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The effect of the addition of SiCp on the mechanical behaviour of silane treated epoxy and polyester composites reinforced with unidirectional carbon fiber fabric.

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ABSTRACT

The prime material for performance intensive applications is carbon fiber reinforced polymer composites (CFRPC). Researchers have improved the properties of CFRPC by creating a stronger interface between the constituents either by treating the fiber surface with alkalis, oxidization agents or gases. However, there is a possibility of fiber damage during treatment. In this investigation two different matrices viz., epoxy and polyester were modified by incorporating (3-Aminopropyl)trimethoxysilane coupling agent and silicon carbide particulate filler (SiCp). The effect of matrix modification on the mechanical behaviour of CFRPC is investigated in terms of tensile, flexural and impact properties. It was observed that CFRPC with modified matrices had better properties due to improved adhesion between the constituents. In particular, carbon fiber reinforced 10 wt. % SiCp filled silane treated polyester matrix composite had better mechanical properties. The results have been supplemented with morphological investigation.

Indexing terms/Keywords

Carbon fiber reinforced polymer composites; silane treatment; mechanical behavior; matrix modification

Academic Discipline And Sub-Disciplines

Mechanical Engineering, Chemistry, Composites

SUBJECT CLASSIFICATION

Carbon fiber reinforced polymer composites

TYPE (METHOD/APPROACH)

Characterization and Analysis

INTRODUCTION

CFRPC have excellent characteristics such as higher modulus and strength-to-weight ratio, better fatigue and corrosion resistances [1].The consumption of CFRP is increasing in performance intensive applications such as aerospace, automobile,wind energy, construction, sports equipment, marine and military due to reduced manufacturing cost and better technologies.The mechanical behaviour of polymer composites due to inclusion of SiCp filler is encouraging [2-5].The performance of CFRP depends on the interfacial adhesion between fibers and matrix [3]. Interfacial bonding methods such as carbon fiber surface treatment, filler treatment [3], matrix modification [9] was used to increase the bonding between the constituents. Silane coupling agents are generally used as sizing and reactive sites in treatment of fiber and matrix respectively.The interfacial adhesion could be improved if the silane coupling agent forms a bond between the fiber and the resin [5].The coupling mechanism of amino silanes and fiber reinforced polymers have been reported by authors [10]. Limited work is available relating to matrix modification by silane coupling agent to enhance the mechanical behaviour of CFRPC.

In this work, to study the influence of SiCp on the matrix, six composites were synthesized by incorporating SiCp (with 0, 5 and 10 wt.%) in silane treated epoxy and silane treated isophthalic polyester without reinforcement. The effects of SiCp filler addition on mechanical properties of the specimens were observed. Further, the mechanical behavior of silane treated epoxy and isophthalic polyester composites reinforced with unidirectional carbon fiber fabric was investigated by synthesizing six composites with varying (0, 5 and 10wt. %) of SiCp filler. SEM microphotographs of fractured samples revealed the aspects of fractured surfaces and confirmed the improvement in fiber/matrix interfacial adhesion.

Experimental

Materials

Isophthalic polyester resin, Methyl ethyl ketone peroxide (catalyst) and cobalt naphthenate (accelerator) used for this investigation were purchased from Vasavibala resins (P), India. Epoxy resin (LY 556 CS) and Hardener (HY 951) were procured from Huntsman advanced materials (India) Pvt. Ltd. The silane coupling agent (3-Aminopropyl)trimethoxysilane with 97 % purity was purchased from Alfa Aesar, Gt.Britan. SiCp with size 20µm was procured from Vazirbun trading, India. Unidirectional carbon fiber fabric (UDCFF) was procured from Hangzhou Suoqi Advanced Composite Material Co., Ltd. (China.).The properties of UDCFF [9] Isophthalic polyester resin [11] and epoxy [12] have already been reported elsewhere.

Composite Fabrication

Synthesis of SiCp filled silane treated epoxy composites (SE)

An optimum concentration (0.5 wt. %) of coupling agent (3-Aminopropyl)trimethoxysilane [C6H17No3Si] was directly incorporated with the epoxy resin [9] and mixed well using a mechanical stirrer. SiCp (0.5 wt. %) was also added in tiny quantities and was subsequently sonicated in an ultrasonic sonicator for 3 h. Hardener (10 wt. %) was added to this matrix solution and mixed well further. The prepared matrix solution was degassed. This modified matrix solution was applied on a sealed aluminium mould with dimensions (250 mm × 250 mm× 4mm).Teflon films coated with a release agent was kept at the top of the mould, for easy removal of the composite panel after fabrication. After solidification, the composite was post cured at 80°C for 4h in a hot air oven. Optical microscopic image of 10 wt. % SiCp filled epoxy matrix synthesized in accordance with this procedure revealed that the SiCp distribution was homogeneous, no additional parameters such as particle distribution and agglomeration were observed in the matrix of fiber composites as shown in Fig. 1.

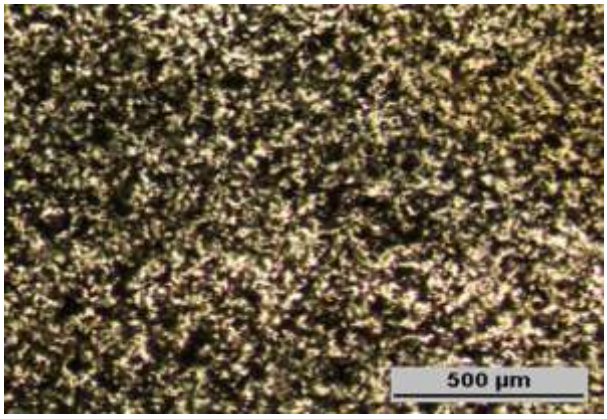

Fig. 1: Optical Microscopic image of [94.5wt.%Epoxy+5wt.%SiC+0.5wt . % (3-Aminopropyl) trimethoxysilane] + 10wt. %Hardener.

Synthesis of SiCp filled Silane treated polyester composites (SP)

To synthesize (5 and 10) wt.% of SiC filled polyester matrix composites, similar procedure done for preparing silane treated epoxy matrix was adopted, but instead of a hardener, an accelerator (Cobalt Napthanate) and a catalyst (Methyl Ethyl Ketone Peroxide) with 1.5 wt. % and 1 wt. % respectively were used.

Synthesis of SiCp filled UDCFF reinforced Silane treated epoxy matrix composites (UDCFFSE)

The modified epoxy matrix was synthesized as detailed in the previous sections. CF composites with (0, 5, 10 wt. %) of SiCp content were synthesized as follows: Five layers of as received UDCFF were used. They were dried in a hot air oven at 40ºC for one hour to remove moisture content. The surface of fibers was inspected carefully to ensure fiber uniformity and also to remove any extraneous matter. The composites were fabricated by compression moulding method as follows: A thin layer of modified matrix solution synthesized as detailed in section 2.2.1 was applied on the prepared mould. One layer of UDCFF was laid on the resin. The resin was impregnated into the fibers by using a brush. A ribbed metal roller was rolled over the fabric by applying slight pressure for consolidation, to remove the air bubbles and also to ensure the adherence of resin with the fiber. Voids or resin rich pockets were removed due to repeated impregnation and rolling actions. The uniformity of fibers was also maintained during this course of action. A teflon film coated with releasing agent was applied on the top of this composite. The mould was careully sweeped on the top to remove the air bubbles present. It was also inverted and again sweeped to remove the air bubbles at the bottom. The mould was closed and kept under a pressure of 0.5 MPa in a hydraulic press for twenty four hours to obtain partial curing. The composites were then post cured at 80°C for four hours in a hot air oven.

Synthesis of SiCp filled UDCFF reinforced Silane treated polyester matrix composites (UDCFFSP)

The modified polyester was synthesized as detailed in previous sections. Further, It was used to synthesize three UDCFF reinforced (five layers each) silane treated polyester matrix composites with (0, 5,10wt.%) of SiCp by compression molding method.

Specimen preparation

Specimens of dimensions according to ASTM standards were cut by diamond tipped cutter with speed and feed of 2500 rpm and 0.5mm/sec respectively. Five identical successful samples were tested in each test. The designation and composition of the synthesized composites were detailed in Table 1.

Table 1 Composition and designation of composites

Sl.No.	Composite (Designation)	Fiber (wt.%)	Matrix (wt.%)	SiC Filler (wt.%)	Silane Coupling agent (wt.%)
1.	Epoxy(E)	-	Epoxy 100	-	-
2.	5wt. % SiC filled-epoxy (5SE)	-	Epoxy 94.5	5	0.5
3.	10wt. % SiC filled-epoxy (10SE)	-	Epoxy 89.5	10	0.5
			Polyester		
4.	Polyester(P)	-	100	-	-
5.	5wt. % SiC filled-polyester (5SP)	-	Polyester 94.5	5	0.5
6.	10wt. % SiC filled-polyester (10SP)	-	Polyester 89.5	10	0.5
7.	UDCFF-epoxy (UDCFFE)	UDCFF 32±1	Epoxy 67.5±1	-	0.5
8.	5wt. % SiC filled UDCFF-epoxy (5UDCFFSE)	UDCFF 32±1	Epoxy 62.5±1	5	0.5
9.	10wt. % SiC filled UDCFF-epoxy (10UDCFFSE)	UDCFF 32±1	Epoxy 57.5±1	10	0.5
10.	UDCFF-polyester (UDCFFP)	UDCFF 32±1	Polyester 67.5±1	-	0.5
11.	5wt. % SiC filled UDCFF-polyester (5UDCFFSP)	UDCFF 32±1	Polyester 62.5±1	5	0.5
12.	10wt. % SiC filled UDCFF-polyester (10UDCFFSP)	UDCFF 32±1	Polyester 57.5±1	10	0.5

Material Characterization

Mechanical characterization of the polymer composite

The tensile and flexural strength of the UDCFF reinforced composites were conducted as per ASTM-D3039 and ASTM-D790 respectively in a universal testing machine having 100kN of loading capacity at a cross head speed of 2.5mm/min.

The remaining composites were tested in the same machine for tensile and flexural strength as per ASTM D 638-10 TYPE –I and ASTM D 790-A respectively at a cross head speed of 1 mm/min. Energy absorption capacity of the composites were determined by conducting Izod impact test according to ASTM Standard D 256 on unnotched specimens.

Scanning electron microscopy

Fractured samples after flexural test were selected and their surfaces were coated by a thin gold film by sputtering to make a conductive layer. Afterwards, the coated samples were examined by a scanning electron microscope (JSM-6610LV model of JEOL make).

RESULTS AND DISCUSSION

Mechanical Properties

The effect of SiCp addition on the flexural strength of UDCFF reinforced composites is shown in Fig. 2 (a).The failure process of these specimens initiated first in the tensile side of the specimen and is followed by catastrophic failure. 10UDCFFSP had the highest flexural strength as expected. As the Young's modulus of SiCp is higher than the polymer matrix, there is a possibility of stress transfer from particles to the matrix. The stronger interface created due to incorporation of silane coupling agent favored the stress transfer between these constituents. Similar observation has also been reported by [7-9]. Fig. 2 (b) reveals that the samples without SiCp have less tensile strength. Tensile strength is also an indication of the maximum stress required to make the longest crack in the matrix of the composite. Particulate fillers resist crack initiation and propagation in the composite. From Fig. 2 (b) it is evident that the composite with more SiCp content has the highest tensile strength due to improved stiffness of polymer matrix by uniformly distributed SiCp [5-7]. 10UDCFFSP composite had the highest tensile strength due to the better adhesion between the constituents. The enhancement in tensile strength is due to high strength and stiffness of CF and also the improved adhesion among the constituents.

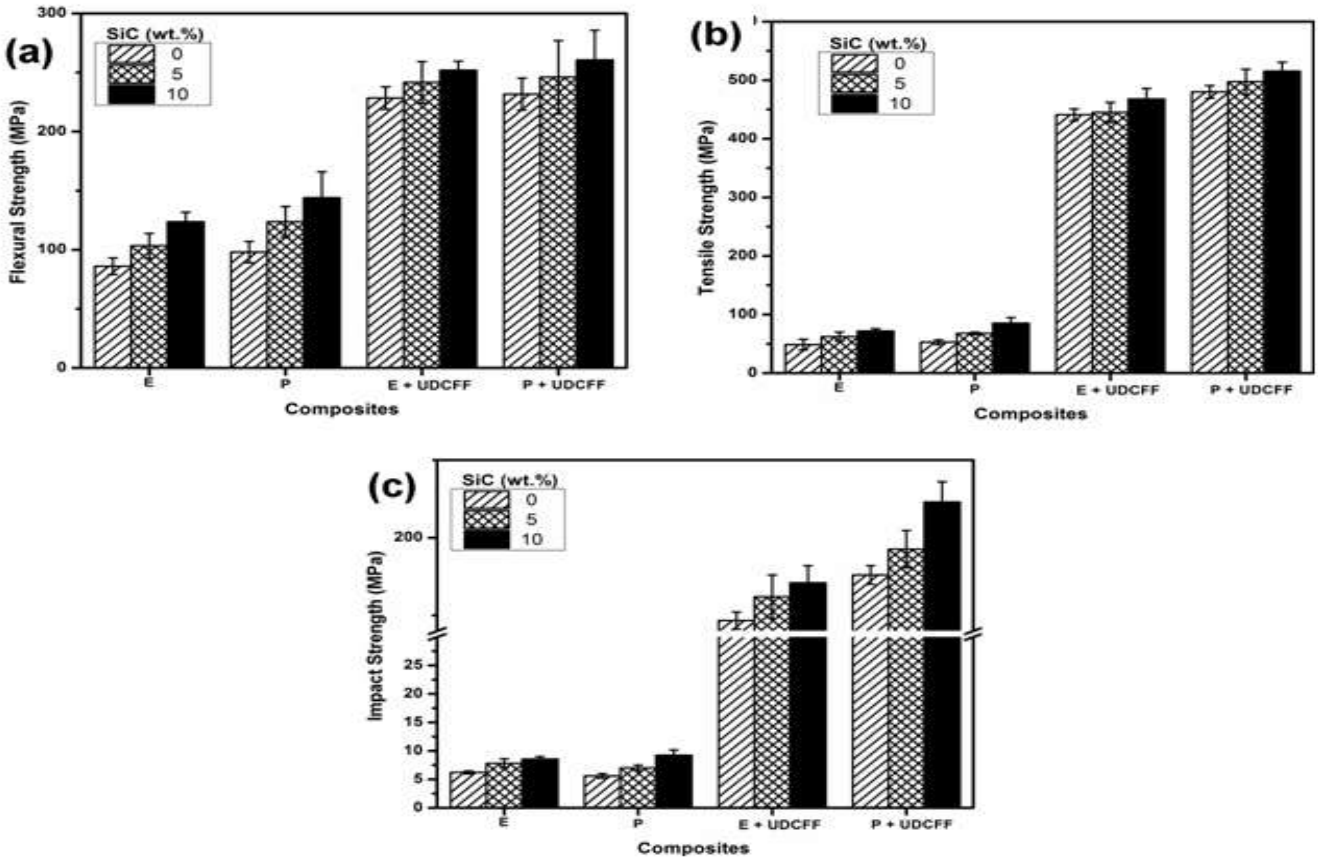

Fig 2: Mechanical behaviour of UDCFF composites (a) Flexural strength, (b) Tensile strength, (c) Impact strength.

SiCp addition in silane treated polymer matrix enhances the impact strength of UDCFF composites, which is shown in Fig. 2(c). As more SiCp fillers are incorporated in the polymer matrix, the toughness of the matrix increases. Furthermore, the synergetic effect of the constituents has dissipated the energy absorbed throughout the composite [6]. Thus, 10UDCFFSP had the highest impact strength.

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Morphology study

Morphology of UDCFF reinforced composites is shown in Fig. 3. This study can provide better insight into the mechanism of interfacial adhesion between the constituents of a composite.The SEM microphotograph of flexural fractured specimens shows the information about the effective bonding between the fiber, matrix and SiCp. For composites without SiCp the fracture is due to debonding between the fiber and matrix, fiber-pull out and matrix fracture [13] Fig. 3 (a-b). It is evident from Fig. 3 (b) that the adhesion area between the fiber and matrix is reasonably less, so the flexural strength is also less for this composite [7]. The SEM microphotograph of 5UDCFFSE and 5UDCFFSP composite specimen are shown in Fig. 3 (c-d) indicate that the fibers are more or less covered with the matrix and SiC particles. Fiber pullout was observed in the tensile region of the specimen. Flexural strength value indicates that the elongation is maximum due to better stress transfer between the fiber, SiCp and the matrix at the interphase region of the composite. Individual fiber breakage and ductile fracture of fiber surfaces reveal good adhesion between the constituents due to the incorporation of silane coupling agent. The SEM microphotograph of 10UDCFFSE and 10UDCFFSP composite specimen reinforced composite specimen shown in Fig. 3 (e-f) reveal that the fibers were covered with more SiCp incorporated epoxy and SiCp incorporated polyester matrix respectively.This created a strong interface leading to better stress transfer between the constituents. Fiber breakage occurs frequently in both tensile and compressive region. The improvement of mechanical properties of the composites evaluated is mainly due to the enhancement of adhesion among the fibers, matrix, and SiCp filler [9].

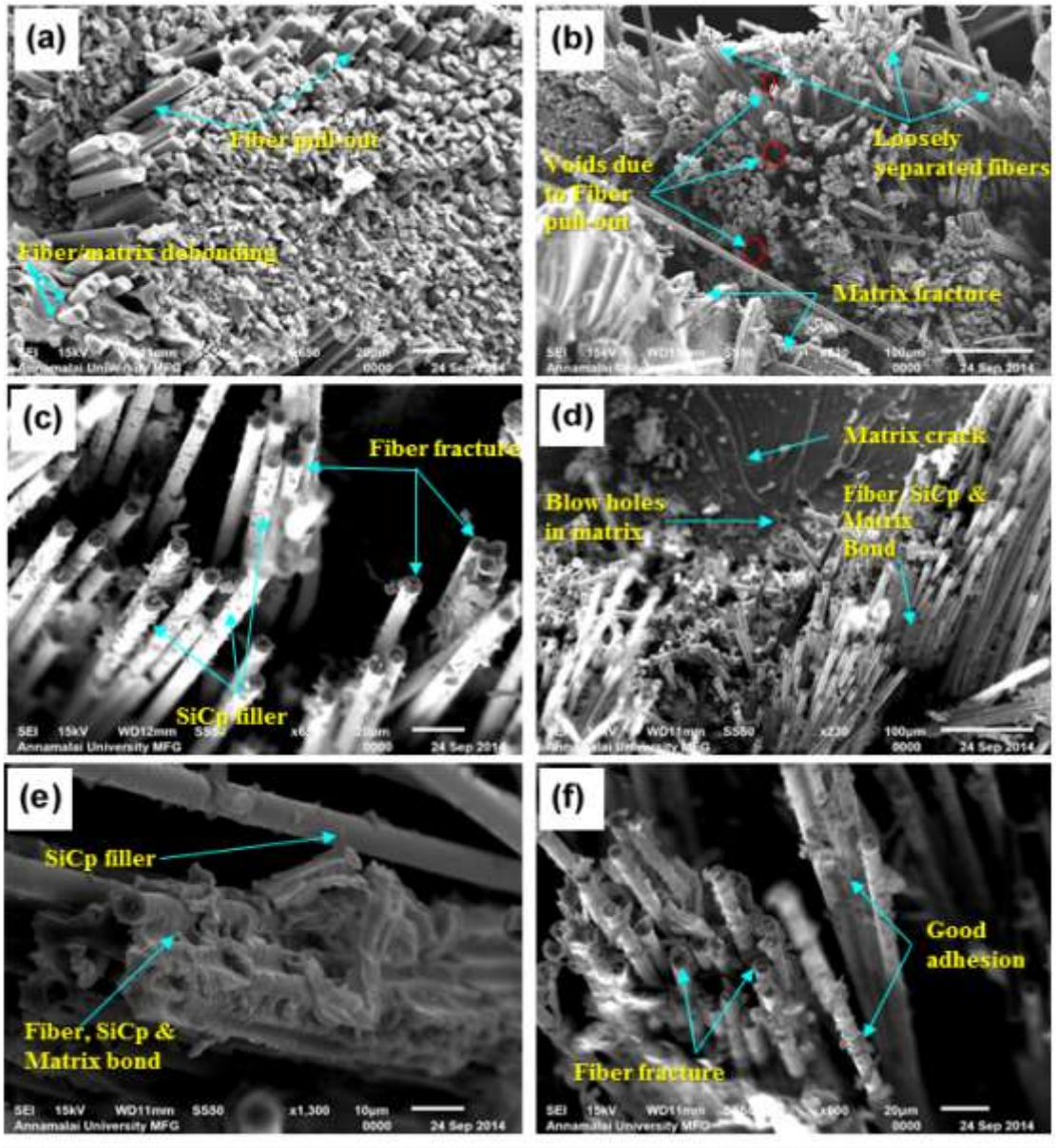

Fig 3: Flexural fractograph of (a) UDCFFE, (b) UDCFFP, (c) 5UDCFFSE, (d) 5UDCFFSP, (e) 10UDCFFSE, and (f) 10UDCFFSP.

Conclusions

In this investigation, SiCp filler was incorporated in silane treated epoxy and polyester matrices to enhance the interfacial adhesion with UDCFF. The mechanical properties of UDCFFP were found to be higher than UDCFFE. Morphological observations revealed the improved adhesion between UDCFF, matrix and SiCp filler. As 10UDCFFSP composite possessed better mechanical properties, it could be used in structural applications.

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