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Characterization of Carbon Fiber / Epoxy Composites with Different Fiber Parametric Quantity

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ABSTRACT

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. 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 mechanical and thermal 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 lengths of the fiber. The results that by taking epoxy 95 % and carbon fiber 5 % as constant with different fiber lengths were increased the mechanical and thermal properties compared with different fiber content in weight percentage. The lengths of the fiber 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).

I. 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 light-weight 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.

II. METHODS AND MATERIAL

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 25^0C. 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 18-25^0 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.

Table 1: 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 variation 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 Fibre/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) mm^3 is used to prepare casting and specimen for tensile test, flexural tests, compressive test, thermal analysis and morphology Figure-1 represents the glass mould.

Figure 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 2 below.

Figure 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 use 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 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 70^0C 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 3. This procedure is applied for all the specimens.

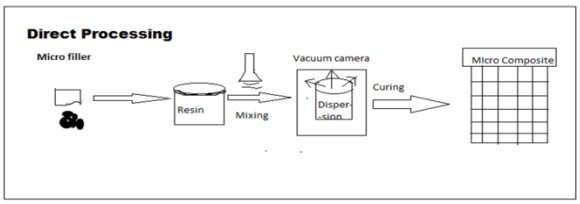

Figure 3: Schematic representations of the direct processing techniques prior to in situ polymerization and synthesis of thermo set composites.

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

Figure 4: Wire extrusion carbon fiber

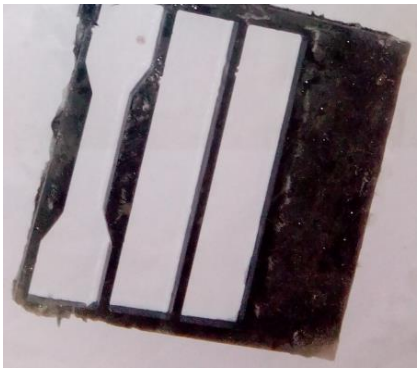

Figure 5: Specimen

Figure 6: Specimen No 1

Figure 7: Specimen No 2

Figure 8: Specimen No 3

Figure 9: 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 were cut in accordance with ASTM D 618.

Figure 10: 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.

Figure 11: 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 (Tg) 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 ach 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.

III. RESULT AND DISCUSSION

Mechanical tests

Flexural Test

The results are tabulated at table 2 and table 3. And the graphs are plotted for the specimens. It is shown in figure 43 and figure 44.

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 2 shows the experimental measurements of flexural strengths both systems 1 & 2.

Table 2: 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	
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	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 3: 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 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.

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

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

- 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 2 and table 3. And the graphs are plotted for the specimens. It is shown in figure 43 and figure 44.

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 2 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 system2 (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 9. The graphs is obtained the Universal Testing Machine for the obtained values shown in the figure 12 and figure 13.

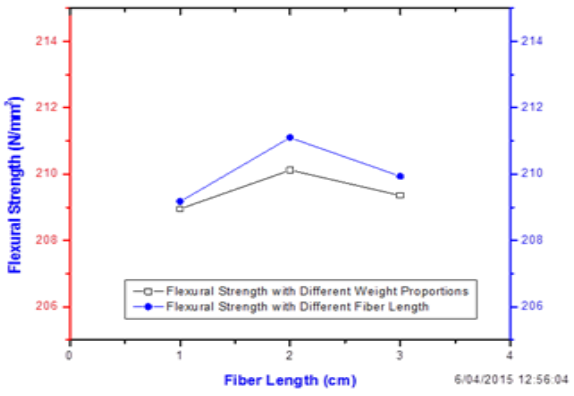

Figure12: System1 & 2 flexural strength variations for different flexural systems

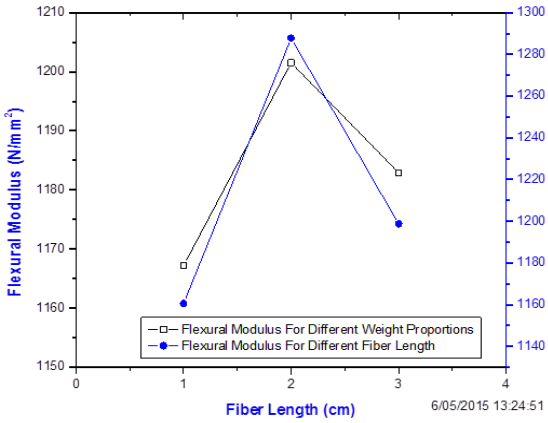

Figure 13: System 1 & 2 flexural modulus variations for different proportions and length of fiber

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 4 and 5. The graph is obtained from the Universal Testing Machine as shown in the figure 14 and 15.

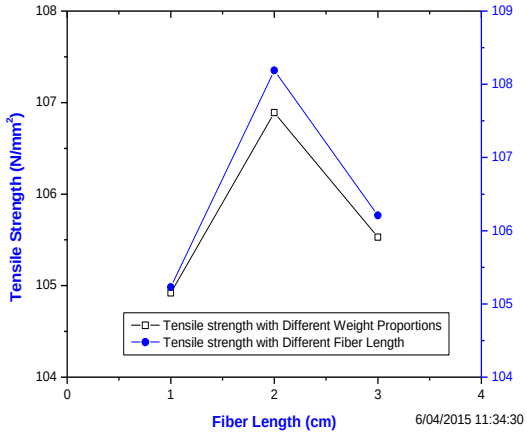

Figure 14: System1 & 2 Tensile Strength variations for different specimen

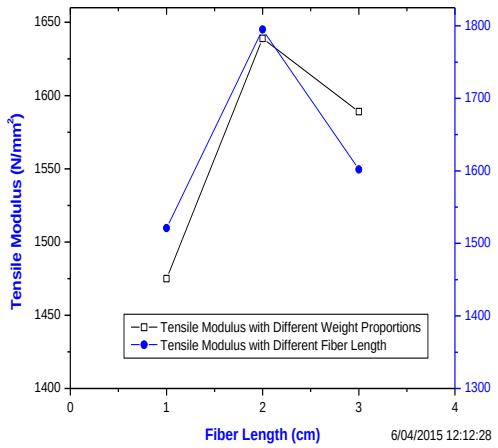

Figure 15: System 1 & 2 tensile modulus variations for different specimens

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

.

Table 4: 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 5: 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. This has highest flexural strength and flexural modulus. The graph shown in figure 16 has obtained showing the glass transition temperature variation for system1 specimen2.

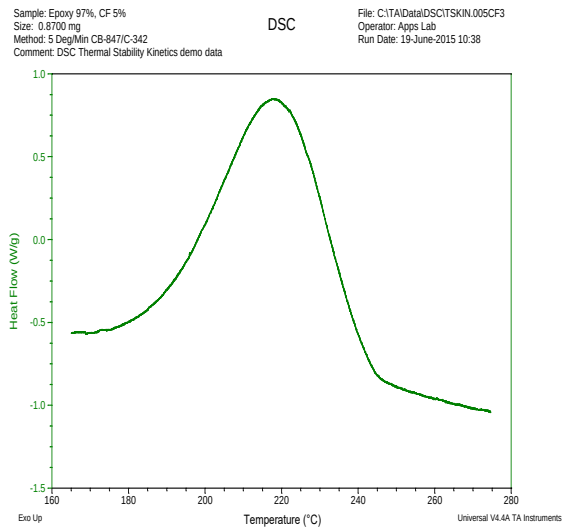

Figure 16: Graph showing the Glass transition temperature for System1 specimen2

From the above graph figure 16 it is observed that the composite system1 specimen2 properties degrade as the heat flow and temperature increases. The system1 specimen2 has the higher glass transition temperature 215^{0}C.

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 250^{0}C and 490^{0}C % Weight loss for both the specimens for temperature variations is obtained in the form of graph as shown in the fig. 17. And fig. 18.

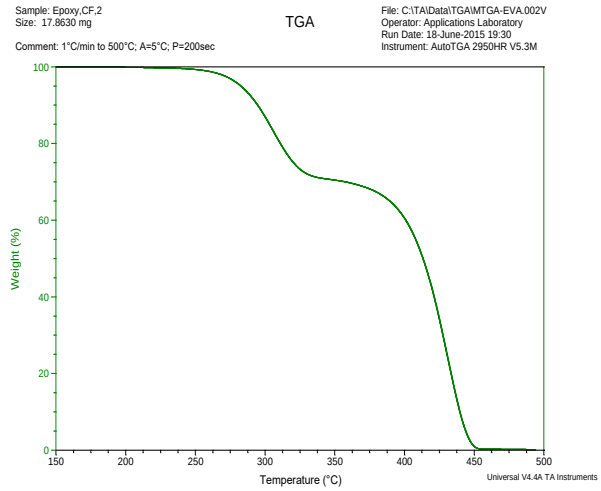

Figure 17: Thermo Gravimetric Analysis for Specimen 2 of System 1.

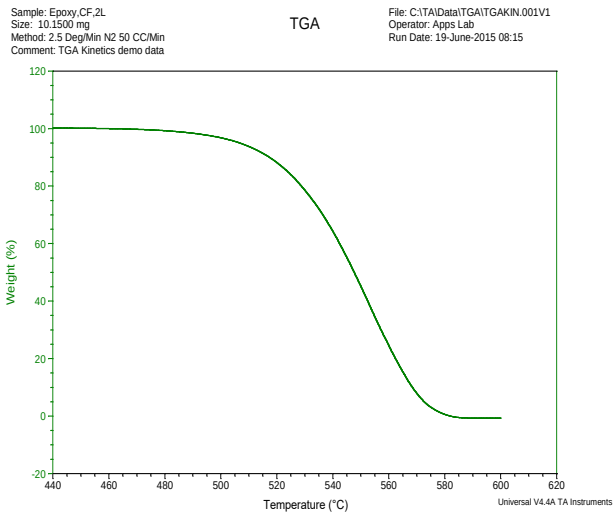

Figure 18: Thermo Gravimetric Analysis for Specimen 2 of System 2.

From the above figures 17 and 18 is observed that specimen2 of system 2 can resist up to 490^{0}C. The weight loss takes place above 490^{0}C. The specimen2 of system 1 can resist up to 250^{0}C. The weight loss takes place above 250^{0}C. 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 specimen 3 and system 2 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.19 and Fig. 20 shows the images of the fractured surfaces.

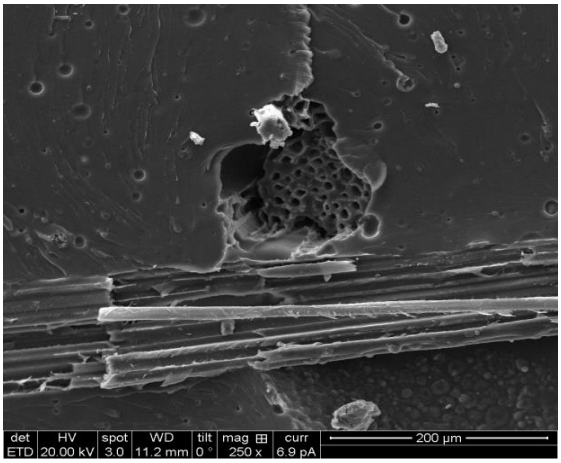

Figure 19: SEM image of fractured surface of system1 specimen3.

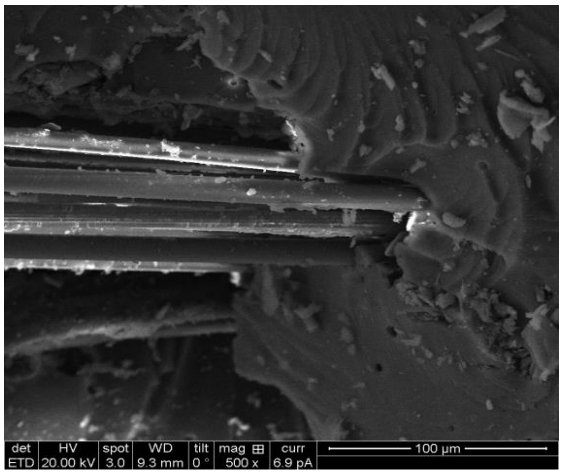

Figure 20: SEM image of fractured surface of System2 specimen 3

From the fig. 19 and fig. 20 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.

IV. CONCLUSION

Carbon fiber reinforced epoxy composites were synthesized with different proportions of fiber weight and different lengths of carbon fiber dispersion through in situ polymerization. Flexural strength, flexural modulus, tensile strength and modulus were increased correspondingly up to 5%wt carbon fiber and 95% epoxy i.e., specimen 2 in system 1 and decreases with further addition of fiber content 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 light weight article applications. Overall studies indicated that the carbon fiber reinforced composites at 2 cm length of fiber with constant epoxy and fiber weight (i.e., 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 weight proportions and length of the carbon fiber on the matrix. This research indicates that the mechanical properties are mainly dependent on the fiber length and unidirectional orientation of polymer composites.

V. REFERENCES

[1] Prashanth Banakar, Influence of Fiber Orientation and Thickness on Tensile Properties of Laminated Polymer Composites Int. J. Pure Appl. Sci. Technol., 9(1) (2012), pp. 61-68 .

[2] R.Varatharajan et al, Mechanical and machining characteristics of GF/PP and GF/Polyester composites, Material Science and Engineering B 132 (2006), pp 134-137

[3] S.A.Hitchen, S.L.ogin and P.A.Smith, Effect of fiber length on Fatigue of short carbon fiber/epoxy composite, Composites, Vol26, No 4,1995, p 303.

[4] Chin-Hsing Chen et al, Pultruded Fiber Reinforced Polyurethane Composites III Static Mechanical, Thermal, and Dynamic Mechanical Properties, Composites Science and Technology 52(1994), pp 427-432.

[5] Craig D.Snyder et al, Low Density Polyurethane composites, Composites 2002 Convention and Trade Show Composites fabricators Association, September 25-27, 2002, Atlanta, Georgia USA.

[6] Deng, S., Ye, L. and Mai, Y.-W. (1999). Influence of Fiber Cross-sectional Aspect Ratio on Mechanical Properties of Glass Fiber/Epoxy Composites, 1. Tensile and Flexure Behavior, Composite Science and Technology, 59: 1331–1339

[7] K. Mohamed Kaleemulla and B. Siddeswarappa(2009). Influence of Fiber Orientation on the In-plane Mechanical Properties of Laminated Hybrid Polymer Composites, Journal of Reinforced Plastics and Composites 2010, Vol. 29, No. 12/2010: 1900–15

[8] Baker, A. A., Callus, P. J., Georgiadis, S., Falzon, P. J., Dutton, S. E. and Leong, K. H. (2002). An Affordable Methodology for Replacing Metallic Aircraft Panels with Advanced Composites, Composites: Part A, 33: 687 696

[9] Mayer S, Cândido GM and Rezende MC. Influence do condicionamentoambientalna Resistencia atraçãode composites de carbon/epoxy reparations. Polímeros2003; 13(3):147153.

[10] ASTM D3039/D3039M00. Standard test method for tensile properties of polymer matrix composite materials.USA: American Society for Testing Materials; (2004). [CDROM].
[11] ASTM D3171. Standard Test Methods for Fiber Content of Resin matrix composites by Matrix Digestion. Philadelphia, PA: American Society for Testing and Materials; 1982. p. 122124.
[12] ASTM D2344. Standard Test Method for Apparent Inter laminar Shear Strength of Parallel Fiber Composites by Short Beam Method.USA: American Society for Testing and Materials; 1984. p. 4345.
[13] ASTM D3410. Standard Test Method for Compressive Properties of Unidirectional or Cross ply Fiber Resin Composites.USA: American Society for Testing and Materials; 1987. p. 132139.
[14] Paiva JMF, Mayer S and Rezende MC. Evaluation of Mechanical Properties of Four Different Carbon/Epoxy Composites Used in Aeronautical Field. Materials Research 2005; 8(1):9197.
[15] Hexcel Composites. Resin systems for advanced composites. Catalog of Hexcel Composites, 2000. Available\ from: http://www.hexcel.com.
[16] Tanoglu M, Robert S, Hider D, McKnigth SH, Brachos V and Gillespie Jr JW. Effects of thermoplastic performing binder on the properties of S2glass fabric reinforced epoxy composites. International Journal of Adhesion & Adhesives.2001; 21(3):187195.
[17] Varley RJ, Hodgkin JH and Simon GP. Toughening of a trifunctional epoxy system. Part VI. Structure property relationships of the thermoplastic toughened system.Polymer.2001; 42:38473858.
[18] Owen MJ. Thermosetting resins. Integrated Design and Manufacture using Fiber Reinforced Polymeric Composites. Owen MJ, Middleton V and Jones IA (editors). USA, England: CRC Press LLC and Wood head Publishing Limited; 2000.
[19] Norwood LS. Fiber reinforced polymers. In: Handbook of Polymer Composites for Engineers. Holloway L(editor). England: Wood head Publishing Limited; 1994. p. 369.
[20] Jang BZ. Advanced Polymer Composites: Principles and Applications. USA: ASM International; 1994.