

Mechanical & Thermal Properties of Carbon Fiber/Epoxy Composites with Different Fiber Orientation

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Abstract:

Room temperature cured epoxy was impregnated with Carbon fiber in order to synthesis composites. Carbon fiber is taken in the 3, 5, 7 % weight in order to suspend on epoxy resin with different fiber lengths such as 1, 2, and 3 cm. The variations of aforementioned properties on Carbon fiber-epoxy composites with different fiber lengths have been studied. Thermal properties such as TGA and DSC are studied to investigate the influence of change in fiber length on Carbon fiber-epoxy composites. Significant improvement in tensile and flexural strengths of Carbon fiber-epoxy composites has been observed by the different fiber lengths.

Aircrafts and cars are made of composites to lighten their weight. Glass fiber reinforced composites due to their high specific strength and specific stiffness have become attractive structural materials not only in weight sensitive aerospace industry, but also in marine, armor, automobile, railways, civil engineering structures, sport goods etc. The results are to be compared weather the fiber content in weight percentage and the fiber length are influenced on the improvement of tensile, flexural, and morphology properties.

Keywords:

Carbon fiber/Epoxy, Flexural Test, Tensile test, Tensile Modulus, Thermo Gravimetric Analysis(TGA), Differential Scanning Calorimetric(DSC), Scanning Electron microscope(SEM).

INTRODUCTION:

The use of composites filled with fiber in epoxy system has gained significant importance in the development of thermosetting composites. One of the most important focuses in achieving this goal is to develop a new material, which possesses a strength-to-weight ratio that far exceeds any of the present materials. Epoxy resin remains the most important matrix used in the high-performance transportation systems. When epoxy combines with carbon fibers, it results in advanced composites, which have sound-specific properties such as impact, hardness, tensile, strength, and modulus and properties. The new found properties make this material very attractive for use in aerospace applications. Estimation has it that for every unit of weight reproduction in an aircraft, there is a considerably less consumption of fuel or higher load capacity, and hence materials offer load saving. Due to their resistance to chemicals, the permeability of water, oxygen, and other gases to composites also decreases, making them ideal for building advanced composite fuel tanks for future reusable launch vehicles. Epoxy resins have played a vital role in polymer matrix materials because of their superior mechanical and adhesive properties. They have been used widely as a matrix to hold the high-performance fiber reinforcement together in composite materials, as well as structural adhesives. Composites are named when the dispersed phase particle size is less than 100 nm, and the reinforcement of polymeric resin with fiber as fillers has resulted in lightweight materials with increased modulus and strength, decreased permeability, less shrinkage and increased heat resistance even at low friction loading.

But in recent times epoxy resin added with modified fiber as filler finds major applications. The introduction of fiber particles increases the mechanical (tensile strength and modulus), physical (permeability and barrier resistance), and thermal (decomposition and mass loss) properties of the polymer composites. Recent researchers have found that commercial organic fiber could be used to make aerospace epoxy Composites, which possess excellent mechanical strength and low co-efficient of thermal expansion with relatively low cost and ease of fabrication. Significant amount of work can be found in the literature on the effect of addition of fiber on the mechanical properties of pure epoxy resin systems. One of the most important consequences of the incorporation of fiber fillers in molten polymers is the significant change in their viscoelastic properties.

The reduction of the filler size down to nano-metric scale can produce substantial differences in the rheology and dynamic of filled polymer in comparison to micron sized particles. The extremely large surface area provided by fiber particles can intensify the effect of particle-particle and/or polymer-particle thermodynamic interactions. The objective of the present study is to fabricate Composite that contain reinforcing carbon fiber in the epoxy matrix and to evaluate the influence of the fiber fillers on Thermal, Mechanical, Morphology, Chemical resistance and Electrical properties. This research presents the work done on the effect of adding fiber on tensile properties and flexural properties of carbon fiber are incorporated in Epoxy in order to study the variation of Mechanical, Thermal, Morphology properties.

In the present study the tensile, flexural, and chemical resistance properties of carbon fiber/epoxy composites should be evaluated. The Carbon fibers with different proportion in length and content are used as reinforcements in epoxy polymer based matrices. The mathematical models of tensile, flexural, and chemical resistance properties are developed and optimized using statistical package to find the optimum fiber parameters for maximum mechanical properties. The results are to be compared weather the fiber content in weight percentage and the fiber length are influenced on the improvement of tensile, flexural, and chemical resistance properties.

EXPERIMENTAL DETAILS: Materials and Methods:

In the present work, epoxy resin (LY-556) thermo setting polymer is used as a matrix, epoxy is the most common thermosetting polymer used as matrix in the polymer composites. It is obtained from Araldite HY-951 Huntsman, Bangalore. Epoxy is a clear liquid with viscosity at 250C. Epoxies are used by the plastic industry in several ways. Hardener is used as reaction agent. It acts as catalyst. It is added to the resin in 10:1 proportion to get hardener. In the recent work Aradur HY-951 is used as hardener in the Epoxy LY-556. It has a shelf pot life of 2 years when it is stored in a dry place in a temperature range of 18-250 C, while for achieving higher pot life, lid should be closed after using the material. Polyvinyl alcohol (PVA) was used as the mould releasing agent in composite fabrication. The mould cavity is coated with a thin layer of aqueous solution of PVA for the easy removal of the sheet from the mould and for a smooth surface finish.

List of raw materials used for micro-composites:

Description	Raw Materials
Matrix	Epoxy resin (LY-556)
Hardener	Hardener (HY-951)
Reinforcing agent	Carbon Fiber
Mould releasing agent	Polyvinyl alcohol (PVA) / Wax
Casting	Glass moulds

Composite Manufacturing:

There are several methods of making carbon fiber but essentially they consists of first making fibers out of a carbon rich precursor material. The original size and shape of the fiber will remain in the finished carbon fiber, but the interior chemical structure will have been greatly modified through the various heating cycles. The first steps are carbonizing and stretching precursor fibers, either PAN: Polyacrylonitrile, Pitch or Rayon. There are several cycles of heating at varying temperatures excluding oxygen. This process drives off most of other elements (hydrogen and nitrogen mainly) of the starting material leaving carbon behind. It also allows the carbon to gradually crystallize in its characteristic honeycomb way.

If you haven't seen it yet, go to my Carbon Research page and look at the video on Carbon fiber structure. It's fabulous. The most important factors determining the physical properties of carbon fiber are degree of carbonization (carbon content, usually more than 92% by weight) and orientation of the layered carbon planes (the ribbons). Fibers are produced commercially with a wide range of crystalline and amorphous contents variations to modify or favor the various properties. Depending on the starting material and process of carbonization Carbon fiber is modified to suit the end purpose. PAN or polyacrylonitrile is the most common precursor for plastic composites. The main variations of characteristics is strength vs stiffness. By using different heating cycles either can be emphasized. Research is being done to modify other features such as heat and electrical conductivity.

Synthesis of Carbon Fiber/Epoxy Composites:

In the present work glass moulds are used to prepare carbon fiber reinforced with epoxy composites. A glass mould of (130 x 130 x 0.4) mm³ is used to prepare casting and specimen for tensile test, flexural tests, compressive test, thermal analysis and morphology Figure-1 represents the glass mould.



Fig. 1: Glass mould

Moulds are prepared for different castings that are made from resin as per ASTM standards. The pre-calculated amount of Epoxy (resin) is mixed in a suitable beaker. Carbon fiber is taken with stipulated quantity of resin based on the predetermined ratio and mixed thoroughly with mechanical shear mixing for about 1 hour at ambient temperature conditions. Then the mixer is carried out through a high intensity Ultrasonic for one and half hour with pulse mode (50s on / 25s off).

External cooling system is employed to avoid temperature during the Ultrasonic process, by submerging the beaker containing the mixer in an ice and then a pre-calculated amount of hardener was mixed and stirred for 20 min before pouring into the mould bath as shown in figure below.



Fig 2: Ultrasonic Bath Indicator

Once the irradiation is completed, hardener is added to the modified epoxy in the ratio of 10:1 parts by weight. A glass mould with required dimensions is used for making sample as per the ASTM standards and it is coated with mould releasing agent enabling easy removal of the sample. In this technique carbon fiber is wetted by a thin layer of an epoxy and epoxy suspension in a mould. Staking of carbon fiber is arranged side by side all over the mould. Stacking of carbon fiber is carefully arranged after pouring some amount of resin against the mould, to keep the poor impregnation at bay. Left over quantity of mixture is poured over the carbon fiber. Brush and roller are used to impregnate fiber. The closed mould is kept under the pressure for 24 hours at room temperature. To ensure complete curing, the composite samples are post cured at 70°C for 1 hour and the test specimens of the required size is cut out from the sheet. The removed castings are cut into the samples in accordance with ASTM standards for further testing. Direct processing technique has been used for the above fiber reinforced composites preparation. A schematic representation of direct processing preparation techniques is presented in the figure 2. This procedure is applied for all the specimens.

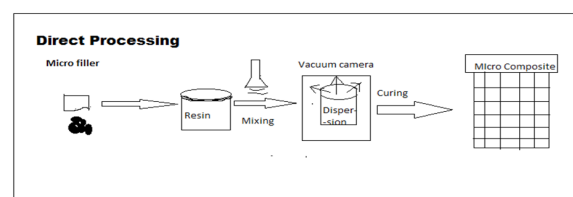


Fig. 2 Schematic representations of the direct processing techniques prior to in situ polymerization and synthesis of thermo set composites.

Characterization encompasses mechanical (tensile, flexural tests), thermal (TGA, DSC tests), Morphology (SEM test). In each case at least three samples are tested and the coefficient intervals (CI), standard error and % change on mean values for the best samples are tabulated. The following different composites are prepared.

Practical work specimen Photographs are listed:

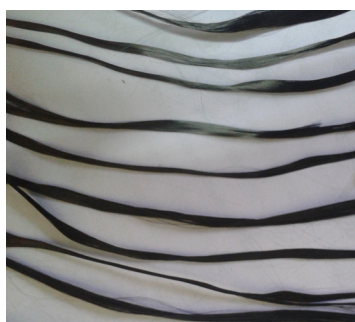


Fig 3: Wire extrusion carbon fiber.

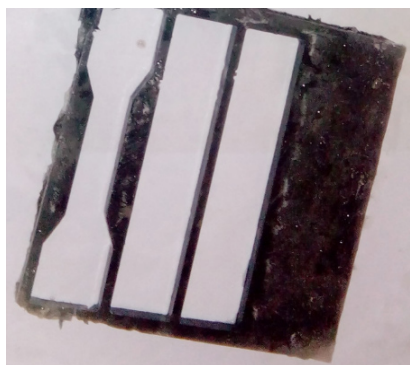


Fig 4: Specimen



Fig.5 Specimen No 1



Fig. 6: Specimen NO 2



Fig. 7: Specimen No 3



Fig.8: Specimen No 4

Flexural Load Measurements:

Flexural strength and modulus were tested using an Instron Universal testing machine with a crosshead speed of 2mm/min. The three-point bending test system was used for all samples. In each case, Six samples were tested and the average value tabulated. Authors used 50 kN load cell used for testing. Furthermore the sample sizes 100 x 20 x 4 mm was cut in accordance with ASTM D 618.



Fig 9: Specimen of ASTM D618 (No 5)

Tensile Load Measurements:

Tensile strength was studied using an Instron Universal testing machine supplied by Instron Corporation; a series-9 automated testing machine was used with a crosshead speed of 5 mm/min. Testing samples were prepared in dumb-bell shapes and these dimensions are 100 x 20 x 4mm³ based on the ASTM D 638 standards. In each case, three samples were tested and the average value tabulated.



Fig 10: Specimen of ASTM D638 (No 6)

THERMAL ANALYSIS:

Thermo Gravimetric Analysis(TGA/DSC):

The thermal characteristics of the epoxy modified with carbon fiber are measured using both thermo gravimetric analysis (TGA) and differential scanning calorimetric (DSC-2015 TA Instrument). Thermo gravimetric analysis(TGA) was used to investigate thermal decomposition behavior of the composites. Differential scanning calorimetric (DSC-2015 TA Instrument) was used to study the glass transition temperature (T_g) of the material. Tests were done under nitrogen at a scan rate of 10°C/min in a programmed temperature range of 30 to 600°C. A sample of 5 to 10 mg was used for each run. The weight change was recorded as a function of temperature.

Scanning Electron Microscopy Analysis (SEM):

A JEOL JSM 840A JAPAN scanning electron microscope (SEM) was used to study the morphology of fractured surfaces of composites samples at uniform magnifications. The fractured surfaces were gold-coated initially subjecting it to SEM analysis. The scanning electron microscope of different cross-sections with uniform magnification (i.e.300x) of the composition of carbon fiber.

RESULTS AND DISCUSSIONS

Mechanical tests

Flexural Test

Table 1 Flexural Strength properties of both systems 1 & 2 of carbon fiber reinforced epoxy composites

Name of the sample	Name of the sample	Flexural strength N/mm ²	
		For Weight Proportions System 1	For Fiber Length System 2
Different Weight Proportions of Epoxy and Carbon fiber (CF) System 1	Constant Weight of Epoxy (95%) + Carbon fiber (5%) & Different Length of Fiber (cm) System 2		
Epoxy (97%) + CF (3%) specimen 1	1	208.95	209.17
Epoxy (95%) + CF (5%) specimen 2	2	210.12	211.10
Epoxy (93%) + CF (7%) specimen 3	3	209.36	209.93

Table 2 Flexural Modulus properties of both systems 1 & 2 of carbon fiber reinforced epoxy hybrid composites

Name of the sample	Name of the sample	Flexural Modulus \bar{N}/mm^2	
Different Weight Proportions of Epoxy and Carbon fiber (CF) System 1	Constant Weight of Epoxy (95%) + Carbon fiber (5%) & Different Length of Fiber (cm) System 2	For Weight Proportions System 1	For Fiber Length System 2
Epoxy (97%) + CF (3%) specimen 1	1	1167.2	1160.5
Epoxy (95%) + CF (5%) specimen 2	2	1201.5	1287.7
Epoxy (93%) + CF (7%) specimen 3	3	1182.9	1198.7

Flexural strength and Flexural modulus is done on the different specimens. The flexural strength and flexural modulus is calculated by using following formula.

$$F.S = (3 * F * L) / (2 * b * d^2) \text{ ----- (I)}$$

$$F.M = (L^3 * F) / (4 * b * h^3 * d) \text{ ----- (II)}$$

F is the load (force) at the fracture point.

L is the length of the support span.

b is width.

d is thickness.

h is height.

The results are tabulated at table 8 and table 9. And the graphs are plotted for the specimens. It is shown in figure 11 and figure 12. In the present work we synthesized two different systems (1) carbon fiber reinforced epoxy with weight proportions of carbon fiber 3%, 5%, 7%, (2) carbon fiber reinforced epoxy with constant weight ratio i.e., Epoxy 95% + Carbon fiber 5% in order to suspend on epoxy resin with different fiber lengths such as 1, 2, and 3 cm. Table 8 shows the experimental measurements of flexural strengths both systems 1 & 2.

It is observed that flexural strength and modulus properties increased up to 5% wt of carbon fiber and 2 cm length of carbon fiber and decreases with further increase in carbon content and length. Similarly for system 2 (Epoxy 95% + Carbon fiber 5%) of different fiber length, experimental measurements of flexural strength properties of the carbon fiber reinforced epoxy composites are shown in table 1. The graphs are obtained the Universal Testing Machine for the obtained values shown in the figure 11 and figure 12.

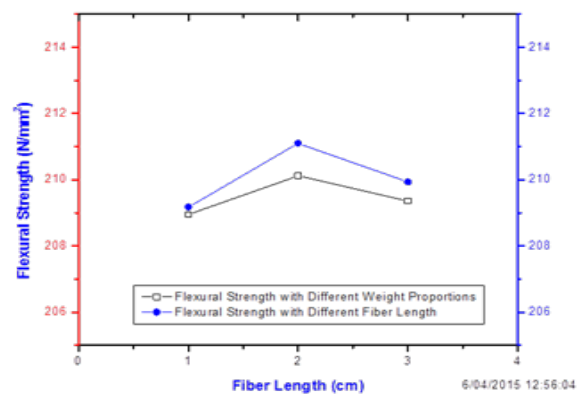


Fig.11 System 1 & 2 flexural strength variations for different flexural systems.

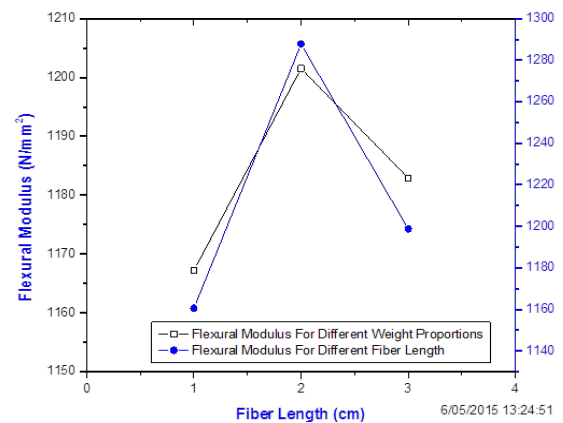


Fig. 12 System 1 & 2 flexural modulus variations for different proportions and length of fiber.

From the above graphs we can observe that specimen 2 of system 2 i.e. Epoxy (95%) + CF (5%) and 2 cm length of fiber has higher flexural strength and flexural modulus compared to the other specimens in the system 2. Similarly the specimen 2 of system 1 i.e. Epoxy (95%) + CF (5%) specimen 2 has higher flexural strength and flexural modulus compared to the other specimens in the same system. From the Flexural test we came to know that system 2 i.e., for fiber length 2 cm has higher flexural strength and flexural modulus compared to system 1.

Tensile Test:

In the present work the tensile strength for the different specimens of system1 and system2 were checked in Universal Testing machine and the variations of tensile strength and tensile modulus were tabulated in the table 3 and 4. The graph is obtained from the Universal Testing Machine as shown in the figure 13 and 14.

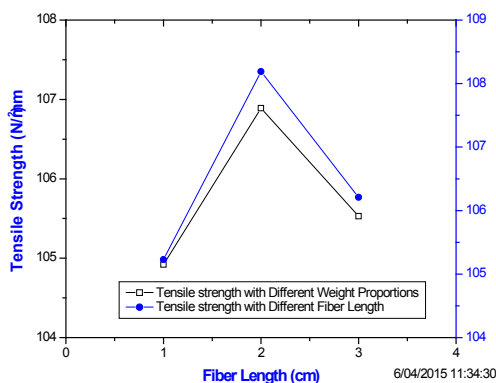


Fig. 13 System1 & 2 Tensile Strength variations for different specimen

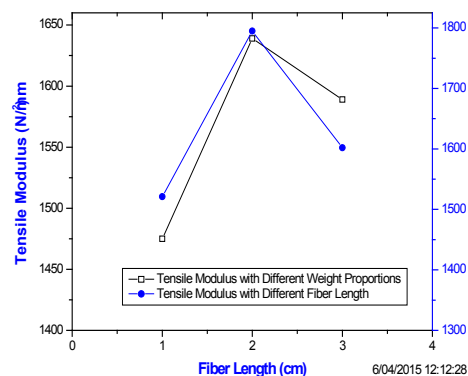


Fig. 14 System 1 & 2 Tensile modulus variations for different specimens

From the graph it is observed that system2 specimen 2 showed highest tensile strength and Tensile modulus compared to system1.

Table 3 Tensile Strength properties of both systems 1 & 2 of carbon fiber reinforced epoxy composites

Name of the sample	Name of the sample	Tensile Strength N/mm ²	
Different Weight Proportions of Epoxy and Carbon fiber (CF) System 1	Constant Weight of Epoxy (95%) + Carbon fiber (5%) & Different Length of Fiber (cm) System 2	For Weight Proportions System 1	For Fiber Length System 2
Epoxy (97%) + CF (3%) specimen 1	1	104.92	105.23
Epoxy (95%) + CF (5%) specimen 2	2	106.89	108.19
Epoxy (93%) + CF (7%) specimen 3	3	105.53	106.21

Table 4 Tensile Modulus properties of both systems 1 & 2 of carbon fiber reinforced epoxy composites

Name of the sample	Name of the sample	Tensile Modulus N/mm ²	
Different Weight Proportions of Epoxy and Carbon fiber (CF) System 1	Constant Weight of Epoxy (95%) + Carbon fiber (5%) & Different Length of Fiber (cm) System 2	For Weight Proportions System 1	For Fiber Length System 2
Epoxy (97%) + CF (3%) specimen 1	1	1475	1521
Epoxy (95%) + CF (5%) specimen 2	2	1639	1795
Epoxy (93%) + CF (7%) specimen 3	3	1589	1602

Thermal Analysis Differential Scanning Calorimetric (DSC)

Differential Scanning Calorimetric (DSC) analysis is done to the system1 specimen 2 specimen 3. Which has highest flexural strength and flexural modulus? The following graph shown in figure 15 is obtained showing the glass transition temperature variation for system1 specimen2 and system2 specimen3.

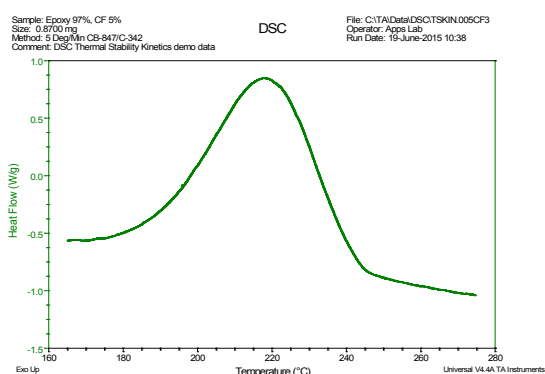


Fig. 15 Graph showing the Glass transition temperature for Sys

From the above graphs figure 15, it is observed that both the composites system1 specimen2 properties degrade as the heat flow and temperature increases. The system1 specimen2 has the higher glass transition temperature 2150C compared to specimen3.

Thermo Gravimetric Analysis (TGA):

Thermo Gravimetric Analysis is done for the specimen 2 in system1 and which has high flexural and tensile strength. The second specimens of system 1 & 2 are maintained up to 2500C and 4900C % Weight loss for both the specimens for temperature variations is obtained in the form of graph as shown in the fig. 16. And fig. 17.

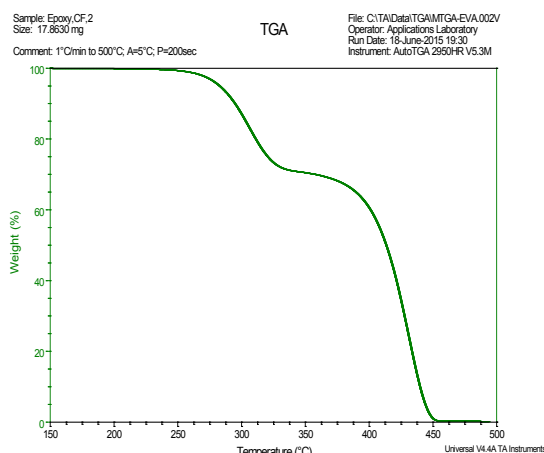


Fig 16: Thermo Gravimetric Analysis for Specimen 2 of System 1.

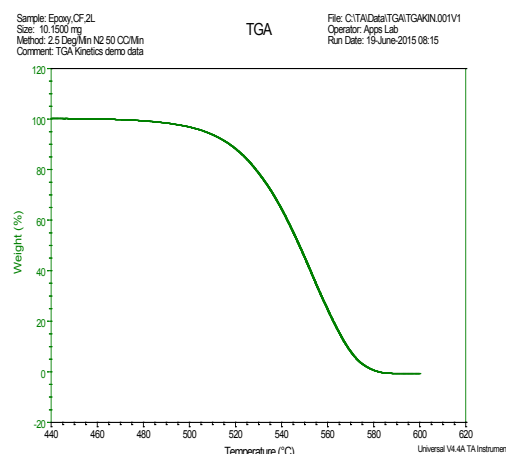


Fig. 17 Thermo Gravimetric Analysis for Specimen 2 of System 2.

From the above figures 16 and 17 is observed that specimen2 of system 2 can resist up to 4900C. The weight loss takes place above 4900C. The specimen2 of system 1 can resist up to 2500C. The weight loss takes place above 2500C. The specimen2 of Carbon Fiber Reinforced Epoxy of fiber length 2 cm has good thermal stability compared to specimen2 of system 1.

MORPHOLOGY: Scanning Electron Microscope (SEM) Analysis:

Scanning Electron Microscope (SEM) Analysis is done for the system1 specimen3 and system2 specimen 3 of fiber length 3 cm which has poor flexural strength. The images of fractured surfaces are taken so as to check the interface and homogeneous dispersion of fiber, filler in the matrix. Fig.18 and Fig. 19 shows the images of the fractured surfaces.

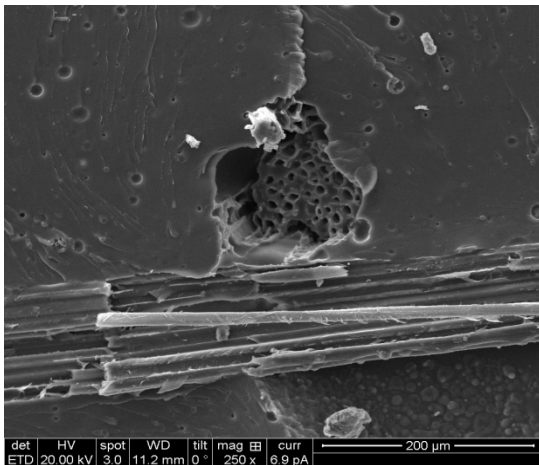


Fig. 18 SEM image of fractured surface of system1 specimen3.

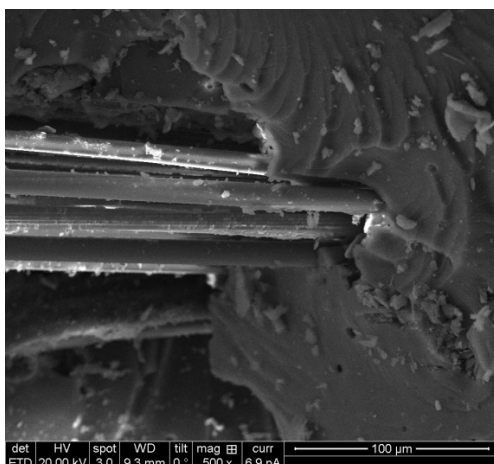


Fig. 19 SEM image of fractured surface of system2 specimen3

From the fig. 18 and fig. 19 it is observed that the good interface is obtained for both the specimens. The observation established good miscibility of Epoxy and Homogenous dispersion of carbon fiber in the matrix. The incorporation of 5% carbon fiber & 95% epoxy is this system2 specimen3 and the incorporation of 7% carbon fiber & 93% epoxy is this system1 specimen3.

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CONCLUSION:

Carbon fiber reinforced epoxy composites were synthesized with different proportions and length of carbon fiber dispersion through in situ polymerization. Flexural strength, flexural modulus, tensile strength and modulus were increased correspondingly up to 5%wt and 2 cm length of carbon fiber reinforced epoxy and decreases with further addition of fiber contents i.e., 7% wt. in system 1 and 3 cm length in system 2. Thus it can be concluded that Carbon fiber–epoxy composites can be used for high strength, stiffness, and bending applications in aerospace, automobile, and marine and lightweight article applications. Overall studies indicated that the carbon fiber reinforced composites at 2 cm length of carbon fiber system 2 specimen 2 loading are promising candidates for structural applications where high strength and stiffness is indispensable. The present study thus bears testimony to all of these findings. Hence the present study not only discloses that different length of fiber overseen through the polymer with different surface treatment promotes the performance of composites, but that unique tailored properties are improved by changing the proportions and length of the carbon filler on the matrix. This research indicates that the mechanical properties are mainly dependent on the fiber length and unidirectional orientation of polymer composites.

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