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INFLUENCE OF SiC FILLER ON MECHANICAL PROPERTIES OF GLASS FABRIC REINFORCED POLYESTER COMPOSITES

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ABSTRACT

In this study, E-glass fabric reinforced polyester composite filled with two levels (2.5 and 5 wt %) of SiC particles were prepared by wet hand lay up technique. The mechanical properties were evaluated by tensile, flexure and hardness tests. Mechanical tests showed that the tensile and flexure strength of glass fabric reinforced polyester increase with increase of SiC filler. The glass fabric reinforced polyester filled with 5 wt. % SiC exhibited drastic improvement in the mechanical properties. Hardness of the SiC filled composites also increased from 94 to 107, which is highest for 5 wt. % SiC. The morphology of fractured surface features was described using scanning electron microscopy (SEM). The failure modes of the tested specimens were evaluated and showed good agreement with the literature.

Keywords: Glass-Polyester Composite, SiC filler, Wet hand lay up technique, Mechanical properties, Morphology of fractured surfaces

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1. Introduction

Composite materials, particularly fiber reinforced polymeric composites (FRPCs) have emerged as an important material system for automotive and aerospace applications due to the possibility of reducing weight, design flexibility, ease of manufacturing and improved mechanical properties. Commonly used fibers are glass, carbon or aramid introduced in to a polymer matrix medium. These composites made of such dissimilar materials, not only retain the high strength, stiffness and thermal resistance, but also show enhanced impact strength, fatigue resistance and dimensional stability [1, 2]. One of the well known composites that is commonly used is glass reinforced polymer material. The reasons for the widespread use of glass fibers in composites, both in the past and present include competitive price, availability, good handleability, ease of processing, high strength, and other acceptable properties. Unsaturated polyester is a family of thermoset with many uses such as engine parts, covers, electrical terminal boxes, boats, tanks and so on [3].

Automotive and aircraft components [4] fabricated with FRPCs present tight requirements in service and they can withstand mechanical damages during utilization. Kim et al. [5] reported that the damage could occur during the fabrication process, transport, storage and maintenance. FRPCs are susceptible to mechanical damages when they are subjected to effects of tension, compression and flexure, which can lead to interlayer delamination. The increase of external load favors the propagation of delamination through the interlayer leading to the catastrophic failure of the component. Another work reported by Unal and Mimaroglu [6] evaluated mechanical properties of Nylon-6 by adding one or combination of more than one filler by varying the weight %. They observed that the tensile strength and modulus of elasticity of Nylon-6 composites increased with increase in filler weight percent. Varada Rajulu et al. [7] studied the tensile properties of epoxy toughened with hydroxyl terminated polyester at different layers of glass rovings and reported that the tensile strength increased with fiber content. For the purpose of verifying the mechanical performance of polymeric composites different types of mechanical tests are conducted. A notable advance in the polymer industry has been the use of fiber and particulate filler as reinforcements in polymer matrix [8,9].

For composites, the tension tests data are designed to produce test data for the control and specifications. These data are useful for qualitative characteristic purposes for research and development [10]. Flexural strength of fiber reinforced polymeric composites is usually performed to characterize these materials due to ease of specimen preparation and testing.

The literature reveals that the type of fiber, its orientation, matrix and filler influences the strength and stiffness of the composites [6, 7, 11-14]. The newly developed materials may be tailored in terms of composition so as to have reasonable properties of the

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polymer. Most of the above findings are based on either randomly oriented or unidirectionally oriented fiber composites. Woven fabric reinforced composites are gaining popularity in many industrial applications because of their balanced properties in the fiber plane as well as their ease of handling during fabrication [15].

An understanding of mechanical properties of fiber/filler reinforced polymer composites is necessary for their industrial application. The use of SiC filler is known to improve the mechanical properties in MMCs [16], but the information on its contribution to polymer system is rather scanty. Hence in the present work, SiC addition as filler material in glass-polyester composite system has been taken up for the investigation with the main intention of characterizing them for mechanical properties.

2. Experimental Details

2.1 Materials

The resin system consists of Isothalic polyester, cobalt naphtenate accelerator and methyl ether ketone peroxide (MEKP) catalyst. The filler material used is of uniform sized SiC (15-25 μm) particles in the composites. Glass is an amorphous silica and available as E-glass, S-glass. E-glass fiber, having a useful balance of mechanical, chemical, and electrical properties at very moderate cost and is one of the most commonly used. The chemical composition and mechanical properties of glass fibers are listed in Tables1 and 2 respectively [1]. The reinforcement material used was an E-glass bi-directional fabric (360 g/m^2) with polyester compatible finish.

Table 1: Chemical composition of the E-glass fibers

Type	SiO_2	Al_2O_3	CaO	MgO	B_2O_3
E-glass	54	14.5	17	4.5	8.5

Table 2: Properties of E-glass fibers

Type	E-glass
Specific gravity	2.54
Tensile strength, MPa	2500
Tensile modulus, GPa	72.4
Strain to failure %	4.8

2.2 Fabrication and test samples

E-glass woven roving fabric was placed on a teflon sheet over which the resin mix consisting of Isothalic polyester, cobalt naphtenate accelerator and MEKP catalyst in the weight ratio of 1: 0.015: 0.015 respectively, prepared for this purpose was smeared. Wet hand lay up technique was employed to fabricate the composites. The stacking procedure consists of placing the fabric one above the other with the resin mix well spread between the fabrics. A porous teflon film was again used to complete the stack. To ensure uniform thickness of the sample, a 3.5 mm spacer was used. The mould plates were coated with release agent to aid the ease of separation on curing. The whole assembly was kept in a hydraulic press at a pressure of 0.5 MPa and allowed to cure for a day at room temperature and later post cured at 70 ˚C for about 10 h. The slabs so prepared measured 250 mm x 250 mm x 3.5 mm by size. To prepare SiC particulate filled glass fabric reinforced polyester composites, besides the polyester resin and hardener mixture, required amount of SiC filler by weight was included to form the resin mix. The cured composite laminates were cut using a diamond tipped cutter to yield test samples as per ASTM standards. The glass fiber content is of about 48 ± 2 wt. %.

2.3 Mechanical property testing

Densities of the composites were determined by using a high precision Mettler Toledo machine Model AX 205 by using Archimedes principle.

The hardness of the samples was measured, as per ASTM-E-10 standard, by using Rockwell hardness tester. Test samples of 25 mm X 50 mm X 3 mm of G-P and SiC-G-P composites were used for the hardness test. The specimen was placed on the anvil of the apparatus and minor load is applied by lowering the steel ball on to the specimen. The minor load indents the surface slightly, assures the good contact. The dial is adjusted to zero and the major load is applied by releasing the trip lever. After 15 seconds, the load is removed and the reading was taken for the specimen at different locations to circumvent the possible effects of fiber segregation. Five readings at different points were noted and average value is reported.

The tensile and three-point bend tests were carried out at room temperature using Universal Testing Machine (JJ Lloyd, 1–20 kN) at cross head speed of 5 mm/min, in accordance with ASTM D638 and D790 respectively [17, 18]. Sample size of five is chosen for experimental studies. All samples, before tests the surface preparation was achieved by mechanically polishing using fine (600 grade) emery paper.. Flexural strength was computed using equation (1).

WhereP = rupture Load, N

$$\text{Flexural strength} = 3PL / 3b\,h^2 \quad (1)$$

L = support span, mm

b = width of specimen, mm

h = thickness of specimen, mm

2.4 SEM study

Morphology of fractured surfaces was observed using scanning electron microscopy (SEM), Model (LEICA S440i, Model-7060, Oxford) operated at 5 KV. Before taking photomicrographs, the samples were coated with thin layer of gold by sputtering.

3. Results and Discussions

3.1 Mechanical and hardness properties

Fig. 1 shows stress-strain behaviour of glass fabric reinforced polyester (G-P) and 5 wt % SiC filled G-P (SiC-G-P) composites. Fig. 2 shows the tensile fracture surfaces of G-P and SiC-G-P composites. Table 3 gives the results of density, ultimate tensile strength, elastic modulus, tensile elongation percentage, flexural strength, flexural modulus, and hardness of the composites tested. From Table 3 it is evident that increase of SiC filler percentage from 2.5 to 5 by wt. has increased the ultimate tensile strength. A comparison of the results (Table 3) revealed that SiC-G-P composite showed the highest tensile strength value, confirming the effect of incorporation of SiC filler, which improves the fiber-matrix interface in the composite. This may be attributed to the fact that in the absence of SiC, the failure would propagate along the loading direction. Silicon carbide is composed of tetrahedral crystals of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material providing good reinforcement. Elongation properties as seen from Table 3, decreased with the presence of filler that indicates interference by the filler in the mobility or deformability of the matrix.

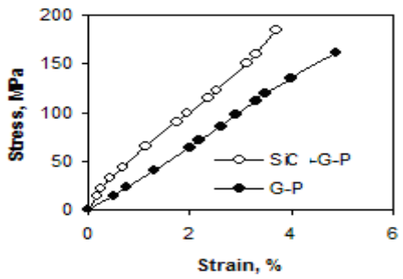

Fig. 1 Stress vs. strain of G-P and SiC-G-P composites

This interference was created through the physical interaction and immobilization of the polymer matrix due to the SiC particles imposing mechanical constraints. The failure therefore propagates in a direction as dictated by the dispersoid concentration in the matrix. This means that the failure would propagate easily in those directions where the dispersoid concentration is less leading to increased tensile strength, tensile modulus, lower elongation and increased surface hardness meaning better dimensional stability. It is clear from Table 3 that, addition of SiC increased the ultimate tensile strength, elastic modulus of G-P composite by 14 and 30 % respectively.

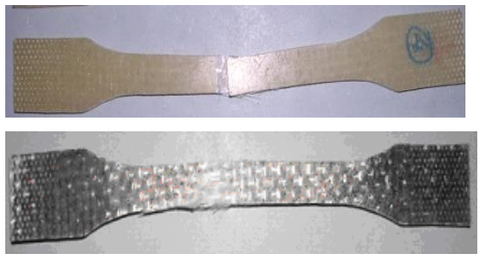

Fig .2 Fractured surface of G-P and SiC-G-P specimen

The flexural strength data of the G-P and SiC-G-P composite is given in Table 3 and the load-deflection curve is shown in Fig. 3. Figs. 4 and 5 show the fractured samples of the flexure test. From Fig. 3 and Table 3 it is clear that the introduction of SiC filler in thermoset composites increases the flexural strength. Observations made during the duration of the test their testimony to this fact. It was observed that in almost all G-P samples, the failure process initiates first in the tensile side of the specimen and is followed by gradual and catastrophic failure (Fig. 4). However, with SiC filled samples, the tensile region has noticeable fiber pullout features (Fig. 5). This is in addition to matrix cracking and fiber debonding noticed when compared to unfilled G-P samples. It should be pointed out that the presence of SiC fillers improved adhesion and it has been proved to be beneficial in thermoset composites. Addition of SiC in G-P composite, the flexural strength and modulus increases by about 25 and 36 % respectively.

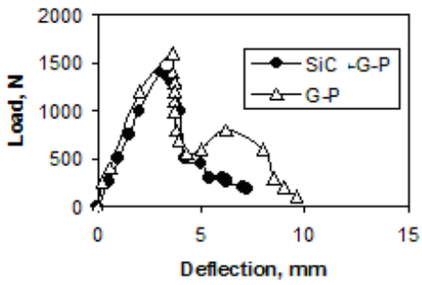

Fig. 3 Load vs. deflection of G-P and SiC-G-P composites

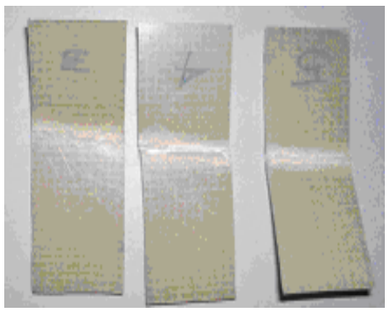

Fig. 4 Fractured surface of G-P flexure specimen

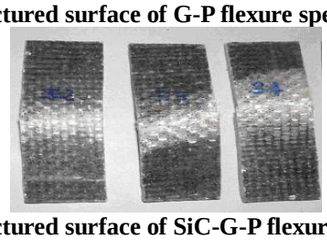

Fig. 5 Fractured surface of SiC-G-P flexure specimen

Table 3 Mechanical properties of SiC-G-P composites

Property	G-P	2.5%SiC filled G-P	5%SiC filled G-P
Density, g/cc	1.84	1.90	1.93
Tensile strength, MPa	159.2	178.3	184.6
Tensile modulus, GPa	7.2	9.02	10.02
Tensile elongation at break %	5.6	4.31	4.19
Flexural strength, MPa	226	295.8	315.4
Flexural modulus, GPa	0.92	1.36	1.43
Hardness, (HRC)	94	103	107

The surface hardness of SiC-G-P composite is higher than that of G-P composite (Table 3). Further it is also seen that the hardness of SiC-G-P composite improved by about 13 % compared to G-P composites.

3.2 FRACTOGRAPHY

It is well known that fractography directly describes the fracture process and provides valuable evidence for the cause of failure. Therefore, the fracture profiles of fractured tensile samples were investigated. SEM pictures in Figs. 6a and b show the fractured surface of G-P composites. Although no chemical reaction is possible, some physical interaction has to be considered. It is interesting to note that composite characterized by higher tensile strength show brittle fracture. For G-P composite, the fracture can be explained by the plastic deformation of the matrix after fiber–matrix debonding (marked X in Fig. 6a). The SEM photograph (Fig.6b) supports this idea because the fibers on fractured surfaces are clean (marked Y in Fig. 6b), which shows brittle fracture. Fiber-matrix debonding and more fiber breakage could explain the brittle fracture.

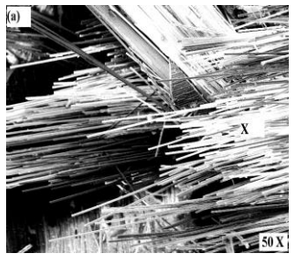

Fig. 6a SEM picture of G-P composite showing broken fiber ends and fiber-matrix debonding

Fig. 6b SEM picture of G-P composite showing broken fiber ends and matrix bonding

SEM characterization of the SiC-G-P fractured surface shows (Figs. 7a and b) that the fibers are more or less covered with the matrix and SiC particles (marked Z in Fig 7b), a qualitative indication of a greater interfacial strength. Disorientation of transverse fibers, fibers pull out, inclined fracture of longitudinal fibers, matrix cracking are also seen. The improvement reported for the mechanical properties of the composites is mainly due to the enhancement of adhesion or interfacial interactions among the fibers, matrix and SiC filler.

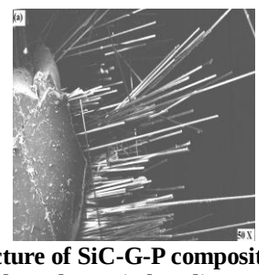

Fig. 7a SEM picture of SiC-G-P composite showing broken fiber ends and matrix bonding

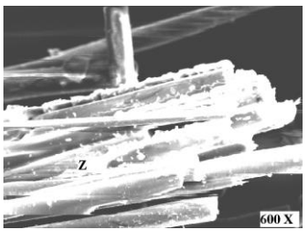

Fig. 7b SEM picture of SiC-G-P composite showing broken fiber ends and matrix bonding

5. Conclusions

- A significant improvement in tensile strength and tensile modulus and marginal reduction in percentage elongation at break was noticed with an increase in the filler loading.
- There was a significant increment in the flexural properties with an increase in the filler loading.
- The G-P composite with 5 wt % SiC filler loading showed the most superior mechanical properties with an elastic modulus of 10.02 GPa, a tensile strength of 184.6 MPa and the highest flexural strength. The superior mechanical properties exhibited by the SiC filler loading in G-P can be explained by the increased polymer network density caused by physical entanglements from the dispersion of SiC particles in G-P composite.
- Fracture mechanism of G-P and SiC-G-P composites is based on plastic deformation of the matrix, fiber–matrix debonding, matrix cracking, disorientation of transverse fibers, fiber breakage, fibers pull out, and inclined fracture of longitudinal fibers.

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