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Effect of cenosphere on moisture absorption performance of woven hybrid bamboo-glass fiber reinforced epoxy composites

This paper presents the moisture absorption behaviour and its influence on mechanical properties of cenosphere filled hybrid bamboo-glass fiber reinforced epoxy composites (BGFRECs). The hand lay-up technique has been adopted with various weight percentages (0.5, 1.0, 1.5, and 2.0) of cenosphere as a filler content. The moisture absorption tests conducted in distilled-water, and saline-water for 10 days at room temperature. With the help of ASTM standards, the moisture absorption and mechanical properties of these composites have been estimated. The tensile and flexural strengths found to increase when filler percentage increases in different environmental treatments. The obtained results revealed that the cenosphere filler loading has a great impact on the moisture absorption and mechanical properties of the hybrid BGFRECs. However, the influence of moisture absorption presented a substantial drop in the mechanical properties of all the hybrid composites.

Keywords: Bamboo and glass fiber, cenosphere filler, hand lay-up, mechanical properties, moisture absorption.

1.0 Introduction

The environmental benefits today motivate investigators concerning the study of natural fiber composite as a supplement for traditional materials. An appropriate choice of raw materials and effective manufacturing method essential to produce a cost-effective system of material. Henceforth, investigators have concentrated their consideration on the composites with natural fiber, mostly to decrease the raw material cost [1, 2]. Even though under enhanced-matrix interaction, the natural fiber reinforced composites have lesser strength as related to the manmade fiber composites. But their lesser density and cost make them a worthwhile option to select in place of glass fiber composite for precise application [3, 4]. Hybridisation in system of composite material is an emergent method to attain improved mechanical properties [5]. The hybrid composite system comprises reinforcement, matrix, and an additional reinforcement such as filler. This filler is a significant phase for enhancing the properties of the composites. Cenosphere is essentially alumino-silicate hollow micro spherical shape, and it is used in polymer matrix composite due to its fine distribution, homogeneity, inert-ness, and chemical constancy [6]. Pichor [7] have considered cenosphere nearly 60% of volume with the fiber reinforced cement composites. Although, there are numerous applications of cenosphere with epoxy matrix composites, study of its influence on natural fiber composites are extremely limited [8, 9]. But being hydrophilic in nature, the natural fiber becomes too weak interfacial bonding between matrix and fibers which in turn declines its mechanical properties [9]. The water absorption of composites depends on the resistance of the fibers to moisture absorption, and of the polymer matrix. The moisture absorption takes place by diffusion of water molecules inside micro-gaps between polymer chains, flaws at interfaces between epoxy polymer and fibers [10, 11]. Fillers, compatibilizers, coupling agents, or other chemical modifications are used to enhance the moisture resistance of composites and described by various researchers [12-15]. Hybridization of natural fiber with distinct artificial fibers can enhance its moisture resistance [12, 13, 15]. The fillers are added to composite material to diminish the cost of material, enhance the mechanical properties, and process-ability. Addition of TiO_2 and ZrO_2 fillers into hybrid BGFRECs addressed by Latha et al. [15]. Still, the influence of cenosphere filler on the moisture absorption study on hybrid BGFRECs has not been addressed so for. Henceforth, the

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research work emphases on cenosphere impact on the moisture absorption behaviour of woven hybrid BGFRECs.

2.0 Materials and method

In this section, the raw materials used for preparation of hybrid composite laminates are discussed.

2.1 Materials used

2.1.1 Fibers

The current work uses bamboo fiber in the epoxy to make a sequence of samples with woven glass reinforcement. The bamboo fiber mat was procured from the West Bengal supplier as shown in Fig.1.

Both fibers procured from most trusted suppliers and woven bamboo and glass has a density of 1.2 and 2.54 g/cm^3,

Fig.1: Bamboo woven fiber mat

Fig.2: Glass woven fiber mat

respectively. Fig.2 illustrates woven glass fabric mat used during preparation of laminates.

2.1.2 Matrix material

For the present study, HSC 7600 used as epoxy resin and HSC 8210 used as corresponding hardener. The hardener and epoxy resin purchased by the Hindusthan Urban Infrastructure supplier. The densities of epoxy resin, and hardener taken as 1.2 and 0.9 g/cm^3, respectively from the supplier's data sheet.

2.1.3 Cenosphere

It is a hollow spherical particle which is used to maintain lower density values for the various composites. Cenosphere addition into epoxy matrix composites leads to good enhancement of properties of composites. Cenosphere obtained from thermal power plant and purchased by KULIN Corporation, Mumbai is as shown in Fig.3.

Fig.4 describes EDX analysis of cenosphere filler primarily contains SiO_2, Al_2O_3 and Fe_2O_3 mixtures. The chemical compound of cenosphere grade VA-LD-300 as described in the Table 1 and the physical and mechanical properties of

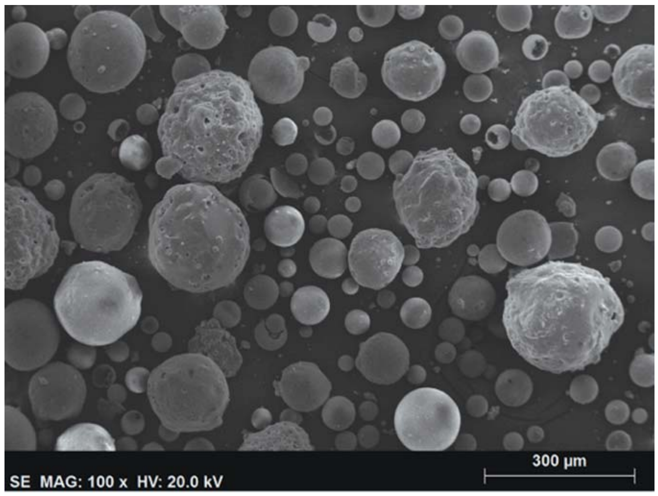

Fig.3: SEM image of cenosphere

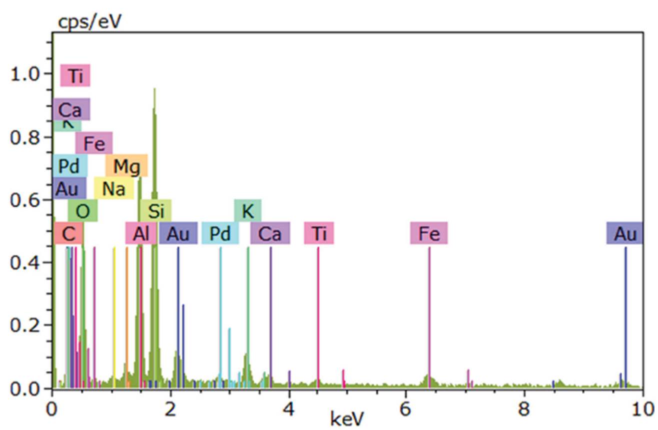

Fig.4 EDX analysis of cenosphere particle

Table 1: Chemical Composition of Cenosphere Particles

Element type	Wt.%
SiO_2	51-58
Al_2O_3	23-25
Fe_2O_3	3.6-6.6
CaO	1-3.5
MgO	0.5-0.9
K_2O	0.5-0.8
Na_2O	0.5-0.6
Others	0.1-0.2

Table 2: Physical and mechanical properties of cenosphere grade VA-LD-300 particles

Properties	Units	Value
Density	g/cm^3	0.75-0.85
Bulk density	kg/m^3	350-450
Hardness	Moh's	5-6
Compressive strength	kg/cm^2	180-280
Shape	-	Spherical
Colour	-	Light grey
Melting point	Degree celcius	1200-1350
PH in water	-	6-7
Moisture	%	Max.0.5
Sinkers	%	Max.7
Oil absorption	-	16-18G/100G
Packing factor	%	60-65
Wall thickness Diameter	%	5-10 of shell
Thermal conductivity	W/mK	0.11
Loss on ignition	%	Max.2

cenosphere particles are as shown in Table 2. The density of cenosphere taken as 0.8 g/cm^3 from the supplier's data sheet.

2.2 Composite Preparation

The hand lay-up technique adopted to prepare the composite laminates. The steel mould of size 320 mm* 320mm cleaned with a solution of thinner and then applied mould release agent. The composite laminate comprises 6 bamboo layers and 7 glass layers positioned consecutively till the wanted thickness is reached. The specimens prepared with varying wt.% of cenosphere filler as presented in Table 3. The mixture of epoxy resin and corresponding hardener prepared in a ratio of 10:1 as per the recommendations of the manufacturer and then applied to each layer of fabric. Ultimate care taken during laminate preparation and entrapped air bubbles are removed. Once curing completes, mould unlocked, and laminate removed cautiously. Then supplementary curing takes place in hot oven at a 40°C temperature for about 2 hours. The composite samples have been prepared as per ASTM dimensions for different tests. The similar procedure repetitively adopted to make other laminates in terms of weight basis, such as 1, 1.5 and 2 wt.% of cenosphere filler particles. The theoretical density of composite computed by eqn. (1),

$$\rho_t = \frac{1}{\frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} + \frac{w_p}{\rho_p}} \quad \text{... (1)}$$

here, the suffix '*p*', '*f*', and '*m*' stand for the particulate, fiber, and matrix, respectively.

The experimental density determined by the liquid displacement procedure to help of ASTM D-792. It is measured by immersing a specimen size of 20mm*20mm hanged by a thread in a graduated beaker. Finally, the volume fraction of voids are calculated using eqn. (2),

$$v_v = \frac{\rho_t - \rho_{exp}}{\rho_t} \quad \text{...(2)}$$

here ρ_{exp} stands for experimental density.

2.3 Moisture Absorption and Thickness Swelling Test

According to ASTM D 570-98, the moisture absorption behaviour conducted with specimen size of 20mm*20mm. The weights of the specimens measured before immersed in saline water and distilled water environments. The specimens removed from the environmental bath at every 24 hours and rubbed with tissue paper to eliminate the presence of moisture on the surface. Then weights of the specimens measured after immersion. This process repeated at consistent intervals of 24 hours till an equilibrium value is achieved. The percentage of moisture absorption computed by weight difference between the specimens submerged in water and the dry specimens by eqn. (3),

Table 3: Laminate Stacking Sequence of Cenosphere filled hybrid BGFRECs.

Laminates	Cenosphere (wt.%)	Total fiber		Theoretical density	Measured density	Volume fraction of voids	Thickness
		Volume Fraction (%)	Weight Fraction (%)	(g/cm^3)	(g/cm^3)	(%)	(mm)
L_1	0.5	33.14	40.00	1.3574	1.3450	0.91	5.5
L_2	1.0	34.03	40.59	1.3544	1.3437	0.79	5.5
L_3	1.5	34.69	41.04	1.3431	1.3395	0.26	5.5
L_4	2.0	35.34	41.49	1.3453	1.3438	0.11	5.5

$$\%M = \frac{W_t - W_o}{W_o} * 100 \quad (3)$$

here, w_t and w_o stands for weight of specimens after time t and before submerged in water, respectively.

According to ASTM D 570-98, the thickness swelling behaviour performed with specimen size of 20mm*20mm. The initial thickness of the specimens measured before immersed in environmental baths. The specimens are removed from the environmental bath at every 24 hours, then the thickness of the specimens are measured after submerged. The thickness swelling is evaluated by eqn. (4),

$$\%TS = \frac{T_t - T_o}{T_o} * 100 \quad (4)$$

here T_o and T_t refer the thickness of specimen before and after submerged in water, respectively.

2.4 Testing of the Mechanical Properties

2.4.1 Tensile strength

According to ASTM D3039 standard, the tensile test is conducted with the help of 50 kN capacity of servo-hydraulic type UTM. The specimens prepared with width 25 mm, length 250 mm and then specimens positioned in the grips and pull out at 5mm/min strain rate till failure takes place [18]. Further the tensile test continued to stretch till specimen breakdowns. Total 5 specimens are tested for each sample and average values stated. Then the ultimate tensile strength is determined by eqn. (5),

$$UTS = \frac{P}{b*d} \quad \ldots (5)$$

here, '*b*' and '*d*' refer to the width and the thickness of the specimen, respectively and '*P*' presents the applied load.

2.4.2 Flexural strength

According to ASTM D790 standard, the flexural test conducted using 3-point bending test on same UTM. The specimens prepared with size of 130mm*13mm mm and then specimens loaded with 80 mm span length at crosshead speed of 5mm/min. The flexural strength is evaluated using the eqn. (6),

$$\sigma_{\max} = \left(\frac{3P_{\max}L}{2wh^2}\right) \quad \ldots (6)$$

here, L, w and h refer to the span length, width and thickness of specimen, respectively and $P_{\max}$ presents the maximum applied load at failure.

3.0 Results and discussion

3.1 Effect of filler loading on moisture absorption

Figs.4 and 5 illustrate the moisture absorption versus immersion time of cenosphere filled hybrid BGFRECs in distilled-water and saline-water, respectively. The moisture absorption increases as immersion time increases, attaining an equilibrium point and beyond this point the moisture

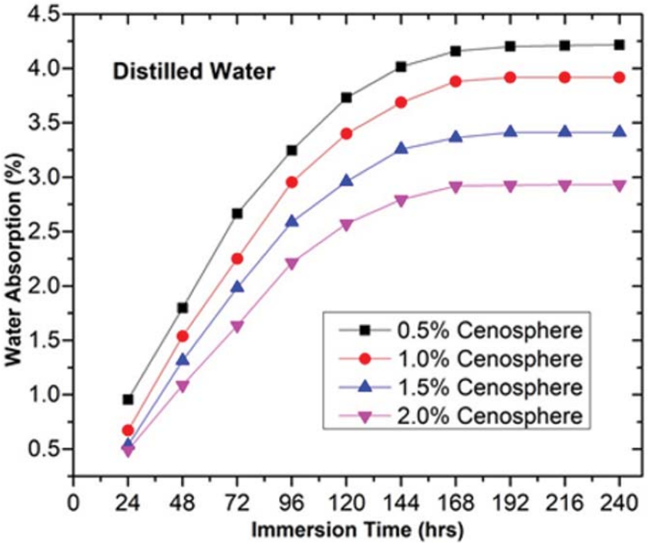

Fig.5: Moisture absorption (%) versus immersion time for distilled-water treatment

absorption becomes slowdown. The maximum moisture absorption reduces to 31% and 42% for distilled-water and sea-water conditions, respectively.

It is noticed that the saturation time is 192hrs for distilled-water and 216 hrs for saline-water treatments for cenosphere filled hybrid BGFRECs. Similar trend noticed in earlier study of moisture absorption behaviour of hybrid BGFRECs [16]. The maximum moisture absorption rate in cenosphere filled hybrid BGFRECs is in the increasing order as $L_4 < L_3 < L_2 < L_1$. The moisture absorption rate in distilled-water treatment appears to be more than that of saline-water treatment and this happens due to the gathering of NaCl ions in the surface of fiber submerged in saline-water treatment [8].

3.2 Effect of filler loading on Thickness Swelling

A contrast of thickness swelling of cenosphere filled

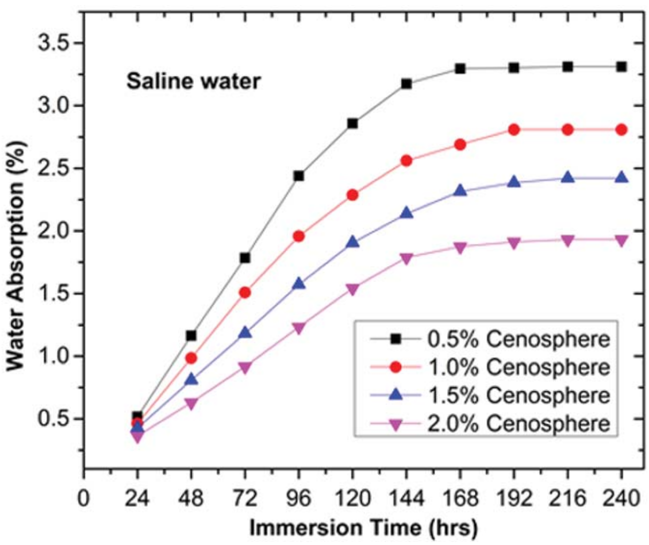

Fig.6: Moisture absorption (%) versus immersion time for saline-water treatment

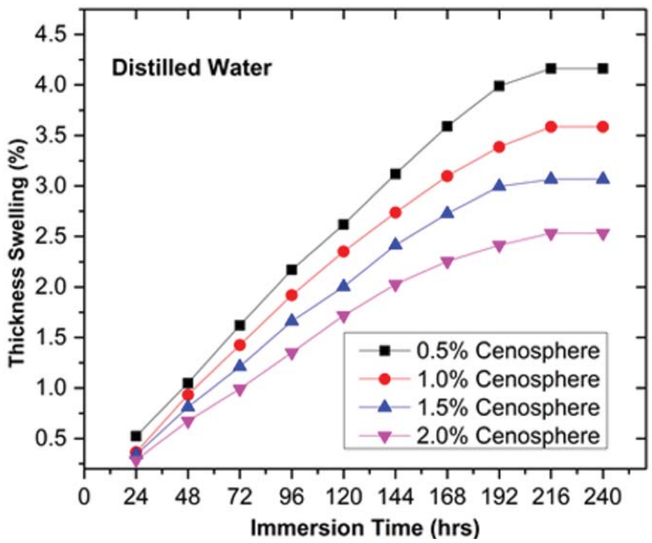

Fig.7: Thickness swelling (%) versus immersion time for distilled-water treatment

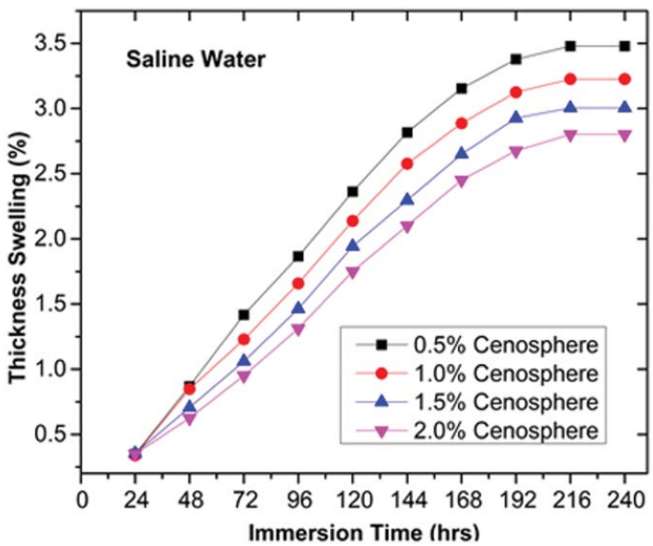

Fig.8: Thickness swelling (%) versus immersion time for saline-water treatment

hybrid BGFRECs presented in Figs.6 and 7 for distilled-water and saline-water, respectively.

The thickness swelling takes place in composites due to natural bamboo fiber contains the free OH group voluntarily builds-up moisture when submerged in water. The thickness swelling of saline-water treatment is less than distilled-water treatment. The moisture absorption happens primarily due to the hydrophilic nature of the fibers and micro-pores may give a pathway for capillary action [17]. The thickness swelling for hybrid BGFRECs with 0.5 wt.% of cenosphere displays a value of 4.3% and 3.5% for distilled-water and sea-water treatments, respectively. As cenosphere content increases in hybrid BGFRECs, the thickness swelling decreases. This happened due to the decreased micro-voids caused by the larger amount of powerfully bonded area between the filler and the matrix.

3.3 Impact of Moisture Absorption on Tensile Properties

Figs.8 and 9 demonstrate the tensile properties of both moisture absorbed and dry specimens. It is noticed that the tensile strength and their modulus of cenosphere filled hybrid BGFRECs increases due to the addition of cenosphere from 0.5 to 1.5 weight%, with supplementary incorporation of cenosphere up to 2.0 weight %, the tensile strength and their modulus decreases as presented in Figs.8 and 9 in dry condition. This happened due to weakening of the epoxy matrix may not transfer the tensile stress [8, 19]. The tensile strength and their modulus attained for moist treated specimens follows the similar trend as dry specimens as shown in Figs.8 and 9. It is clearly noticed that tensile strength and its modulus reduces due to absorption of moisture rate. It is also addressed that the drop in properties significantly affected by the filler weight percentage and the nature of treatment.

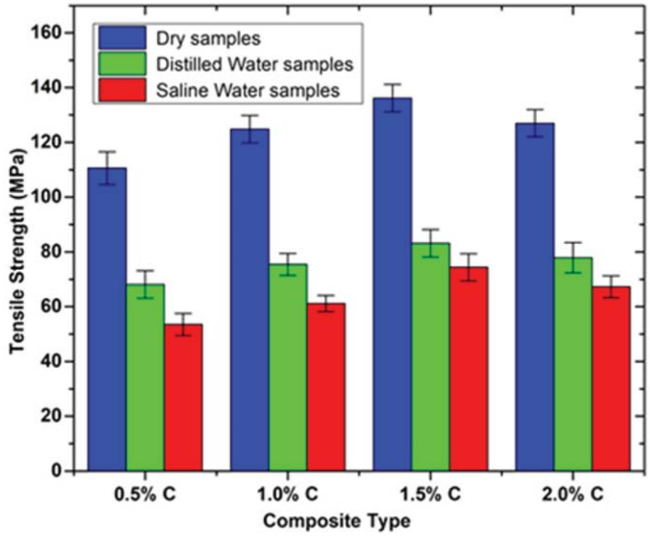

Fig.9: Tensile strength of cenosphere filled hybrid BGFRECs

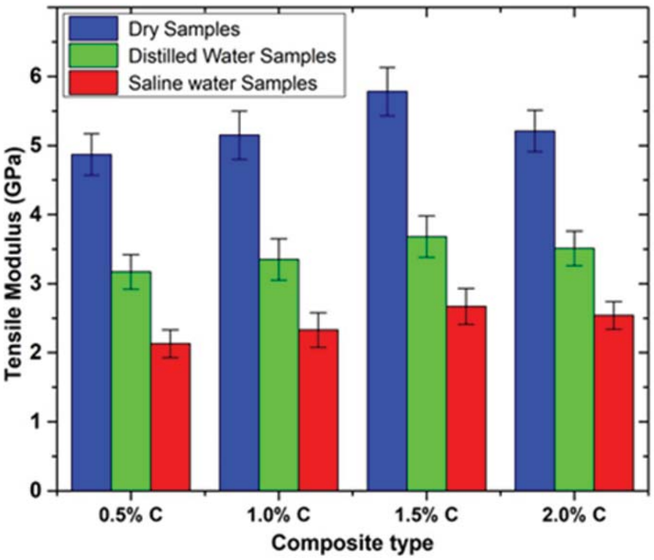

Fig.10: Tensile modulus of cenosphere filled hybrid BGFRECs

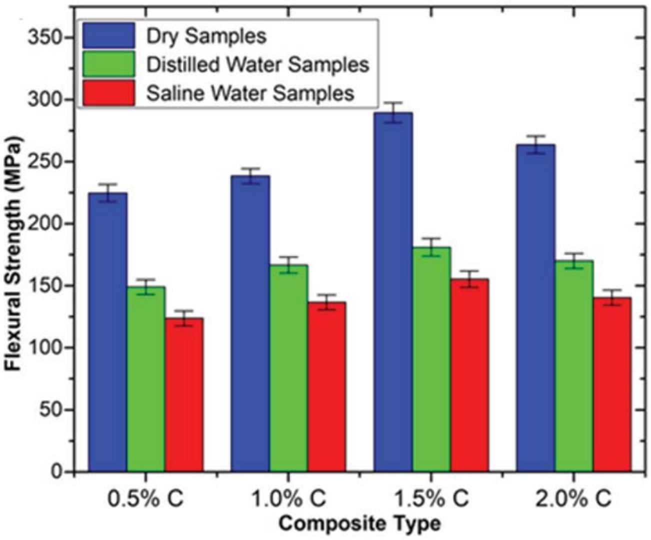

Fig.11: Flexural strength of cenosphere filled hybrid BGFRECs

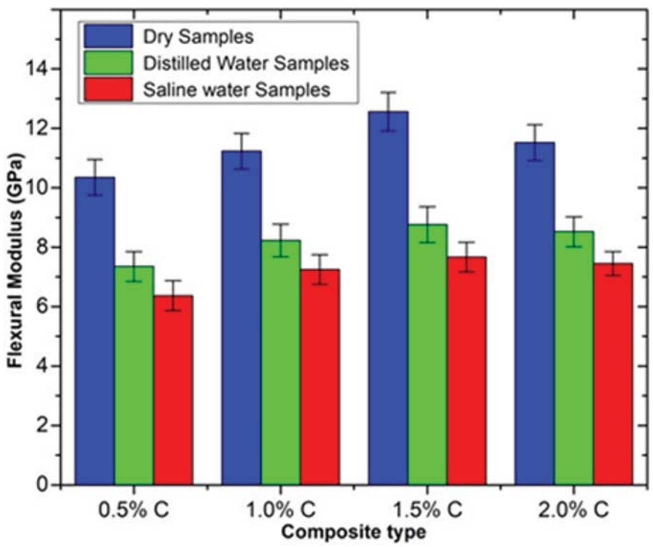

Fig.12: Flexural modulus of cenosphere filled hybrid BGFRECs

3.4 Impact of Moisture Absorption on Flexural Properties

Figs.10 and 11 illustrate the flexural properties of both moisture absorbed and dry specimens. The flexural strength and their modulus increase as the filler content up to 1.5 weight % and then decreases further addition of cenosphere filler. The maximum flexural strength and its modulus identified for the hybrid composite with 1.5 weight % of cenosphere. The flexural properties of moist treated specimens decrease due to absorption of moisture and shadows the similar nature as tensile properties. After immersion, the decrement in flexural properties happened due to the weakening of interface between the fiber and matrix [16, 20]. The results revealed that the tensile and flexural properties of the cenosphere filled hybrid BGFRECs at wet conditions follows the similar nature as in dry conditions. The strengths found to be decreased with an increase in the rate of water intake, and the position of bamboo fabric at the outer layer.

4.0 Conclusions

From the study, the absorption of moisture behaviour of various weight percentages (0.5, 1.0, 1.5 and 2.0%) of cenosphere filled hybrid BGFRECs with distilled-water and saline-water treatments, the resulting decisions can be stated.

1. The successful preparation of hybrid BGFRECs with cenosphere filler achieved by hand lay-up technique.
2. The maximum moisture absorption and thickness swelling increases to 1.5wt.% of cenosphere and then decrease at 2wt.% cenosphere for distilled-water and saline-water treatments.
3. Influence of cenosphere on mechanical properties of BGFRECs studied and directs that addition of cenosphere improved the mechanical properties.
4. The maximum degradation of properties takes place in saline-water treatment.

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