Scientific Research Publishing

Open Journal of Composite Materials, 2019, 9, 1-20
http://www.scirp.org/journal/ojcm
ISSN Online: 2164-5655
ISSN Print: 2164-5612

Influence of Water Ageing on Mechanical Properties of $CaCO_3$ Filler Filled Epoxy Resin and *Sansevieria*/Carbon Fiber Reinforced Composites

Naveed Anjum[1], Bheemappa Suresha[2*], Somanahally Lingaiah Ajit Prasad[3]

[1]Department of Mechanical Engineering, Vidya Vikas Institute of Engineering & Technology, Mysuru, India
[2]Department of Mechanical Engineering, The National Institute of Engineering, Mysuru, India
[3]Department of Mechanical Engineering, PES College of Engineering, Mandya, India
Email: *sureshab@nie.ac.in

How to cite this paper: Anjum, N., Suresha, B. and Prasad, S.L.A. (2019) Influence of Water Ageing on Mechanical Properties of $CaCO_3$ Filler Filled Epoxy Resin and *Sansevieria*/Carbon Fiber Reinforced Composites. *Open Journal of Composite Materials*, **9**, 1-20.
https://doi.org/10.4236/ojcm.2019.91001

Received: November 1, 2018
Accepted: January 15, 2019
Published: January 18, 2019

Abstract

The present paper studies water absorption behavior and its consequence on mechanical properties of untreated and chemically treated *Sansevieria*/carbon fiber reinforced hybrid epoxy (Sria/CF-Ep) composite with calcium carbonate ($CaCO_3$) nanoparticles. *Sansevieria*/carbon fiber (30/5 wt%) reinforced hybrid epoxy composite with 1.5, 3 and 4.5 wt% of $CaCO_3$ have been developed by hand lay-up method followed by heat press. The water absorption characteristics of the Sria fibers were obtained by immersing the composite samples in sea water at room temperature, until reaching their water content saturation level. The dry and water-immersed hybrid composite samples were subjected to hardness, interlaminar shear, tensile, flexural, and impact tests. The water absorption development of hybrid composites was found to follow Fickian diffusion behavior. Diffusion coefficients and maximum water uptake results were evaluated; the outcome showed that both increased with an increase in filler loading to study the consequence of water penetration in the fiber/matrix interface. The study shows that the mechanical and water-resistant properties of the Sria were improved through chemical treatment and hybridization. Nevertheless, as a result of water penetrating the fiber/matrix interface, longer water-immersion times reduced the tensile and flexural strength of the composites.

Keywords

Epoxy, Sria, Nano $CaCO_3$, Sea Water, Mechanical Properties

1. Introduction

The environmental awareness in addition to the government stringent rules throughout the globe has encouraged the scholarly and industrial researches to expand eco-friendly, sustainable, and biodegradable composite materials, as a result often referred to as green composites [1]. The habit of utilizing fiber reinforced polymer composites has considerably increased since last 3 decades, by glass fiber reinforced composites taking on a significant role [2] [3]. The development of glass fiber reinforced polymer composite materials and their extensive application has caused a number of ecological problems, predominantly with regards to waste management [4]. Renewable and biodegradable materials are substitute to synthetic fibers and polymers derived from petroleum used in traditional fiber reinforced polymer composites [5] [6]. The use of natural plant fibers (kenaf, jute, hemp, flax etc.) as reinforcement in matrix with little styrene substance and emissions represents a suitable explanation to this problem [7] [8]. Previous research works has shown that natural fibers have the potential to substitute glass fibers in various applications [9]. Because, natural fibers have high strength to weight ratio, abundant in nature and biodegradability, corrosion resistance, are critical at the end of life of products, and have similar specific strength and modulus as conventional glass fibers.

Areas such as automotive and construction [10] have started the manufacturing of pipelines for water desalination plants, water storage vessels, manufacture of leisure boats etc., goods using natural fiber, to develop the environmental impact of the product due to the reasonably priced of natural reinforcements. Alone natural fiber reinforced polymer composite cannot be used as promising material in mechanical applications, hence, synthetic fibers such as aramid, glass, carbon etc., can be used as reinforcements along with natural fiber to form strengthened hybrid composites. Hybridization is a technique in composites which is usually termed as the mixture of two or more reinforcing fibers in a single matrix system. Throughout proper fiber choice and plan, the stability involving price and performance of hybrid composites might be achieved all the way through hybridization [11]. For example, the integration of carbon fiber with different cellulosic fibers such as jute, abaca, hemp, and banana have been reported earlier in the literature [12] [13] [14] [15]. Experimental results show the mechanical properties of the hybrid composites being better compared to the single-fiber reinforced composites. Previously published works concerning synthetic/natural [16] and cellulosic/cellulosic [17] [18] [19] fibers based on reinforced hybrid composites. In addition, the performance of a hybrid kenaf/Kevlar composite was tested by Yahaya *et al*. [20] [21] discovered that the composite had the potential to be used in impact applications.

Plant fiber reinforced composites are hydrophilic and hygroscopic materials. Moisture content in plant fiber composites considerably affects their physical and mechanical properties. Moisture transfer in plant and plant fiber composites influences dimensional steadiness, viscoelastic properties, fiber play a vi-

tal role in the ageing of bio-composites in a wet atmosphere or by immersion in water and durability. These parameters lead to a lowered fiber/matrix bonding strength those results in a weaker mechanical performance of fiber/matrix hybrid composites [22] [23] [24]. Akil *et al*. [25] investigated that when jute/glass fibred reinforced polyester hybrid composites were exposed to moisture environments, water molecules penetrated the composites during various paths, such as: throughout the flaws at the composites interphase attributed to the poor wettability between the fiber and matrix, through micro-gaps between the polymer chains, and through the cracks in the polymer matrix induced by the fiber swelling.

Less than the fiber saturation point, moisture transport by the plant fiber is restricted by diffusion. Bounce moisture diffusion is a grouping of two movements: the vapor diffusion by void structure, and the bound water diffusion by the cell wall. A diffusion model based on Fick's second law has been created to describe corresponding mass transfer process. The transfer of water molecules by the micro cracks that can appear in the matrix as a result of the fiber swelling. According to this mechanism, there are three cases of diffusion behaviour [26] [27] known as Fickian diffusion model, anomalous or non-Fickian, and an intermediate case between Fickian and non-Fickian.

Moisture absorption is a big hurdle in the growth to utilize natural fibers in composites because the mechanical properties of composites degrade and reduce in wet conditions. The opportunity for using these fresh materials in outdoor applications requires complete study and to evaluate their mechanical characteristic in a violent environment, mainly in a moisture environment, during a long time. In addition synthetic fibers like glass (GF) or carbon fibers (CF), short aramid fibers (AF) are adopted to intensify the compressive strength and the creep resistance of the polymer matrix composites [28]. Accumulation of fibers is to make sure the strength of the material while the matrix helps to retain the shape of the composite. Still synthetic fibers extended exposure of carbon/polyester and carbon /vinyl ester composites to seawater was observed to reason for degradation in flexural strength and modulus [29]. Lessening in fracture toughness by 30% has been listed in carbon/vinyl ester composites due to constant exposure to sea water [30]. To prevail over the hydrophilic character of natural fibers many literature have shown that the degradation of mechanical properties of plant fibers with water uptake can be reduced by the use of fiber treatment and chemical surface treatment to make the composite durable [31].

Toughness is the ability of a material to sustain its original mechanical, thermal, physical and chemical properties for several years. For oceanic application, composites are estimated to be robust and not to be degraded in seawater for extended age of time. Owing to the viscoelastic behavior of polymeric matrix, composites exhibit time-dependant degradation in modulus and strength [32]. Alone fibers and matrix cannot withstand against sea water ageing so a little quantity of nanofillers can develop the composite properties significantly [33].

The high aspect ratio of nanoparticles produces a huge amount of surface area, which facilitates a better interaction between matrix and fiber as well as reduces the polymer chain mobility [34]. In the direction of obtaining superior mechanical properties whole exfoliation and homogeneous dispersion of nanofillers is significant.

Selection of resin is also very important parameter for designing a FRP for marine applications so epoxy resin is considered because it represents several of the highest performance resin due to the mechanical properties and resistance to environmental degradation, which leads to their almost exclusive use in aircraft components, marine application etc. Epoxies are distinct as cross-linked polymers which have cross-linking derived from chain reactions of the epoxy group. Epoxy resin typically used in coating industry as surface coating materials that combine flexibility, toughness, adhesion, and chemical resistance [35]. In count, epoxy resin also can be utilized in both laminating and molding techniques to build fiber reinforcement with better mechanical strength, chemical resistance and electrical insulating properties [36]. Epoxy resin used with reinforcing fibers for superior composites application. This is due to the ability of epoxy resin that showed superior adhesion to the embedded fiber [37]. Furthermore, epoxy resin absorbs high degree of water content which in order degrades the functional, structural and mechanical properties of the composites [38].

Glass/polyurethane and glass/epoxy are amongst various materials suggested for use in marine infrastructure. Many researchers have investigated the consequences of moisture on glass/epoxy composites [39] [40] [41]. Absorption of sea water in glass/epoxy composites has been observed to cause changes in the mechanical, physical, and chemical characteristics of the epoxy matrix by hydrolysis and plasticization [42] [43]. Also, it has been noted that the decrease in mechanical properties and degree of damage depend on the immersion liquid. During normal working temperature, swelling and plasticization lead to relaxation of curing stresses thus compensating for any interfacial degradation that might have been caused by moisture. Koutsoubos *et al.* Identified that glass fibers coated with an emulsion-based size and carbon fibers are coated with epoxy-based size [29]. This showed emulsion-based size leads to absorb water at humid environment [44] for that reason; glass fiber-based composites have a more chance to debond at the fiber matrix interfacial region. The quantity of water absorption depends on the relative humidity of the environment. Moisture absorption by carbon fiber is negligible, that does not reduce carbon fiber properties significantly [45].

Carbon/epoxy composites are appropriate for light weight structures and may be a healthier substitute to other materials presently in use in oceanic applications. Although there have been a number of work on the mechanical behavior of carbon/epoxy composites, to the best of our understanding, no studies have been reported in the literature on the effects of sea water on mechanical properties of nano-sized $CaCO_3$ filled Sria/carbon fiber epoxy composites. The objec-

tive of this study is to investigate the effects of sea water on the mechanical properties of $CaCO_3$ filled Sria/CF-Ep composites.

2. Materials and Methods

2.1. Materials

In the present investigation unidirectional *sansevieria* (Sria) plant fiber which was collected from farm near Annur, Tamil Nadu, India, using a mechanical procedure called decortication. The extracted plant fibers are weaved in mat form such that all fibers are oriented unidirectional. Unidirectional carbon fibers (CFs) woven was collected from Master Micron International, Bengaluru, India. Nanofillers like calcium carbonate ($CaCO_3$) were obtained from Global nano-tech, Kolkata, India. Epoxy (Lapox-12, K6 hardener) resin was purchased from Yuje Enterprises, Bengaluru, India.

2.2. Chemical Treatment of *Sansevieria* Fiber

The *sansevieria* (Sria) fibers were drenched in a glass tray containing 4.5% NaOH solution for 1 h. After that the fibers were washed carefully with distilled water in order to get rid of the excess NaOH content in the fibers [46]. Last washing was completed in water containing acetic acid. Fibers were dried in room temperature for 6 h and in hot air circulated at 60˚C for 2 h. later, the NaOH treated Sria fibers were subjected to potassium permanganate treatment. The Sria fibers were drenched in 0.05% potassium permanganate in acetone for 45 min [47] [48] [49]. The fibers were then decanted and dried in open air for 24 h and in hot air circulated at 60˚C for 2 h.

2.3. Preparation of Composite Slabs

The composite materials used for the existing investigation is fabricated by way of hand layup process. Sria fiber unidirectional woven mat of 300 mm × 300 mm size and unidirectional woven carbon fibers were used to put together the final slabs. The chemically handled Sria fiber mats were stored beneath daylight for 6 h and in addition dried in hot air oven for 2 h to get rid of the dampness content in the fibers. The composite slab consists of whole three layers in which carbon fibers layers are positioned at the top and backside of Sria mat. The layers of fibers are fabricated through smearing the required quantity of epoxy and hardener mix over the stacked mats and two rollers are used to trick all the air bubbles. During fabrication, the fiber orientation and alignment in the composites is maintained via two metal rollers that are always rolled on the fiber in the die. The procedure is repeated for preparation of nano-hybrid composites by way of mixing $CaCO_3$ nanofiller with epoxy with special wt.%. Finally these stacked composite slabs are taken to the hydraulic press for curing and the period of cure is maintained for about 24 h (final size after cure: 300 × 300 × 4.5 mm^3). Table 1 listing the quite a number of composites organized for the existing work.

Table 1. Designation and composition of Sria based hybrid epoxy composites.

Designation	Composition (wt.%)	$CaCO_3$ (wt.%)
S1	Sria (30%) + Ep (70%)	0
S2	Sria (30%) + CF (5%) + Ep (65%)	0
S3	Sria (30%) + CF (5%) + Ep (63.5%)	1.5
S4	Sria (30%) + CF (5%) + Ep (62%)	3
S5	Sria (30%)+ CF (5%) + Ep (60.5%)	4.5

Sria—*Sansevieria* Fiber, CF—Carbon Fiber, Ep—Epoxy.

2.4. Moisture Absorption Test

Water absorption tests were conducted as per ASTM D570 [50]. Initially, the specimens were flooded in a vessel filled with sea water; composite samples were immersed in a water bath until it reached saturation point. Afterward, to check the mass throughout the ageing process, the specimens were removed from the water with a gap of 24 h on regular basis, wiped dry to get rid of any surface moisture, after that weighted using a high accuracy analytical balance. For each type of composite, four specimens were tested, and then the average result was recorded. The moisture content percentage, $\Delta M(t)$, was calculated using the following equation:

$$\Delta M\left(t\right)=\frac{M_t-M_o}{M_o}\times 100 \tag{1}$$

M_O and M_t symbolize the mass of the dry and immersed sample, at exact time. The moisture absorption percentage was plotted against the square root of time (hours). The effects of ageing on the hardness, Interlaminar shear strength, tensile, and flexural properties of the woven composites were investigated after 792 h (at saturation).

Several linear Fickian diffusion processes for composites were listed [51] [52]. As per the developed model the diffusion coefficient; D is defined as the ability of water molecules to enter through laminate composites. It is computed from the slope of moisture content versus the square root of time by:

$$D=\pi\left(\frac{h}{4M_\infty}\right)^2\left(\frac{M_2-M_1}{\sqrt{t_2}-\sqrt{t_1}}\right)^2 \tag{2}$$

where, M_∞ is the percent moisture absorbed at saturation, h is the specimen thickness; M_2-M_1 is the slope of the plot of the moisture absorption rate during the first ageing time and $\sqrt{t_2}-\sqrt{t_1}$ is the linear portion of the curve. Assuming the absorption process is linear at an early stage of immersion; times are taken at the beginning of absorption process, so that the weight change is expected to vary linearly with the square root of time.

3. Characterization

3.1. Hardness

The hardness of Sria/Ep (S1) primarily based hybrid nanocomposites was de-

cided in accordance to ASTM D2583 standard [53] using a Barcol hardness tester. Test specimens have been used to measure the hardness of all the composite slabs prepared. The test specimens had been held firmly in position and load was applied manually by using hand. Ten indentations on every coupon at specific points were used and the mean value for each of the tested coupons used to be viewed for the investigation.

3.2. Interlaminar Shear Strength

The Interlaminar shear strength (ILSS) of the Sria/Ep primarily based hybrid nanocomposites was measured using a Universal Testing Machine (Kalpak Instruments & Control, K TEST Series, 100 kN), based on the ASTM D2344 [54]. The rectangular formed coupon was 35 × 12.5 × 4.5 mm^3 and cross head speed was 0.5 mm/min. Each coupon measured for five instances have been averaged.

3.3. Tensile and Flexural Tests Sria/Ep Based Nanocomposites

The tensile tests for Sria/Ep primarily based nanocomposites had been carried out using Universal Testing Machine (Kalpak Instruments & Control, K TEST Series, 100 kN) at a cross head speed of 5 mm/min, using 4 coupons for every measurement. An extensometer with gauge length 50 mm was once used for the elongation measurements, at room temperature as per ASTM D-638 [55]. Flexural tests have been performed in the three-point bend-mode using the identical Universal Testing Machine as per ASTM D790 [56]. The effective length and cross head speed have been 60 mm and 1.5 mm/min, respectively.

3.4. Impact Testing

Izod impact test has been performed under ASTMD256 standard [57] on specimens of dimensions 64 × 12 × 4.5 mm^3 using a 2.7 J pendulum at a striking velocity of 3.46 m/s. The minimum of 5 samples was once examined and the average value was used for analysis.

3.5. Scanning Electron Microscopy Observations

Fracture surfaces obtained from tensile assessments have been examined via Scanning Electron Microscopy (SEM) using JSM-7900F equipment. Prior to SEM observation, all tensile broken coupons were sputter coated with a skinny layer of gold to keep away from electric charging.

4. Results and Discussion

4.1. Water Absorption Behaviour

Water absorption of Sria/CF-Ep composites with varying percentage of $CaCO_3$ are shown in **Figure 1** with weight gain percentage as a function of the square root of time for various sample composites. From the graph it can observed that increasing in immersion time had increased the amount of water uptake by composite. In the early stage both unfilled and filled composites had significantly

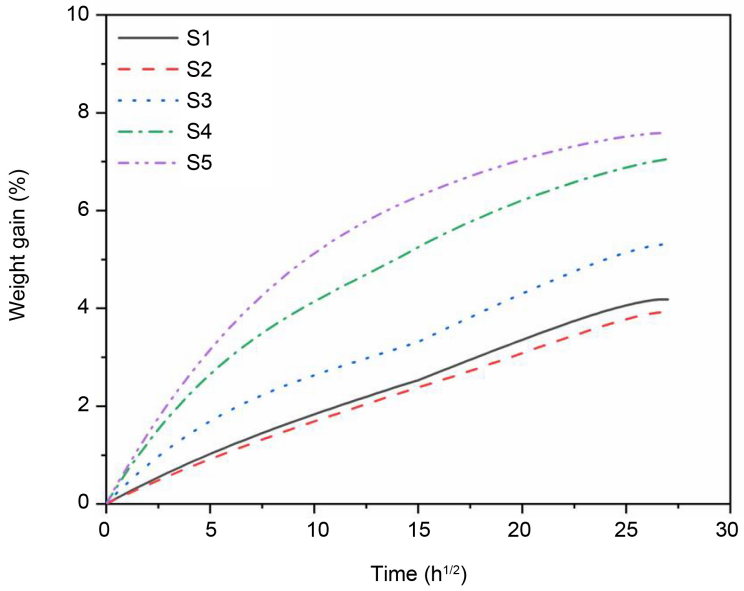

Figure 1. Water absorption curves of various woven composites.

increase in water absorption and after a certain time all composites start to reduce the water uptakes from the surrounding till it reach saturation point. Saturation point is where composite absorb no more water and the water content in composite remained constant. Related work was highlighted in earlier works where the water absorption effects of natural fiber reinforced polymer composites were investigated [24] [58] [59]. Moisture uptake route of the woven composites was linear at the start, demonstrating the rapid moisture diffusion into the composite materials. Moisture uptake then slowed down and approached saturation following an extended time period. The moisture uptake is pursuing Fickian behaviour. Cellulose which is present in the order of 79.9% is a major constituent of Sria fiber, potassium permanganate treatment can alter the crystalline structure of the cellulose and thus able to restrict water absorption to a certain extent [60]. Epoxy in addition serves as a binder for reinforcement and helping to transfer the load to the fibers, also protects the fibers from harsh environments [61].

On the other hand, while the composites are constantly exposed to water, the brittle thermosetting resin will experience micro cracking due to the swelling behaviour of the fibers. Cellulose content in the Sria fibers additional supports to more water penetrating into the fiber-matrix interphase developing stress concentration leading to failure of the composite. While, more micro cracks were found in coupons and water transport through these micro cracks [62]. The water molecules flow inside the capillary cracks and constantly assault the interface, ensuing in debonding of the fiber from the matrix. This explanation is supported by the SEM picture as shown in **Figure 2**.

Furthermore, the addition of nanofiller $CaCO_3$ in composites had increased the moisture absorption rate. This might be due to the properties of the $CaCO_3$ that have high tendency to agglomerate. It is well recognized that the smaller the

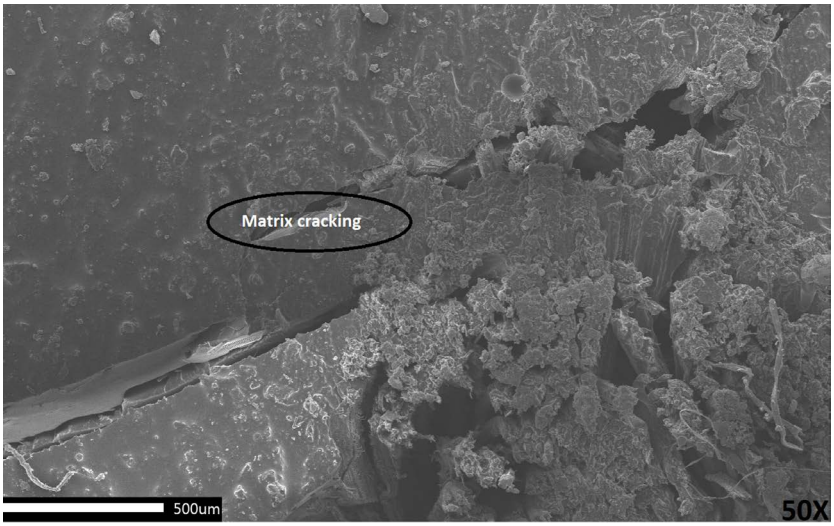

Figure 2. Matrix cracking of an immersed sample due to attacks by the water molecules (50× Magnification).

size of particle the more easily the particle to agglomerate. This agglomeration would have damaged the interfacial adhesion between the filler and matrix which therefore lead to variation in the formation of gap in interfacial region. Raising the gap in interfacial region could increase the amount of water molecules to penetrate into composite and the being trapped inside the gap.

From literature, it is understood that filler had superior tendency to produce agglomerate. Results showed that the water absorption of Sria/CF-Ep composite was increasing with addition of $CaCO_3$ filler loading. This could be due to the higher cellulose in Sria fiber, When $CaCO_3$ introduced in the composite; the presence of high amount of agglomeration had increased the gap in interfacial between the filler and matrix therefore increasing the water absorption of the composite. Nevertheless, the amount of cellulose in Sria fiber given more impact for water absorption properties compared to the gap appears between the filler and matrix in all filled composites. Sria fiber had the ability to absorb water due to the high cellulose content which formed high hydrogen bonding from its hydroxyl group and water molecules.

Even though $CaCO_3$ have hydrophilic sites and polar, it may not be as fine as the cellulosic fibers of the Sria do attract water content. Also, the Sria fiber used in this study was potassium permanganate treated. Therefore, the possibility to absorb water molecule are minimal, predictable to be brought about by Sria fiber compare to $CaCO_3$ filler loading in the hybrid composite.

4.2. Effect of Water Absorption on the Mechanical Properties

4.2.1. Hardness

Figure 3 suggests the measured hardness of all the prepared Sria composite samples. It can be viewed that the hardness of dry S2 composite will increase from 46 to 52 (Barcol hardness number) when it is stuffed with 4.5 wt % $CaCO_3$. Similarly the hardness of water absorbed samples decreased in comparison with

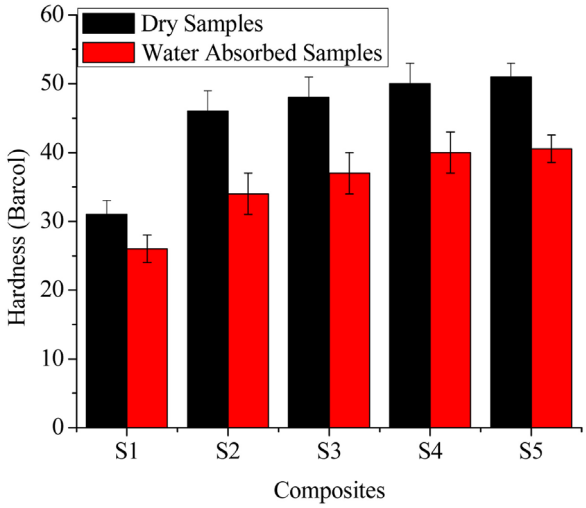

Figure 3. Hardness (Barcol) of Sria based hybrid nanocomposites.

dry samples. This could additionally be credited to degree of cure of the epoxy resin, consistent dispersion and higher interfacial bonding between the $CaCO_3$ particles in the epoxy resin. In the same way, the hardness improved for composites containing $CaCO_3$ and their hybrid sample composites.

4.2.2. Interlaminar Shear Strength

The interlaminar shear strength (ILSS) consequences of $CaCO_3$ crammed S2 hybrid composites are proven in **Figure 4**. The outcomes exhibit that the ILSS of the S2 composites has multiplied with the loading of $CaCO_3$ nanoparticles. The outcomes confirmed similarities to studies in the literature. The experimental data acquired by He and Co-workers [63] [64] validated that the ILSS of CF/Ep layered composites can be multiplied up to 36% with the aid of 4 wt.% $CaCO_3$ nanofiller loading. In the current experimental work, the most massive enhancement of 55.7% has been proven through 4.5 wt.% $CaCO_3$ in S2 as in contrast to all unique composites studied. The most massive improvement of 55.7% has been proven through 4.5 wt.% $CaCO_3$ in S2 as in contrast to all different composites studied.

This enhancement in ILSS can be credited to the uniform dispersion of $CaCO_3$ inside the epoxy matrix, which helps in growing the bonding between the fibers and higher transfer of stress. Correspondingly the water absorbed samples ILSS decreased when compared to the same dry samples this may be attributed to the water absorption behaviour of Sria fiber and $CaCO_3$.

4.2.3. Influence of Water Ageing on Tensile Properties of Sria/CF-Ep Based Nanocomposites

The results of the tensile properties obtained for S1, S2, and their composites are shown in **Figure 5**. Higher aspect ratio or unidirectional fiber as reinforcing agents provides long fiber composites with increased strength. This interprets the capability to resist creep or deformation under loads and fatigue endurance

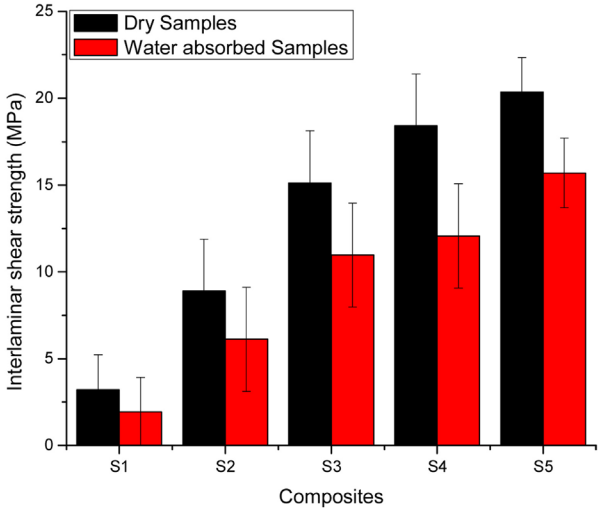

Figure 4. Interlaminar shear strength of the dry and water absorbed Sria/CF-Ep hybrid nanocomposites.

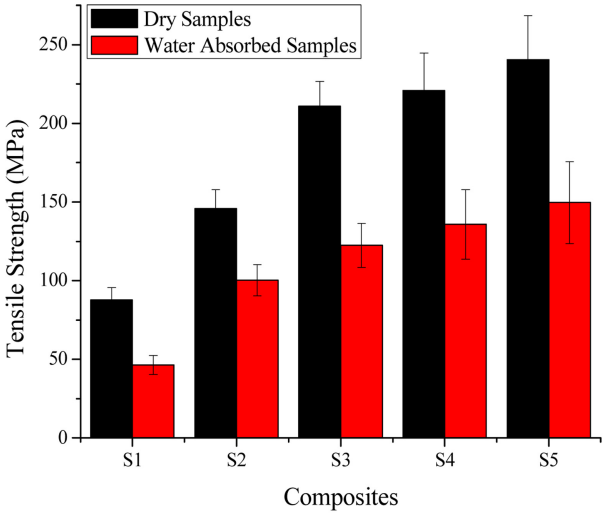

Figure 5. Tensile strength of the dry and water absorbed nano-$CaCO_3$ filled Sria/CF-Ep hybrid composites.

with minimum compression. Increased fiber outside region provides the ductile polymer with more capability in order to capture and transfer stress to the fiber. Further, the composite strength is considerably influenced by the orientation of reinforcing fibers within the epoxy matrix.

Figure 5 shows the tensile properties of S1, S2, and $CaCO_3$ filled hybrid (S3 to S5) nano composites. The tensile strength of Sria based composites were notably improved with the reinforcements of CF and $CaCO_3$ nanofiller. Under tensile loading, observed increase in tensile strength and Young's modulus could be due the improved adhesion at CF/Sria fiber–epoxy matrix interface and along with the uniform dispersion and better adhesion $CaCO_3$ filler ensuing in an capable load transfer from the matrix to the filler and reinforcement. The surface modification by potassium permanganate allows it to respond with the Sria fiber sur-

face, their by forming a bridge of chemical bonds between the fiber and matrix in the hybrid composites.

For S2 composite filled with different wt.% of nano $CaCO_3$, the tensile strength increased from 145 MPa to 240 MPa. The tensile moduli of 1.5, 3.0 and 4.5 wt.% nano $CaCO_3$ filled hybrid composites are 39%, 61% and 67% higher than that of S2 (1.41 GPa), respectively (**Figure 5**). These results were regular with the general examination that the introduction of high strength carbon fiber and nano-sized $CaCO_3$ particles into epoxy matrix increases the tensile properties. The improvement was reasonable because of the carbon fiber in S1 can carry more tensile load. In addition, the CF has high strength and stiffness when compared to the Sria fibers and the epoxy matrix, which adds stiffness to the mono-composites (S1). This data corresponded with that in the literature [65] [66] [67]. **Figure 6** shows SEM Picture of water absorbed S5 sample after tensile test it shows due to complete absorption of water the diameter of sria fibers was increased leading to cracking of matrix.

4.2.4. Influence of Water Ageing on Flexural Properties of Sria/CF-Ep Based Nanocomposites

The flexural properties of S2 and their nanofillers stuffed hybrid composite are illustrated in **Figure 7**. As the $CaCO_3$ loading increased, the flexural strength of the S2 improved. The $CaCO_3$ containing composite systems (S3, S4 and S5) exhibited an extra rigid structure than the composite systems that did not contain $CaCO_3$. The increase in the flexural modulus of the S2 used to be higher than the increase in the flexural strength. For example, the flexural modulus of the S2 with 4.5 wt.% $CaCO_3$ accelerated by means of 261%, whilst the flexural strength improved by 21%. The flexural modulus of the S2 was once notably affected by the quantity of $CaCO_3$. **Figure 7** also indicates that the maximum flexural strength was 319.36 MPa in the $CaCO_3$ containing 4.5 wt.% $CaCO_3$. Similarly,

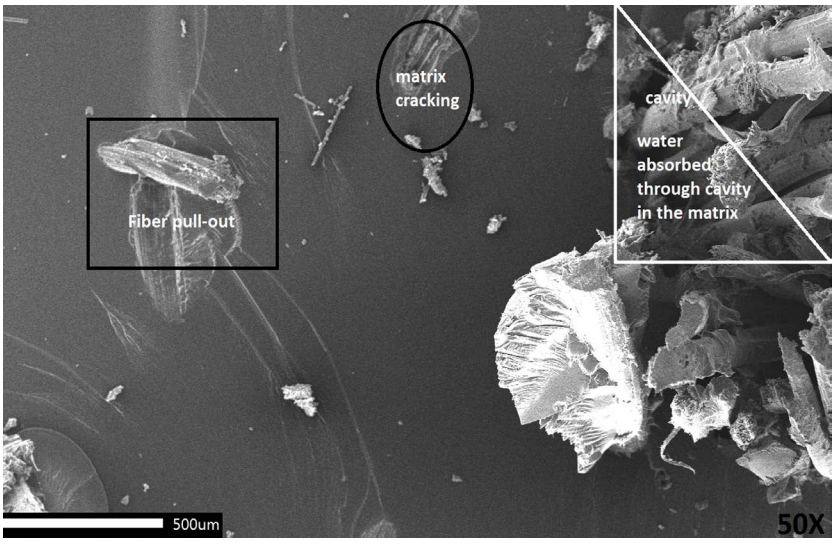

Figure 6. SEM Picture of water absorbed S5 sample after Tensile test (50× Magnification).

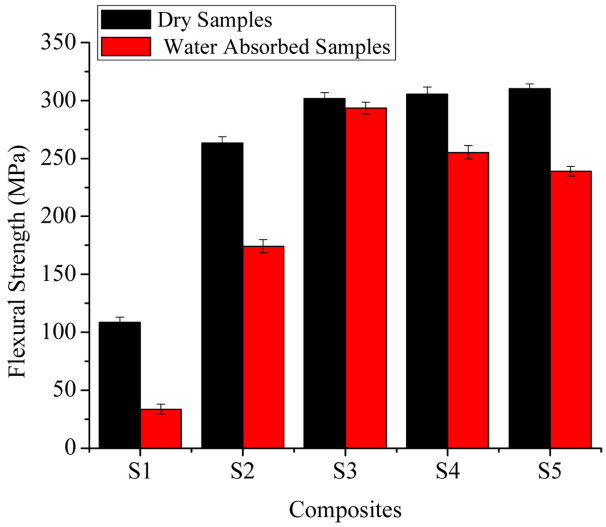

Figure 7. Flexural strength of the dry and water absorbed nano $CaCO_3$ filled Sria/CF-Ep hybrid composites.

the minimal flexural strength was 263.22 MPa in the control group without $CaCO_3$ (S2).

The flexural strength improved as the $CaCO_3$ quantity in the hybrid nanocomposite system increased. This was attributed to the top compatibility between the $CaCO_3$, carbon/chemically treated Sria fibers, and epoxy matrix. The outcomes confirmed similarities to research in the literature [2] [32] [64] [65]. Rong *et al.* [65] investigated the impact of fiber remedy on the mechanical properties of unidirectional sisal-fiber strengthened epoxy composites. However, the flexural strength and flexural modulus values of the epoxy composite multiplied due to the fact that of an increase in the alkali treated sisal fibers. This can be explained with the aid of the desirable interfacial adhesion between fiber and epoxy matrix. Reis [68] found that coconut fiber reinforcement displays a marginal increase in the flexural strength of epoxy polymer concrete in contrast to unfilled and artificial fiber bolstered materials. Yan *et al.* [69] investigated the impact of alkali therapy on mechanical properties of coir fiber bolstered epoxy composites. They observed that the flexural strength of treated coir fiber/epoxy composites used to be 17% greater than that of untreated coir/epoxy composites. The alkali remedy appreciably improved the flexural strength of composites. In the current work, the flexural strength of $CaCO_3$ stuffed S2 hybrid nanocomposite will increase with increasing filler wt.% likely due to the uniform dispersion of nanoparticles, higher filler-matrix interface, chemical bonding at the interface between fiber and matrix might also be too robust to switch strength. The flexural strength of $CaCO_3$ stuffed S2 hybrid nanocomposites (**Figure 7**). The viable motive is that although these samples are damaged when the most stresses was once reached. The enhancement of flexural properties of $CaCO_3$ stuffed S2 hybrid nanocomposites is possibly due to the elimination of outer fiber surface of Sria; increase of cellulose content and interfacial adhesion through potassium permanganate treatment. However, the outcomes show that the influence of chem-

ical therapy on flexural properties is much less than that on the tensile properties. The viable reason is that the flexural failure mode indicates much less fiber pull-out, as a consequence of the direction of the applied stress being perpendicular to the composite coupon in the three-point bending test. Flexural failure in fiber strengthened PMCs is characterized by means of the presence of compressive and tensile stresses. The deflection of 1.5, 3.0 and 4.5 wt.% nano-$CaCO_3$ crammed hybrid composites are 1.99 mm, 2.36 mm and 2.58 mm which are greater than that of S2 (0.97 mm), respectively. According to the results, the mechanical properties of the Sria/CF-Ep composites accelerated primarily based on an increased loading of $CaCO_3$ nanoparticles. The researchers attributed this increase to the excessive slenderness ratio of fibers and extensive surface area of the nanoparticles.

4.2.5. Impact Testing

The outcomes of the impact strength testing of S1, S2, and their nano-$CaCO_3$ stuffed hybrid composites (S3 to S5) is proven in **Figure 8**. The test results confirmed that the impact strength of the S2 composites improved with increase in $CaCO_3$ nanoparticles.

The most increase of 67% has been confirmed with the aid of 4.5 wt.% $CaCO_3$ crammed S2 hybrid composites. Fibers and fillers play a vital role in enhancing the impact resistance of the material, which is related to the usual longevity of the material. With the increase of nanofiller loading, the interfacial adhesion between fiber, epoxy resin, and nanofiller increase, which assist in higher load transfer and promotes stress switch from fiber and filler to the matrix. Furthermore, the cause for this behaviour was the large amount of nanoparticles of the $CaCO_3$/Sria/CF phase and their appropriate dispersion in the epoxy matrix inflicting an extended transfer of impact energy to the fiber and filler phase. This

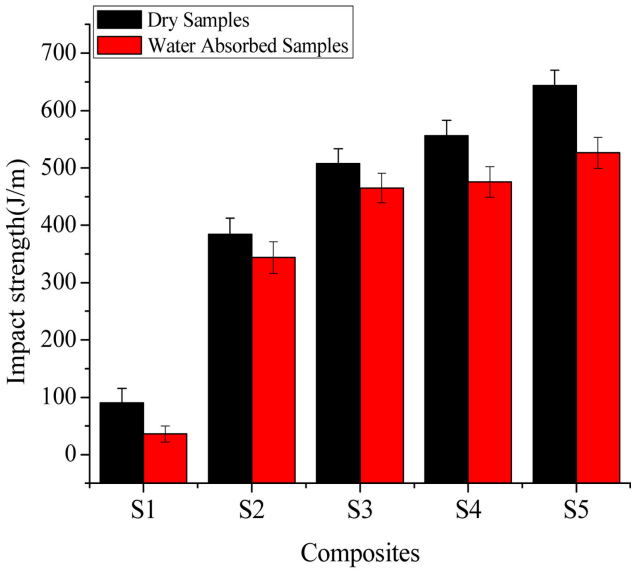

Figure 8. Impact strength of the dry and water absorbed nano $CaCO_3$ filled Sria/CF-Ep hybrid composites.

implies that stronger interfacial interplay between chemically dealt Sria fiber/carbon fiber phase and $CaCO_3$ phase improved the impact strength of the epoxy.

5. Conclusions

The mechanical properties of fabricated Sria/Ep, Sria/CF-Ep and their nano-$CaCO_3$ stuffed hybrid composites are evaluated. The following conclusions have been derived from the experimental investigations.

- *Sansevieria* fibers can be efficaciously modified by way of bodily and chemical treatments. Potassium permanganate treated *sansevieria* fibers brings about an active surface by means of introducing some reactive groups and grant the fibers with larger extensibility via partial elimination of lignin and hemicellulose.
- The profitable fabrication of Sria/EP and Sria/CF-Ep composites with different share (0 to 4.5 wt %) of nano-$CaCO_3$ filler loading can be accomplished via easy by simple hand lay up procedure accompanied by heat press.
- The hardness and interlaminar shear strength test outcomes confirmed that the Sria/CF-Ep composite with nano-$CaCO_3$ improved properties when compared to water absorbed Sria/Ep and Sria/CF-Ep hybrid composites. The dry composite Sria/CF-Ep with 4.5 wt.% nano-$CaCO_3$ (S5) sequence presented the best interlaminar shear strength.
- The tensile and flexural properties of mono-composite (Sria/-Ep, S1) multiplied with small weight share of carbon fibers (5 wt.%) and an increased quantity of nano-$CaCO_3$ filler. The greater values may perhaps due to the fact of good dispersion of nano-$CaCO_3$ particles in the epoxy matrix material. Also showed the decreasing trend with the water absorption for the same samples.
- The notched Izod have an effect on tests confirmed an increase in the impact energy of both Sria/CF and CF with varied $CaCO_3$ coupons (S2 to S5) as in contrast to the mono-composite (Sria/Ep, S1). The highest impact strength of 643 J/m used to be bought for 4.5 wt.% $CaCO_3$ nanoparticles stuffed Sria/CF-Ep as compared to mono-composites. These outcomes suggest that the used nano-modifier in the hybrid fiber bolstered epoxy matrix introduced a proper compatibility with each carbon/chemically treated Sria fiber, with the benefit of increasing the mechanical properties of the epoxy matrix material.

Declaration of Conflicting Interests

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no financial support for this work that could have prejudiced its outcome.

References

[1] Baillie, C., Ed. (2004) Green Composites. Polymer Composites and Environment. Wood Head Publishing Limited, Cambridge. https://doi.org/10.1016/B978-1-85573-739-6.50004-X

[2] Mouritz, A.P., Gellert, E., Burchill, P. and Challis, K. (2001) Review of Advanced Composite Structures for Naval Ships And Submarines. *Composite Structures*, **53**, 21-41. https://doi.org/10.1016/S0263-8223(00)00175-6

[3] Davies, P., Mazeas, F. and Casari, P. (2001) Sea Water Aging of Glass Reinforced Composites: Shear Behaviour and Damage Modeling. *Journal of Composite Materials*, **35**, 1343-1372. https://doi.org/10.1106/MNBC-81UB-NF5H-P3ML

[4] Shuaib, N.A. and Mativenga, P.T. (2016) Energy Demand in Mechanical Recycling of Glass Fiber Reinforced Thermoset Plastic Composites. *Journal of Cleaner Production*, **120**, 198-206. https://doi.org/10.1016/j.jclepro.2016.01.070

[5] Netravali, A.N., Huang, X. and Mizuta, K. (2007) Advanced Green Composites. *Advanced Composite Materials*, **16**, 269-282. https://doi.org/10.1163/156855107782325230

[6] La Mantia, F.P. and Morreale, M. (2011) Green Composites: A Brief Review. *Composites Part A*: *Applied Science and Manufacturing*, **42**, 579-588. https://doi.org/10.1016/j.compositesa.2011.01.017

[7] Fragassa, C. (2016) Effect of Natural Fibers and Bio-Resins on Mechanical Properties in Hybrid and Non-Hybrid Composites. *Proceedings of the* 8*th Conference on Times of Polymers & Composites*: *From Aerospace to Nanotechnology*, Vol. 1736, Ischia, 19-23th June 2016, American Institute of Physics (AIP). https://doi.org/10.1063/1.4949693

[8] Fragassa, C., Santulli, C., Sljivic, M. and Pavlovi, C.A. (2015) Improving Performance and Applicability of Green Composite Materials by Hybridization. *Contemporary Mathematics*, **4**, 35-43.

[9] Wambua, P., Ivens, J. and Verpoest, I. (2003) Natural Fibers: Can They Replace Glass in Fiber Reinforced Plastics. *Composites Science and Technology*, **63**, 1259-1264. https://doi.org/10.1016/S0266-3538(03)00096-4

[10] Karus, M. and Kaup, M. (2002) Natural Fibers in the European Automotive Industry. *Journal of Industrial Hemp*, **7**, 119-131. https://doi.org/10.1300/J237v07n01_10

[11] Jawaid, M. and Khalil, H.P.S.A. (2011) Cellulosic/Synthetic Fiber Reinforced Polymer Hybrid Composites: A Review. *Carbohydrate Polymers*, **86**, 1-18. https://doi.org/10.1016/j.carbpol.2011.04.043

[12] Ramnath, B.V., Kokan, S.J., Raja, S.N., Sathyanarayanan, R., Elanchezhian, C. and Prasad, A.R. (2013) Evaluation of Mechanical Properties of Abaca-Jute-Glass Fiber Reinforced Epoxy Composite. *Materials & Design*, **51**, 357-366. https://doi.org/10.1016/j.matdes.2013.03.102

[13] Braga, R.A. and Magalhaes, J.P.A.A. (2015) Analysis of the Mechanical and Thermal Properties of Jute and Glass Fiber as Reinforcement Epoxy Hybrid Composites. *Materials Science and Engineering*: *C*, **56**, 269-273. https://doi.org/10.1016/j.msec.2015.06.031

[14] Bhoopathia, R., Ramesha, M. and Deepa, C. (2014) Fabrication and Property Evaluation of Banana-Hemp-Glass Fiber Reinforced Composites. *Procedia Engineering*, **97**, 2032-2041. https://doi.org/10.1016/j.proeng.2014.12.446

[15] Ridzuan, M.J.M., Majid, M.S.A., Afendi, M., Azduwin, K., Amin, N.A.M., Zahri, J.M., *et al.* (2016) Moisture Absorption and Mechanical Degradation of Hybrid Pennisetum Purpureum/Glass-Epoxy Composites. *Composite Structures*, **141**, 110-116. https://doi.org/10.1016/j.compstruct.2016.01.030

[16] Burks, B., Armentrout, D. and Kumosa, M. (2011) Characterization of the Fatigue Properties of a Hybrid Composite Utilized in High Voltage Electric Transmission. *Composites Part A*: *Applied Science and Manufacturing*, **42**, 1138-1147.

https://doi.org/10.1016/j.compositesa.2011.04.019

[17] Athijayamania, A., Thiruchitrambalamb, M., Natarajana, U. and Pazhanivel, B. (2009) Effect of Moisture Absorption on the Mechanical Properties of Randomly Oriented Natural Fibers/Polyester Hybrid Composite. *Materials Science and Engineering*: *A*, **517**, 344-353. https://doi.org/10.1016/j.msea.2009.04.027

[18] Singha, N.P., Aggarwalb, L. and Gupta, V.K. (2015) Tensile Behavior of Sisal/Hemp Reinforced High Density Polyethylene Hybrid Composite. *Materials Today*: *Proceedings*, **2**, 3140-3148. https://doi.org/10.1016/j.matpr.2015.07.102

[19] Venkateshwaran, N., ElayaPerumal, A., Alavudeen, A. and Thiruchitrambalam, M. (2011) Mechanical and Water Absorption Behaviour of Banana/Sisal Reinforced Hybrid Composites. *Materials & Design*, **32**, 4017-4021. https://doi.org/10.1016/j.matdes.2011.03.002

[20] Yahaya, R., Sapuan, S.M., Jawaid, M., Leman, Z. and Zainudin, E.S. (2014) Mechanical Performance of Woven Kenaf-Kevlar Hybrid Composites. *Journal of Reinforced Plastics and Composites*, **33**, 2242-2254. https://doi.org/10.1177/0731684414559864

[21] Yahaya, R., Sapuan, S.M., Jawaid, M., Leman, Z. and Zainudin, E.S. (2015) Effect of Layering Sequence and Chemical Treatment on the Mechanical Properties of Woven Kenaf-Aramid Hybrid Laminated Composites. *Materials & Design*, **67**, 173-179. https://doi.org/10.1016/j.matdes.2014.11.024

[22] Skaar, C. (1958) Moisture Movement in Beech below the Fiber Saturation Point. *Forest Products Journal*, **8**, 352-357.

[23] Haameem, M.J.A., Majid, M.S.A., Afendi, M., Marzuki, H.F.A., Hilmi, E.A. and Fahmi, I. (2016) Effects of Water Absorption on Napier Grass Fiber/Polyester Composites. *Composite Structures*, **144**, 138-146. https://doi.org/10.1016/j.compstruct.2016.02.067

[24] Salleh, Z., Taib, Y.M., Hyie, K.M., Mihat, M., Berhan, M.N. and Ghani, M.A.A. (2012) Fracture Toughness Investigation on Long Kenaf/Woven Glass Hybrid Composite Due to Water Absorption Effect. *Procedia Engineering*, **41**, 1667-1673. https://doi.org/10.1016/j.proeng.2012.07.366

[25] Akil, H.M.D., Santulli, C., Sarasini, F., Tirillò, J. and Valente, T. (2014) Environmental Effects on the Mechanical Behaviour of Pultruded Jute/Glass Fibre-Reinforced Polyester Hybrid Composites. *Composites Science and Technology*, **94**, 62-70. https://doi.org/10.1016/j.compscitech.2014.01.017

[26] Collings, T.A. (1994) Moisture Absorption—Fickian Diffusion Kinetics and Moisture Profiles. In: Jones, F.R., Ed., *Handbook of Polymer-Fiber Composites*, Longman Scientific and Technical, Essex, UK, 366-371.

[27] Shen, C.H. and Springer, G.S. (1976) Moisture Absorption and Desorption of Composite Materials. *Journal of Composite Materials*, **10**, 2-20. https://doi.org/10.1177/002199837601000101

[28] Friedrich, K., Zhang, Z. and Schlarb, A.K. (2005) Effects of Various Fillers on the Sliding Wear of Polymer Composites. *Composites Science and Technology*, **65**, 2329-2343. https://doi.org/10.1016/j.compscitech.2005.05.028

[29] Kootsookos, A. and Mouritz, A.P. (2004) Seawater Durability of Glass- and Carbon-Polymer Composites. *Composites Science and Technology*, **64**, 1503-1511. https://doi.org/10.1016/j.compscitech.2003.10.019

[30] Siriruk, A., Penumadu, D. and Weitsman, Y.J. (2008) Effect of Sea Environment on Interfacial Delamination Behavior of Polymeric Sandwich Structures. *Composites Science and Technology*, **69**, 821-828.

[31] Alix, S., Philippe, E., Bessadok, A., Lebrun, L., Morvan, C. and Marais, S. (2009) Effect of Chemical Treatments on Water Sorption and Mechanical Properties of Flax-Fibers. *Bioresource Technology*, **100**, 4742-4759. https://doi.org/10.1016/j.biortech.2009.04.067

[32] Raghavan, J. and Meshiib, M. (1997) Creep Rupture of Polymer Composites. *Composites Science and Technology*, **57**, 375-388. https://doi.org/10.1016/S0266-3538(96)00156-X

[33] Xu, Y. and Hoa, S.V. (2008) Mechanical Properties of Carbon Fiber Reinforced Epoxy Clay Nanocomposites. *Composites Science and Technology*, **68**, 854-861. https://doi.org/10.1016/j.compscitech.2007.08.013

[34] Yasmin, A., Luo, J., Abot, J.L. and Daniel, I.M. (2006) Mechanical and Thermal Behavior of Clay-Epoxy Nanocomposites. *Composites Science and Technology*, **66**, 2415-2422. https://doi.org/10.1016/j.compscitech.2006.03.011

[35] Wilkinson, S.B. and White, J.R. (1996) Thermosetting Short Fiber Reinforced Composites in Short Fiber-Polymer Composites. Woodhead Publishing Limited, Cambridge, 54-81.

[36] Zhou, Y., Pervin, F., Biswas, M.A., Rangari, V.K. and Jeelani, S. (2006) Fabrication and Characterization of Montmorillonite Clay-Filled SC-15 Epoxy. *Materials Letters*, **60**, 869-873. https://doi.org/10.1016/j.matlet.2005.10.042

[37] Bao, L. and Yee, A.F. (2002) Effect of Temperature on Moisture Absorption in a Bismaleimide Resin and Its Carbon Fiber Composites. *Polymer*, **43**, 3987-3997. https://doi.org/10.1016/S0032-3861(02)00189-1

[38] Kim, J.K., Hu, C., Woo, R.S.C. and Sham, M.L. (2005) Moisture Barrier Characteristics of Organo Clay-Epoxy Nanocomposites. *Composites Science and Technology*, **65**, 805-813. https://doi.org/10.1016/j.compscitech.2004.10.014

[39] Aktas, A. and Uzun, I. (2008) Sea Water Effect in Pinned-Joint Glass Fiber Composite Materials. *Composite Structures*, **85**, 59-63. https://doi.org/10.1016/j.compstruct.2007.10.007

[40] Wood, C. and Bradley, W.L. (1997) Determination of the Effect of Seawater on the Interfacial Strength of an Interlayer E-Glass/Graphite/Epoxy Composite by *in Situ* Observation of Transverse Cracking in an Environmental SEM. *Composites Science and Technology*, **57**, 1033-1043. https://doi.org/10.1016/S0266-3538(96)00170-4

[41] Ray, B.C. (2006) Temperature Effect during Humid Ageing On Interfaces of Glass and Carbon Fibers Reinforced Epoxy Composites. *Journal of Colloid and Interface Science*, **298**, 111-117. https://doi.org/10.1016/j.jcis.2005.12.023

[42] Ellyin, F. and Maser, R. (2004) Environmental Effects on Mechanical Properties of Glass-Fiber Epoxy Composite Tubular Specimens. *Composites Science and Technology*, **64**, 1863-1874. https://doi.org/10.1016/j.compscitech.2004.01.017

[43] Selzer, R. and Friedrich, K. (1997) Mechanical Properties and Failure Behavior of Carbon Fibre-Reinforced Polymer Composites under the Influence of Moisture. *Composites Part A*: *Applied Science and Manufacturing*, **28**, 595-604. https://doi.org/10.1016/S1359-835X(96)00154-6

[44] Yang, G., Fu, S.-Y. and Yang, J.-P. (2007) Preparation and Mechanical Properties of Modified Epoxy Resins with Flexible Diamines. *Polymer*, **48**, 302-310. https://doi.org/10.1016/j.polymer.2006.11.031

[45] Ellyin, F. and Rohrbacher, C. (2000) Effect of Aqueous Environment and Temperature on Glass-Fibre Epoxy Resin Composites. *Journal of Reinforced Plastics and Composites*, **19**, 1405-1427. https://doi.org/10.1177/073168400772678518

[46] Sreenivasan, V.S., Somasundaram, S., Ravindran, D., Manikandan, V. and Narayanasamy, R. (2011) Microstructural, Physico-Chemical and Mechanical Characterisation of *Sansevieria cylindrica* Fibres—An Exploratory Investigation. *Materials & Design*, **32**, 453-461. https://doi.org/10.1016/j.matdes.2010.06.004

[47] Sreenivasan, V.S., Ravindran, D., Manikandan, V. and Narayanasamy, R. (2012) Influence of Fiber Treatments on Mechanical Properties of Short *Sansevieria cylindrica*/Polyester Composites. *Materials & Design*, **37**, 111-121. https://doi.org/10.1016/j.matdes.2012.01.004

[48] Paul, S.A., Boudenne, A., Ibos, L., Candau, Y., Joseph, K. and Thomas, S. (2008) Effect of Fiber Loading and Chemical Treatments on Thermophysical Properties of Banana Fiber/Polypropylene Commingled Composite Materials. *Composites Part A*: *Applied Science and Manufacturing*, **39**, 1582-1588. https://doi.org/10.1016/j.compositesa.2008.06.004

[49] Malenab, R.A.J., Ngo, J.P.S. and Promentilla, M.A.B. (2017) Chemical Treatment of Waste Abaca for Natural Fiber-Reinforced Geopolymer Composite. *Composite Materials*, **10**, 579-598.

[50] ASTM D570-98 (2010) Standard Test Method for Water Absorption of Plastics.

[51] Springer, G.S., Ed. (1981) Environmental Effects on Composite Materials.

[52] UNE-EN ISO 62 (2008) Plastics. Determination of Water Absorption.

[53] ASTM D2583-13a (2013) Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor.

[54] ASTM D2344/D2344M-16 (2016) Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates.

[55] ASTM D638-14 (2014) Standard Test Method for Tensile Properties of Plastics.

[56] ASTM D790-17 (2017) Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.

[57] ASTM D256-10e1 (2010) Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics.

[58] Wang, W., Sain, M. and Cooper, P.A. (2006) Study of Moisture Absorption in Natural Fiber Plastic Composites. *Composites Science and Technology*, **66**, 379-386. https://doi.org/10.1016/j.compscitech.2005.07.027

[59] Akil, H.M.D., Cheng, L.W., Ishak, Z.A.M., Bakar, A.A. and Rahman, M.A.A. (2009) Water Absorption Study on Pultruded Jute Fiber Reinforced Unsaturated Polyester Composites. *Composites Science and Technology*, **69**, 1942-1948. https://doi.org/10.1016/j.compscitech.2009.04.014

[60] Akil, H.M., Omar, M.F., Mazuki, A.A.M., Safiee, S., Ishak, Z.A.M. and Bakar, A.A. (2011) Kenaf Fiber Reinforced Composites: A Review. *Materials & Design*, **32**, 4107-4121. https://doi.org/10.1016/j.matdes.2011.04.008

[61] Dan, M.Y., Abdullah, M.Z., Yusoff, P.S.M.M. (2014) The Effect of Hybridization on Mechanical Properties of Woven Kenaf Fiber Reinforced Polyoxy Methylene Composites. *Polymer Composites*, **35**, 1900-1910. https://doi.org/10.1002/pc.22846

[62] Dhakal, H.N., Zhang, Z.Y. and Richarson, M.O.W. (2007) Effect of Water Absorption on the Mechanical Properties of Hemp Fiber Reinforced Unsaturated Polyester Composites. *Composites Science and Technology*, **67**, 1674-1683. https://doi.org/10.1016/j.compscitech.2006.06.019

[63] He, H. and Li, K. (2012) Silane Coupling Agent Modification on Interlaminar Shear Strength of Carbon Fiber/Epoxy/Nano-$CaCO_3$ Composites. *Polymer Composites*, **33**, 1755-1758. https://doi.org/10.1002/pc.22311

[64] He, H., Gao, F. and Li, K. (2013) Effect of Epoxy Resin Properties on the Mechanical Properties of Carbon Fiber/Epoxy Resin Composites. *International Journal of Materials Research*, **104**, 899-902. https://doi.org/10.3139/146.110937

[65] Rong, M.Z., Zhang, M.Q., Liu, Y., Yang, G.C. and Zeng, H.M. (2001) The Effect of Fiber Treatment on the Mechanical Properties of Unidirectional Sisal-Reinforced Epoxy Composites. *Composites Science and Technology*, **61**, 1437-1447. https://doi.org/10.1016/S0266-3538(01)00046-X

[66] Uday Kumar, P.A., Ramalingaiah, Suresha, B., Rajini, N. and Satyanarayana, K.G. (2017) Effect of Treated Coir Fiber/Coconut Shell Powder and Aramid Fiber on Mechanical Properties of Vinyl Ester. *Polymer Composites*, **39**, 4542-4550.

[67] Siva, I., Jappes, J.T.W. and Suresha, B. (2012) Investigation on Mechanical and Tribological Behavior of Naturally Woven Coconut Sheath-Reinforced Polymer Composite. *Polymer Composites*, **33**, 723-732. https://doi.org/10.1002/pc.22197

[68] Reis, J.M.L. (2006) Fracture and Flexural Characterization of Natural Fiber-Reinforced Polymer Concrete. *Construction and Building Materials*, **20**, 673-678. https://doi.org/10.1016/j.conbuildmat.2005.02.008

[69] Yan, L., Chouw, N., Huang, L. and Kasal, B. (2016) Effect of Alkali Treatment on Microstructure and Mechanical Properties of Coir Fibers, Coir Fiber Reinforced-Polymer Composites and Reinforced-Cementitious Composites. *Construction and Building Materials*, **112**, 168-182. https://doi.org/10.1016/j.conbuildmat.2016.02.182