Assessment on jute/coir fibers reinforced polyester hybrid composites with hybrid fillers under different environmental conditions

K. Ganesan[1], C. Kailasanathan[2], N. Rajini[3, *], S. Kalirasu[3, *], S. O. Ismail[4], Suchart Siengchin[5], Nadir Ayrilmis[6]

[1]Department of Mechanical Engineering, VSB College of Engineering Technical Campus, Coimbatore 642 109, Tamilnadu, India.

[2]Department of Mechanical Engineering, Sethu Institute of Technology, Kariapatti 626 115, Tamilnadu, India.

[3]Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Tamilnadu, India.

[4]Department of Engineering, Center for Engineering Research, School of Physics, Engineering and Computer Science, University of Hertfordshire, Hatfield, AL10 9AB, England, UK.

[5]Department of Mechanical and Process Engineering, The Sirindhorn International Thai-German Graduate School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok, 1518 Wongsawang Road, Bangsue, Bangkok 10800, Thailand.

[6]Department of Wood Mechanics and Technology, Faculty of Forestry, Istanbul University-Cerrahpasa, Istanbul, Turkey.

*Corresponding author's e-mail: rajiniklu@gmail.com

Abstract

In this work, the synergistic impact of hybrid fibers and hybrid fillers on the mechanical, moisture absorption, and morphological properties of polyester matrix composites at dry and wet conditions was examined. The hybrid composite laminates were fabricated by compression molding technique using the new combinations of Jute and coir fibers as primary reinforcement and the waste eggshell powder (ESP) and montmorillonite nanoclay (MMTK10-NC), as secondary reinforcement in a polyester matrix. The impact of fillers such as ESP and NC were applied in differing amounts to the jute and coir fiber blended hybrid (pristine) composite. The maximum tensile strengths of pristine composites was estimated to be 24.57, 21.77 and 22.63

MPa when fillers were added in equivalent weight percent (wt.%) for dry, river and sea water (wet) conditions, respectively. For same aforementioned conditions, flexural strengths of 46.97, 44.85 and 42.36 MPa as well as impact strengths of 2.697, 2.572 and 2.607 J were obtained. The occurrence of swelling, agglomeration, and porosity on the composites was discovered to be the crucial factors causing the strength reduction. The findings demonstrate that the addition of hybrid fillers in different weight proportions increased mechanical performance over pristine composites. Mechanical properties were diminished in the wet state due to deterioration of the fiber and matrix interface. SEM micrographs indicated that it was due to weak fiber-matrix adhesion. With the addition of hybrid filler to the pristine composites, the moisture absorption rate was reduced. Based on results, the optimal/best composite sample can be used as an alternative substitute for low load bearing structural components in building construction industries, such as trusses and frames, wooden flooring and scaffold.

Keywords: Hybrid jute/coir composites, Hybrid fillers, Environmental conditions, Mechanical properties, Moisture absorption, Optimum behaviors.

1. Introduction

Due to the great awareness of waste disposal, environmental impacts, health implication and industrial policies, material designers and manufacturers must have concentrated efforts to select materials based on their availability, performance, economic as well as environmental friendliness. Imbibe in them the natural fiber reinforced polymer composites (NFRC) are used to replace the man-made fiber reinforced composites for different applications due its desirable properties like low density and good mechanical strength [1,2]. All these customer attractive properties enforce the usage of natural fiber composites in various applications such as aircraft, marine and automotive, construction and packaging industries [3]. However, the predominant drawbacks such as poor compatibility between the fiber and matrix and high moisture absorption in NFRPCs overcome by the suitable chemical treatment techniques and hybridization [4-8]. Comparatively, the hybridization of natural fibers with synthetic fibers and filler was showed better performance with respect to moisture absorption, thermal and mechanical properties [9]. However, the new combination of hybrid composites needs to be explored further and therefore the range of property variation can be recorded for further analysis.

In general, the hybridization process gives the flexibility to design and enhance the customized material properties based on the unique characteristics of the constituents which have been proved from the several previous investigations [10]. In this regard, Sujon et al. [11] studied the mechanical and water absorption properties of jute carbon hybrid composite with different stacking sequence. Result shows that placing four layers of carbon fiber centrally and three layers of jute fiber on both sides had produced better mechanical and moisture absorption. Venkateshwaran et al. [12] established that hybridization of natural fibers increases the mechanical properties and reduce the moisture absorption. Athijeyamani et al. [13] studied mechanical and moisture absorption properties of sisal and roselle hybrid composite under different moisture environment. The result showed the hybridization produce the positive effect. Sanjay et al. [14] analyzed the hybridization of synthetic fiber with jute kenaf fiber epoxy composite the result shows the hybrid glass/ jute/ kenaf composite shows low moisture absorption. Panthapulakkal et al. [15] studied the moisture absorption properties of sisal/ glass fiber reinforced composites. The observation shown that there is no improvement in strength properties on the aged samples and they indicated that the moisture absorption should not be a physical process and eternal damage arose to the composite after aging. Saw et al. [16] investigated into the thickness swelling water absorption and mechanical properties of jute/coir hybrid composite. Results showed that the hybridization of coir with jute composite has produced good dimension stability, extensibility and density compare pure coir composite. in order to enhance the strength and resistance of moisture absorption. Furthermore, the reinforcement effect in the form of fillers was studied and found to be exhibited better mechanical properties (strength, toughness), thermal properties (thermal expansion, thermal stability, flammability) and physical properties (shrinkage and permeability) due to their strength hardening mechanisms [17-19]. Accordingly, Almari et al. [20] proved that addition of nanoclay in the natural fiber composite had reduce the moisture absorption. Also, the impact strength was increased in the wet samples compared to dry samples. Vijay et al. [21] examined the jute epoxy composite filled with *Azadirachta indica* seed powders, Camellia sinensis powders. Filler filled composite had produce better mechanical strength and lesser voids and having thermal stability compared to non-filler filled jute epoxy composite. Ismail et al. [22] noticed that reinforcing of fillers with natural fibers had an admirable advantage of high stiffness and low density. It shown that, the fillers have high aspect ratio and it allows the larger interface area which increases the reinforcing effect. Several researchers have proved that the polymer composite prepared by incorporation of fillers like montmorillonite [23,24], $CaCO_3$ [25], Al_2O_3 [26], TiO_2 [26], talc [28], graphene [29] and carbon nano tubes [30] show the notable development in mechanical, thermal, physical properties and degradability compare to normal composites. The addition of filler in different scaling like nano and micro meter can also influence the structure-property relationships based on their dispersion ability with the polymer matrix.

Multiple filler composite has been producing the combined reinforcing effect of dual fillers and reported that the addition of fillers resulted the higher bonding and transfer the effective stress to the fiber and matrix [30]. Therefore, adding of two fillers into fiber-reinforced composite is a new advancement in the field of composite technology. Presence of fillers in the reinforced composites changes the base property of the actual material [31]. Montmorillonite nanoclay (MMT-NC) is the most promising filler found to enhance the mechanical, thermal and electrical properties and also reduces the water absorption [23-24,32,33]. Eggshell powder (ESP) is an inorganic bio-filler and suitable reinforcement in plastic/polymer composites. Eggshell powder can be the suitable alternative for the $CaCO_3$ particluate. ESP can perform better than $CaCO_3$ due its characteristics like good tensile, compressive strengths and low water-uptake [34,36].

Many studied have been reported on hybridization of various composites, using natural fiber/natural fiber, natural fiber/synthetic fiber, synthetic fiber/filler, natural fiber/filler, filler/filler, single fiber with multiple filler combination. However, to the best of our knowledge, no work has been reported on jute fabric and coir mat-based hybrid composite filled with eggshell powder and nanoclay fillers in polyester resin matrix. Therefore, objective of this current work focuses on manufacturing of hybrid fibers/hybrid fillers composites, using compression molding process and study on their mechanical properties, such as tensile, flexural and impact under different environmental conditions: dry and wet (river and sea water) conditions.

2. Materials and methods

2.1. Materials

Among various natural fibers, jute and coir are selected as primary reinforcement fibers considering the abundantly availability, high aspect ratio, toughness and good tensile strength.

Further, Jute and coir fiber were used in various applications in the construction and automotive field, due to its higher strength and modulus when compared with other conventional fibers [18] and expected to be more suitable for structural component in construction industries as well. Unsaturated polyester resin of 1.2 g/cm^3, methyl ethyl ketone peroxides (MEKP) as a catalyst and cobalt naphthenate (accelerator) were purchased from Aiswarya polymers, Coimbatore, Tamilnadu, India. For 100 g of resin, 1.5 mL of methyl ethyl ketone peroxide (MEKP) and 1 ml cobalt naphthenate were taken for room temperature curing. NaOH was used to treat the fibers. They were purchased from Ponmani Chemicals, Madurai, Tamilnadu India. MMT K10 (Montmorillonite) of 1.9 g/cm^3 and nanoclay with surface area of 220 – 270 m^2/g were added to strengthen the matrix supplied by Sigma–Aldrich, Bangalore, Karnataka, India. Eggshell powder was used as another filler to enhance the strength of the matrix. It primarily contains calcium, magnesium carbonate (lime) and protein. Preliminary biocompatible biomaterial contained 90.5% of calcium carbonate, 6.8% of calcium hydroxide, 0.7% of calcium oxide and the remaining constituents were organic materials, such as X-type collagen, sulfated polysaccharides and other proteins [30]. Eggshell powder was prepared from raw waste eggshell by ball milling process. Jute mat and coir mat were used as reinforcements of the composite. They were purchased in a local market. The properties of jute and coir are shown in Table 1.

2.1.1. Chemical treatment

The jute and coir fabrics were immersed in to the 5% NaOH solution at room temperature for 12 hr. The drenched fabrics were washed many times with normal water to remove the sticking NaOH from the fibers. For neutralization of fiber were washed thro the acidic acid and distilled water. After the washing of fibers were dried in the room temperature at 48 hrs.

2.1.2. Fabrication of composite

Fabrication of polyester composite was prepared by compression molding process. The mold with dimension of 300 x 300 x 3 mm^3 was used to fabricating the composite of different combination. Combination of composites are shown in Table 2 as per the combination the composites were manufactured. The fiber mats were cut in to size of 300 x 300 mm. Hybridization of fiber ratio was 1:1 and constantly 20 wt.% of fiber mats used in the all combinations and the filler mixed in the proportion of all combinations are 3 wt.%. because of reinforced composites showed a decrease in strength at filler loadings of greater than 3% [34,35]. The high viscosity of the matrix caused by the excess filler content resulted in increased porosity, which affected the composite strength [31]. The agglomeration of excess filler content caused a stress concentrated area, lowering the strength of reinforced composites [32].

For the preparing the matrix for each combination, the NC/ ESP were mix homogeneously by mechanical stirring by shear mixture at a speed of 500 r/min for 1 hr at room temperature and then the mixture held in the vacuum oven for degas before adding the catalyst and accelerator. The 1.5 wt.% of MEKP and CN were added in the total weight percentage of resin. Wax coating will apply to the mold box, because it is used to avoid the sticking of composite in the mold after the molding process. After degassing the small amount matrix mixer were poured on the wax coated (for avoid the sticking of composite in the mold after the molding process) mold box by the help of brush to avoid poor impregnation, then the fiber mats were placed carefully one by one in the mold and also the matrix mixer were poured in between the layers of fiber and the remaining mixer was poured over the fiber mat and the mold box were kept closed. The pressure of was applied on the mold box and maintained up to 6 hrs at room temperature. After removal of composite plate from the compression molding the solid composites plates were applied to the post curing of 80 ^{o}C up to 4 hrs.

2.2. Testing

2.2.1. Void content

The formation of voids in the composites can be possible during the processing or else inherent failure in the surface of the reinforcement constituents. Further these voids can lead to the failure of composites by means of creating the path way for the crack advancement. Voids presents in the composite may leads low moisture resistance and attributed to the lower mechanical properties. In general, the presence of not to exceed 2% is acceptable limit whereas the void content up to 5% are known as poorly made composite [26,27]. The theoretical and experimental densities were measured then the void content of the hybrid composite was calculated according to Eq. (1).

$$void\ content = \left(\frac{\rho_{theoritical} - \rho_{experimental}}{\rho_{experimental}}\right) X100 \tag{1}$$

The experimental density was measured by the water immersion method on the other hand the theoretical density was measured, using Eq. (2).

$$\rho_{theoritical} = \frac{1}{\frac{W_J}{\rho_J}+\frac{W_C}{\rho_C}+\frac{W_E}{\rho_E}+\frac{W_{Nc}}{\rho_{Nc}}+\frac{W_R}{\rho_R}} \tag{2}$$

Where W_J, W_C, W_E, W_{NC} and W_R are weight fraction of jute fiber, coir fiber, eggshell powder, nanoclay and polyester resin respectively, while ρ_J, ρ_C, ρ_E, ρ_{Nc} and ρ_R are densities of jute, coir, ESP, NC and matrix, respectively.

2.2.2. Moisture absorption test

The samples used for moisture absorption test were cut in accordance with the ASTM D570 standard. After, they were dried before immersing them in both river and sea water, separately. The river and sea water have pH values of 6 and 8, respectively. At a regular 20 hrs. interval, the samples were taken out from the water, then wiped by cloth and weighed using the precise digital weighing machine with a resolution of 0.01 mg. Therefore, moisture absorption was determined by an increase in weight when compared with the dry samples. The moisture absorption of the sample at a certain time was calculated, using Eq. (3).

$$M_t = \frac{W_t - W_o}{W_t} \tag{3}$$

Where W_o and W_t are the weights of the dry and wet samples after aging at specific time, respectively.

2.2.3. Tensile testing

Instron series 3382 universal testing machines was used to conduct the tensile test on the composites. The machine contained a loading capacity of 400 kN. The test samples were prepared into a dimension of 200 x 20 x 3 in accordance with the ASTM D3039 standard. 50 mm gauge length was constantly maintained during the testing and the test speed of 5 mm/min was maintained throughout the experiments.

2.2.4. Impact testing

Measurement of impact strength is one of the important requirements in the engineering applications, especially to characterize a newly developed material. Izod and Charpy are the two tests that directly measure the impact strengths of materials. The impact strength is estimated by the measure of energy required to break the composite. This energy causes crack initiation and propagation. Impact resistance of composite material depends on the following factors: fiber matrix bonding, matrix toughness and adhesion between the fiber/filler and matrix.

In this current investigation, the impact test was performed on all the six hybrid composite samples, using a Charpy test. According to the ASTM D256 standard, the impact strength was measured by Charpy impact tester. The samples were prepared into test sample size of 65 x 13 x 3 mm^3. The average amount of energy absorbed by each of the samples was obtained, using impact tester with a capacity of 25 J.

2.2.5. Flexural testing

The ultimate flexural strength was measured by using the flexural testing machine, according to the ASTM standard D790. Size of the test sample was 127 x 12.7 x 3 mm^3. The parameters used during the flexural test were load of 58 kN, crosshead speed of 1.3 mm/min and span length of 50 mm.

2.3. Surface morphology

JEOL M- 6390 scanning electron microscope (SEM) machine model was used to examine the fiber-matrix interfacial properties. SEM is one of the main tools for analyzing the causes and modes/mechanisms of sample surface fracture. An accelerating voltage of 10-15 kV was used. Fracture behaviors and fiber-matrix interaction of the fractured samples after mechanical tests were observed and analyzed.

3. Result and discussion

3.1. Density and void fraction

Table 3 presents theoretical, experimental and percentages of void density of the fabricated composites. Density of the pristine composite (S1) was 1.195 g/cc. As fillers were added to the hybrid composites, the densities improved when compared with that of sample S1. As compared to theoretical densities, the value of experimental densities is smaller, which may be attributed to the creation of voids during composite fabrication. There was a risk of air entrapment in the mold cavity during the combining of fillers in the polymer, and the displacement of resin during the compression effect will also produce voids [27]. Most notably, because of the lack of wetability, the surface of natural fibers such as coir and jute will have porous areas that have not been filled by the resin.

The percentages of voids in the various manufactured hybrid composites are shown in Table 3. S1 recorded higher level of void content, which was 4.4%, and S4 has the lowest number of void content of 1.48%. In general, the insertion of filler will cover the gaps at the fiber surface to the greatest degree possible depending on the pore size present in the fibers, which can range from micron to nano. In this scenario, the addition of similarly filled composite (NC1.5% - ESP 1.5%) eliminates the void content of the whole composite. This demonstrates that both S4 and S5 samples exhibited a strong wetting surface capacity, and the findings indicated an improved bonding between the fiber and matrix [22]. S2, S3 and S6 fillers, on the other hand, can spread poorly in the polyester matrix, resulting to a higher void material.

3.2. Moisture absorption

The samples were separately immersed in river and sea water to study their moisture absorption behaviors. Figs. 1 and 2 show that the moisture absorption for pure hybrid jute/coir composite sample (S1), with highest values under both wet conditions and when compared with other composite samples. It was observed that the plain S1 presence of void on the surface of the composite. Therefore, the weight of the composite S1 increased by entrapping more water particles inside the voids. In contrast, the moisture absorption of the hybrid filler with equal wt.% composite sample (S4) produced the lowest value, because the hybrid filler reinforced matrix acted as a water resistant [25]. Also, the other fillers filled hybrid fiber reinforced composite samples showed relatively low water absorption. which evident by SEM images of tensile, flexural and impact samples which shows the hybrid filler composite has produce the high strength and the single filler composite may have produce low strength properties compare with hybrid combination. This may cause due to agglomeration of filler, if filler agglomerates it reduces the adhesion between the fiber and matrix. The causes of agglomeration may be the improper degassing or mixing of filler in the resin preparation [18].

Additionally, the pattern of moisture absorption of all the samples was similar under both river (Fig. 1) and sea water (Fig. 2) immersion conditions, with exception of samples S1 and S3. Though, both samples reached a maximum absorption around 96 hrs. (4 days) under sea water condition, while S1 and S3 achieved a maximum absorption around 72 hrs. (3 days) and 96 hrs. (4 days), respectively. Also, the presence of 3.0 wt.% of MMT-NC filler only recorded higher moisture absorption in sample S3 than the addition of same 3.0 wt.% of ESP filler only in the sample S2, under both wet/water conditions. It can be deduced that MMT-NC filler exhibited greater moisture absorption than the ESP filler, which was much higher under river water condition. Evidently, it can be conclusively explained that addition of hybrid fillers reduced the moisture absorption of the composite, because the voids have been filled with matrix during the development of the hybrid fillers/hybrid fibers reinforced polyester composites.

3.2.1. Surface morphology of wet specimen

Scanning electron microscopy is a powerful tool for studying the surface morphology of composite specimens. The surface morphology of the moisture absorbed composite specimen is expected to vary from that of the dry composite specimen, especially in terms of voids, swelling, porosity, sorption in micro-cracking, and disbanding around the filler. Pores may act as stress concentration points, causing composites to fail prematurely during loading. As a result, studies of composite surface topography provide crucial information on the level of interfacial adhesion that exists between the fiber, fillers and the matrix when used as a reinforcement fiber in a wet condition [20]. It is observed that the moisture absorption for plain jute coir hybrid polyester composite high among the other composite in both river water immersion and sea water immersion state. This indicated that voids or micro crack presence in the surface of composite. Generally, the micro crack penetrating the more water in to the composite and swell the fibers to lead failure. Capillarity and transport through micro-cracks became active as the composite cracked and was damaged. Water molecules flowed along fiber–matrix interfaces and diffused through the bulk matrix as part of the capillarity mechanism. The water molecules actively attacked the interface, causing the fiber and matrix to deboned. The evidence of SEM image fig 3 a , b and c assist the explanation. Matrix material was lost as the cracks expanded, most likely in the form of resin particles Water transport mechanisms became more active after damage to the composites occurred [15].

3.3. Tensile strength

Mechanical properties of fiber reinforced composites depend on the nature of the polymer matrix, reinforced fibers and distribution of fillers. Figs 4(a) and (b) show the effects of the environmental conditions on the tensile strengths and moduli of the pure hybrid jute/coir fabrics and their reinforced polyester composite samples with varying wt.% of ESP and MMT-NC fillers, under dry and wet (sea and river water) conditions. The maximum or optimum tensile strengths of the hybrid composites with each/equal filler of 1.5 wt.% combinations (S4) were 21.77, 22.63 and 24.57 MPa (Fig. 4a), under river, sea water (wet) and dry conditions. Several studies proved, low filler content loading is improved the tensile strength of composite, causes it creates the strong hydrogen bonding between the fiber and matrix [36]. The results further indicated that tensile strengths of the hybrid fibers/hybrid fillers composite samples decreased under wet conditions causes due to presence of voids on the composites. Furthermore, the presence of low void content 1.475% compared to other combination the results in the positive effect (Fig. 4a). These were similar to the results obtained from the tensile moduli of the same six samples (Fig. 4b). It can be attributed to the weaker interfacial fiber/filler-matrix adhesion within the wet samples, due to the presence of moisture when compared with dry samples [38].

The percentages of improvement on tensile strengths of hybrid fibers/hybrid filler reinforced polyester composite samples (S4) were 32% under dry condition, 38 and 41% under the wet conditions (river and sea water, respectively). Similarly, their tensile moduli increased by 37% in dry condition, 44 and 48% under wet conditions (sea and river water, respectively), when compared with the pure hybrid fibers reinforced polyester composite sample without filler combination (S1). It was evident that the tensile strengths of the hybrid composites increased with combined fillers, especially with equal wt.% at dry condition. However, the percentages of improvement slightly decreased in the wet samples, when compared with the dry samples in the same combinations, and increased in the wet samples S5 and S6 of the remaining combinations. The reason behind failure of composite is agglomeration of filler, voids and microcrack in the surface which shown in Figs 5(a) and (b). Due to voids and microcrack the water particles penetrate inside the composite [10]and penetration grow the shear stress at the interface of. agglomeration of filler leads to debonding of fiber and matrix.

3.4. Flexural strength

Another significant and extensively measured property of composite materials is flexural strength. The flexural strength results replicate similar benefits of the hybrid fibers with equal wt.% of hybrid filler reinforced polyester composites. The maximum value of flexural strength (Fig. 6a) of the S4 combination was obtained at 46.97 MPa, under dry condition. This was almost 30% higher than the bending strength of the plain hybrid fibers reinforced composite (S1). Meanwhile, the same sample S4 increased up to 27% and 21% than the sample S1, under river and sea water (wet) conditions, respectively. These were very similar to their flexural moduli (Fig. 6b). Summarily, Figs 6(a) and (b) depict that the improved mechanical properties, caused by equal wt.% of hybrid fillers and hybrid fibers of the S4 combination resulted to significant changes in both strength and modulus values of the same sample. Precisely, the fillers changed/enhanced the properties of the matrix, including the overall strengths of the composite [39]. It was evident that the intercalation of matrix and filler was uniformly dispersed grew the proper adhesion and it controls the elasticity of matrix [32]. SEM images (Fig.7a and b) show the flexural failure of the composite, failure causes due to bending the matrix ruptured and resulting in fiber pullout from the matrix, when the adhesion of fiber and matrix bonding is low [34]. The flexural strength decreased in wet condition due to enhanced moisture absorption causes the cracks formed in the composite and agglomeration of filler, while agglomeration leads to debonding [19].

Summarily, the results depicted that hybridization of fillers in an equal wt.% within the optimum composite sample S4 was capable to convey the loads more efficiently together with the hybrid fibers.

3.5. Impact strength

The Impact strength results obtained from all the six samples were compared among themselves, under the three different environmental conditions. Fig. 8 similarly shows significant optimum impact performance of the sample S4. It exhibited the highest similar impact strengths of approximately 3 J, under all the three conditions, when compared with other combinations. However, it can be observed that the impact strengths decreased across all the wet samples in comparison with the same or corresponding dry samples (Fig. 8). This was attributed to the adverse effects of moisture on interfacial adhesion between the reinforcements and matrix of the composites, as earlier discussed Comparatively, this further established the presence of best interfacial adhesion between the fiber and filler reinforced matrix of composite sample S4. Also, it was evident that hybrid fillers enhanced the impact strength properties of the hybrid composite samples, especially under dry condition and when compared with sample S1.

Moving forward, the presence of 3.0 wt.% of ESP filler only recorded higher impact strengths in samples S2 than the addition of same 3.0 wt.% of MMT-NC filler only in the samples S3, under all the conditions. Hence, it can be deduced that the addition of ESP filler to the hybrid composite exhibited better impact strength than the MMT-NC filler, irrespective of the environmental conditions. This was further confirmed with greater impact behaviors of samples S5 with higher 2.0 wt.% of ESP filler, when compared with samples S6 with lower 1.0 wt.% of ESP filler. These results were significantly observed, despite of the higher 2.0 wt.% of MMT-NC filler present in the samples S6 with 1.0 wt.% of MMT-NC filler added to the samples S5, under both dry and wet conditions. The reduction in impact strength after water absorption can be attributed to swelling. Debonding causes of moisture attack in the fiber matrix interface. The voids and porosity were blame for the composite failures. Some fiber pull-outs were observed in the impact fractured specimens, as shown in Figs 9(a) and (b). After fracture of the composite matrix and it was weakened, then water flowed through fiber–matrix interfaces, based on capillary action [19].

More also, the property of the matrix was also enhanced. However, the use of good/strong matrix does not always produce composite of a higher impact strength. Impact strength of a composite material can be attributed to the interfacial bond between its reinforcement and matrix. Hence, the optimum impact strength results obtained with the composite samples S4 depicted that their filler-mixed matrix efficiently transmitted the applied impact load in the direction of hybrid fibers, under all conditions.

4. Conclusion

The mechanical properties of the hybrid composite laminates were analyzed under dry and wet (river and sea water) conditions. As compared to the pristine composites, the inclusion of fillers resulted in improved results in both situations. Under both river and sea water (wet) environments, the hybridization of jute/coir fabric with similarly hybridized 1.5 wt.% of ESP/MMT-NC fillers reinforced polyester composite sample (S4) reported the lowest moisture absorption rates of 3.8 and 4.0%, respectively. Higher moisture absorption was obtained as a result of the uniform dispersion of fillers and the closure of pores on the fiber surface. At equivalent amounts of ESP/MMTNC fillers with pristine jute/coir composites, the highest rise of 61, 40 and 66% were observed for the tensile strength. Furthermore, the increased tensile strength also was observed for S4 composites under river and sea water conditions, with the increases of 20 and 22%, respectively compared to pristine composites. Similarly, flexural and impact properties were observed to be high in case of composite sample S4 when compared with other types.

According to the SEM morphological analysis, the weak fiber-matrix interfacial bonding was clearly noticed at wet conditions due to the advancement of crack by the water uptake. Based on their performances, hybrid composite samples S4 exhibited best properties, due to their enhanced interfacial adhesion between fibers and matrix as well as fibers and fillers. As a result, the optimal composite sample S4 can be a viable, potential and alternative sustainable, lightweight and environmentally friendly material for building, structural, automotive (door, internal works, truck and boat interiors) and aerospace, among other low-load applications.

References

[1] F.M. AL-Oqla, S.M. Sapuan, M.R. Ishak, A.A. Nuraini, A model for evaluating and determining the most appropriate polymer matrix type for natural fiber composites, Int. Polym. Anal. Charact. 20 (3) (2015) 191–205.

[2] P.S.S. Kumar, K.V. Allamraju, A review of natural fiber composites [jute, sisal, kenaf], Mater. Today Proc. 18 (7) (2019) 2556-2562.

[3] M. Arul, K.S.K. Sasikumar, M, Sambathkumar, R. Gukenddran, N. Saravanan, Mechanical and fracture study of hybrid natural fiber reinforced composite – Coir and sugarcane leaf sheath, Mater. Today Proc. 33 (7) (2020) 2795-2797.

[4] R.A. Reddy, K. Yoganandam, V. Mohanavel, Effect of chemical treatment on natural fiber for use in fiber reinforced composites – Review, Mater. Today Proc. 33 (7) (2020) 2996-2999.

[5] M. Sood, G. Dwivedi, Effect of fiber treatment on flexural properties of natural fiber reinforced composites: A review, Egyp. J. Petrol. 27 (4) (2018) 775-783.

[6] V. Fiore, G. Di Bella, A. Valenza, The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites, Compos. Part B Eng. 68 (2015) 14-21.

[7] G. Ma, L. Yan, W. Shen, D. Zhu, L. Huang, B. Kasal, Effects of water, alkali solution and temperature ageing on water absorption, morphology and mechanical properties of natural FRP composites: Plant-based jute vs. mineral-based basalt, Compos. Part B Eng. 153 (2018) 398-412.

[8] T.H. Nam, S. Ogihara, N.H. Tung, S. Kobayashi, Effect of alkali treatment on interfacial and mechanical properties of coir fiber reinforced poly (butylene succinate) biodegradable composites, Compos. Part B Eng. 42 (6) (2011) 1648-1656.

[9] R.A. Khan, H.U. Zaman , M.A. Khan, F. Nigar, T. Islam, R. Islam, S. Saha, M.M. Rahman, A.I. Mustafa, M.A. Gafur, Effect of the Incorporation of PVC on the mechanical properties of the jute-reinforced LLDPE composite, Polym. Plast. Technol. Eng. 49 (7) (2010) 707-712.

[10] S. Shahinur, M. Hasan, Jute/coir/banana fiber reinforced bio-composites: Critical review of design, fabrication, properties and applications, Encylop. Renew. Sust. Mater. 2 (2019) 751-756.

[11] M.A.S. Sujon, M.A. Habib, M.Z. Abedin. Experimental investigation of the mechanical and water absorption properties on fiber stacking sequence and orientation of jute/carbon epoxy hybrid composites, J. Mater. Res. Technol. 9 (5) (2020) 10970-10981.

[12] N. Venkateshwaran, A.E. Perumal, A. Alavudeen, M. Thiruchitrambalam, Mechanical and water absorption behavior of banana/sisal reinforced hybrid composites, Mater. Des. 32 (7) (2011) 4017- 4021.

[13] A. Athijayamani, M. Thiruchitrambalam, U. Natarajan, B. Pazhanivel, Effect of moisture absorption on the mechanical properties of randomly oriented natural fibers/polyester hybrid composite, Mater. Sci. Eng. A 517 (1-2) (2009) 344-353.

[14] M.R. Sanjay, B. Yogesha, Study on water absorption behavior of jute and kenaf fabric reinforced epoxy composites: hybridization effect of e-glass fabric, Int. J. Compos. Mater. 6 (2) (2016) 55 - 62.

[15] S. Panthapulakkal, M. Sain, Studies on the water absorption properties of short hemp-glass fiber hybrid polypropylene composites, J. Compos. Mater. 41 (15) (2007) 1871-1883.

[16] S.K. Saw, K. Alhtar, N. Yadav, A.K. Singh, Hybrid composites made from jute/coir fibers: Water absorption, thickness swelling, density, morphology and mechanical properties, J. Nat. Fib. 11 (1) (2014) 39-53.

[17] E. Rosamah, H.P.S.A. Khalil, S.W. Yap, C.K. Saurabh, P.M. Tahir, R. Dungani, A.F. Owolabi, The role of bamboo nanoparticles in kenaf fiber reinforced unsaturated polyester composites, J. Renew. Mater 6 (1) (2018) 75-86.

[18] D.M. Krishnudu, D. Sreeramulu, P.V. Reddy, A study of filler content influence on dynamic mechanical and thermal characteristics of coir and Luffa cylindrica reinforced hybrid composites, Constr. Build. Mater. 251 (2020) 119040.

[19] N. Rasana, S. Murugan, G. Rammanoj, T. Hariprasanth, K.A. Kumar, K. Jayanarayanan, The effect of different nanofillers on the morphology, mechanical, sorption and thermal properties of polypropylene based hybrid composites, Mater. Today Proc. 24 (2) (2020) 1273-1281.

[20] H. Alamri, I.M. Low, Effect of water absorption on the mechanical properties of nanoclay filled recycled cellulose fiber reinforced epoxy hybrid nanocomposites, Compos. Part A Appl. Sci. Manuf. 44 (2013) 23-31.

[21] R. Vijay, A. Vinod, R. Kathiravan, S. Siengchin, D.L. Singaravelu, Evaluation of *Azadirachta indica* seed/spent *Camellia sinensis* bio-filler based jute fabrics – epoxy composites: Experimental and numerical studies, J. Ind. Text. 49 (9) (2020) 1252-1277.

[22] A.S. Ismail, M. Jawaid, J. Naveen, Void content, tensile, vibration and acoustic properties of kenaf/bamboo fiber reinforced epoxy hybrid composites, Materials 12 (13) (2019) 1-14.

[23] N. Rajini, J.T.W. Jappes, S.R. Rajakarunakaran, I. Siva, Effect of processing variables on mechanical properties of montmorillonite clay/unsaturated polyester nanocomposite using Taguchi based grey relational analysis, J. Polym. Eng. 32 (2012b) 555 – 566.

[24] N. Rajini, J.T.W. Jappes, S. Rajakarunakaran, P. Jeyaraj, Mechanical and free vibration properties of montmorillonite clay dispersed with naturally woven coconut sheath composite, J. Reinf. Plast. Compos. 31 (20) (2012a.) 1364 – 1376.

[25] S.O. Adeosun, M.A. Usman, E.I. Akpan, W.I. Dibie, Characterization of LDPE reinforced with calcium carbonate – fly ash hybrid filler, J. Min. Mater. Charact. Eng. 2 (2014) 334–345.

[26] M. Jawaid, H.P.S.A. Khalil, A.A. Bakar, P.N. Khanam, Chemical resistance, void content and tensile properties of oil palm/jute fiber reinforced polymer hybrid composites, Mater. Des. 32 (2) (2011) 1014 – 1019.

[27] S.S. Chee, M. Jawaid, M.T.H. Sultan, O.Y. Alothman, L.C. Abdullah, Effects of nanoclay on physical and dimensional stability of bamboo/kenaf/nanoclay reinforced epoxy hybrid nanocomposites, J. Mater. Res. Technol. 9 (3) (2020) 5871 - 5880.

[28] H.G.B. Premalal, H. Ismail, A. Baharin, Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites, Polym. Test. 21 (7) (2002) 833 – 839.

[29] F. Sarker, N. Karim, S. Afroj, V. Koncherry, K.S. Novoselov, P. Potluri, High-performance graphene-based natural fiber composites, ACS Appl. Mater. Interf. 10 (40) (2018) 34502-34512.

[30] K. Ganesan, C. Kailasanathan, M.R. Sanjay, P. Senthamaraikannan, S.S. Saravanakumar, A new assessment on mechanical properties of jute fiber mat with egg shell powder/nanoclay-reinforced polyester matrix composites, J. Nat. Fib. 17 (4) (2018) 482-490.

[31] N. Saba, M.T. Paridah, K. Abdan, N.A. Ibrahim, Physical, structural and thermos-mechanical properties of oil palm nano filler/kenaf/epoxy hybrid nanocomposites, Mater. Chem. Phys. 184 (2016) 64-71.

[32] V. Mortazavi, M. Atai, M. Fathi, S. Keshavarzi, N. Khalighinejad, H. Badrian, The effect of nanoclay filler loading on the flexural strength of fiber reinforced composites, Dent. Res. J. 9 (3) (2012) 273–280.

[33] M. Panchal, G. Raghavendra, P.S.K. Reddy, M. Omprakash, P. Srikar, Study of moisture absorption and its effect on erosion wear behavior of eggshell nanoparticulate epoxy composite, Mater. Today Proc. 33 (8) (2020) 5746 - 5750.

[34] A. Alhuthali, I.M. Low C. Dong, Characterization of the water absorption, mechanical and thermal properties of recycled cellulose fiber reinforced vinyl-ester eco nanocomposites, Compos. Part B Eng. 43 (7) (2012) 2772–2781.

[35] M. Arul, K.S.K. Sasikumar, M. Sambathkumar, R. Gukendran, N. Saravanan, Mechanical and fracture study of hybrid natural fiber reinforced composite – Coir and sugarcane leaf sheath, Mater. Today Proc. 33 (7) (2020) 2795-2797.

[36] S.R. Lee, H.M. Park, H. Lim, T. Kang, X. Li, W.J. Cho, C.S. Ha, Microstructure, tensile properties, and biodegradability of aliphatic polyester/clay nanocomposites, Polymer 43 (8) (2002) 2495 – 2500.

[37] O.J. Gbadeyan, S. Adali, G. Bright, B. Sithole, O. Awogbemi, Studies on the mechanical and absorption properties of *Achatina fulica snail* and eggshells reinforced composite materials, Compos. Struct. 239 (2020) 112043.

[38] B. Mylsamy, S.K. Palaniappan, S.P. Subramani, S.K. Pal, K. Aruchamy, Impact of nanoclay on mechanical and structural properties of treated *Coccinia indica* fiber reinforced epoxy composites, J. Mater. Res. Technol. 8 (6) (2019) 6021- 6028.

[39] S.Y. Fu, X.Q. Feng, B. Lauke, Y.W. Mai, Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate–polymer composites, Compos. Part B Eng. 39 (6) (2008) 933 – 961.