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MECHANICAL CHARACTERIZATION OF GLASS-EPOXY HYBRID COMPOSITES REINFORCED WITH SiC DERIVED FROM BAMBOO LEAVES

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ABSTRACT

This article depicts the processing and mechanical characterization of a new class of multi-phase hybrid composites consisting of epoxy resin reinforced with glass fiber and filled with silicon carbide (SiC) particulates. The SiC used as filler material in this work has been prepared from bamboo leaves through plasma-processing technique. The effect of filler in modifying the physical and mechanical properties of glass-epoxy composites has been studied. It is found that the incorporation of bamboo leaf derived SiC modifies the tensile and flexural strengths of the composites. The micro-hardness and density of the composites are also greatly influenced by the presence of these fillers. By incorporating these particulate fillers, synergistic effects, as expected are achieved in the form of modified mechanical properties. Inclusion of glass fibers in neat epoxy improved the load-bearing capacity (tensile strength) and the ability to withstand bending (flexural strength) of the composites. But with the incorporation of SiC fillers, the tensile strengths of the composites are found to be less although there is reasonable improvement in the bulk hardness.

Key words: Hybrid glass-epoxy composites, SiC, bamboo leaf, Mechanical Characterization.

INTRODUCTION

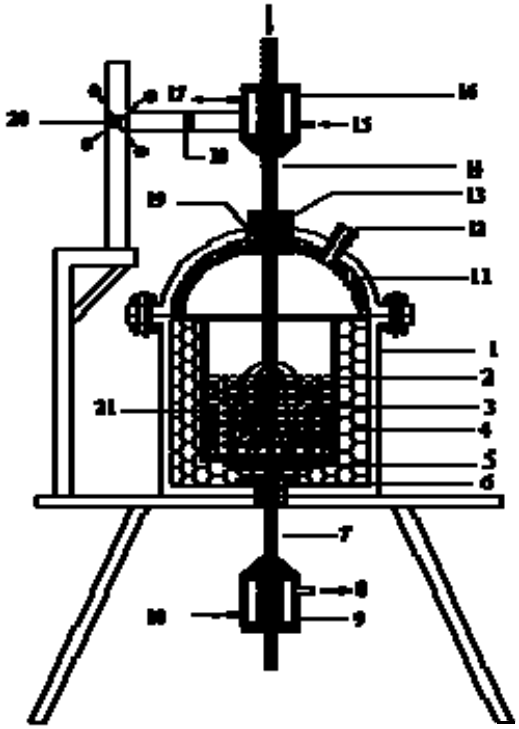
Polymer composites reinforced with fibers are routinely used in diverse applications such as automobiles, aircraft, space vehicles, off-shore structures, containers and piping, sporting goods, electronics and appliances. A fiber-reinforced composite is not simply a mass of fibers dispersed within a polymer. It consists of fibers embedded in or bonded to a polymer matrix with distinct interfaces between the two constituent phases. The fibers are usually of high strength and modulus and serve as the principal load-carrying members. The matrix acts as the load-transfer medium between fibers and in less ideal cases where loads are complex, the matrix may even have to partly bear loads. The matrix also serves to protect the fibers from environmental damage before, during and after the composite processing. In a composite, both fibers and matrix largely retain their identities and yet result in many properties that cannot be achieved with either of the constituents acting alone. A wide variety of fibers are available for use in composites. The most commonly used fibers are various types of carbon, glass, and aramid fibers. Besides, natural fibers such as jute, sisal, and ceramic fibers like alumina, silicon carbide (SiC), mullite, and silicon nitride are also used in composite making. The unique combinations of properties

available in these fibers provide the outstanding functional and structural characteristics such as high specific strength and specific stiffness to the fiber-reinforced composites. A key feature of fiber composites that makes them so promising as engineering materials is the opportunity to tailor the material properties through the control of fiber and matrix combinations and the selection of processing techniques. A judicious selection of matrix and the reinforcing phase can lead to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials [1]. The physical and mechanical characteristics can further be modified by adding a solid filler phase to the matrix body during the composite preparation. It has been observed that by incorporating filler particles into fiber-reinforced composites, synergistic effects may be achieved in the form of higher modulus and reduced material cost, yet accompanied with decreased strength and impact toughness [2,3]. Garcia et al. [4,5] suggested this kind of multi-phase composite technique for improving the matrix-dominated properties of continuous fiber-reinforced composites. In this technique, a supplementary reinforcement such as particulates, whiskers, or micro-fibers is added to the matrix prior to resin impregnation. Jang et al. [6, 7] found a significant improvement in impact energy of such hybrid composites incorporating either particulates or ceramic whiskers. Hard particulate fillers consisting of ceramic or metal particles and fiber fillers made of glass are being used these days also to dramatically improve the wear resistance of composites, even up to three orders of magnitude [8]. However, such multi-component hybrid composites form complex systems and there is inadequate data available about phenomena behind the property changes due to the addition of particulate fillers to the fiber-reinforced polymeric components. Hence the objective of this article is to know how the incorporation of SiC (derived from bamboo leaf) particulates affects the mechanical properties of glass fiber-reinforced epoxy composites. SiC is a ceramic material that has the potential to be used as filler in various polymer matrices. It is an excellent abrasive used in grinding wheels and other abrasive products for over 100 years. The high thermal conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock-resistant qualities. Moreover, SiC has low density, low thermal expansion, high elastic modulus, high strength, high hardness and superior chemical inertness. Although the effect of SiC (produced from mineral sources) as a filler material has been investigated earlier [9] in glass–polyester composites, there is no report available on the potential of SiC particles derived from a bio-resource like bamboo leaf in glass fiber-reinforced polymer composites

Preparation of ultra fine SiC powder from bamboo leaf

India is one of the largest bamboo producing countries with total bamboo forest covering 960 million hectors. Besides this bamboo is cultivated by a major section of rural India. Though bamboo is extensively used for various industrial and household purposes, bamboo leaf is a shear agricultural wastage. Fortunately, bamboo leaf is found to contain necessary carbon and silica (in hydrated amorphous form) intimately dispersed throughout the leaf, and is thus one of the inexpensive renewable potential source for production of silicon carbide (SiC). SiC is one of the advanced ceramics having wide range of industrial and engineering applications. Extended arc DC thermal plasma has been employed for synthesis of ultra fine power of SiC. Particularly β-SiC was found to be formed in a short interval of time of 5 minutes. The plasma yield contains unreacted silica, free carbon and traces of metal ion impurities. Carbon was removed by heating the plasma yield in a muffle furnace at 700 ^{0}C for two hours and on subsequent leaching with 40 % HCl & HF, it was made free from metal ion impurities and unreacted silica. The purity of the final product was found to be comparable with commercial grade SiC available in the market. Fig. 1 represents the schematic view of plasma hearth used for the purpose. [Indian patent no. 1086/Del/2001; S.K Singh ,B. C. Mohanty and Basu, Bull. Mat. Sci. 25 (2002) 561-563].

The plasma hearth consists of two graphite electrodes, which are arranged in a vertical configuration. Initially both the electrodes were kept in contact with each other and then the crucible was partially filled with charge. The charge is essentially dried bamboo leaf cut into small pieces (0.5 to 1.0 cm.). A graphite lid with a central hole is kept as a cover on the graphite crucible. The plasma forming gas argon was injected to the reactants present in the graphite crucible through the axial hole of the top electrode. The rate of flow of plasma forming gas and water for cooling of the electrodes were regulated. As soon as the power to the reactor was switched on, the top electrode was slowly pulled up after striking the arc to form extended/expanded arc plasma in the hearth. The arc current and voltage were regulated during the course of experiment. The plasma forming gas and the graphite lid on the top of the graphite crucible help maintain desired atmosphere inside the hearth for preparation of SiC. The lid also prevents the charge to be blown out of the hearth due to arc pressure.



1. M.S. casing
2. Graphite crucible
3. Plasma
4. Bubble alumina
5. Graphite base
6. Alumina bush
7. Bottom electrode (graphite)
8. Water outlet
9. Copper connector
10. Water in
11. Magnesia lining
12. Exhaust
13. Graphite bush
14. Top electrode (graphite)
15. Water in
16. Copper connector
17. Water out
18. Electrical insulation
19. Alumina bush
20. Rack & pinion
21. Charge

Fig. 1 Schematic view of plasma hearth used for the purpose

EXPERIMENTAL DETAILS

Composite fabrication

Epoxy LY 556 is the resin which is used as the matrix material. Its common name is Bisphenol-A-Diglycidyl-Ether and it chemically belongs to the 'epoxide' family. The epoxy resin and the hardener (HY951) are supplied by Ciba Geigy India Ltd. Woven roving E-glass fibers (supplied by Saint Gobain Ltd. India) have been used as the reinforcing material in the composites. E-glass fiber has an elastic modulus of 72.5 GPa and possess a density of 2.59 gm/cc. Composite samples C_1 C_2 and C_3 with particulate fillers (SiC derived from bamboo leaf) of three different amount (0 wt%, 10 wt% and 20 wt% respectively) but with fixed glass-fiber loading (40 wt %) are fabricated. This fabrication of the composite slabs is done by conventional hand-lay-up technique followed by light compression moulding technique. The fillers are mixed thoroughly in the epoxy resin before the respective fiber mats are reinforced into the matrix body. The low temperature curing epoxy resin and corresponding hardener are mixed in a ratio of 10:1 by weight as recommended. Each ply of fiber is of dimension 200 × 200 mm^2. A stainless steel

mould having dimensions of 210 × 210 × 40 mm^3 is used. A releasing agent (Silicon spray) is used to facilitate easy removal of the composite from the mould after curing. The cast of each composite is cured under a load of about 50kg for 24 h before it removed from the mould. Then this cast is post cured in the air for another 24 h after being removed from the mould. Specimens of suitable dimension are cut using a diamond cutter for physical characterization and mechanical testing. Utmost care has been taken to maintain uniformity and homogeneity of the composite. The designation and detailed composition of the composites are given in Table 1.

Designation	Composition		
Composites	Measured density (gm/cc)	Theoretical density (gm/cc)	Volume fraction of voids (%)
C_1	Epoxy + 40 wt% glass fiber + 0 wt% SiC		
C_2	Epoxy + 40 wt% glass fiber + 10wt% SiC		
C_3	Epoxy + 40 wt% glass fiber + 20wt% SiC		

Table 1 Designation and detailed composition of the composites

MECHANICAL CHARACTERIZATION

Density and Void Fraction

The composites under this investigation consists of three components namely matrix, fiber and particulate filler. The theoretical density of composites in terms of weight fraction can easily be obtained as per the following equation [10]

$$\rho_{ct} = \frac{1}{\left(W_f / \rho_f\right) + \left(W_m / \rho_m\right) + \left(W_p / \rho_p\right)} \quad (1)$$

Where, W and ρ represent the weight fraction and density respectively. The suffix *f, m* and *ct* stand for the fiber, matrix and the composite materials respectively. The suffix '*p'* indicates the particulate filler materials. The actual density (ρ_{ce}) of the composite, however, can be determined experimentally by simple water immersion technique. The volume fraction of voids (V_v) in the composites is calculated using the following equation:

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \quad (2)$$

The theoretical and measured densities of the composites along with the corresponding volume fraction of voids are presented in Table 2. It may be noted that the composite density values calculated theoretically from weight fractions using Eq.(1) are not equal to the experimentally measured values. This difference is a measure of voids and pores present in the composites. It is clearly seen that with the addition of silicon carbide as the filler material, more voids are found in the composites. As the filler content increases from 0 wt% to 10 wt% and subsequently from 10 wt% to 20 wt% the volume fraction of voids is found to be increasing. This trend is observed in both the particulate filled composites (C_2 and C_3).

Glass-Epoxy + 0 wt% SiC (C_1)	1.535	1.544	0.647
Glass-Epoxy + 10 wt% SiC (C_2)	1.676	1.702	1.527
Glass-Epoxy + 20 wt% SiC (C_3)	1.812	1.894	4.329

Table 2 Measured and theoretical densities of the SiC filled glass-epoxy composites

Density of a composite depends on the relative proportion of matrix and reinforcing materials and this is one of the most important factors determining the properties of the composites. The void content is the cause for the difference between the values of true density and the theoretically calculated one. The voids significantly affect some of the mechanical properties and even the performance of composites in the workplace. Higher void contents usually mean lower fatigue resistance, greater susceptibility to water penetration and weathering [10]. The knowledge of void content is desirable for estimation of the quality of the composites. It is understandable that a good composite should have fewer voids. However, presence of void is unavoidable in composite making particularly through hand-lay-up route.

Micro-hardness

Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces, is forced into the material under a load of 24.54N. The variation of composite micro-hardness with the weight fraction of SiC particulates is shown in Figure 2. It is seen with the incorporation of filler particulates into the composites, the mean hardness is seen to have improved.

Tensile and Flexural Strength

The tensile test is generally performed on flat specimens. The commonly used specimens for tensile test are the dog-bone type and the straight side type with end tabs. During the test a uniaxial load is applied through both the ends of the specimen. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. The length of the test section should be 200 mm. The tensile test is performed in the universal testing machine (UTM) Instron 1195 and results are analyzed to calculate the tensile strength of composite samples.

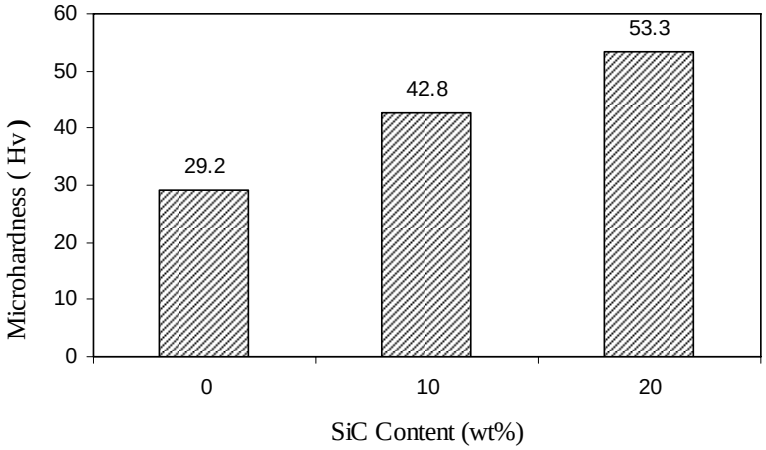


Fig. 2 Variation of micro-hardness of the composites with SiC content

The flexural strength of a composite is the maximum tensile stress that it can withstand during bending before reaching the breaking point. The three point bend test is conducted on all the composite samples in the universal testing machine Instron 1195. The dimension of the

specimen is 60 mm ×10 mm × 4 mm. A thickness of 4mm is maintained for the unfilled as well as particulate filled composite specimens. Span length of 40 mm and the cross head speed of 10mm/min are maintained. The data recorded during the 3-point bend test is used to evaluate the flexural strength. The flexural strength (F.S.) of any composite specimen is determined using the following equation.

$$F.S = \frac{3PL}{2bt^2} \quad (5)$$

where, L is the span length of the sample.
P is maximum load,
b the width of specimen and
t the thickness of specimen.

The test results for tensile and flexural strengths for the particulate filled composites C_1, C_2 and C_3 are shown in Figures 3 and 4 respectively. It is seen that the tensile strength of the composite decreases with increase in the filler content. The unfilled glass epoxy composite has a strength of 519 MPa in tension and it is seen that this value drops to 413 MPa and 357 MPa with addition of 10 wt% and 20 wt% of silicon carbide respectively. Similar trend is observed in case of flexural strength of these composites. This kind of observations has been reported by Harsha et al. [11] for fiber reinforced thermoplastics such as poly-aryl-ether-ketone (PAEK) composites. It may be mentioned here that both tensile and flexural strengths are important for recommending any composite as a candidate for structural applications.

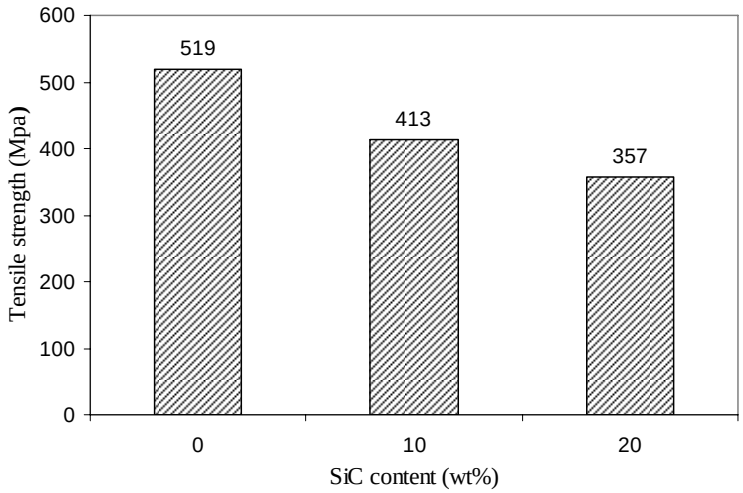


Fig. 3 Variation of tensile strength with SiC content

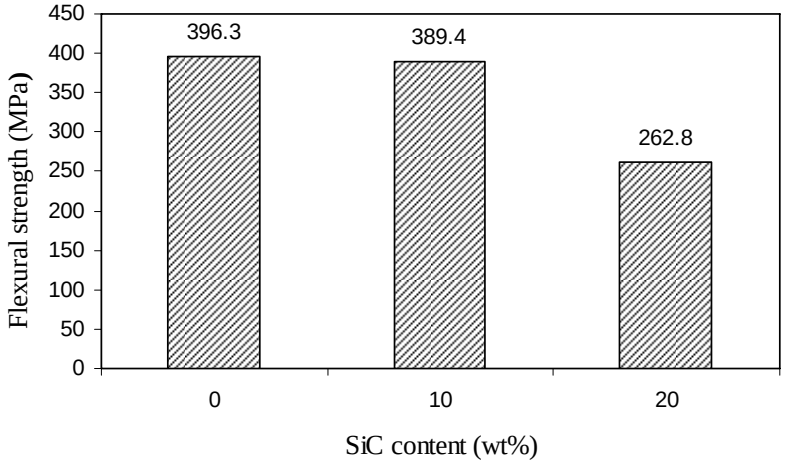


Fig. 4 Variation of flexural strength with SiC content

By incorporating these particulate fillers into the glass-fiber reinforced epoxy, synergistic effects, as expected are achieved in the form of modified mechanical properties. Inclusion of glass fiber in neat epoxy improved the load bearing capacity (tensile strength) and the ability to withstand bending (flexural strength) of the composites. But with the incorporation of silicon carbide fillers, the tensile strengths of the composites are found to be less. There can be two reasons for this decline in tensile strength of these particulate filled composites compared to the unfilled one. One possibility is that the chemical reaction at the interface between the filler particles and the matrix may be too weak to transfer the tensile stress; the other is that the corner points of the irregular shaped particulates result in stress concentration in the epoxy matrix.

Hardness values have been found to have improved for the SiC particulate filled composites. The reduction in tensile strength and the improvement in hardness with the incorporation of fillers can be explained as follows: under the action of a tensile force the filler-matrix interface is vulnerable to debonding depending on interfacial bond strength and this may lead to a break in the composite. But in case of hardness test, a compression or pressing stress is in action. So the polymeric matrix phase and the solid filler phase would be pressed together and touch each other more tightly. Thus, the interface can transfer pressure more effectively although the interfacial bond may be poor. This might have resulted in an enhancement of hardness.

CONCLUSIONS

Successful fabrication of glass-epoxy composites with reinforcement of SiC derived from bamboo leaf is possible. Incorporation of these fillers modifies the tensile and flexural strengths of the glass-epoxy composites. The micro-hardness and density of the composites are also greatly influenced by the content of fillers.

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