EXPLOITATION OF COIR COMPOSITES: ENHANCEMENT OF ABSORBENCY AND IMPACT STRENGTH

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Abstract: In the face of existing research findings on natural fibre reinforced composites, there exists knowledge-gap in the influence of porosity and water absorption on impact performance of coir reinforced composite products. In this study, coir fibres were treated and utilized in reinforcing polyester matrix by hand lay-up technique, and subsequently characterized by impact testing, porosity and water absorption analysis. The results showed that impact strength of treated-coir composites decreased from 603.89 J/m at 10 wt. % to 209.12 J/m/m at 70 wt. %. Conversely, the porosity values of treated-coir composites increased from 2.93% at 10 wt. % to 6.66% at 70 wt. %, whilst the water absorption values of treated-coir composites increased from 3.12% at 10 wt. % to 5.66% at 70 wt. %. The results of raw-coir composites showed least improved property characteristics. Accordingly, inference is made that the combined effect of alkali and silane treatments was evident on the improved impact behavior of treated-coir composites. This work will espouse the knowledge-gap in the utilization potentials for the sustainable production of low-to-medium impact applications of coir composites, with emphasis on the enhancement of porosity and water absorption effects.

Keywords: Coir, composites, impact strength, porosity, silane treatment, water absorption

Introduction

In recent times, issues of weight reduction in the face of moderate-to- high impact behavior have taken a centre stage in material application. The obvious inference of this is the continued expansion and utilization of biodegradable material based products. Of necessity therefore, is the utilization of natural fiber reinforced polymer composites, which has found a variety of application because of their many advantages such as relatively low cost of production, easy to fabricate, and superior strength compare to neat polymer resins.

Particularly attractive is the utilization of alternative suitable natural renewable material such as the coconut palm (*Cocos nucifera)* empty fruit bunch fibre, generally referred to, as 'coir'. These products are in abundance in most parts of the world, and have been in use for hundreds of years for many applications such as mattresses, brushes, and of recent in acoustic and less impact-related engineering areas. However, not much has been carried out to characterize these classes of materials with a view to exploring their full potentials in areas of correlation between porosity and water absorption on the impact strength characteristics.

Coir has high lignin but low cellulose content, as a result of which they are resilient, strong, and highly durable, thus making them highly abrasive and tough **(**Goulart *et al.*, 2000). The high lignin content of coir is due to the presence of strong polarized hydroxyl group, which often lead to poor interfacial bonding between the fibers and the matrix. This characteristic generally affects the mechanical properties of the composites, but can be rectified by modifying the fibre as shown by various research findings. For example, Fortea-Verdejo *et al.* (2015) reported that composites containing random short plant fibres, such as coir, possess similar properties to randomly oriented glass fibre reinforced plastics at a lower overall part weight. This espouses the potentials for adaptation in applications requiring improved mechanical performance, particularly in applications where cost of use of synthetic fibres is less attractive.

In general, the drawback of high moisture absorption that often results in swelling of coir, and concerns on the dimensional stability is often minimized through chemical modification as reported by Rowell *et al.* (2001). These surface modifiers penetrate and deposit into lumens of cell wall of coir, causing a minimization of moisture ingress **(**Bledzki and Gassan, 1996). Other works show that the effect of chemical treatment on mechanical and water-sorption properties of coir -unsaturated polyester displayed lower water absorption properties in comparison to those of untreated fiber composites **(**Abdullah and Ahmad, 2012).

Another concern of effect of fiber volume fraction on the mechanical properties of coir composite showed that properties increased as a function of increase in fiber volume fraction except for impact strength (Siva *et al.,* 2013). Another study indicated that the coir is firmly embedded in the modified epoxy matrix leading to increased area of bonding at the interfacial region of the matrix and coir, which resulted in improved mechanical properties of composite structure (Natarajan and Balasubramanya, 2013). Similarly, other findings showed that poor wetting of natural fibers has direct consequence on the impact strength properties of composites. The improved adhesion parameters arising from silane treatment was reported to have improved the impact strength properties from 10% fiber content to 60% fiber content after which problems of poor wetting set-in (Anyakora and Abubakre, 2011). Also, the effect of alkali treatment and fiber length on impact behavior of coir reinforced composites using hand-layup production process indicated improvement in impact strength of 15% when compared with untreated coir composites (Karthikeyan and Balamurugan, 2012).

Additionally, some other works indicated that 20% volume fraction of coir demonstrated optimum tensile and impact properties, including a significant reduction of impact strength under low temperature condition was due to the brittleness of both coir and matrix (Salleh *et al.,* 2015). Other works showed that fibre content and surface treatment cannot lead to improved impact strength of fibre composite panels (Anyakora, 2013). Correspondingly, a study showed that strength of coir reinforced composites tends to decrease with the amount of fibre indicating ineffective stress transfer between the fibre and matrix (Bujang *et al.,* 2007). Also, the effects of fiber length and fiber content on the physical, mechanical and water absorption behavior of coir reinforced composites indicated that, the void content and percent of water absorption increases with increase in fiber length and fiber content (Das and Biswas, 2016). Likewise, Shakil *et al.*

(2017) reported that impact strength increased with the increasing fibre loading.

The wide-ranging inference that impact behavior of reinforced composite depends largely on the matrix, fibre and fibre-matrix interface, should consider also, the issues of processing conditions which must play a dominant role in reducing the voids associated with porosity and water absorption intensities, which this work intends to espouse. The relative vantages offered by linking impact strength with water absorption and porosity will adduce to the importance of coir fiber as an ad-mixture for roofing and other applications justifications such as low cost, recyclability, non-corrosiveness, low thermal conductivity as reported (Dhandhania and Sawant, 2014).

It is obvious from the various reports that past studies delved much into some mechanical properties of coir reinforced composites for utilization in engineering application without necessarily espousing the inherent connections between the porosity and water absorption associated with processing methods, fibre surface treatment on the incipient effects on impact strength. Additionally, the need to adopt materials at optimal characteristics in satisfying the concept of loss prevention and reliability in design, rather than expending on additional processes that often increase the production costs is espoused. This work therefore attempts, to address this knowledge-gap, including the exploration of other viable areas of application, especially in the production of medium impact strength products, with emphasis on the enhancement of porosity and water absorption effects on impact strength potentials.

Materials and Methods

Materials

A commercially blended polyester resin (Siropol 7440) with specific gravity - 1.04, viscosity - 0.24 Pa.s at 25°C. Other ancillary products used were the cobalt in styrene and Bisphenol-A diglycidylether. Phenyltrimethoxysilane - $[(CH_3O)_3SiC_6H_5]$ of molecular weight-198.3, specific gravity at 25°C - 1.06, assay-98%, produced by Sigma-Aldrich, and purchased from Zayo Nigeria limited, Jos, Nigeria, including 98% Methanol and 0.5 mol of NaOH were adopted in the work.

The coir was extracted from the husk of mature and fruited coconut palm plants with known ages, and used within two weeks of felling.

Other equipment used were: Izod impact testing machine (Nominal energy – 850 J, Maximum Impact velocity of 7.5m/s, continuous adjustable pendulum angle up to 150°C); Compact Scale (Model - FEJ, Capacity – 1500 g, 1500A), a-two-part mould facility and carbolite muffle furnace (2330 watts, 1100°C).

Methods

Fibre extraction

The coir was processed by chemico-mechanical process which involved the impregnation of sample with a strongly alkaline solution of sodium hydroxide and sodium sulfide. Conversion of the softened sample into fibre by mechanical means was followed by thorough washing, screening and drying. The extracted coir was subsequently separated, re-washed and dried in the forced-air circulation type oven, further weighed, and percentage yield determined. The fibres were fluffed and separated into two tangled- mass bulks, one for surface-treated fibre composite and the other, for the untreated fibre composite production (Chibudike *et al.*, 2011).

Surface treatment of the extracted fibre

Varying weights of 100 – 700 g of extracted coir were soaked in prepared in varying weights of 300 – 900 g of 0.5 mol/litre of NaOH for 2 h. The products were removed and washed with distilled water before air-drying. Subsequent processes included soaking the treated coir in 2% phenlysilane solution for 24 h. The product was removed, dried at 60°C and stored in specimen bag ready for use.

Preparation of moulding facility

A two-part mould system fabricated from mild steel flat 4mm thick sheet was adopted in the production of test specimen plates. The pre-designed cavity is maintained at a 5 mm thickness with clamping bolts in place. The mould is of dimensions 150 x 150 mm with active surfaces ground.

Production of test specimen

The specimen prepared was fabricated by hand layup method, with different fibre weight percent of 10, 20, 30, 40, 50, 60, 70%. Following the BS ISO 1268-3:2000, as follows:

a. Coir was weighed on a calibrated compact scale/balance, and the weights recorded.
b. The weighed fibres were manually placed in the mould facility in random orientation.
c. The matrix mix was poured into the mould cavity containing tangled fibre mass fully laid-in.
d. The top mould was subsequently placed and clamping bolts fully secured.
e. The mould containing the un-cured composite was placed in an oven operated at 110°C, and removed from the oven after 30 min.
f. The moulding was allowed to cool to room temperature before placing in humidity controlled bag.
g. The test samples were conditioned to the room temperature of 27°C at relative humidity of 65%, and cut into beams of varying dimensions for impact strength, porosity and water absorption tests.

Composite characterization

Izod impact test

The izod impact test was conducted according to BS EN ISO 180:2019 method. The Impact test analysis was commenced with the notched specimens cut into dimensions of 200 x 200 x 5 mm for which the support displacement of machine was 240 mm.

Porosity test

The boiling point method was used to evaluate the volume of open pores, into which a liquid can penetrate as a percentage of the total volume. During the test, identical coir reinforced polyester test pieces of dimensions 100 x 100 x 5 mm of the samples were prepared. Each of the test pieces was placed in an oven operated at 110°C for 30 min, while another test piece was submerged in distilled water for 2 h and then removed. Their weights were taken after those processes, and applied for the evaluation of apparent porosity of the sample using the expression in Eq. 1 (BS EN 993-1:1995).

$$AP(\%) = \frac{(W-D)100}{W-A} \quad (1)$$

Where AP = apparent porosity of the sample, W= weight specimen in air, D = weight of specimen dried in oven at 110°C and A = weight of specimen submerged in water.

Water absorption test

The percent increase in weight of each material was evaluated after exposure in water. The exposed coir reinforced polyester test pieces of dimensions 100 x 100 x 5 mm were dried and cooled, and the initial weights recorded. Identical specimens for the treated and untreated fibre composite type were soaked in distilled water at a temperature of 23°C, later removed from the soak after 24 h, weighed and final weight recorded. The percentage water absorbed by the specimens was evaluated using the expression in Eq. 2 (BS EN 2378:1994);

$$W_A(\%) = \frac{(W_2 - W_1)100}{W_1} \quad (2)$$

Results and Discussion

Impact strength

Figure 1 shows the variation of impact strength at different coir wt. % composites. It can be observed that as the coir wt. % increases, there is poor interfacial bonding between fibre and resin resulting into existence of micro-cracks at the point of impact, and consequent inability of the reinforcements to block the crack propagation which leads to decrease in impact strength of composites. The impact strength of treated coir composites decreased from 603.89 J/m at 10 wt. % to 209.12 J/m /m at 70 wt. % fibre content whilst that of untreated coir composites decreased from a value of 306.76 J/m at 10 wt. % to 143.05 J/m at 70 wt. % fibre content. The recorded high percentage of coir resulted in poor wetting between the coir and polyester matrix, which led to the less area of fibre being bonded by the matrix that caused weak interface and attendant weak bonding. This made the composite to become easier to deform as fibre content increased (Bujang *et al.*, 2007). This result corroborates the works of other researchers that adhesion between the fibre and the matrix is highest at lower fibre content (Anyakora and Abubakre, 2011; Salleh *et al.*, 2015; Das and Biswas, 2016; Shakil *et al.*, 2017).

Additionally, it is observed that the effect of coir treatment resulted in corresponding higher impact strength values of treated coir composites. It can be observed that surface treatment of coir fibre content caused the decrease in the statistical impact strength values of treated coir composites from 96.90% at 10 wt. % to 46.20% at 70 wt. %. It is obvious from the result that coir was firmly embedded in the matrix leading to increased area of bonding at the interfacial region of the matrix and coir that resulted in an improvement in impact strength properties of the treated coir composite, as reported by other researchers (Karthikeyan and Balamurugan, 2012).

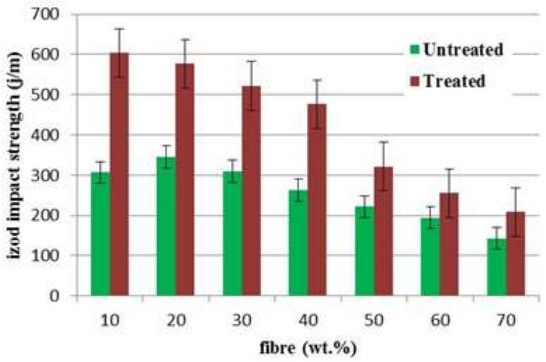

Fig. 1: Variation of impact strength at different coir wt. % composites

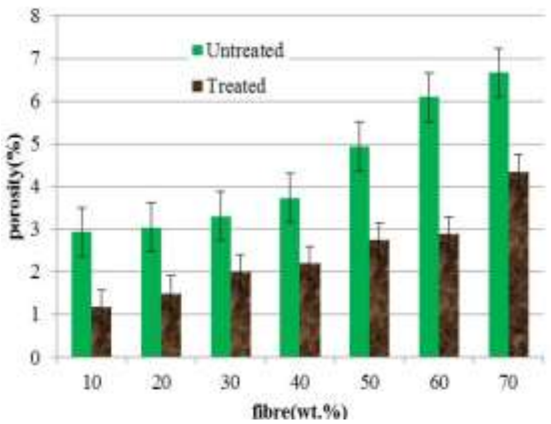

Fig. 2: Variation of porosity at different coir wt. % composites

Porosity

Figure 2 shows the variation of porosity at different coir wt. % composites. It can be observed that increasing the fibre content resulted to increase in percentage porosity of untreated coir reinforced polyester composites from 2.93% at 10 wt. % to 6.66% at 70 wt. %, whilst the values of treated coir composites similarly increased from 1.18% at 10 wt. % to 4.35% at 70 wt. %. The observed significant difference in porosity levels between the treated and untreated coir composites confirms the positive effect of fibre treatment.

It is recognized however, that the lack of interfacial interactions that often leads to internal strains and high level of porosity, generally affect the mechanical behaviour of fibre composites as reported by other researchers, thus, issues of strong adhesion at the fibre-matrix interface must be addressed for an effective transfer of stress and load distribution throughout the interface, if reduced level of porosity is expected. Residence of voids and porosity in materials often encourage stress initiation which is a function of resistance to several factors such as toughness behavior. The percentage of porosity, their positions in the material indicates the trend with which the pattern of failure may be experienced. Generally, short fibre lengths require higher matrix alignment, thus, the high porosity percentages exhibited by the composites of short coir composites at higher fibre content corroborates the findings of other researcher (Das and Biswas, 2016).

Water absorption

Figure 3 shows the variation of water absorption at different coir wt. % composites. It can be observed that percentage water absorption level of untreated coir composites increased with increasing fibre loading from 3.51 % at 10 wt. % to 9.02 % at 70 wt. %, whilst the values of treated coir composites similarly increased from 3.12 % at 10 wt. % to 5.66 % at 70 wt. %. The observed significant difference in porosity levels between the treated and untreated coir composites was due to the hydrophilic characteristics of coir, which is composed of cellulose and lignin of hydroxyl group presence that take-up water easily. Thus, higher fibre loading causes greater presence of hydroxyl content in the composite, and consequent higher water absorption, as reported by other researchers (Shakil *et al.*, 2017).

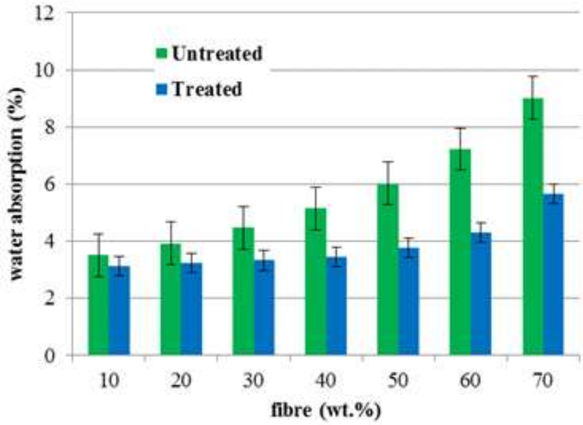

Fig. 3: Variation of water absorption at different coir wt. % composites

Expectedly, large water absorption value between the treated and untreated fibre composites was reported by other researchers **(**Rowell *et al.*, 2001; Abdullah and Ahmad, 2012), from different natural plants. Thus, the higher water absorption values in treated coir composites was an indication of improved compatibility between the treated fibre and matrix, based on the combined effects of alkali and silane treatments which provided the micro-voids for entrapment of matrix. The fibre treatment obviously led to a build-up in the cell wall and in the fibre-matrix inter-phase region, which resulted in fibre swelling, which resulted in high water absorption intensities as the fibre loading increased.

A cursory look at the percentage values of porosity and water absorption parameters as related to the impact strength values of coir reinforced polyester composites indicated that silane treatment provided rough surfaces on the fibres, that resulted in the increased reactive sites that enabled resin to fill the pores and achieve better bonding between the fibre and the matrix, which in effect improved the impact behavior.

Conclusions

On the basis of results obtained, the following conclusion can be drawn:

i. The impact strength properties of untreated and treated coir reinforced polyester composites decreased with increasing fibre content.
ii. The percentage porosity and water absorption parameters of untreated and treated coir reinforced polyester composites increased with increasing fibre content respectively.
iii. The combined effect of alkali and silane treatments was evident in the improved impact behavior of treated coir composites.

In consequence therefore, the findings from this work will aid in appreciating varied effects of levels of porosity and water absorption on impact behavior of products. This will come handy when choosing the type of fibre treatment process and suitable manufacturing technique to achieve the desired properties in the optimal utilization of coir reinforced composites. Inference is therefore made that, the property values of treated coir composites are adduced optimal for utilization in the sustainable production in some engineering applications, especially in supporting loss prevention and reliability in the design of low cost, light weight with medium impact strength products.

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Conflict of Interest

Authors declare that there is no conflict of interest related to this study.

References

Abdullah NM & Ahmad I 2012. Effect of chemical treatment on mechanical and water-sorption properties coconut fiber-unsaturated polyester from recycled PET. *ISRN Materials Science*, pp. 1 – 8.

Anyakora AN & Abubakre OK 2011. Effect of silane treatment on the impact strength properties of oil palm empty fruit bunch fiber- reinforced polyester composites. *World J. Engr. and Pure and Appl. Sci..*, 1(2): 40-45.

Anyakora AN 2013. Investigation of impact strength properties of oil and date palm frond fiber reinforced polyester composites. *Int. J. Current Engr. and Techn.*, 3(2): 493-497.

Bledzki AK & Gassan J 1996. Effect of coupling agents on the moisture absorption of natural fibre-reinforced plastics. *Angew Makromol Chem*., 236: 129-138.

BS EN ISO:180 2019. Plastics. Determination of Izod Impact Strength.

BS EN 993-1 1995. Methods of Test for Dense Shaped Refractory Products. Determination of Bulk Density, Apparent Porosity and True Porosity (British Standard).

BS EN 2378:1994 - Fibre Reinforced Plastics. Determination of Water Absorption by Immersion (British Standard).

Bujang IZ, Awang MK & Ismail AE 2007. Study on the dynamic characteristic of coconut fibre reinforced composites. Regional Conference on Engineering Mathematics, Mechanics, Manufacturing & Architecture (EMARC) (Noise, Vibration and Comfort Research Group): pp. 184-202.

Chibudike HO, Anyakora AN, Suleiman MAT, Adeyoju OA, Aruwolo AB, Akabeze EU, Etoamaihe MA, Asieba GO & Samuel AE 2011. Utilization of bamboo in the production of ceiling board. *J. Engr. Res.,* 16(1): 1-9.

Das G & Biswas S 2016. Effect of fiber parameters on physical, mechanical and water absorption behaviour of coir fiber-epoxy composites. *J. Reinforced Plastics and Composites*, 35(5): 644-653.

Dhandhania VA & Sawant S 2014. Coir fiber reinforced concrete. *J. Textile Sci. and Engr.*, 4: 163.

Fortea-Verdejo M, Bumbaris E, Burgstaller C, Bismarck A & Lee K 2015. Plant fibre-reinforced polymers: Where do we stand in terms of tensile properties? *Int. Materials Rev*., 62(8): 441-464.

Goulart SG, De Souza DA, Machado JC & Hourston DJ 2000. Mechanical and thermal characterization of native Brazilian coir fiber. *J. Appl. Polymer Sci.,* 76(7): 1197 – 1206.

Karthikeyan A & Balamurugan K 2012. Effect of alkali treatment and fiber length on impact behavior of coir fiber reinforced epoxy composites. *J. Scientific & Indu. Res.*, **7**1(9): 627-631.

Natarajan K & Balasubramanya PC 2013. Mechanical and morphological study of coir fiber reinforced modified epoxy matrix composites. *Int. J. Emerging Techn. and Advanced Eng*., 3(12): 583-587.

Rowell MR, Han JS & Rowell JS 2001. Natural polymers and agrofibers composites fibers. *Journal of Plastics Composites,* 31: 21-23.

Salleh Z, Hyie KM, Yunus S, Taib YM, Berhan MN & Kalam A 2015. Tensile and impact strength of coir fibre reinforced polypropylene composites: effect of different temperature conditions. *Applied Mechanics and Materials,* 763: 25-29.

Shakil A, Ashraful A & Mahbub H 2017. Physico-mechanical properties of coir and jute fibre reinforced hybrid polyethylene composites. *Int. J. Automotive and Mech. Engr.*, 14(1): 3927-3937.

Siva I, Winowlin Jappes JT, Sankar I, Amico SC & Ravindran D 2013. Effect of fiber volume fraction on the mechanical properties of coconut sheath/usp composite. *J. Manufacturing Eng.,* 8(1): 060-063.