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Effect of Distilled and Sea Water Absorption on Mechanical Behaviour of Short Coir Fibre Epoxy Composite/Sawdust Filler

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ABSTRACT

Research on natural fibres has been carried out from past decades as a result of developing low cost, eco-friendly materials. The objective of this study is to fabricate composites utilising sawdust of various proportion and compare the mechanical properties like tensile, flexural and hardness within dry condition and with respect to specimens immersed in distilled and salt water. The composites with constant reinforcement 15%, different percentage of matrix (85, 80, 75, 70%) and filler (0, 5, 10, 15%), respectively by mass, are developed by hand layup method and is compared for their mechanical properties. Mechanical properties of composite fabricated from sawdust up to certain percentage showed an improvement when compared to composite with no filler; with further increase in filler, a drop in mechanical performance is noticed. An increase in tensile strength by 12.75%, flexural strength by 5.94%, hardness by 18.34%, tensile modulus by 100.3%, flexural modulus by 60.4% is observed in dry condition compared to the composite with no filler. Mechanical degradation in tensile strength, tensile modulus, hardness, flexural strength for the samples subjected to ageing in sea and distilled water is observed. Flexural modulus after ageing increased with filler addition up to a certain percentage and with further increase in filler, a decrease is noticed. Higher mechanical degradation (except flexural modulus) is observed for those specimens immersed in sea water.

Keywords: Ageing, composite, epoxy, mechanical properties, sawdust, short coir fibre

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INTRODUCTION

As a result of increased environmental awareness, natural fibres have gained importance due to their unique properties such as ease of availability, being light weight, strength, renewability, eco-friendliness, being low cost, low density and biodegradability. Glass fibre composites are environmentally inferior when compared to natural fibre composites in most cases for the following reasons: (a) Production of natural fibre prevents environmental impressions compared to glass fibre; (b) Fibre content is high in natural fibre, resulting in reduced base polymer pollution content; (c) lightweight natural fibre composites improve productivity and diminish pollution in the use phase of the component, especially in auto applications and (d) Disposed natural fibres are incinerated to ebb energy and carbon credits (Joshi et al., 2004). Plant fibres are of interest due to their availability and reinforcement, which can be done at low cost (Ramesh et al., 2012). Most commonly used eco-friendly materials are plant fibres such as coir, jute, sisal, kenaf, banana, hemp and pineapple. Natural fibre composites are being more and more extensively used. Coir-fibre-reinforced polymer composites are being utilised for industrial and socioeconomic advantages such as automotive interior, panelling and roofing as building materials, storage tank, packing material, helmets, post boxes, mirror casing, paperweights, projector covers and voltage stabiliser (Ayrilmis et al., 2011; Yousif et al., 2012; Verma et al., 2013; Abilash & Sivapragash, 2013). Maximum application of natural fibre composites is noticed in the automobile sector (Emad et al., 2016).

Coir is extracted from coconut husk. Durability of coir is better than that of any other natural fibres due to its high lignin content (Verma et al., 2013; Khan et al., 2012). Total world coir fibre production is 250,000 tones/year (Coir Board Ministry of MSME, Govt. of India). Today India, mainly from the coastal region of Kerala State, produces 60% of the total world supply of coir fibre. Coir fibre is more productive and pompous in reinforcement performance compared to other reinforcement composites (Ticoalu et al., 2010). Coir exhibits low moduli due to a high microfibrilar angle. Toughness and percentage break elongation is higher in coir and it has good resistance to weather, fungal and bacterial infection due to its high content of lignin (Nam et al., 2011). Coir possesses 26-43% cellulose, 0.2% hemicellulose and 41-45% lignin content by mass (Nam et al., 2011). Due to high lignin and low cellulose content, unlike other natural fibres, coir needs treatment for effective interfacial bonding (Binu, 2012). The major drawbacks of natural fibres are weak adhesion with the matrix material as a result of incompatibility and a high water-absorption rate due to its hydrophilic nature. Incompatibility occurs when reactive groups of hydrophilic fibre are covered by dirt and polar groups, resulting in inept coupling with hydrophobic matrix (Chern et al., 2014).

Moisture diffusion in polymeric composites is governed by three different techniques (Papanicolaou et al., 2008; Zainab, 2009). The first involves diffusion of water molecules inside the micro gaps between the polymer chains. The second involves capillary transport into the gaps and flaws at the interfaces between the fibre and the matrix. This is a result of poor wetting and impregnation during the initial manufacturing stage. The third involves transport of micro cracks in the matrix arising from the swelling of fibres. To make fibres more compatible with hydrophobic matrix surfaces, treatments are performed to improve interfacial adhesion between them and other materials. Chemical treatment of fibres is a common method of cleaning and modifying the fibre surface in order to lower the surface tension and enhance the interfacial adhesion between a natural fibre and a polymeric matrix (Bledzki & Gassan, 1999). Hydrogen bonding from the fibre structure is removed with the help of alkali treatment, which substantially decreases moisture absorption and also alters surface morphology (Ramadevi et al., 2015). Due to changes in surface morphology more reactive groups of hydrophilic fibres are exposed, promoting efficient integration with hydrophobic matrices (Chern et al., 2014).

In this study short coir fibres are reinforced with epoxy matrix and sawdust as filler. The main factors like fibres election, matrix selection, fibre orientation and the fabrication process should be pre-decided to determine the final mechanical properties (Pickering et al., 2016). Epoxy resins have an advantage that they reduce volume shrinkage (Sheng et al., 2012). The ring-opening polymerisation of the epoxy resin frees its constrained three-member ring structure, resulting in a much larger free volume (Odian, 2004). Water-immersed specimen behaviour is influenced by reinforcement, matrix and filler nature along with relative humidity and the type of fabrication method employed, which influences porosity and volume fraction of the fibres. Water intake for some natural fibres can also result in the water plasticing effect (Stambouliset al., 2000).

Sawdust is a major biological waste generated in wood polishing firms. Its storage in uncontrolled condition can be a factor responsible for environmental pollution (Deac et al., 2016). Variation in chemical composition for sawdust observed was 27.2-31.7% of lignin, 44.5-46.65% cellulose, 15.69-16.29% hemicellulose and 0.01-0.02% nitrogen content (Mercy et al., 2011; Campbell et al., 1966). From the environmental point of view, it is very important to prevent pollution resulting from sawdust. In this research sawdust waste was utilised to improve the mechanical performance of short coir fibre epoxy composite by replacing a proportion of epoxy with sawdust.

MATERIALS AND METHOD

Coir fibre procured from local resources was used for the preparation of the composites. Initially, the coir fibre was segregated, finely alkalised and minced to a length of 12-15 mm. An epoxy resin (LY 556) was used as the matrix binder. The mechanical and thermal properties of epoxy resins are extremely poor. To improve the properties, the resin should undergo a curing reaction in which the linear epoxy resin assembly is modified to form a three-dimensional cross-linked thermoset structure. A hardener, a curing agent in ratio to epoxy 1:10, is added to accelerate the curing action. The hardener-epoxy reaction releases an enormous amount of heat, resulting in the homopolymerisation of the resin. The curing agent or hardener used in this study was triethylenetetramine (HY-951). Sawdust was procured from local resources and tested for its physical properties.

Alkali Treatment

In alkali treatment in this study, pre-washed coir fibres were immersed in 6% (w/v) NaOH aqueous solution for 72 h. The fibres were removed from the alkali solution and rinsed with distilled water and dried to constant weight.

Composite Fabrication

In this study the fabrication of the composite was completed using an economical method called the hand lay-up method as this technique can be successfully employed in composite fabrication

(Srinivasababu et al., 2009). A mould of dimensions 300×300×6 mm^3 was used. A composite of 300 × 300 × 3.2 mm^3 was fabricated for different proportions of reinforcement, matrix and filler as shown in Table 1. Epoxy resin with hardener in a ratio of 10:1 was thoroughly mixed with a certain proportion of sawdust. Mould releasing wax was used on the mould for easy removal of the final product. Chopped fibre, agitated with epoxy, was gently poured on to the sheet inside the mould. The mixture was then allowed to settle within the mould for a whole day under pressure over the cast. The final specimen was machined as per ASTM standard dimension for mechanical testing.

Table 1
Proportion of coir fibre, epoxy and sawdust used for fabrication

Sample / Specimen Number	Type of Fibre Used	Reinforcement (Mass Percentage)	Matrix (Mass Percentage)	Filler (Mass Percentage)
1	Short Fibres	15	85	00
2	Short Fibres	15	80	05
3	Short Fibres	15	75	10
4	Short fibres	15	70	15

Calculation used for fabrication of composite. Table 2 shows the calculation to determine the quantity of short coir fibre, epoxy resin and sawdust utilised for fabrication of composites based on different proportions.

Table 2
Calculation to determine quantity of materials utilised for composite fabrication

Density of epoxy	‘X’ g/cm^3
Density of fibre	‘Y’ g/cm^3
Density of Sawdust	‘Z’ g/cm^3
Density of composite ($\rho_{composite}$)	Density of epoxy × (Mass Percentage of epoxy)+ Density of fibre× (Mass percentage of coir fibre) + Density of sawdust× (Mass percentage of sawdust)
$\rho_{composite}$	‘G’ g/cm^3
Mass of composite	$\rho_{composite}$ × volume of plate = G × (300 × 300 × 3.2) × 10^{-3}
Mass of composite	‘M’ g
Mass of Epoxy	Mass percentage of epoxy × M = ‘E’ g
Mass of Fibre	Mass percentage of fibre × M = ‘F’ g
Mass of Sawdust	Mass percentage of sawdust × M = ‘S’ g

Physical Properties of Sawdust

Specific gravity (IS:2720, Part 3, 1964). Specific gravity is determined using bottle density as per IS:2720 (Part 3), 1964. A clean, dry and cool density bottle with stopper was weighed initially (w_1), $^2/_3$ of the bottle was filled with sawdust sample for weighing (w_2). After removing the entrapped air, the sample was filled with distilled water and weighed (w_3). The empty bottle with water was weighed (w_4). Specific gravity was calculated using Eq. [1].

$$\textit{Specific gravity } (G) = \frac{(w2-w1)}{(w2-w1)-(w3-w4)} \quad [1]$$

Particle size determination (IS:2720, Part 4, 1965). Particle size is determined using the hydrometric method as per IS:2720 (Part 4), 1965. A sample of 50 g (w) was accurately weighed and mixed with distilled water to form a smooth paste. An amount of 1 g of sodium silicate was added to the paste and the mixture was washed into the mixer. Mixing was carried out for 10 min and the specimen was graduated into a specimen jar. Enough water was added to bring the volume to 1000 cc (v). Water was added to the mixture. A hydrometer was inserted and a stopwatch was started. The hydrometer reading (Rh) was taken at different elapsed times (t) without removing the hydrometer. A graph was plotted with particle size readings in the x-axis and percentage finer in the y-axis. Particle size was determined using Eq. [2]. The percentage finer was calculated using Eq. [3].

$$\text{Particle size } = \sqrt{\frac{18\mu}{G-1}} \times \frac{He}{t} \quad [2]$$

where, He = Effective height (cm)
μ = viscosity of sample-water suspension (g-s/cm^3)

$$\text{Percentage finer} = \left[\frac{Rh}{1000} \times \frac{G}{G-1}\right] \times 1000 \quad [3]$$

Density of particle. Particle density of the sawdust was determined (Araki & Terazewa, 2004; Ruhlmannetal, 2006). It was calculated by adding the sawdust (100 cm^3) into a graduated volumetric cylinder to reach the marked 100 cm^3 volume (V_o), and its weight (g) could then be known by subtracting the combined weight of the sawdust and volumetric cylinder (W_b) with the weight of the empty volumetric cylinder (W_a) alone. Sawdust – particle density could then be calculated using Eq. [4].

$$\text{Particle density } = \frac{Wb-Wa}{Vo} \quad [4]$$

Porosity of sawdust particle. Sawdust porosity is measured by unoccupied space, which principally is composed of the inter-space among and intra-space within the particles (Agnew & Leonard, 2003; Bouma et al., 2003) or the percentage of sawdust volume occupied by air and water that fills the void (Baker et al., 1998). The percentage of porosity was determined (Horisawa et al., 1999). Sawdust with an apparent volume of 100 cm^3 and known weight (W_s in g) was at first placed in a volumetric cylinder. Tap water was then poured gently into it until the surface of the water reached a marked line at the 100 cm3 level. A meshed top as a stopper was equipped at the 100 cm^3 level so that the sawdust, mostly floating on water, would not go beyond its surface. Porosity was expressed as the following Eq. [5].

$$\text{Porosity (\%)} = \frac{Va}{Vo} * 100 \qquad [5]$$

where, V_a and V_o are consumptively the volume of poured water (cm^3) together with the water in the sawdust, and the volume of sawdust (100 cm^3), respectively. The volume of poured water, with the water in the sawdust could be calculated using Eq. [6].

$$V_a\ (\text{cm}^3) = W_{comb} - W_s - W_{vs} \qquad [6]$$

where, W_{comb} is the combined weight (g) of the volumetric cylinder, sawdust particles and poured water (g); W_s is the weight (g) of the sawdust particles (oven-dry weight equivalent) and Wvs is the weight (g) of the volumetric cylinder. Note that the density of tap water was assumed to be unity (1 gcm^3).

Properties of Distilled Water and Sea Water

Distilled water collected from the Environmental Engineering Lab, MIT Manipal, was tested for its pH value using a pH meter. Sea water collected from Panambur Beach, Mangalore, was checked for its pH using a pH meter. Salinity was determined using a salinity refractometer.

Mechanical Property Tests

Density test. A change in density will be observed in the actual composite laminate when compared to theoretical density due to the presence of void content, which accounts for the change in mechanical performance. Air void content was calculated using Eq. [7]

$$\text{Void content (\%)} = \frac{\text{Theoretical density} - \text{Actual density}}{\text{Theoretical Density}} \qquad [7]$$

Tensile test. ASTM D3039 standard was employed for performing a tensile result using a Universal Testing Machine (UTM). A composite laminate with dimensions of 250 × 25 × 3.2 mm^3 was machined. The test was conducted at a constant strain rate of 2 mm/min tensile strength and the modulus was calculated using Eq. [8] and Eq. [9], respectively.

$$\text{Tensile strength (MPa)} (\sigma_t) = \frac{\text{Load in KN}}{\text{Cross-sectional area of specimen(mm*mm)}} \qquad [8]$$

$$\text{Tensile modulus (GPa)} = \frac{\text{Tensile strength*Length (mm)}}{\text{Displacement (mm)}} \qquad [9]$$

Flexural test. The flexural test on composites was performed as per ASTM D790-03 standards with the dimensions 12.5 × 125 × 3.2 mm^3. The three-point bend test was performed on the composites using the same UTM (FIE UNITEK 9450) at a crosshead speed of 1 mm/min with a span length to depth ratio of 16:1. The flexural strength was determined using Eq. [10]. Flexural modulus was calculated using Eq. [11]

$$\text{Flexural strength (MPa) } (\sigma f) = \frac{3PL}{2bt*t} \quad [10]$$

where, L is the span length of the sample (mm); P is maximum load (N); b the width of specimen (mm); t the thickness of specimen (mm) and d is displacement(mm);

$$\text{Flexural modulus (GPa)} = \frac{P*L*L*L}{4*b*t*t*t*d} \quad [11]$$

Micro Vickers hardness. The Matzusawa micro-hardness tester was employed in measuring the micro-hardness of composite specimens as per ASTM E384-16. A diamond intender with an apical angle of 136° was indented over the surface of the specimen under a load of 100 gf under a dwell time of 15 s. After the removal of the load the two diagonals, D1 and D2, of the indentation were measured. The hardness value was noted.

Water absorption test. Water absorption specimen of size 75 × 25 × 3.2 mm^3 was machined as per ASTM D 570 and immersed in distilled water and sea water at room temperature (27ºC). The water absorption percentage was calculated using Eq. [12]. A graph of the moisture intake percentage vs time in hours was plotted and the diffusion coefficient (m^2/sec) was calculated using Eq. [13].

$$\text{Water absorption (\%)} = \frac{\text{Final weight after immersion} - \text{Initial weight before immersion}}{\text{Initial weight before immersion}} \quad [12]$$

$$\text{Diffusion coefficient } (m^2/\text{sec}) = \pi \text{ x } \left(\frac{B}{4Ms}\right)^2 \text{ x } (\text{slope})^2 \quad [13]$$

RESULTS AND DISCUSSION

Physical Properties of Sawdust

Table 3 shows the physical properties of sawdust like density, specific gravity, porosity and particle size, all of which play a major role in mechanical performance.

Table 3
Physical properties of sawdust

Specific gravity	2.68
Density (g/m^3)	0.83
Porosity (%)	37
Particle size (µm)	< 65µ, Well graded

Density Test

Change in initial density and final density of composite samples shows the percentage void content present in the sample (Menard, 1999). Density test results for short coir fibre composites are shown in Table 4. Void content increased with increase in filler up to 10% mass and a decrease was noticed with 15% filler by mass. This may be due to improved fabrication skill. A higher void content percentage of 27.7% was observed for 10% filler by mass. This could have been the result of agglomeration of filler and matrix, resulting in improper wetting due to higher porosity at the agglomerated area. Surface voids and pores were minimal, so the chance of water diffusing through the sample was limited. Short coir fibre epoxy composites showed lower void content than long coir fibre epoxy composites i.e. three times more than that of the short coir fibre epoxy composite. This was mostly due to agglomeration of long coir fibre offering resistance to epoxy towards uniform distribution. Due to a pile up of fibre the resin disintegrated, causing the specimen to fracture (Venkatasubramanian & Raghuraman, 2015). The density result of the short coir fibre epoxy composite shows an acceptable void content in the composite, confirming the fabrication route as a noble one. The overall density test results showed that short coir fibre gave a better end product with less void than did the long coir fibre epoxy composite.

Table 4
Void content in composite sample

Sample No.	1	2	3	4
Void content (%)	23.6	23.8	27.7	25.6

Water Absorption Test

Water absorption specimens of different proportions were machined as per ASTM D 570 standard and were immersed in distilled water (pH = 7) and sea water (pH = 8.1, salinity = 29 ppt). Figure 1 and 2 shows that weight gain of the composite increased with immersion time at the initial stage and later kept stable, indicating that the specimens were apparently saturated with moisture. The distilled water absorption percentage decreased with the increase in filler loading up to 10% by mass. This was because well graded fillers clogged the pores and micro cracks within the surface of the composite, causing a lower water absorption percentage. It has been reported that water absorption can significantly be minimised if the filler is thoroughly encapsulated by the matrix (Sanadi et al., 1995). A further increase in the filler resulted in increased water absorption percentage as in Figure 1.

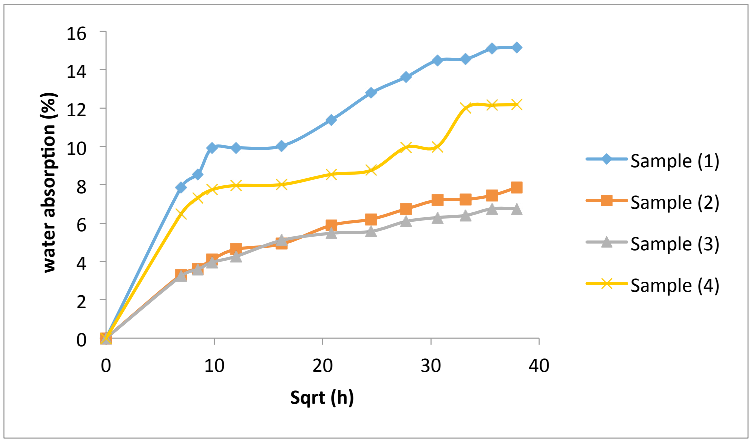

Figure 1. Percentage of distilled water absorbed

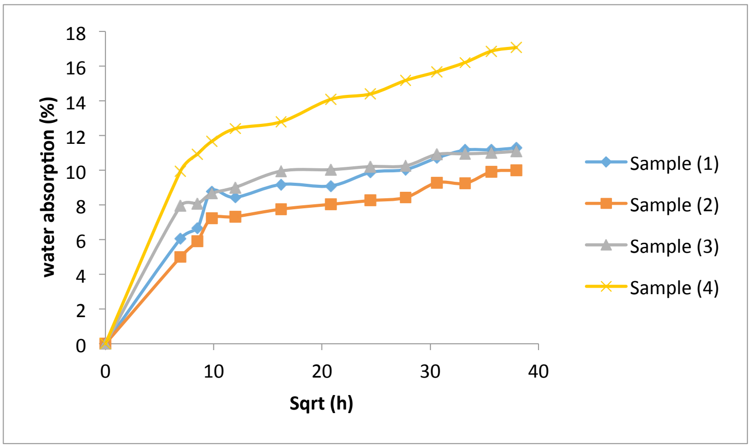

Figure 2. Percentage of sea water absorbed

From the density test it was clear that the third sample exhibited a higher void content. Figure 1 shows that lower water absorption was observed in the third sample; this was due to the fact that the sample machined for the distilled water absorption test had a lower void content than the overall composite laminate i.e. the voids were not uniformly distributed over the composite laminate.

The percentage moisture gain in samples immersed in sea water was higher than that of distilled water. This may be due to perforation of solution with greater pH, which induces more micro cracks leading to weight gain (Karbhari & Chu, 2005). Higher weight gain is due to the salts accumulated in the rough surface of the specimen; this was clear from the morphological analysis seen in Figure 9(e). When the filler concentration increased to 5% by mass, the water absorption percentage was reduced and with further loading, an increase in water absorption was noticed. Increase in the sawdust filler elevated the agglomeration developed due to non-uniform dispersion of filler. Filler clouding in the composites escalated the water absorption percentage of the composites (Abdullah et al., 2011).

Table 5 shows the diffusion coefficient of the composite samples immersed in sea water and distilled water. The diffusion coefficient of the samples immersed in distilled water went on decreasing with the increase in filler content. This was because an increase in clouding of the filler load along with the matrix will withstand the passing of water molecules through the nano pores (Sunil et al., 2015). A sudden increase in absorption percentage in the fourth sample was noticed in Figure 1 after 10% water absorption. This was because when the composite was exposed to moisture, the hydrophilic nature of fibre causes it to swell. As a result, the brittle thermosetting resin developed microcracks, allowing a higher percentage of water to penetrate the composite. Further penetration of water into the interface through micro cracks was due to the high cellulose content of the fibre, leading to the composite failure (Bismarck et al., 2002). As the composite material undergoes cracks, capillarity mechanism and transport via micro cracks become more active (Dhakal et al., 2007).

Table 5

Diffusion coefficient of samples immersed in sea and distilled water

Sample No.	Diffusion coeff- Distilled water (m^2/sec) ($\times 10^{-13}$)	Diffusion coeff- Sea water (m^2/sec) ($\times 10^{-13}$)
1	4.62	3.92
2	4.56	3.36
3	4.06	2.52
4	3.80	3.58

The diffusion coefficient in sea water observed is less than that of distilled water. This clearly shows that most of the weight gain was due to salts accumulated in the composite sample surface. This was because the surface finish of the randomly orientated coir fibre composite was rough. Resin surface condition is influenced by rate of diffusion (Asmaashawky et al., 2013). As the surface of the samples had a minimum number of pores and voids, the overall diffusion rate of the short coir fibres was less than that of the long coir fibres.

Hardness Test

About seven sets of trials for hardness values in each sample were conducted, and the average of all the values exhibited the hardness value of each sample as shown in Figure 3. Due to agglomeration of filler at a higher percentage resulting in improper matrix wetting, the composite exhibited a larger variation in hardness value. This was seen in the third and fourth samples as seen in Table 6. The hardness value improved with the increase in filler percentage as increase in filler loading improves matrix surface resistance to indentation. A maximum value of 30.6 HV was observed with the fourth sample, which was 8.8% more than that of the long coir fibre epoxy composite.

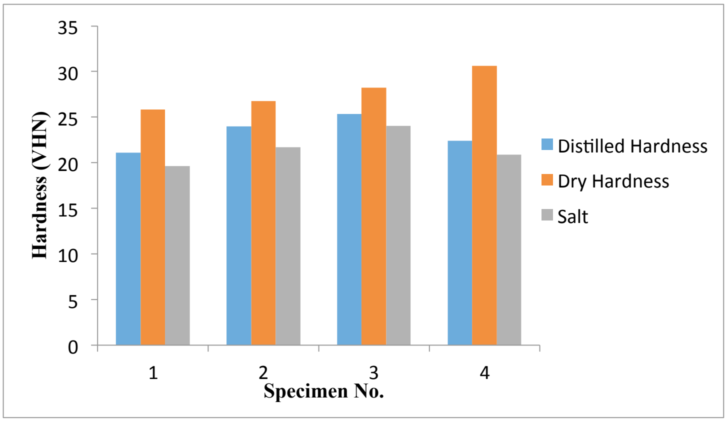

Figure 3. Hardness value of composite

Table 6
Change in hardness value (VHN) observed throughout the trails

Sample 1	Sample 2	Sample 3	Sample 4
26.2	24.91	29.37	36.14
24.62	29.36	38.16	35.13
29.08	24.91	25.92	25.20
29.37	29.37	24.62	29.08
25.34	26.92	25.77	28.80
25.63	25.05	31.24	31.30
22.46	22.66	29.80	28.50

An increase by 18.34% in hardness value was noticed compared to the composite with no filler. A drop in hardness value was noticed when subjected to distilled and sea water immersion. A higher drop by 26.7 and 31.69% for both distilled and sea water immersion was observed in the fourth sample due to the existence of more voids, sawdust agglomeration, improper wetting by matrix and higher water absorption. Figure 1 and 2 show that the fourth sample absorbed a higher moisture percentage than did the other composite with filler percentage. Increased water absorption resulted in bound water absorption and a drop in free water. In this situation, water diffused into the fibre cellulose network through capillaries and gaps between the low bound fibril area. Groups in the cellulose molecules were chemically linked by water. Water molecules in the cellulose network structure behave as a plasticiser and ruin the rigidity of the cellulose, permitting cellulose molecules to bulge independently. Simultaneously, the cellulose mass gets mushy, which in turn can easily alter the dimensions of the fibre with the execution of a load.

When absorption reaches the threshold level, bound water and free water continue as a reservoir, leading to softening of fibres and the weakening of fibre matrix adhesion, resulting in a reduced hardness value (Alomayria et al., 2014). The intra molecular hydrogen bond between polar groups of resin have to be broken under low temperature in order to develop bonding between the OH groups and water, forming hydrogen bonds between the water molecules. The polar hydroxyl groups of the network will disrupt the inter change hydrogen bonding, thereby altering the structure of the molecule due to which the mechanical performance is affected (Nogueiraet al., 2001). Higher degradation is observed for those samples immersed in sea water due to NaCl, which exists as cations and anions, causing more damage to the matrix, fibre and their interface (Ashbee & Wyatt, 1969).

Tensile Test

Figure 4 shows the effect of filler percentage on tensile strength. It can be noticed that a maximum tensile strength of 20.8 MPa was exhibited by the sample with 5% filler by mass. With further increase in filler, a drop in tensile strength was observed due to the increase in interfacial area with worsening interfacial bonding between filler and matrix (Mosadeghzad et al., 2009). At a higher filler percentage, a drop in tensile strength occurred due to the agglomeration of the filler, which results in improper curing of the composites (Rahul et al., 2014). At a higher filler percentage, the filler starts engulfing the matrix isolating the hardener and resin, causing improper curing of the composite. The result exhibited an increase by 57.40% in tensile strength compared to that of the long coir fibre epoxy composite.

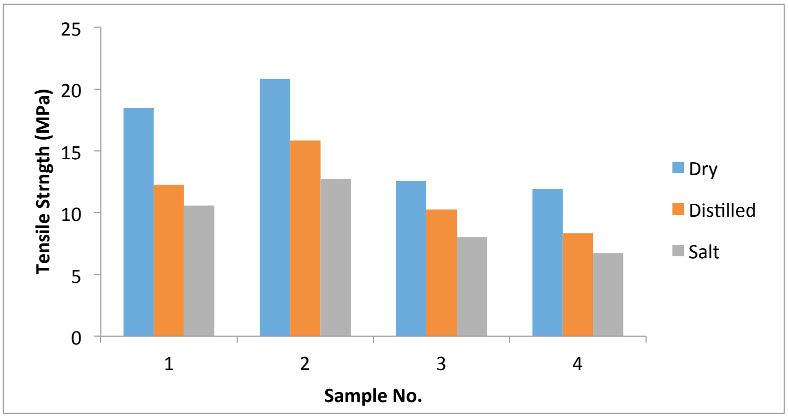

Figure 4. Tensile strength of composites

It is believed that fillers act as flaws at a higher filler mass fraction due to lack of resin, which wets fibre surfaces, resulting in inept stress transfer. An increase in the filler also increased the micropores between the filler and matrix, which in turn weakened the adhesion between the matrix and filler interface, affecting tensile strength and modulus (Hardinnawirda & Sitiribiatull, 2012).

A higher loss in tensile strength was noticed in the third sample i.e. the sample with 10% filler by mass. The density test revealed that the third sample had higher void content, resulting in a greater drop in tensile strength. Lack of resin and improper curing in the third and fourth samples resulted in fibre pull out.

A decrease in mechanical properties was noticed in those specimens immersed in distilled and sea water. The specimen immersed in sea water solution had the largest reduction, with a reduction of 42.79, 38.65, 36.21 and 43.55% for the first, second, third and fourth specimens. The specimen immersed in water had the smallest reduction, with a reduction of 33.61, 26.3, 28.01 and 29.9% for the first, second, third and fourth specimens.

Higher degradation was observed in the first specimen due to localised shrinkage of the epoxy occurring because of non-uniform distribution and in the fourth specimen due to epoxy deficiency, resulting in improper wetting leading to higher water absorption settled as both bound water and free water. The comparison in strength reduction indicated that the presence of NaCl in sea water solution led to faster degradation in tensile strength compared with in water that had no ions as was the case with distilled water. The possible reason is that the alkali metal oxides in sea water might accelerate transmission of water into the fibre/matrix interface, resulting in debonding (Ashbee & Wyatt, 1969).

Figure 5 shows the tensile modulus of the specimens. The tensile modulus increased with increase in filler loading up to 5% by mass. A higher tensile modulus of 5.55 GPa was observed in the second sample. This was due to the fact that filler material resulted in more uniform distribution of the epoxy matrix material, resulting in improved bonding between the matrix-fibre interphase. At higher filler loading, the tensile modulus decreased (Agomide et al., 2009). The possible reason is that at higher percentage of filler, the observed drop in tensile behaviour of the composites occurred due to the agglomeration of the filler molecules around the matrix, preventing the proper curing of the composite (Rahul et al., 2014).

Tensile modulus reduced by 40.9, 49, 55.1 and 65.6% in the first, second, third and fourth samples, respectively, that were immersed in distilled water. The percentage was 70.6, 64.7, 75.2 and 79.8% for the first, second, third and fourth samples immersed in salt water. A lower drop of tensile modulus in the second specimen immersed in sea water was due to the lower water absorption percentage as observed in Figure 5.

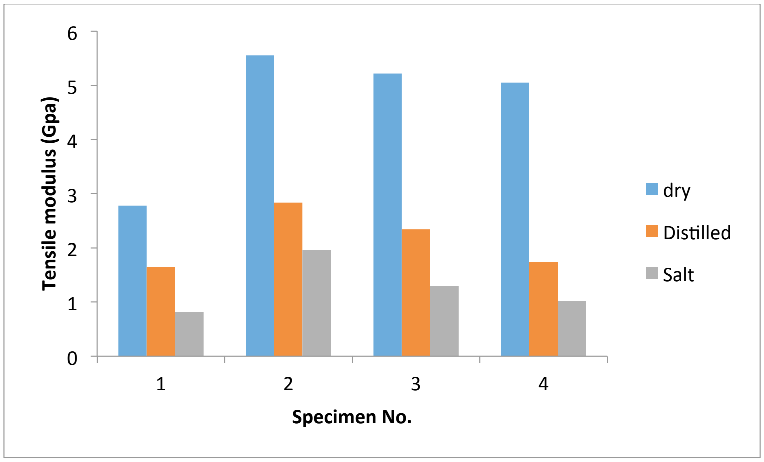

Figure 5. Tensile modulus of specimens

Flexural Test

The results of different filler loading are plotted in Figure 6. Initially, the flexural property increased with the increase in filler loading by mass up to 5%, and from 10% filler loading by mass, there was a decrease in flexural strength. The reduction in mean flexural strength of specimen above 5% filler by mass may have been due to the fact that the deficiency of epoxy resin and increased filler led to poor wetting of the fibre. This in turn might have led to matrix failure as shown in Figure 7. The same was reported by Binu (2012). Improved interfacial adhesion between the fibre and matrix resulted in higher flexural strength of the composites; this was mainly due to alkali treatment of the coir fibre. An increase in strength by 5.9% was observed in the filler compared with the short fibre composite without filler. An increase by 54.8% was observed in flexural strength compared with that of the long coir fibre epoxy composite.

From Figure 6 it is clear that lower degradation took place in the third sample due to less water absorption. A decrease by 14.7, 14.8, 6.25 and 18.38% when immersed in distilled water and 24.23, 21.3, 14.5 and 40.9% when immersed in salt water was noticed in the first, second, third and fourth specimens. In both the immersions, higher degradation was observed in the fourth specimen due to epoxy deficiency, resulting in improper wetting that led to higher water absorption that settled as both bound water and free water.

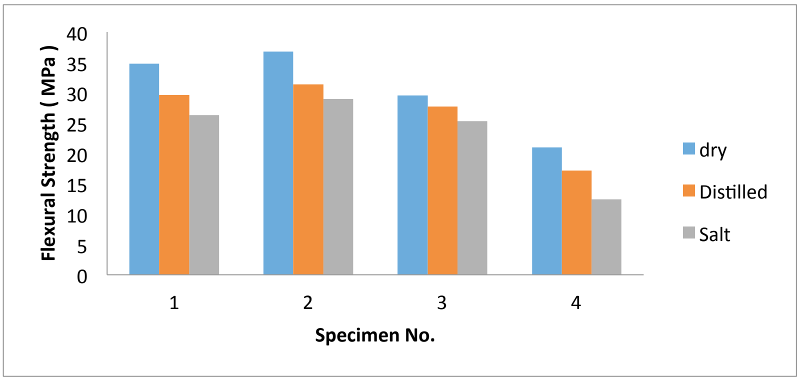

Figure 6. Flexural strength of composites

Figure 7. Matrix crack observed in composite specimen

Figure 8 shows the flexural modulus of short coir fibre composites. The flexural modulus increased with an increase in sawdust. Higher flexural modulus in dry condition was observed in the third sample, in which the molecules were tightly bound to each other (Agomide et al., 2009). With further increase in filler, a decrease in flexural modulus was noticed due to epoxy deficiency, resulting in improper wetting of the fibre and sawdust agglomeration.

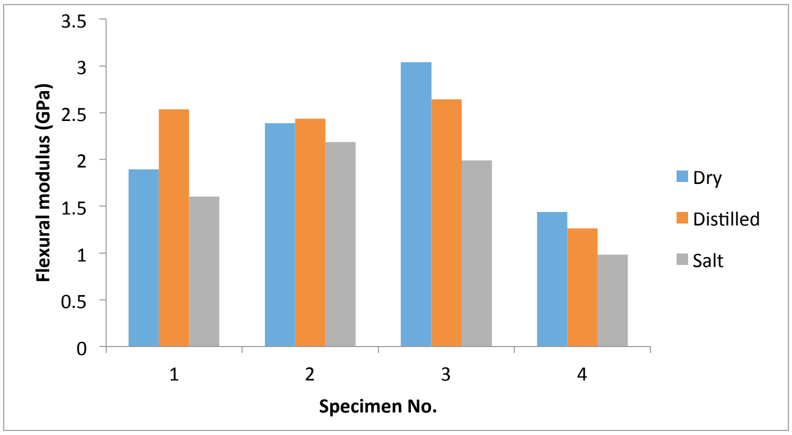

Figure 8. Flexural modulus of the composite

The strain observed in the third sample was lower even though the stress was high. If, however, the molecules were loosely bonded to each other, a relatively small amount of stress would have caused a large amount of strain (Agomide et al., 2009). The strain was higher for the first and second samples immersed in distilled water compared to the dry specimens of the same; this could have been due to the fact that fibre swelling caused by water absorption crowds the space between the fibre and polymer matrix and eventually leads to an increase in the mechanical properties of the composites (Karmakar & Hoffmann, 1994). Similar observations have been reported for jute fibre reinforced polymer composites (Ayensu, 2000).

In the third sample, due to the increased voids, water absorbed may have been present as free water, reducing the integrity of the matrix interface. When the fibre swelled, the weakened matrix had a higher chance to crack, failing to fill in the gaps. At higher filler loading resulting in water absorption led to higher elongation as the water molecules acted as a lubricant. The fibres could slip over one another during loading, resulting in extra extension and elongation (Azwa et al., 2013).

Mechanical properties like tensile, flexural and hardness degrade at a higher moisture rate due to generation of hydrogen bonding across water molecules and cellulose fibre. A high percentage of hydrogen bonding is formed between cellulose macromolecules and polymers due to hydroxyl groups (–OH) present in hydrophilic natural fibres (Sombastsompop & Chaochanchaikul, 2004).

Low moisture resistance is exhibited by natural fibres like coir due to the presence of a significant –OH group percentage. This alters the dimensional aspects of composites and causes deficient interfacial bonding between the fibre and matrix, causing a decrease in the mechanical properties (Diamant et al., 1981). Water absorbed in polymers is generally divided into free water and bound water (Alomayria et al., 2014). Water with molecules that are free to move through available space is considered free water and water with molecules that are dispersed in epoxy matrix and adhered to polar groups is termed bound water (Maggana & Pissis, 1999).

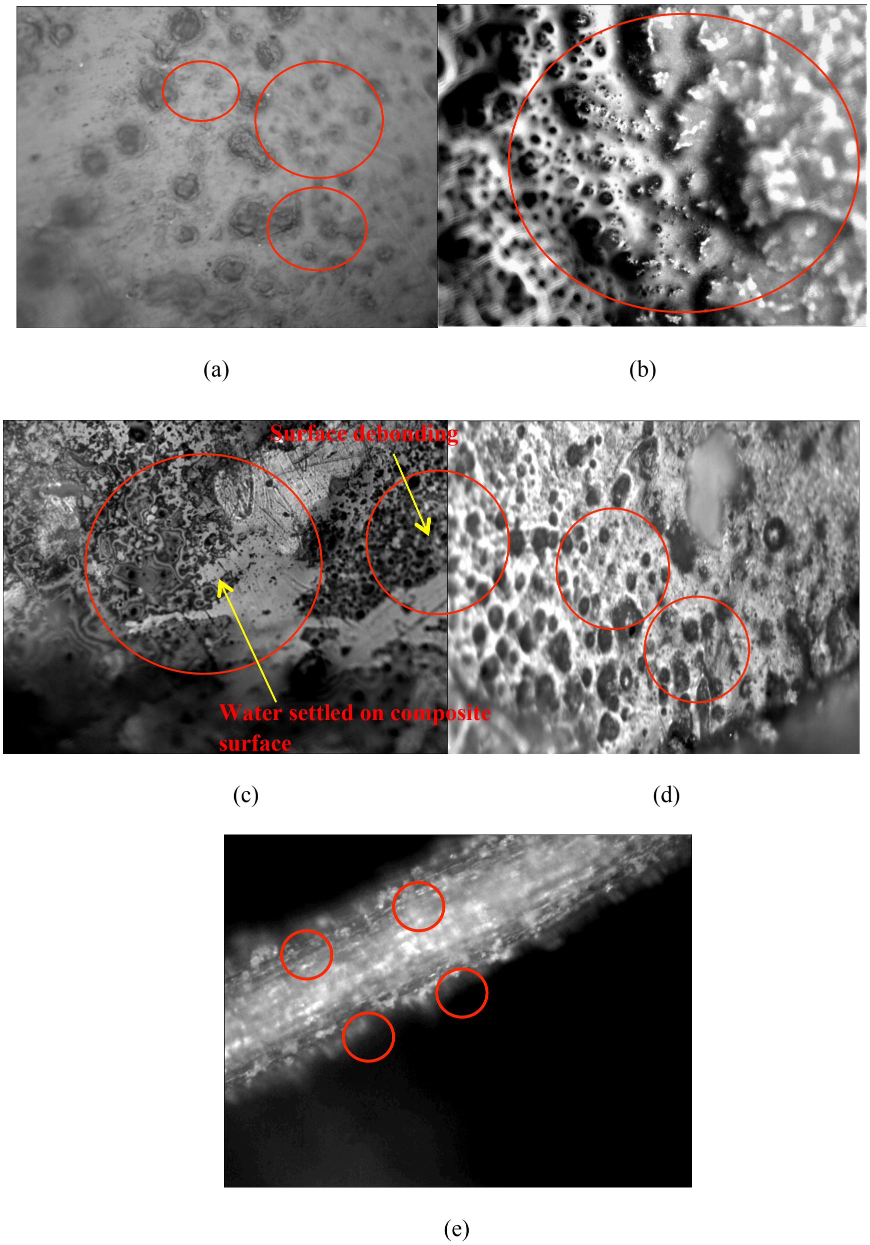

Figure 9. Microstructure analysis of composite samples (a) Sawdust agglomeration at higher filler percentage, (b) Non-uniform wetting at lower matrix percentage, (c) Water settled on uneven composite surface after ageing, resulting in surface debonding, (d) Pores formed on composite surfaces (e) Salt settled on fibre surface

Morphological Analysis

Microstructure analysis was carried out to study the surface morphology of the composite specimen. Alkalisation treatment of coir fibre resulted in fibre roughness, which exhibited advanced fibre and matrix, concluding substantially higher mechanical properties. As filler percentage increased, agglomeration was noticed in Figure 9(a), influencing improper curing of matrix, being a major rationale for varying hardness value and drop in tensile strength. Often, the composite fabricated by the hand lay-up process results in voids, cracks and flaws (Libo & Nawawi, 2015).

Figure 9(d) shows voids formed due to gas porosity and sawdust porosity, which have an effect on mechanical performance. Voids can also be formed as a result of improper matrix wetting and by implementation of the hand lay-up technique as it is person dependent. Figure 9(b) shows a web-like structure due to improper wetting of the epoxy matrix in the fourth composite sample, which is a major cause for reduced mechanical performance.

Figure 9(c) shows water accumulated on the uneven surface of the composite, resulting in weight gain. The water accumulated on the surface can soften the matrix surface, resulting in surface matrix debonding. This could be the effect of water absorption by the hydrophilic fibre due to the presence of -OH radicals. Incompatibility is higher when hydrophilic sawdust is adhered with hydrophobic epoxy matrix; this incapability was utilised by the water molecules, forming a hydrogen bond with free -OH radicals, causing sawdust swelling. This swelling resulted in matrix debonding and cracks that resulted in the mechanical degradation.

CONCLUSION

Composites fabricated using a short coir fibre epoxy showed variation in density. A higher diffusion rate was observed in the sample without a filler that was immersed in distilled water and sea water, respectively due to the higher percentage of water absorption. An increase by 18.34% in hardness value was noticed compared to composites with no filler. An increase in tensile strength by 12.75%, flexural strength by 5.94% and a higher tensile modulus of 5.55 GPa in dry condition was observed in the specimen with a 5% filler by mass. A higher flexural modulus of 2.3 GPa i.e. an increase by 60.4% in dry condition was observed in the specimen with a 10% filler by mass due to tightly bonded filler molecules. Reduction in tensile strength, hardness and flexural strength was observed in specimens immersed in distilled and sea water, respectively. Flexural modulus for the specimen without filler immersed in distilled water showed a remarkable increase, but with an increase in filler, higher degradation due to the hydrophilic nature of the fibre and filler was noticed, resulting in reduced flexural modulus. Flexural modulus for the specimen immersed in sea water increased with an increase in the filler up to 5% loading by mass and then reduced with a further increase in loading by mass. An improved fabrication method is suggested to fabricate high strength and durable short coir fibre epoxy composites with sawdust filler.

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