



Tensile and Microstructural Properties of Unidirectional Coir Bio-Derived Epoxy Composites

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Abstract

The study investigates the possibilities of reinforcing bio-derived epoxy (bio-epoxy) polymer with unidirectional arrays of coir fibre using hand layup. The coir fibres were unidirectionally prepared in two layers. The tensile properties such as strength, Young's modulus and elongation at break were found to be 43.83 MPa, 2.4 GPa and 2.72 % respectively. The tensile strength of coir/bio-epoxy composite was higher than the unreinforced bio-epoxy resin. The fibre volume fraction of the composites obtained using ImageJ on an 8-bit grey scale was 34%. The optical microstructure of the composites shows the distribution of the fibres within the bio-epoxy matrix.

Keywords: Bio-epoxy, coir, composites, fibre volume fractions, tensile properties, unidirectional

1.0 INTRODUCTION

Global focuses on greener processes and technologies, regulations and growing environmental awareness have significantly boosted the use of natural fibres as reinforcement in composites. The non-renewable nature of fossil resources and environmental concerns have sharpened awareness of potential uses of agricultural wastes [1–5]. Natural fibres are environmentally friendly, sustainable and they offer high specific strength and modulus [6]. The Polymeric resins although previously synthesized from fossil fuels can now be manufactured from biological resources instead. Starches, plant oils and other naturally derived building blocks have been discovered that can be used to prepare thermoplastic resin.

Typical examples of fibres which have been used as reinforcements include; flax, jute, bamboo, sisal, kenaf, coir and bagasse. [3, 7–11]. Natural fibres are cost-effective, non-brittle and renewable. Natural fibres are much lighter than glass and most synthetic fibres and therefore offer significant weight savings and fuel efficiency when compared with synthetic fibres [12, 13]. This light weight advantage has propelled its adoption in the automotive sector [13, 14]. Coir, a natural ligno-

-cellulose fiber has been in abundance with an average production standing at 1000 metric tons in 2019 [15]. Coir possesses the advantages of natural fibres such as light weight and non-toxicity consequently its relatively low density of 1150 kg/m³ [16, 17] is a major attraction in low weight applications. The failure strain of coir fiber is in the range of 30–47% [17, 18]. Coir fibre composites have been produced using synthetic polymer matrix such as synthetic epoxy [19, 20]; polypropylene [21]; polyester [22], Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) [24]. However, not much work has been reported on the use of bio-derived epoxy as matrix for coir fibre composite, hence this study was carried out.

2.0 MATERIALS AND METHOD

2.1 Material

2.1.1 Matrix: Bio-derived epoxy resin

Super sap ® epoxy systems [Epoxy (Part A) and hardener (Part B)] as shown in Figure 1 are low viscosity bio-derived epoxy resin compatible with glass and natural fibres. Super sap bio-epoxy resin reduces carbon footprint without reduction in performance. Super sap epoxy systems are used in composites manufacture via hand layup, resin infusion and resin transfer mouldings. It was manufactured by Entropy resins USA and supplied by Ferrer Dalmau, UK. The stoichiometric mixing ratio of resin to hardener by weight is 100:47. The required quantities of the epoxy resin (Part A) and the hardener (Part B) were weighed out carefully using an Ohaus

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Analytical Plus model AP110S, 5-digit balance. Mixing was carried out with a wooden spatula until a single consistency and thorough blend was achieved before degassing for about 15 minutes in a vacuum chamber using Gallenkamp vacuum oven (model OVL570 supplied by Island Scientific Ltd, UK,). The weighing and mixing of the resin and hardener were carried out under a fixed air-extraction system.



Figure 1: Super sap bio-derived epoxy and hardener used for the composite manufacture.

2.1.2 Reinforcement: Coir fibre

As-received coir fibres as shown in Figure 2 of average diameter 0.242 mm were selected. The coir fibres were washed four times in warm water (50 °C) for 15 minutes per wash and dried at room temperature for two days. These coir fibres were unidirectionally-aligned on a PTFE-coated aluminium plate on which thin strips of adhesive were placed at the opposite ends to form single layers of 20 mm width by 130 mm length samples as shown in Figure 3.



Figure 2: Washed and dried coir fibres



Figure 3: Coir fibre arrays in single layers

2.2 Method

2.2.1 Manufacture of unidirectional coir epoxy composites

The manufacture method employed was hand layup. The prepared layers as shown in Figure 3 were used to manufacture the composites in double layers. The second layer was placed on the first layer in the same unidirectional manner and securely held with adhesive tape and the resin applied. The mixed resin was dropped in a zigzag manner onto the coir fibre layers using rubber pipette until the layers were sufficiently wetted. At the end of resin application, a rectangular aluminium weight of 1kg was placed on the yet-to-cure composite. The composites were left to cure at room temperature for 24 hours after which post curing was carried out in air oven at 80 °C for 6 hours. The polymerization of bio epoxy resins with hardener is slower, hence the temperature of 80 °C and long curing time of 6 hour [23]. The samples were trimmed to meet the standard requirements and end-tapped using aluminium end tabs as shown in Fig. 4. 3M Scotch – Weld resin system was used for the end tab. The resin system Part A and Part B was prepared in the ratio 27:100 respectively. The end tab regions were grinded with P400 silicon carbide paper for good adhesion to the Scotch Weld resin prior to end-tapping.

2.2.2 Tensile testing of resin and composites

The tensile testing of the resin and manufactured composites were carried out in accordance with EN ISO 527-5:1997 on Instron Universal testing machine 5566 at a cross-head speed of 1mm/minute using a load cell of 10 KN.

2.2.3 Optical microscopy and scanning electron microscopy

The single fibres and composites were sectioned into 12mm lengths. The samples were mounted by placing the specimens individually in a plastic mould designed to fit the polishing machine sample holders and potted in epoxy resin to preserve the fibre structure and allowed to cure for one day at room temperature after which the samples were post cured by placing in the lab oven at 80 °C for six hours for full cure.

Grinding was achieved using silicon carbide abrasive paper corresponding to grades (MetPrep) 600, 800, 1200, 2500 and 4000 grit sizes in a LaboPol grinder polisher with PH100 Grinder/Polishing head, this was followed by polishing with MD system consumables. The samples were ultrasonically washed afterwards.

Zeiss Axioskop-2 optical microscope was used to obtain good quality images for volume fraction. At this point, ImageJ software was introduced and used to determine the fibre volume fraction. Table top scanning electron microscope TM3030 was used to obtain microstructures of the samples.

3.0 RESULTS

3.1 Tensile properties

A sample of the manufactured composite is as shown in Figure 4. The tensile properties obtained are shown in Table 1 and displayed in Figure 5(a and b). The average tensile strength of the coir/bio-epoxy composite manufactured was 43.83 MPa. The tensile strengths from literature with synthetic epoxy matrix as reported by [19, 20, 25, 26] were 17.86 MPa, 13.05 MPa, 28.3 MPa and 30.44 MPa. Therefore the tensile strength obtained in this study is higher than those obtained using synthetic epoxy

matrix. This can be attributed not only to the type of matrix but also to the sample preparation, degree of

interfacial bonding, fibre orientation, sample gauge length, fibre volume fraction and manufacturing method [27–30] [27, 29–31]. The samples were carefully cleaned to remove debris and care was taken to align the fibres without much gaps in-between the fibres, these must have contributed to the increase in strength. Mechanical properties of bio based resins are lower than the petroleum-based epoxy resins [32] however certain factors such as preprocessing and post-processing can negate this finding. The tensile strength obtained was also higher than that of the neat bio-epoxy resin as shown in Figure 5a. Nevertheless; the tensile modulus and the elongation at break are comparable with the literature values for natural fibre composites.



Figure 4: Manufactured composites

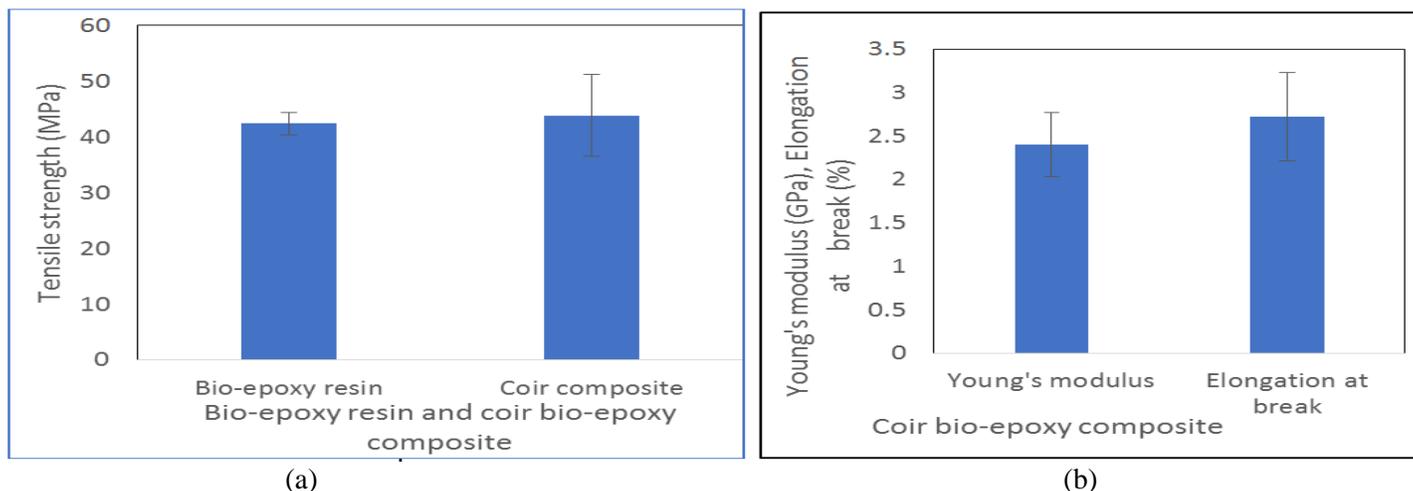


Figure 5: Bar charts showing: (a) Tensile strength and (b) Young's modulus and elongation at break of coir bio-derived epoxy composites.

Table 1: Tensile properties of the manufactured coir bio-epoxy composites

Thickness (mm)	Tensile properties		
	Strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
1.72 ± 0.28	43.83 ± 7.31	2.40 ± 0.37	2.72 0.51

3.2 Failure mode of the coir/bio-epoxy composites

The failure traces of the layered composites are shown in Figure 6. The failure was characterized by initial elastic region. The difference between the maximum failure stress and the minimum failure stress was 36% while the difference between the maximum failure stress and the mid failure stress was 10%. Matrix cracking was observed which can be attributed to poor wettability or thickness swelling; as the fibres get swollen, stress is exerted on the matrix which can lead to the composite micro-cracking and subsequent failure [33–35].

3.3 Morphological characterization

The potted and polished samples for optical microscopy are shown in Figure 7. Cross section of coir fibre (see Fig. 8 (a) and (b) shows that coir fibre is highly porous. The coir fibre surface as observed using optical and SEM microscopy is shown in Fig. 9 (a) and (b). The composites show the arrangement of the fibre within the matrix as shown in Fig. 10. The fibre volume fraction obtained using ImageJ on an 8-bit grey scale was 34%. The tensile strength value can be related to non-too close packing of the fibres within the matrix. This might have

contributed to lower Young's modulus of 2.40 GPa as against 2.82 GPa and 2.90 GPa obtained by [19, 20]

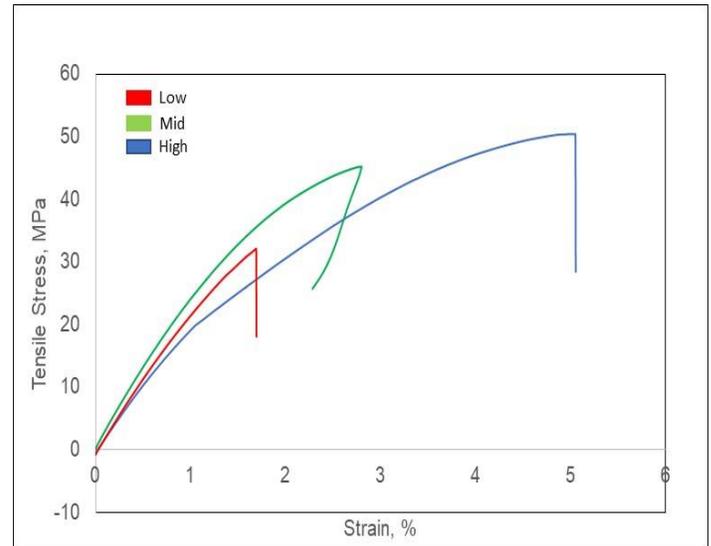


Figure 6: stress-strain curves of the bio-epoxy composites: low strength: 32.13 MPa; mid strength: 45.22 MPa and high strength: 50.42 MPa. The corresponding Young's moduli are: 1.92, 2.31 and 2.92 GPa respectively.

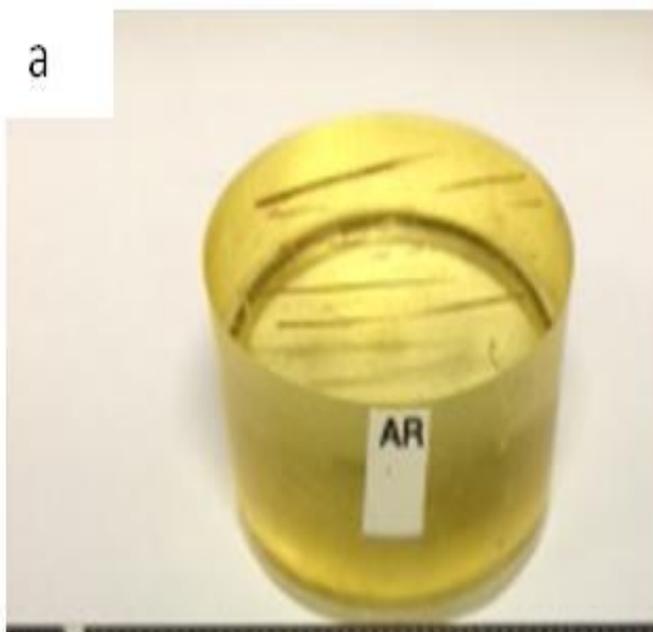


Figure 7: Potted, grinded and polished samples for optical microscopy (a) single coir fibre (b) coir fibre composites.

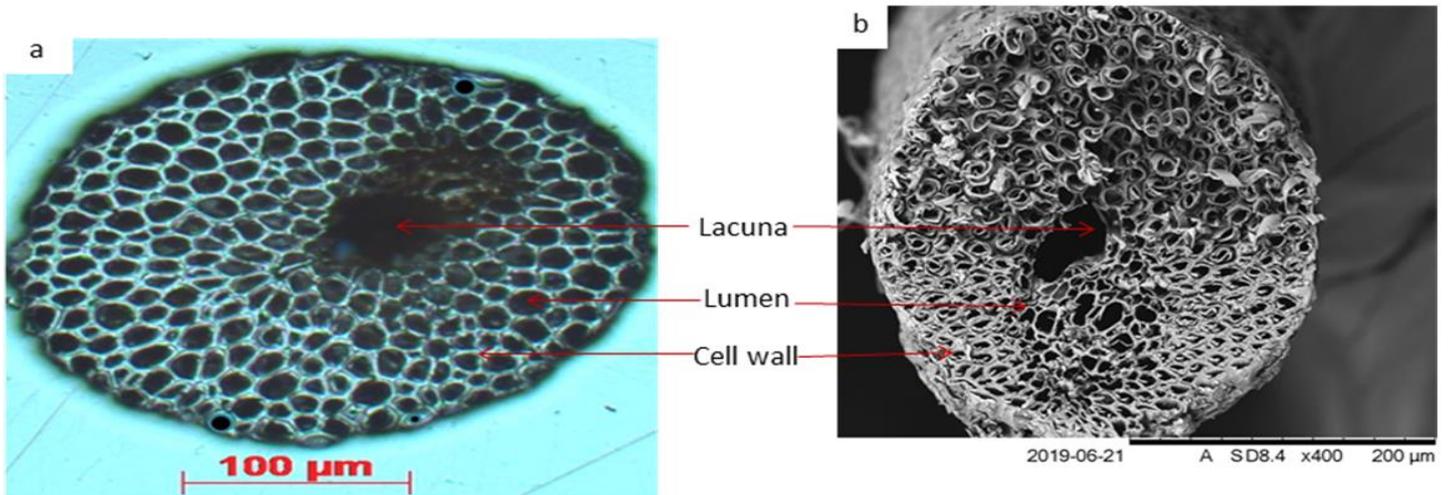


Figure 8: (a) cross-section of coir under optical microscopy (b) cross section of coir under scanning electron microscopy

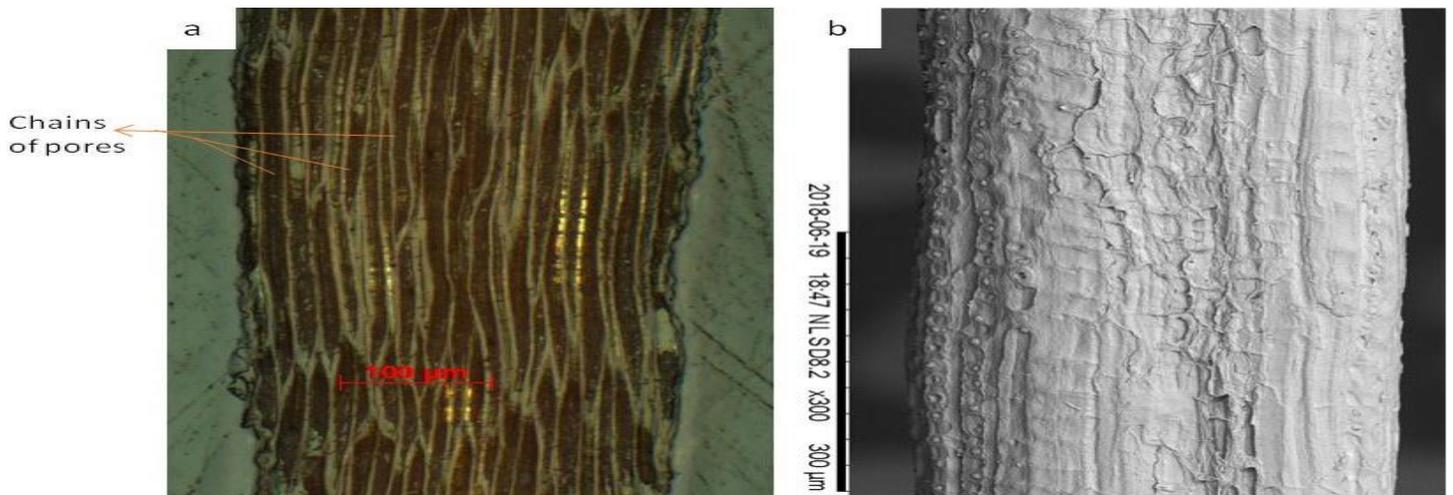


Figure 9: (a) Optical micrograph of coir surface (b) SEM micrograph of coir.

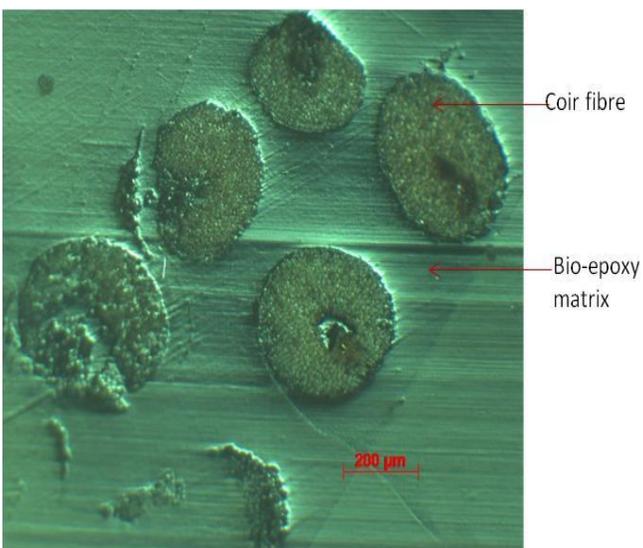


Figure 10: Micrograph of coir bio-epoxy composite

4.0 CONCLUSION

- (i) Coir bio-derived epoxy composites have been produced.
- (ii) The tensile properties of the manufactured composites such as strength, Young's modulus and elongation at break were found to be 43.83 MPa, 2.4 GPa and 2.72 % respectively.
- (iii) The average tensile strength achieved was higher than those obtained using synthetic epoxy matrix and was particularly 70% higher than the value obtained by [25] and 35% higher than the value obtained by [20] for six layers. This was also higher than the value obtained by [37].
- (iv) The optical microstructure of the composites shows the distribution of the fibres within the bio-derived epoxy matrix with fibre volume fraction of 34%.

REFERENCES

- [1] Xie, Y. Hill, C.A.S. Xiao, Z. Militz, H. Mai, C. "Silane coupling agents used for natural fiber/polymer composites: A review". *Compos Part A Appl Sci Manuf.*41(7), 2010, pp 806–19.
- [2] Tobergte, D.R. Curtis, S. "Physical Properties of Coconut Shell Nanoparticles". *J Chem Inf Model.*53(9), , 2013, pp 1689–99.
- [3] Adediran, A.A. Akinwande, A.A. Balogun, O.A. Olasoju, O.S. "Experimental evaluation of bamboo fiber / particulate coconut shell hybrid PVC composite". *Sci Rep.* (0123456789), 2021, pp1–14.
- [4] Obi, F.O. Ugwuishiwu, B.O. Nwakaire, J.N. "Agricultural waste concept , generation , utilization and management". *Niger J Technol.* 35(4), 2016, pp 957–64.
- [5] Madueke, C. Umunakwe, R. Mbah, O. "Comparing the properties of Nigeria coir fibre and those of some other countries for composites applications". *MRS Adv.* (0123456789), 2021, pp 1–4.
- [6] Abdul Khalil, H.P.S. Jawaid, M. Abu Bakar, A. "Woven hybrid composites: Water absorption and thickness swelling behaviours". *BioResources.* 6(2), 2011, pp 1043–52.
- [7] Sawpan, M.A. Pickering, K.L. Fernyhough, A. "Composites: Part A Effect of various chemical treatments on the fibre structure and tensile properties of industrial hemp fibres". *Compos Part A.* 42(8), 2011, 888–95.
- [8] Pickering, K.L. Efendy, M.G.A. Le, T.M. "Composites: Part A A review of recent developments in natural fibre composites and their mechanical performance". 83, 2016, pp 98–112.
- [9] Ranganathan, N. Oksman, K. Nayak, S.K. Sain, M. "Impact toughness, viscoelastic behavior, and morphology of polypropylene-jute-viscose hybrid composites". *J Appl Polym Sci.*133(7), 2016, pp 1–11.
- [10] Tran, L.Q.N. Minh, T.N. Fuentes, C.A. Chi, T.T. Van Vuure, A.W. Verpoest, I. "Investigation of microstructure and tensile properties of porous natural coir fibre for use in composite materials". *Ind Crops Prod.* 65, 2015, pp 437–45.
- [11] Mortazavian S, Fatemi A. "Effects of fiber orientation and anisotropy on tensile strength and elastic modulus of short fiber reinforced polymer composites". *Compos Part B Eng.*72, 2015, pp 116–29.
- [12] Götze, U. Peças, P. Salman, H.M. Kaufmann, J. Schmidt, A. "Risk-sensitive life cycle assessment of green composites for automotive applications". *Green Composites for Automotive Applications.* 2018, pp 219–251.
- [13] Chauhan, V. Kärki, T. Varis, J. "Review of natural fiber-reinforced engineering plastic composites, their applications in the transportation sector and processing techniques". *J Thermoplast Compos Mater.* 2019.
- [14] Suddell, B.C. "Industrial fibres: Recent and current developments". *Proc Symp Nat Fibres.* 44(0), 2008, pp 71–82.
- [15] Rijavec, T. "Natural Fibres and the World Economy – Discover Natural Fibres Initiative". 2017–9, 2019.
- [16] Ticoalu, A. Aravinthan, T. Cardona, F. "A review of current development in natural fiber composites for structural and infrastructure applications". In: Southern Region Engineering Conference, pp. 13-X1, 2010.
- [17] Mukherjee, P.S. Satyanarayana, K.G. "Structure and properties of some vegetable fibres - Part 2 Pineapple fibre (Anannus Comosus)". *J Mater Sci.* 21(1):51–6, 1986.
- [18] Gassan, J. Bledzki, A.K. "Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibres". *Compos Sci Technol.* 59(9), 1999, 1303–9.
- [19] Rait, G.K. "Effect of Surface Treatments on the Mechanical Properties of Coir Fibres and Coir Fibre Reinforced Composites". MSc thesis, University of Birmingham 2014.
- [20] Kim, H. "Hybrid composites with natural fibres". MSc dissertation, University of Bi.
- [21] Haque, M.M. Hasan, M. Islam, M.S. Ali, M.E. "Physico-mechanical properties of chemically treated palm and coir fiber reinforced polypropylene composites". *Bioresour Technol.* 100(20), 2009, 4903–6.
- [22] Chaithanyan, C. Venkatasubramanian, H. Raghuraman, S. Panneerselvam, T. "Evaluation of Mechanical Properties of Coir- Sisal Reinforced Hybrid Composites Using Isophthalic Polyester Resin". 2(12), 2013, 7479–87.
- [23] Kumar, S. Samal, S.K. M. Mohanty, S. Nayak, S.K. "Recent development of bio-based epoxy resins: Review". *Polym. Plast. Technol. Eng.* 57, 2018, 133-155.
- [24] Javadi, A. Srithep, Y. Pilla, S. Lee, J. Gong, S. Turng, L. "Processing and characterization of solid and microcellular PHBV / coir fiber composites". *Mater Sci Eng C.* 30(5), 2010, 749–57.
- [25] Biswas, S. Kindo, S. Patnaik, A. "Effect of fiber length on mechanical behavior of coir fiber reinforced epoxy composites". *Fibers Polym.*12(1), 2011, 73–8.

- [26] Harish, S. Michael, D.P. Bensely, A. Lal, D.M. Rajadurai, A. "Mechanical property evaluation of natural fiber coir composite". *Mater Charact.* 60(1), 2009, 44–9.
- [27] Arib, R.M.N. Sapuan, S.M. Ahmad, M.M.H.M. "Materials & Design Mechanical properties of pineapple leaf fibre reinforced polypropylene composites". 27, 2006, 391–6.
- [28] Nam, T.H. Ogihara, S. Tung, N.H. Kobayashi, S. "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, 1648–56.
- [29] Joseph, K. James, B. Thomas, S. Carvalho, L.H. De. "A review on sisal fiber reinforced polymer". (083), 1999, 367–79.
- [30] Geethamma, V.G. Thomas, M. K. Lakshminarayanan, R. Thomas, S. "Composite of short coir fibres and natural rubber: effect of chemical modification, loading and orientation of fibre". *Polymer (Guildf)*. 39(6–7), 1998, 1483–91.
- [31] Nam, T.H. Ogihara, S. Tung, N.H. Kobayashi, S. "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, 1648–56.
- [32] Derahman, A.A.Z. "Mechanical properties of bio-epoxy resins and synthetic epoxy resins blends Mechanical properties of bio-epoxy resins and synthetic epoxy resins blends". *In: IOP Conference Series.* 2021.
- [33] Ashori, A. Sheshmani, S. "Hybrid composites made from recycled materials: Moisture absorption and thickness swelling behavior". *Bioresour Technol.* 101(12), 2010, 4717–20.
- [34] Masoodi, R. Pillai, K.M. "A study on moisture absorption and swelling in bio-based jute-epoxy composites". *J Reinf Plast Compos.* 31(5), 2012, 285–94.
- [35] Ashik, K.P. Sharma, R.S. Guptha, V.L.J. "Investigation of moisture absorption and mechanical properties of natural /glass fiber reinforced polymer hybrid composites". *Mater Today Proc.* 5(1), 2018, 3000–7.
- [36] Song, S. Hilonga, A. Kim, H. "Characterization of Polycaprolactone and Rice Husk Silica Composite (PCL-SiO₂) by E-Spinning to Apply Supporter for Drug Release Characterization of Polycaprolactone and Rice Husk Silica Composite (PCL-SiO₂) by E-Spinning to Apply Supporter for Drug". *In: IOP Conference Series.* 2018. p. 012013.
- [37] Yan, L. Chouw, N. Huang, L. Kasal, B. "Effect of alkali treatment on microstructure and mechanical properties of coir fibres reinforced-polymer composites and reinforced-cementitious composites. *Constr Build Mater.* 112, 2016, 168–82.