as the largest volume engineering thermoplastic, because of the excellent toughness, high thermal resistance, glass-like clarity, and good processabilty of PC.

Mikio and Katsuji [8] have studied the PC/ABS blends for improving the poor weld line strength. As a result, it was found that a specific composition of ABS and an additive could considerably improve the weld line strength. Electron microscopic photographs and physical properties showed that the specific additive improved the compatibility of PC and ABS resins. Sanjib [9] has studied the failure analysis of polymer composite using the finite element method (FEM), in which he considered the initiation of damage (ply failure) of polymer composite under static loading. He has adopted the first-order shear deformation theory and tensor polynomial failure criteria. Okamoto has investigated the impact resistance of glass fiber reinforced PC using polydimethylsiloxane (PDMS) block copolymer [10]. Very recently, the hydrolytic stability of PC/GF composites has been reported by Jancar [11].

Therefore, considering the importance of composite products for automobiles and other engineering applications, in the present study the authors are interested in mechanical and load bearing properties of the composites; they have reported the physico-mechanical properties, morphological behavior and FEM of short glass fiber reinforced PC composites at different weight percentages glass fiber contents, viz., 10, 20 and 30% by weight.

EXPERIMENTAL

Material

Polycarbonate (PC) was obtained from M/s. SRF, New Delhi, India. The PC T_m is 220–230°C and density is 1.13 g/cc. E-glass short fiber with length 4 mm, was used.

Fabrication of Composite

PC was pre-dried at 105°C for 24 hrs prior to compounding. The short glass fiber is incorporated into PC with different weight ratios viz., 10, 20, and 30% by using twin screw extruder at 280°C (M/s. Brakes India Limited, Nanjangud). The PC is compounded with short glass fiber in a Berst off Extruding machine with l/d ratio 1:18 of capacity 100–120 kg/hr. The machine consists of nine nozzles. Temperature zones maintained at each nozzle are different and lie in the range 245–260°C. The maintained vacuum, torque and speed of the twin screw extruder are 17 Hg/mm, 50–55 Nm and 280–300 rpm,respectively.

The specimen for mechanical properties as per ASTM method has been fabricated using a Windsor Sp80DD, injection moulding machine with 80 ton capacity. The screw speed was 90–100 rpm, nozzle temperature was 240°C, and different zone temperatures were 230, 220 and 210°C. The pre-dried filled PC pellets were injected at a pressure of 70 kg/cm^2 for tensile specimens.

Techniques

The specific gravity and surface hardness of the composites were measured using ASTM D 702 (electrical balance) and ASTM D 785, respectively. The tensile behavior was measured as per ASTM D-638 standard using J J Lloyds universal testing machine, USA, model Z20, 20KN load and a crosshead speed of 5 mm/min.

The surface morphology of short glass fiber reinforced PC composites has been measured using a Leo 435 VP electron probe micro analyzer of Sl. No. 320. The gold-coated composite specimens were scanned for secondary electron image. The morphology has been recorded for both surface and tensile fractured specimens. Finite element analysis (FEM) was performed using ANSYS 5.5.

RESULTS AND DISCUSSION

Physico-mechanical Properties

For the selection of material for space or marine applications, the density of the material plays a very important role. Systems having a high specific strength and specific modulus are acceptable for engineering applications. The measured physico-mechanical properties of GFR-PC are given in Table 1. The specific gravity values of GFR-PC lie in the range 1.27–1.31. The specific gravity is higher for GFR-PC than for neat resin casts. The increase in the specific gravity with increase in short glass fiber content is due to an increase in the high density short glass fiber in the PC matrix. The surface hardness values of GFR-PC lie in the range 87–93 Shore D. A drastic percentage improvement in the hardness value of composites was noticed with glass fiber loading and the percent improvements in dimensional stability of the composites falls in the range 24.3–30%.

Table 1. Experimental results of short glass fiber reinforced PC composites.

Content of short glass fiber in PC (wt. %)	Specific gravity	Surface hardness (shore D)	Impact strength (J/m)	Tensile strength (MPa)	Youngs modulus (MPa)
10	1.27	87	66.5	80.0	1600
20	1.29	90	37.2	98.1	2134
30	1.31	93	31.5	107.4	2966

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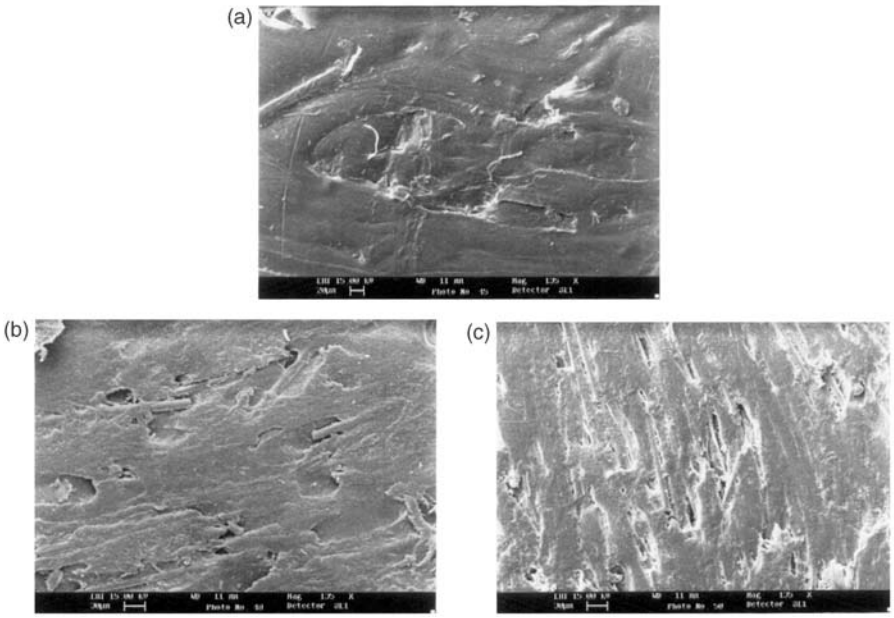

Figure 1. *Surface view of polycarbonate with (a) 10%, (b) 20% and (c) 30% short glass fiber.*

From Table 1 it was noticed that the impact strength values of GFR-PC lie in the range 66.5–31.5 J/m. The decrease in the impact strength was observed with increased glass fiber amount; this is due to the lower critical length of glass fiber. The tensile strength increases from 80 to 107 MPa with increase in fiber content from 10 to 30% by weight. The tensile properties of the short fiber composites are controlled by the fiber volume fraction, fiber aspect ratio, fiber strength, fiber orientation and the degree of adhesion between the fibers and the matrix. Percent improvement in tensile strength by 29.2, 58.3, and 73.4% for 10, 20, and 30% short glass fiber filled PC composites, respectively, were observed. It may be concluded that the improvement in the tensile strength, strain at break, and Young's modulus has been obtained with incorporation of glass fiber into PC matrix. The increased strain value at the break point improved the interface, allowing more ductile behavior.

The surface morphology of PC composites has been performed using a scanning electron microscope (SEM). To probe the adhesion between PC and short glass fiber, the SEM photomicrographs of surface and brittle fractured composites are shown in Figures 1(a)–(c) and 2(a)–(c), respectively. Figure 1 does not reveal much data on the distribution of second phase of the composites. The fractured surface morphology of PC composites clearly indicates fiber pullout (Figure 2) and breakage of fibers. As a result, the composite specimen reinforced by glass fiber shows some regions characterized by weak interfacial adhesion and some holes as a consequence of the fiber pullout phenomenon. From SEM photomicrographs it was noticed that the fiber length was not reduced drastically. The photomicrographs also revealed the uniform distribution of short glass fiber in the matrix of PC.

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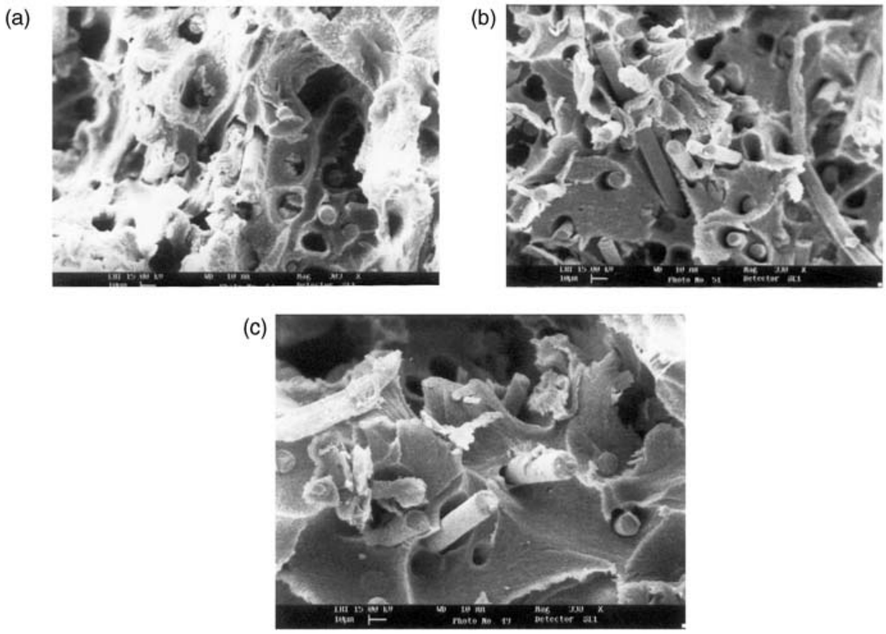

Figure 2. *Fractured surface view of polycarbonate composites with (a) 10%, (b) 20% and (c) 30% short glass fiber.*

Finite Element Analysis of GFR-PC

FEM is used to estimate the stress distribution theoretically, by using experimental tensile values in the bearing component made of GFR-PC. The finite element analysis has been carried out by a three-dimensional, 20-noded brick element. The three-dimensional mesh gives higher values for the load carrying capacity, assuming the bearing constrained in all degrees of freedom (DOF) except rotation in the X direction [12,13]. Stress distribution in the bearing component for GFR-PC is shown in Figures 3(a)–(c). The red zone in the figure represents the maximum stress in the bearing component, which is sensitive to failure. From FEM results the maximum allowable pressure was calculated, and the obtained results are given in Table 2. The finite element analysis shows that the load carrying capacity of the bearing component increases with increase in percentage of glass fiber composition. The above conclusion is true for any dimensions of the bearing. The theoretically predicted values of maximum allowable pressure by FEM follow the same trend of maximum stress.

CONCLUSION

In the present work, an experimental study has been made to investigate the effect of short glass fiber reinforcement on polymer composites. It offers a combination of properties not found in other materials. Tensile results revealed a drastic improvement in tensile strength and modulus of PC composites with an increase in glass content. Significant reductions in the impact strength and marginal enhancement in dimensional

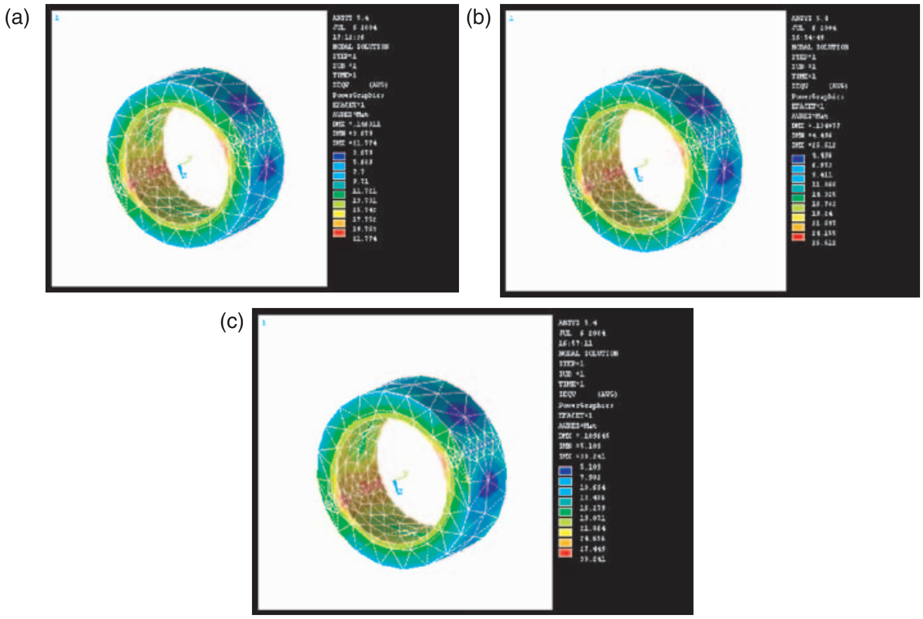

Figure 3. Stress distribution for polycarbonate composites with (a) 10%, (b) 20% and (c) 30% short glass fiber.

Table 2. Maximum allowable pressure for short glass fiber reinforced PC composites obtained from FEA.

Content of short glass fiber in PC (wt. %)	Max. stress at break (N/mm^2)	Allowable pressure (N/mm^2)	Max. allowable pressure from FEA (N/mm^2)
10	80.07	8.70	21.77
20	98.12	10.53	26.61
30	107.49	12.09	30.25

stability of the composites were also noticed. Fiber pullout and fiber breakage was confirmed by SEM micrographs. The finite element analysis shows that the load carrying capacity of the bearing component increases with increase in percentage of short glass fiber composition. The above conclusion is true for any dimensions of the bearing.

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