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Development of SiC Filled Bamboo/Epoxy Composites and its Mechanical Properties Evaluation

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Abstract: Conventional fiber reinforced plastics (FRP's) have long been important if not indispensable in many crucial applications such as transportation, renewable energy, defense applications, as well as many others. Composite materials are of interest to these industries due to their attractive properties including high strength to weight ratio and high modulus to weight ratio. Comprehensive research has been conducted on conventional composite materials to optimize their processing parameters as well as optimize their mechanical behavior and reliability. Although composites provide excellent mechanical properties, certain applications demand improved mechanical behavior as well as the presence of additional properties. Recent developments in polymers have developed nano composites, which are composites reinforced by nano powders. In these materials, the nano powders have shown great enhancements in mechanical properties, thermal properties, and electrical properties. Never the less, these composites lack the strength for applications where FRP's are currently used. The addition of nano powders as reinforcement to conventional composites shows great promise to not only enhance the existing properties of these composites, but also add many other properties that would maximize their applications. The objective of this project work is to investigate the fiber orientation reinforced hybrid polymer nano composites that combine with hybrid composites i.e BAMBOO/E-GLASS and epoxy polymer in the ratio of 0.1wt %, 0.2 wt% and 0.3 wt% percent of volume are to be considered. The mechanical properties are to be calculating by carrying out tests on specimens intension, compression and flexure in accordance with the test procedure laid down in ASTM standards. Finally after obtaining the tested results, those values are checked.

Keywords: FRP's, Hybrid Composite, BAMBOO, E-Glass, ASTM Standards.

I. INTRODUCTION

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals. A composite material can be defined as the material that is obtained by judicial combining of two or more dissimilar materials, having different physical and electrical properties, in such a way that the resultant material properties are superior to any of the parental one. Composites are usually made of two phases-one is reinforcement phase and other is matrix phase. Composites are usually made of two phases-one is reinforcement phase and other is matrix phase. Development of new composites and new applications of composites is accelerating due to the requirement of materials with unusual combination of properties that cannot be met by the conventional monolithic materials. Actually, composite materials are capable of covering this requirement in all means because of their heterogeneous nature. Properties of composites arise as a function of its constituent materials, their distribution, and the interaction among them and as a result an unusual combination of material properties can be obtained.

II. FABRICATION OF COMPOSITES AND SPECIMEN PREPERATION

There are several techniques available for fabrication of fiber reinforced composite laminates. In the present work, hand layup technique was used. The specimens were fabricated as per ASTM standards. This chapter describes the details regarding the materials used, laminate fabrication and specimen preparation for different mechanical testing.

A. Materials Used

Reinforcement materials:

- Bamboo fibers in the form of woven mat -(300×5× 0.5) mm
- Filler -Silicon carbide(SiC) – 48 µm mesh size

In this study, the Silicon Carbide (SiC) particles with an average particle size of 48 µm were used as filler in 5%wt, 10%wt, 15%wt with respect to weight of Epoxy resin. Fig.1 shows the SiC filler material. SiC is one of the most widely used engineering materials due to its high elastic modulus, high wear resistance and chemical corrosion resistance, excellent oxidation, high-temperature stability, and the retention of strength at high temperatures. However, the major problem with the use of SiC as a structural material is its inherent brittleness and poor fracture toughness, which is the common characteristic of ceramic material.

Fig.1. Silicon Carbide.

B. Resin System

The resin system consists of Epoxy resin (LY 556) and Hardener (HY951) in the ratio 10:1 by weight, both supplied by Petro Araldite Pvt. Ltd., Manali, Chennai. Table .1 shows the physical and mechanical properties of typical epoxy resin.

Various advantages of epoxy are:

- Excellent adhesion to many different materials.
- Excellent resistance to chemical attack.
- Negligible shrinkage.
- Aspect (visual) clear, pale yellow liquid.

TABLE I: Physical And Mechanical Properties of Epoxy

Tensile strength, Mpa	69
Tensile modulus, Gpa	4.3
Viscosity at 25 °C, MPa-s	10000 - 12000
Density at 25 °C, g/cm^3	1.15 - 1.20
Flash point, °C	> 200
Storage temperature, °C	2 - 40

C. Preparation of Bamboo Fiber Mats

Bamboo culms were obtained from the forest department. Bamboo strips of size (300×5×0.5) mm were first extracted from the bamboo culms manually. Fig.2 shows the bamboo strips. The thickness of the strips is maintained uniformly using go-gauge and dried in sunlight for about 24hrs. the go-gauge is prepared by taking two ply wood sheets in which one is of smaller size and the other is of larger size and riveted together by placing the smaller ply sheet over the larger one and by placing the spacers of 0.5mm thickness and 20mm wide at both the ends. Fig.3 shows the go-gauge prepared. Chemically untreated (as is received) bamboo strips were then used to weave the mats manually for the size (280×250×1) mm. Care is taken during weaving process to maintain uniform spacing between each strip. Fig.4 shows the bamboo mat woved manually. These mats are used for the fabrication of composite laminates. The average surface density of the prepared mats was found to be 400 gsm.

Fig.2. Bamboo strips extracted from the bamboo pulp.

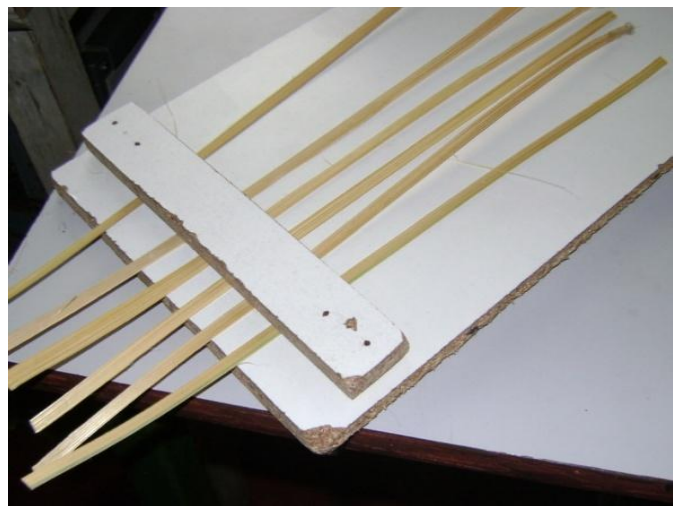

Fig.3. Measuring thickness of bamboo strips using go-gauge.

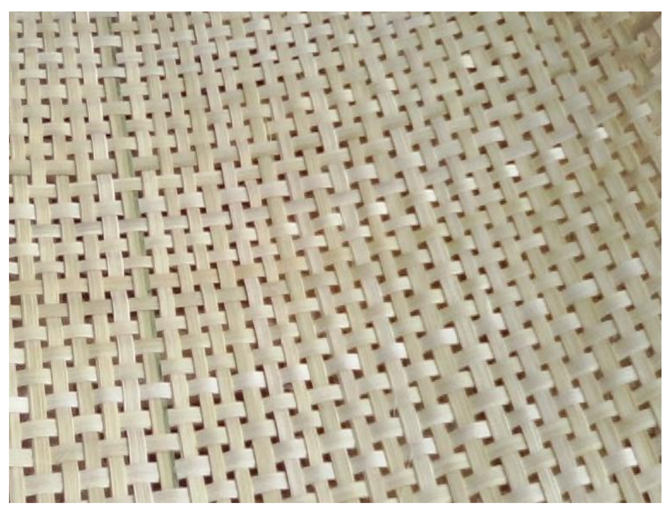

Fig.4. Bamboo mat woven manually.

D. Processing of the Composites

All the laminates were fabricated by Hand Layup technique using a mold and cured under pressure (30 bar) using hydraulic press. The bamboo mats woven and dried in sunlight for about 24hr are used for making bamboo composites. Six layered composites are prepared in each case. The principle of hand lay up technique is shown in Fig.5. Hand lay-up is a simple method for composite laminate preparation. A mold must be used for hand Lay-up parts unless the composite is to be joined directly to another structure. The mold can be as simple as a flat sheet or have infinite curves and edges. For some shapes, molds must be joined in sections so they can be taken apart for part removal after curing.

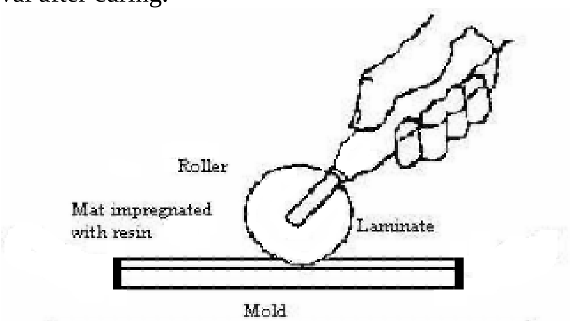

Fig.5. Hand Lay-Up technique.

Before lay-up, the mold is prepared with a release agent to ensure that the parts do not adhere to the mold. Reinforcement fibers are cut and laid in the mold. Resin is then catalyzed and added to the fibers. A brush, roller or squeegee is used to impregnate the fibers with the resin.

E. Fabrication Set Up

(a) Hydaulic Press

(b) Mold

Fig.6. Fabrication Setup.

Fig6(a) and 6(b) shows the hydraulic press and mold used for the fabrication of composite laminates. The bamboo mats of size (280×250) mm are used for fabrication of laminates. The weight and dimensions of each mat is noted. Poly propylene paper was laid on the surface of the mold to facilitate easy removal of the laminate after curing. The bamboo mats are laid on the surface of the mold. Fig.7(a) to 7(c) shows the process for laminate fabrication. The resin hardener mixture is applied on both surfaces of the bamboo mat using brush and with the help of the roller the resin hardener mixture is uniformly distributed throughout the bamboo mat and the procedure is continued for all the layers of bamboo mat and the mold is then closed and placed under the hydraulic press and is pressed at 30bar pressure for about 24 hrs for curing. Fig.8 shows the unfilled bamboo laminate.

(a) Applying epoxy resin and hardener

(b) Applying pressure in Hydraulic mixture to the mat using brush press.

(c) Cured laminate

Fig.7. Fabrication Process.

Fig.8. unfilled bamboo laminate

For the preparation of SiC particle filled bamboo-fiber reinforced epoxy resin composites, the SiC in the required proportion is added to the epoxy resin and thoroughly stirred to ensure unifom distribution of filler particles in the resin. The hardner is then added to filled epoxy resin and further stirred. The process of stirring was continued till the resin system is applied to last layer. In order to evaluate the effect of SiC particles loading in the epoxy matrix on mechanical properties of bamboo-fiber reinforced epoxy resin composites, the composite specimens with three different filler proportions are prepared. The weight fractions of the filler in the matrix were 5%, 10% and 15% with respect to the weight fraction of the epoxy resin. Laminates are prepared as in the same procedure done for unfilled bamboo/epoxy composites. Fig.9 shows the filled bamboo laminates. After finishing all these processes the laminates are removed from the mold, the weight and dimensions (length, width and thickness) are noted for unfinished laminates. Finally the laminates are finished to the required size using diamond wheel saw manually, and the weight and dimensions (length, width and thickness) are noted for finished laminates. Table 2shows the details of bamboo/epoxy laminates.

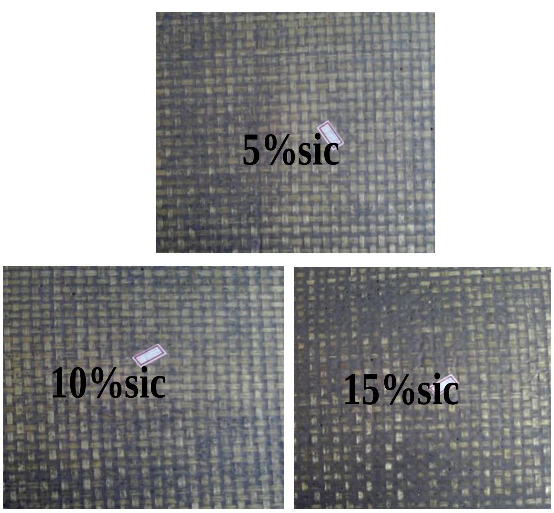

Fig.9. 5, 10, 15% SiC filled (with respect to wt% of epoxy) bamboo laminates.

The weight fraction of fiber and filler in the finished laminate is calculated using the equations 3.1 and 3.2.

$$W_{fiber} = \frac{W_t}{W_{fl}} \qquad (1)$$

Where,
W_{fiber} = Weight fraction of fiber, %
W_t = total weight of six mats, grams
W_{fl} = weight of finished laminate, grams

$$W_{filler} = \frac{W_{ffl}}{W_{fl}} \qquad (2)$$

Where,
W_{filler} = weight fraction of filler, %
W_{ffl} = weight of filler in finished laminate, grams
W_{fl} = weight of finished laminate, grams

TABLE II: Details Of Bamboo/Epoxy Laminates

Sl. No.	Laminate Code	Before casting			Finished plate			Bamboo fiber wt. fraction %	Filler wt. fraction Based on weight of the resin %
		Bamboo fabric wt grams	Resin wt grams	Filler wt grams	Size mm	Bamboo fabric wt grams	Filler wt grams		
1	1-B-0	190	286	----	264×236	148.77	----	50.4	----
2	2-B-0	170	249	----	264×236	158	----	56.68	----
3	1-B-5SiC	185	275	12.5	270×229	156.55	8.32	48.93	5
4	2-B-5SiC	160	211.76	10.58	257×234	126.85	7.08	46.98	5
5	1-B-10SiC	195	291.5	26.5	265×230	158.87	18.07	45.35	10
6	2-B-10SiC	175	254.77	23.16	255×232	155.28	15.85	50.05	10
7	1-B-15SiC	178	253	34.5	265×236	149.28	25.93	42.65	15
8	2-B-15SiC	175	254.85	34.66	265×238	153.09	23.88	47.84	15

F. Specimen Preparation

All specimens are prepared according to American Standard for Test Methods (ASTM).

Tensile Test Specimen: According to ASTM D 3039, the specimen is cut into required dimension (250×25.4×5) using diamond wheel saw and is finished to size using emery paper. Aluminium end tabs are mounted at the both ends of the specimen for the purpose of gripping. The geometry of the test specimen is shown in Fig.10. The bamboo composite specimens prepared are shown in Fig.11.

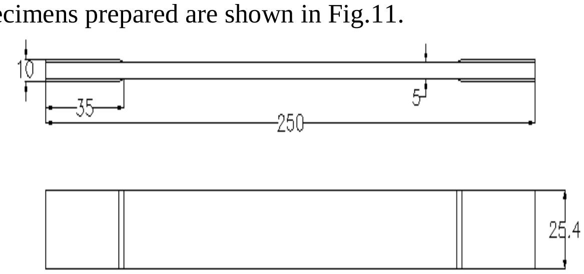

Fig.10.Geometry of Tensile Test Specimen.

Fig.11. Tension Test Specimens.

Flexural Specimen: According to ASTM D 790.the specimen is cut into required dimension (125×10×5) using diamond wheel saw and is finished using emery. The geometry of the test specimen is shown in figs.12 and 13.

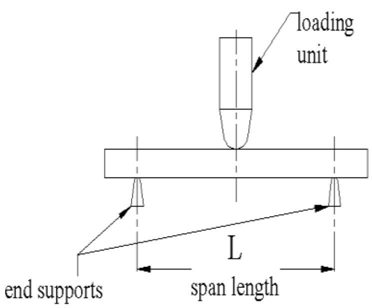

Fig.12. Geometry of Flexural Test Specimen.

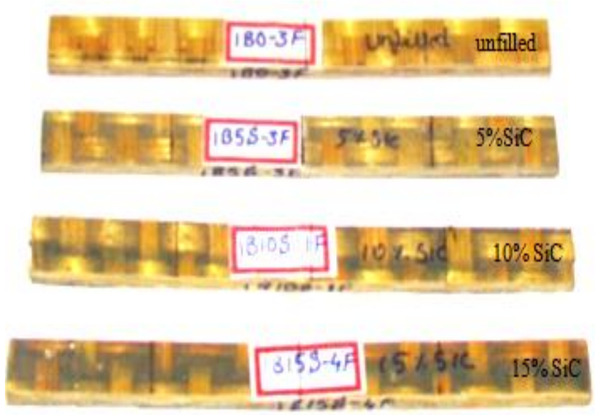

Fig.13. Flexural Test Specimens.

Compression Test Specimen: According to ASTM D 3410.the specimen is cut into required dimension (125×25.4×5) using diamond wheel saw and is finished using emery. The end tabs are mounted on both the ends of the specimen for the purpose of gripping (usually aluminum tabs are used). The geometry of the test specimen is shown in figs.14 and 15.

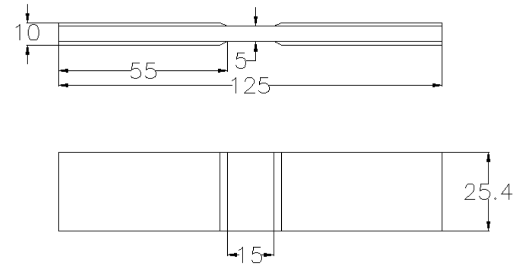

Fig.14. Geometry of Compression Test Specimen.

Fig.15. Compression Test Specimens.

Water Absorption Test Specimen: Water absorption test is conducted according to ASTM D 570. The specimen is cut into required dimension (76.2×25.4×5) mm using diamond wheel saw and is finished using emery. All edges of the specimen are sealed with resin system. The geometry of the test specimen is shown in figs.16 and 17.

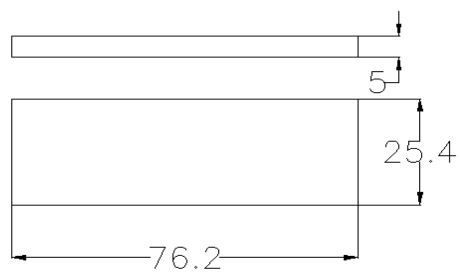

Fig.16. Geometry of Water Absorption Test Specimens.

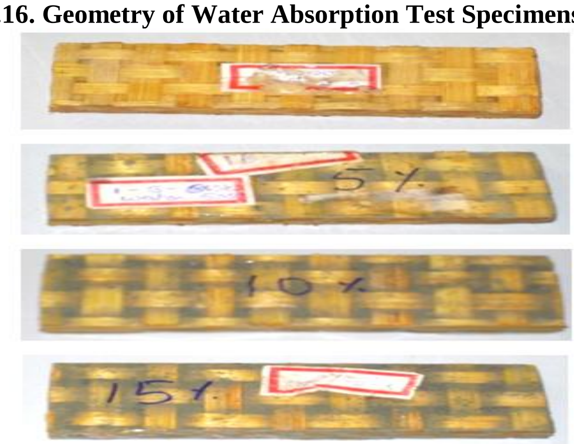

Fig.17. Water Absorption Test Specimens.

III. EXPERIMENTATION

Both tension and bending tests were conducted on LLYOD LR50K machine with a capacity of 50 kN. Data acquisition software 'Windap' was used for testing. For both the tests, the rate of loading was 2 mm/min. Compression test was conducted on computer-interfaced universal testing machine SR.NO. 060601, with a capacity of 10 kN.

A. Tension Test

The tension test set up is shown in fig.18. For each composition, three identical specimens were tested and average results were reported. The samples were loaded along the fiber direction. Stress-strain diagram was recorded.

Fig.18. Tensile test setup.

Ultimate tensile stress is calculated using the equation 4.1,

$$\sigma_f = \frac{P}{A_0} \quad \textbf{(3)}$$

Where,
σ_f = Ultimate tensile stress, Mpa
P = Peak load, N
A_0 = Original cross-sectional area, mm^2

B. Flexural Test

The three point flexural test set up is shown in fig.19. L/d ratio was 16. For each composition, four identical specimens were tested and average results were reported. Load-deflection plot was recorded.

Fig.19.Flexural test setup.

Maximum stress in the outer fibers occurs at midspan and this stress is calculated using the equation 4.2.

$$\sigma_f = \frac{3PL}{2bt^2} \quad \textbf{(4)}$$

Where,
σ_f = Stress in the outer fiber at the midspan, Mpa
P = Load at the given point on the load-deflection curve, N
L = Span length, mm
b = Width of beam tested, mm
t = Depth of beam tested, mm

The tangent modulus of elasticity is the ratio, within the elastic limit, of stress to corresponding strain. It is calculated using the equation 4.3.

$$E_B = \frac{L^3 m}{4bd^3} \quad \textbf{(5)}$$

Where,
E_B = Modulus of elasticity in bending, Mpa,
L = Span length, mm.
b = Width of the beam tested, mm.
d = Depth of beam tested, mm.
m = Slope of the tangent to the initial straight-line portion of the load deflection curve N/mm

C. Compression Test

Compression testing of the composite materials is one of the most difficult types of testing because of the tendency for premature failure due to global buckling or end crushing. The compression test set up is shown in fig.20. For each composition, three identical specimens were tested and average results were reported. The samples were loaded along the fiber direction. Stress-strain diagram was recorded.

Fig.20. compression test setup.

Ultimate compressive stress is calculated using the equation 4.4.

$$\sigma_c = \frac{P}{A_0} \qquad (6)$$

Where,
σ_c = Ultimate compressive stress, Mpa
P = Peak load, N
A_0 = original cross-sectional area, mm^2

D. Water Absorption Test

This test method covers the determination of the relative rate of absorption of water by composite materials when immersed. The dried bamboo samples in groups of three for each case were first weighed and then immersed in distilled water at room temperature as shown in fig.22(a). Samples were periodically (every 24 hours) taken out of water, surface water was wiped off with soft cloth or tissue paper and weighed to the nearest 0.001 g using the digital balance (fig.22(b)). The procedure is repeated until the saturation level is reached.

(a) Samples immersed in water

(b) Digital balance

Fig.21. water absorption testing

The percentage of water gain was calculated using equation 4.5.

$$M(\%) = \frac{W_w - W_d}{W_d} \qquad (7)$$

Where,
M = moisture gain, %
W_d = weight of dry sample, grams
W_w = weight of wet sample, grams

The diffusion co-efficient is calculated using the equation 4.6.

$$D_z = \pi \left[\frac{h}{4M_m}\right]^2 \left[\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right]^2 \qquad (8)$$

Where,
D_Z = diffusion co-efficient in Z-direction, mm^2/s
M_m = moisture uptake at fully saturated condition
$\left[\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right]^2$ = slope of moisture gain v/s $\sqrt{t}$ curve

IV. RESULTS AND DISCUSSIONS

In this section experimental results obtained for the tensile, flexural, compression and water absorption tests were discussed.

A. Tensile Test

Since composites are brittle materials they manifest only macroscopic elastic deformation up to the stress at which they fails. These materials follow linear elastic stress-strain relations up to their fracture. The stress-strain diagram for these composites is shown in Fig.22 to Fig.26 all curves indicate non-linear behavior. The point of deviation from linearity is the indication of failure initiation due to development of crack on the tension side. Sudden drop in the curve indicates failure of the material. Young's modulus is determined from the slope of the Stress-Strain curve within the elastic limit. Table 4.1 shows the various tensile properties of each specimen from different samples.

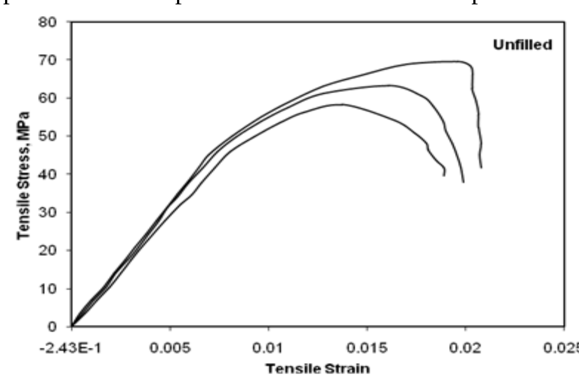

Fig.22. stress v/s strain graph for unfilled specimens .

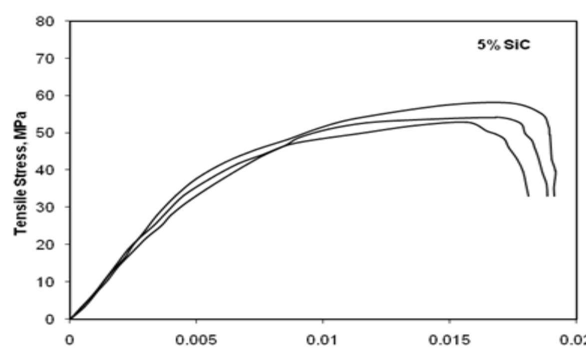

Fig.23. stress v/s strain graph for 5% SiC filled specimens.

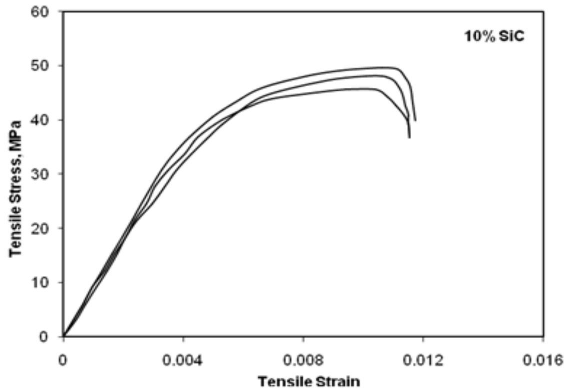

Fig.24. stress v/s strain graph for 10% SiC filled specimens.

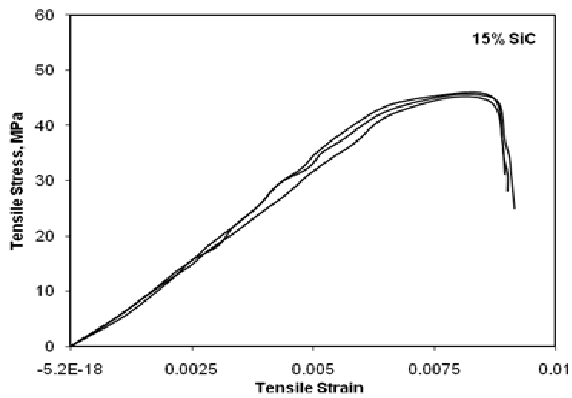

Fig.25.stress v/s strain graph for 15% SiC filled specimens.

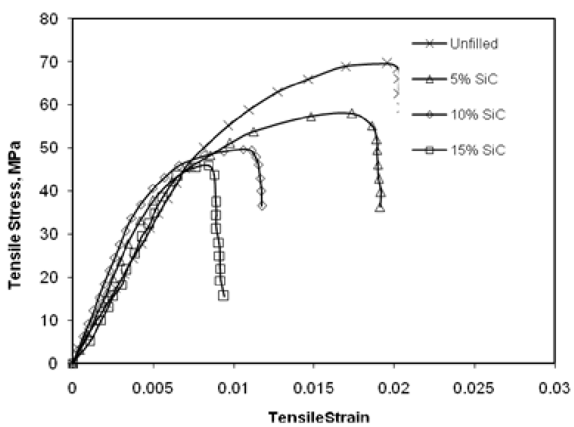

Fig.26.Stress v/s Strain Graph for Different combinations.

TABLE III: Tension Test Results

Sl. No.	Sample Code	Elongation at Break %	Average Elongation at Break %	Ultimate tensile strength MPa	Average Ultimate tensile strength MPa	Young's modulus GPa	Average Young's modulus GPa
1	1B0-1	1.96		70		6.4	
2	1B0-2	1.90	1.93	64	66.6	6.4	6.45
3	1B0-3	1.94		66		6.4	
4	1B5S-1	1.73		58		7.1	
5	1B5S-2	1.68	1.65	54	55.3	7.5	7.51
6	1B5S-3	1.56		52		7.8	
7	1B10S-1	1.06		49		7.9	
8	1B10S-2	1.03	1.05	46	47.9	8.3	8.24
9	1B10S-3	1.07		48		8.3	
10	1B15S-1	0.93		44		6.5	
11	1B15S-2	0.84	0.87	45	45.1	6.4	6.56
12	1B15S-3	0.85		45		6.5	

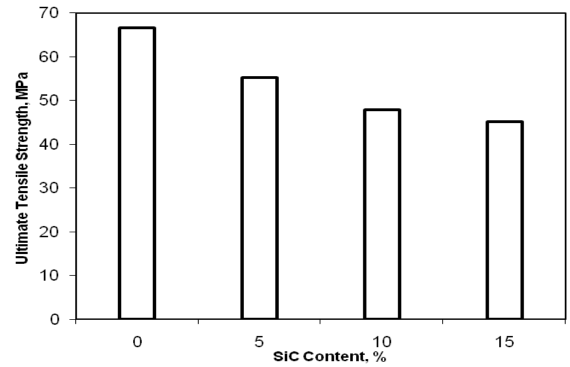

Fig.27. Tensile strength v/s wt% of SiC.

Fig.27 shows the variation of ultimate tensile strength v/s wt% of SiC filler. The laminates with 5, 10, 15 wt% SiC filler exhibit lower tensile strength than unfilled composite. The tensile strength is found to decrease with the increase in filler content.

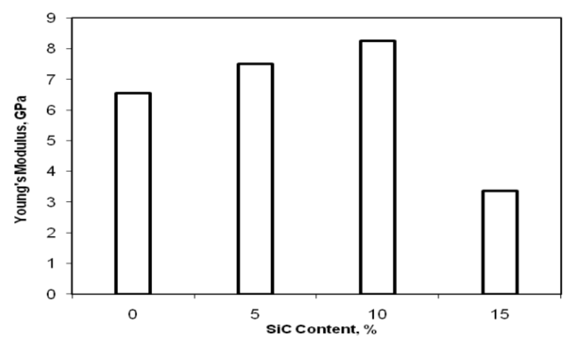

Fig.28. Young's modulus v/s wt% of SiC.

Figs.28 and 29 shows the variation of Young's modulus and total percentage elongation v/s SiC filler. The Young's modulus increased slightly with filler content of up to 10% beyond which it decreased slightly but still remain higher than unfilled composites, Compared with the Young's modulus of the unfilled Bamboo-fiber reinforced epoxy composite and the addition of 10wt% of SiC particle in the matrix, Young's modulus of the Bamboo-fiber reinforced epoxy composite was increased by 20%. Percentage elongation at failure decreased with increase in the SiC particle content.

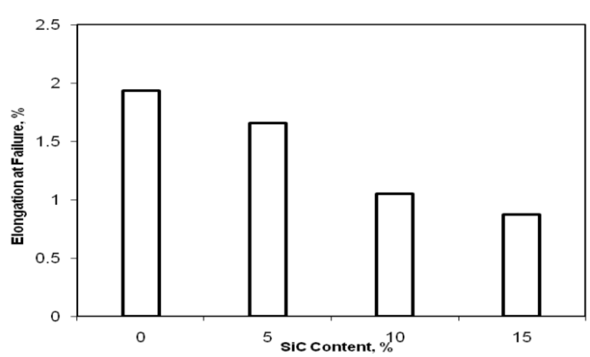

Fig.29. Percentage Elongation at Failure v/s wt% of SiC.

With the incorporation of SiC fillers in the composite laminates, 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 from matrix to fiber. This poor interfacial bonding causes partially separated micro spaces between the filler and epoxy matrix, which obstructs stress propagation, when tensile stress is applied, and induces decreased tensile strength and increased brittleness. The other is that the corner points of the irregular shaped particulates result in stress concentration in the epoxy matrix. Fig.30 shows the fracture occurred in tensile specimen after testing

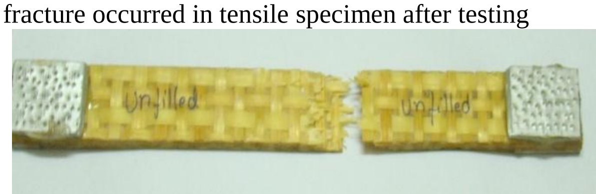

Fig.30. Fractured tension test specimen.

B. Flexural Test

Bending test provides the deformation and maximum load bearing capacity of the materials at the onset of plastic deformation of the composites. From this Ultimate flexural strength is computed. The load v/s deflection diagram for the samples were shown in the Fig.31 to 35. All curves indicate non-linear behavior. In flexural strength, the deflection reading as a function of applied load was recorded during the entire test until the applied load dropped substantially, as a result of internal damage of the specimen.

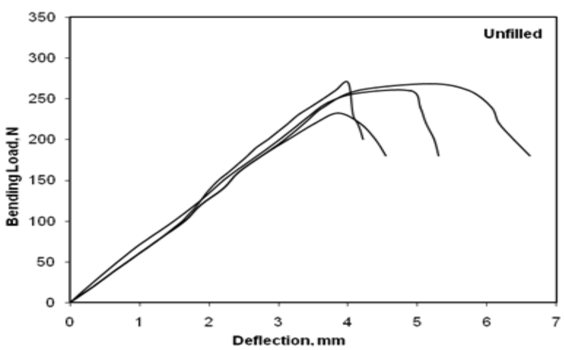

Fig.31. load v/s deflection graph for unfilled specimens.

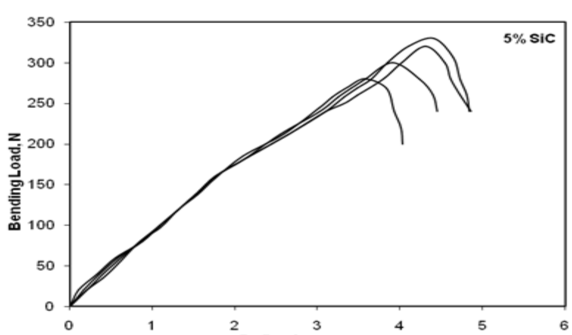

Fig.32. load v/s deflection graph for 5% SiC filled specimens.

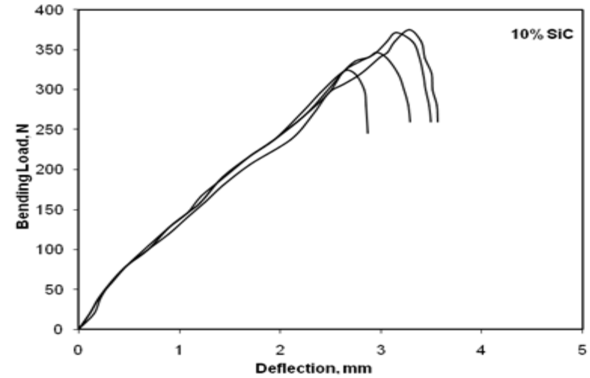

Fig.33. load v/s deflection graph for 10% SiC filled specimens.

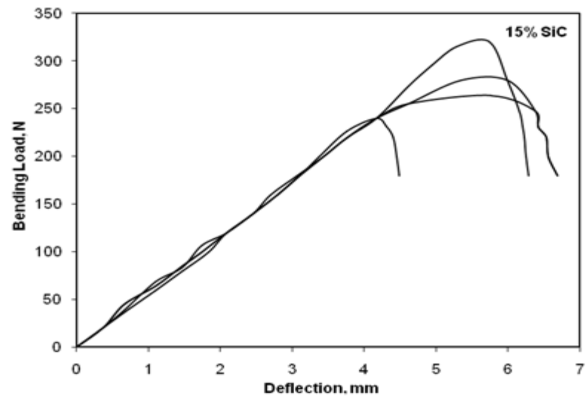

Fig.34. load v/s deflection graph for 15% SiC filled specimens.

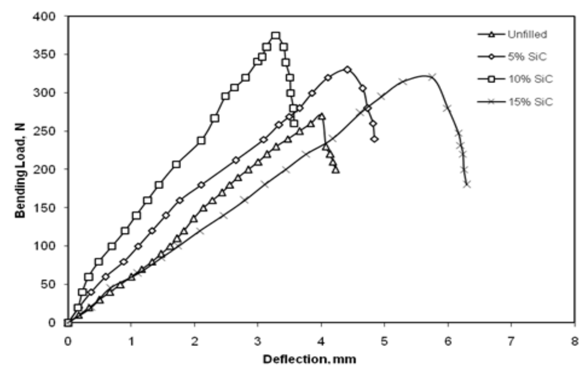

Fig.35. Bending Load v/s Deflection Graph for Different combinations.

The variations of flexural properties (flexural strength, flexural modulus, total deflection) of the Bamboo-fiber reinforced epoxy composites with SiC particle content are shown in Figs.36 & 37 flexural strength of the composites increased with filler content of up to 10% beyond which it decreased slightly but still remain higher than unfilled composites, Compared with the Young's modulus of the unfilled Bamboo-fiber reinforced epoxy composite and the addition of 10wt% of SiC particle in the matrix, Young's modulus of the Bamboo-fiber reinforced epoxy composite was increased by 30%. The flexural modulus and deflection were also increased slightly with filler content of up to 10%

beyond which it decreased slightly but still remain higher than unfilled composites, Compared with the Young's modulus of the unfilled Bamboo-fiber reinforced epoxy composite and the addition of 10wt% of SiC particle in the matrix, Young's modulus of the Bamboo-fiber reinforced epoxy composite was increased by 20%.

TABLE IV: Flexural Test Results

Sl. No.	Sample Code	Max. deflection mm	Average Max. deflection mm	Max. bending stress MPa	Average Max. bending stress MPa	Flexural modulus GPa	Average Flexural modulus GPa
1	1B0-1F	5.18	4.47	87.87	86	2.872	2.80
2	1B0-2F	4.9		82.37		2.760	
3	1B0-3F	4.0		93.68		2.758	
4	1B0-4F	3.8		81.40		2.824	
5	1B5S-1F	4.1	3.99	97.75	93	2.985	3.02
6	1B5S-2F	4.4		99.84		2.915	
7	1B5S-3F	3.91		126.75		3.116	
8	1B5S-4F	3.58		109.98		3.016	
9	1B10S-1F	2.6	2.97	128.28	118	3.348	3.43
10	1B10S-2F	2.95		113.45		3.523	
11	1B10S-3F	3.15		110.23		3.507	
12	1B10S-4F	3.2		119.9		3.352	
13	1B15S-1F	5.76	5.38	91.25	94	3.182	3.01
14	1B15S-2F	5.9		79.9		2.905	
15	1B15S-3F	5.7		100.73		2.919	
16	1B15S-4F	4.17		91.85		3.041	

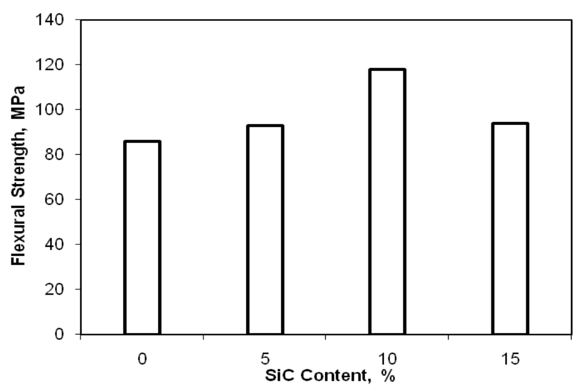

Fig.36. Flexural strength v/s wt% of SiC.

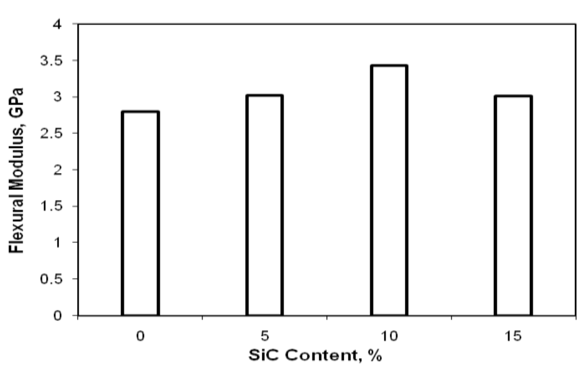

Fig.37. Flexural Modulus v/s wt% of SiC.

It is well known that the interface bonding or adhesions between the filler and the matrix and the homogeneous filler dispersion have a great effect on the mechanical properties of particulate reinforced systems. Furthermore, the presence of agglomeration in the epoxy matrix is to be taken into consideration. Agglomeration can enhance flow characteristics of ultra fine powders, which leads to poor packing and porous composites. The presence of agglomeration and voids in the composites obviously deteriorates their mechanical properties. The increase of the Young's modulus of the bamboo/epoxy composites filled with SiC particles may be attributed to the rigid nature of the fillers. At higher weight fractions of SiC particles, the poor interface bonding or adhesion between the filler and the epoxy resin matrix, or the presence of a large agglomerate phase in the matrix, may have occurred to cause the lower flexural properties. Fig.38 shows the cracked occurred in flexural specimen after testing.

Fig.38. specimen tested under 3-point bending test.

C. Compression Test

The stress-strain diagram for the composites under compression loading is shown in Fig.39 to Fig.45 all curves indicate non-linear behavior. The point of deviation from linearity is the indication of failure initiation due to development of crack between the fiber and the matrix. Gradual drop in the curve indicates failure but still withstands the load. Young's modulus is determined from the slope of the Stress-Strain curve within the elastic limit.

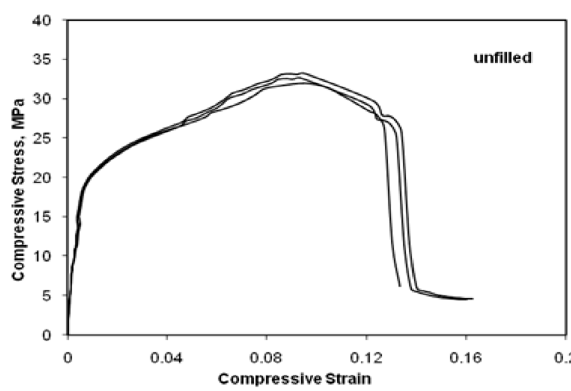

Fig.39. Stress-strain graph for unfilled composites.

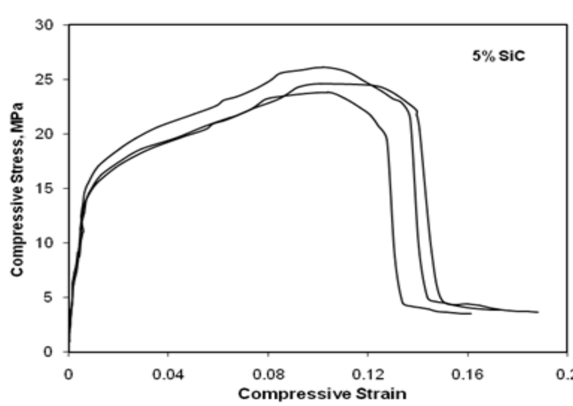

Fig.40. Stress-Strain Graph for 5% SiC filled composites.

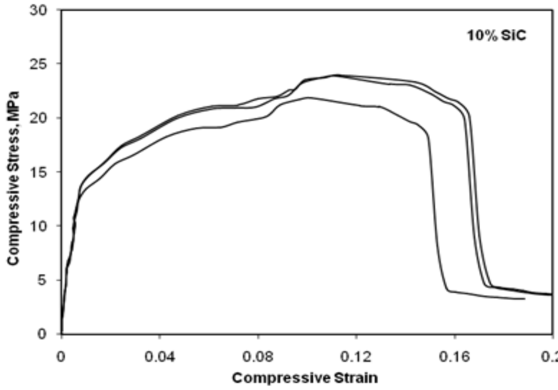

Fig.41. Stress-Strain Graph for 10% SiC filled composites.

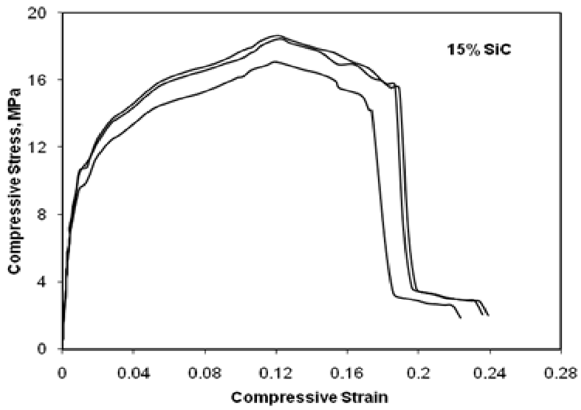

Fig.42. Stress-Strain Graph for 15% SiC filled composites.

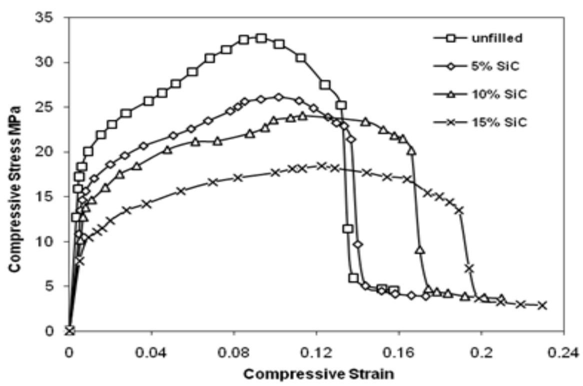

Fig.43. Stress v/s Strain Graph for Different combinations.

TABLE V: Compression Test Results

Sl. No.	Sample Code	Deformation at Break %	Average Deformation at Break %	Ultimate compressive strength MPa	Average Ultimate compressive strength MPa	Young's modulus GPa	Average Young's modulus GPa
1	2B0-1	9.73		33.23		2.042	
2	2B0-2	9.46	9.5	31.98	32.62	2.08	2.04
3	2B0-3	9.32		32.66		2.0	
4	2B5S-1	10.18		26.09		1.702	
5	2B5S-2	10.13	9.93	24.50	24.75	1.562	1.60
6	2B5S-3	9.49		23.67		1.544	
7	2B10S-1	11.17		23.90		1.469	
8	2B10S-2	11.13	10.82	23.58	23.11	1.465	1.43
9	2B10S-3	10.16		21.85		1.343	
10	2B15S-1	12.09		18.67		1.059	
11	2B15S-2	12.24	11.91	18.44	17.97	1.047	1.02
12	2B15S-3	11.40		16.80		0.956	

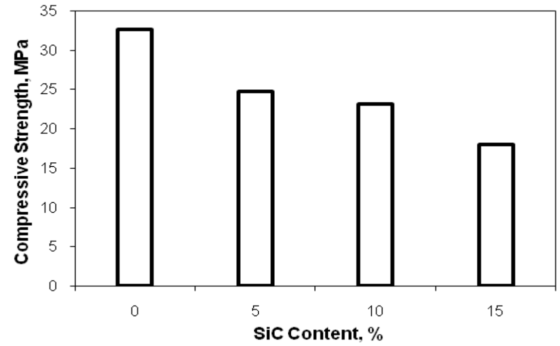

Fig.44. Compressive strength v/s wt% of SiC.

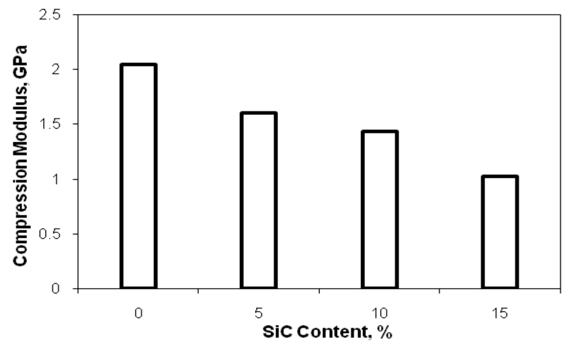

Fig.45.Compression Modulus v/s wt% of SiC.

The presence of filler material in the epoxy matrix gives rise to poor bonding between the matrix and the fiber. The presence of agglomeration and voids in the composites obviously deteriorates their mechanical properties. Poor interfacial bonding between the fiber and matrix contributes to lower compressive properties. The decrease of the compressive modulus of the bamboo/epoxy composites filled with SiC particles may be attributed to the bulk of filler material concentrated at particular region which cause to lower compressive properties. Fig.46 shows the fracture occurred in compression specimen after testing.

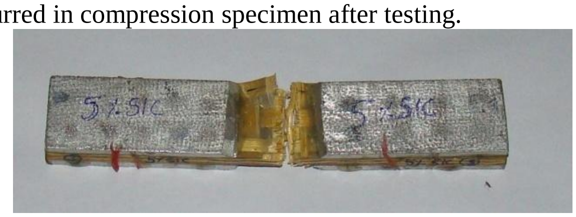

Fig.46. Fractured compression test specimen.

D. Water Absorption Test

The effect of filler on moisture absorption properties of bambooo/epoxy composites is shown in fig.47. It has been observed from Table 4.6 that, for all periods of immersion, the extent of water absorption decreases with the addition of SiC filler. This reduction may be due to the fact that the SiC particles are impermeable in nature. Also, the voids present in the unfilled composites that contributes to gain in the water absorption are filled with filler particles resulting in the reduction of moisture gain in SiC filled composites.

TABLE VI: Water Absorption Test Results

bamboo samples / No. of days Of immersion	Average moisture gain(M%) from 3 identical specimens			
	Unfilled %	5% SiC %	10% SiC %	15% SiC %
Dry (un immersed)	0	0	0	0
1	8.65	8.03	6.97	5.50
2	13.16	12.41	10.78	8.21
3	16.23	14.95	13.31	10.04
4	19.30	17.50	15.84	11.87
5	22.38	20.05	17.79	13.70
6	24.34	22.14	19.38	15.03
7	26.35	25.9	20.45	16.42
8	27.54	26.41	21.36	17.46
9	28.21	26.48	22.0	18.29
10	29.78	27.95	23.3	19.46
11	29.78	28.01	23.45	19.52
12	29.91	28.1	23.42	19.61
13	29.99	28.13	23.45	19.72
14 (saturation level)	30.16	28.14	23.5	19.79

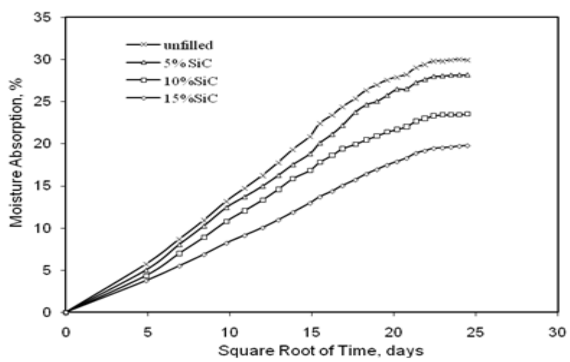

Fig.47.Moisture Absorption v/s Square root of time Graph for Different combinations.

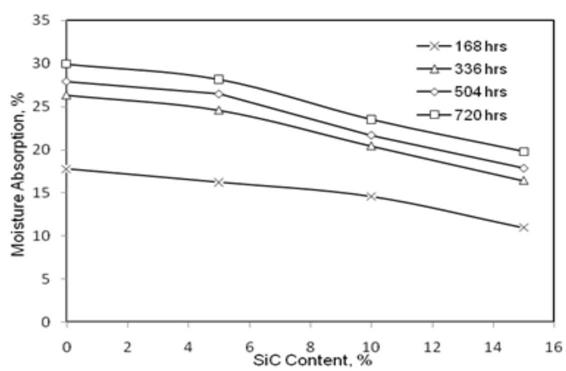

Fig.48.Moisture Absorption v/s SiC content Graph for Different time.

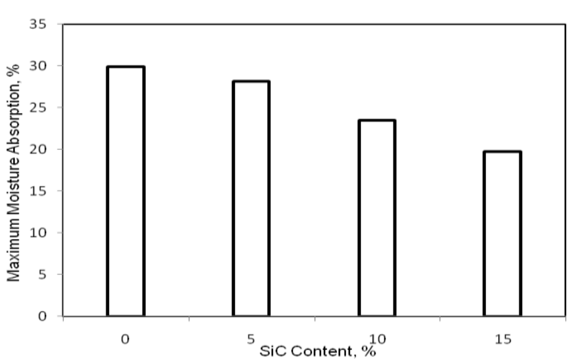

Fig.49.Moisture Absorption v/s wt % of SiC.

Fig.48 shows the plot of Moisture Absorption v/s SiC content Graph for Different time. Fig.49 shows the plot of Moisture Absorption v/s wt % of SiC.

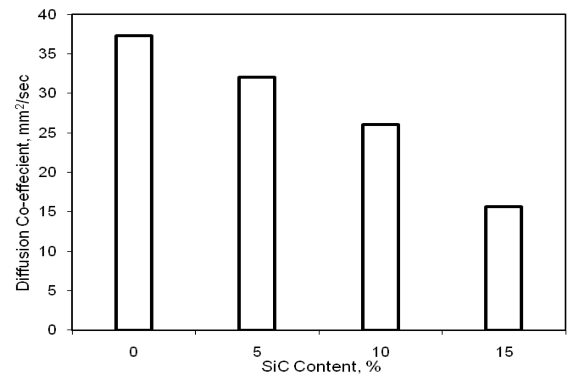

Fig.50. Diffusion Co-efficient v/s wt % of SiC.

The saturation moisture gain for unfilled composites was found to be 30% whereas in 15 wt% SiC filled composites, it was about 20%. The diffusion co-efficient was calculated using the equation (4.6) using the slope of the moisture gain v/s $\sqrt{t}$ curve, from figure 5.4.The diffusion co-efficient as a function of SiC filler is shown in fig.50. Significant reduction in the diffusion co-efficient is noticed with the addition of SiC filler. Fig.51shows the specimen after 30 days of immersion in water.

Fig. 51.Specimen after saturation level.

V. SEM ANALYSIS

SEM study was carried out to investigate the modes of fracture such as fiber splitting, fiber pullout, debonding, matrix cracking and fiber matrix adhesion. The fractured surfaces of the selected tensile and flexural tested specimens of unfilled and 10% SiC filled bamboo/epoxy specimens were examined using Cambridge SEM with EDAX (Energy Dispersive Analysis of X-rays) attachment software controlled scanning electron microscope. The instrument was operated at 12.5 kV and 20 kV. Samples for examination were obtained by cutting sections about 6 to 8mm in length from just below the fracture zone. The fractured surface of the samples were sputter coated with the thin layer of gold to minimize the charging problem. In the case of unfilled bamboo composites we cannot see the adherence of matrix layer on the surface of the fibers which is observed in fig.52 while in case of 10%SiC filled we can observe the layer of matrix adhered to the surface of the bamboo indicating improved adhesion between the fibers and the matrix which is observed in the fig.53 and thereby increasing the brittleness of the bamboo composites.

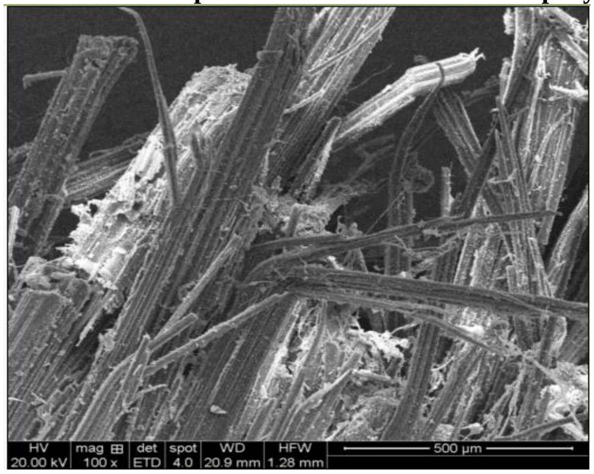

Fig.52. SEM image of Unfilled Tension tested specimen.

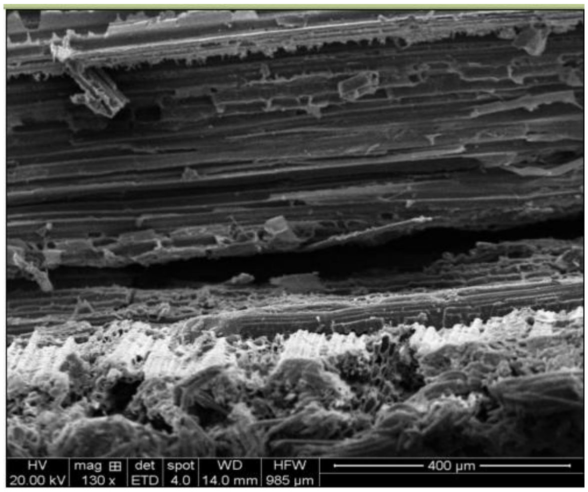

Fig.53.SEM image of 10%SiC filled Tension tested specimen.

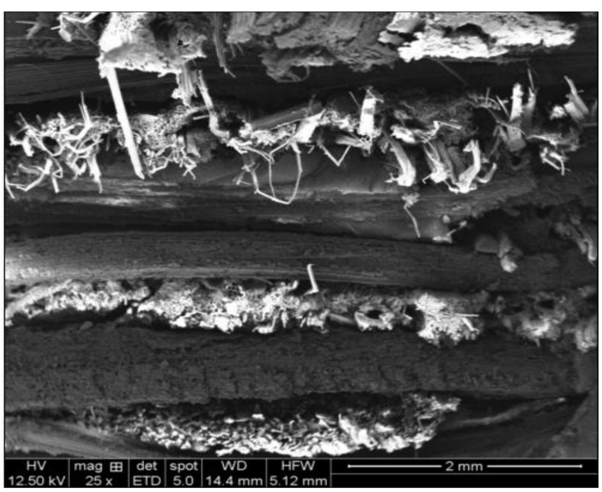

Fig.54.SEM image of Unfilled Flexural tested specimen.

During bending the upper surface of the specimen undergoes tension, the uniform distribution of filler material will helps to withstand the tensile load by increasing its brittleness compared to unfilled one. Fig.54 shows the SEM image of unfilled flexural specimen in tension side. Fig.55 shows the SEM image of 10%SiC filled flexural specimen in tension side. where we can observe the bonding between fiber and matrix will be stronger in case of 10%SiC filled.

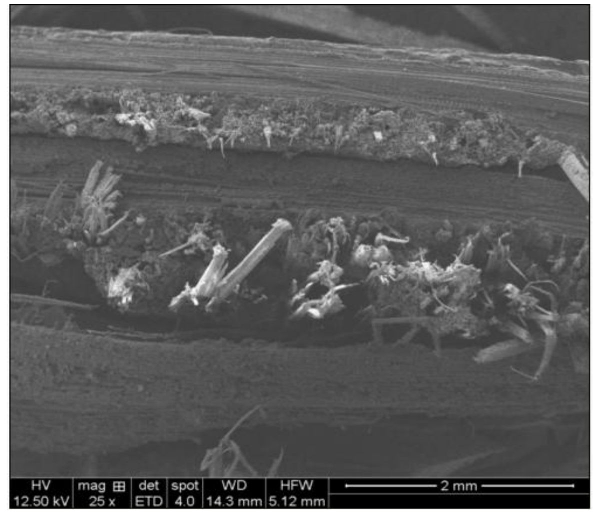

Fig.55. SEM image of 10%SiC filled Flexural tested specimen.

VI. CONCLUSION AND FUTURE WORK

Conclusion: Effect of inclusion of Silicon Carbide powder as filler material in bamboo/epoxy composites on tensile, flexural, compression and water absorption behavior has been investigated experimentally. Based on the results of investigation, following conclusions are made.

- The laminates with 5, 10, 15 wt% SiC filler exhibit lower tensile strength than unfilled composite. The tensile strength is found to decrease with the increase in filler content.
- Compared with the Young’s modulus of the unfilled Bamboo-fiber reinforced epoxy composite and the addition of 10wt% of SiC particle in the matrix.
- Young’s modulus of the Bamboo-fiber reinforced epoxy composite was increased by 20%.
- Flexural strength of the composites increased with filler content of up to 10% beyond which it decreased slightly but still remain higher than unfilled composites.
- The flexural modulus and deflection were also increased slightly with filler content of up to 10% beyond which it decreased slightly but still remain higher than unfilled composites.
- Flexural modulus of the Bamboo-fiber reinforced epoxy composite was increased by 20%.
- Compression strength and compression modulus are decreased with the addition of SiC filler.
- The resistance to water absorption increases with the increase in SiC filler.
- The diffusion co-efficient decreases with the increase in filler material.
- SEM studies proved that the addition of 10% SiC filler will increase the bonding between fiber and matrix.

Future Work:

- The current work is focused on study of mechanical behavior since there is a addition of SiC filler a wear behavior can also be done.
- By increasing the width of the bamboo fibers the mechanical properties can also be evaluated.
- In this current work it is proved that due to addition of SiC filler resistance to water absorption is increased. It can be applied in bamboo wind turbine blades and examined for its other important properties such as fatigue resistance.

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