European Journal of Material Science
Vol.9, No.1, pp.25-43, 2022
Print ISSN: ISSN 2055-6551(Print),
Online ISSN: ISSN 2055-656X (Online)

Metal Matrix Composites Development and The Potential of Sugarcane Bagasse and Coir Fibre: A Review

Obinna Onyebuchi Barah [a]*, Kennedy Onyelowe[b], Emmanuel B.O.Olotu[a], Milon Selvam Dennison[a]
a. Department of Mechanical Engineering, Kampala International University, Uganda
b. Department of Civil Engineering, Michael Okpara University of Agriculture, Nigeria.

Citation: Barah O.O.,Onyeloweb K.,Olotua E.B.O., Dennisona M.S.(2022) Metal Matrix Composites Development and The Potential of Sugarcane Bagasse and Coir Fibre: A Review, *European Journal of Material Science* , Vol.9, No.1, pp.25-42

ABSTRACT: *Sugarcane bagasse (SB) and Coir fibre (CF) are two cellulose fibres/agricultural waste products found to constitute great environmental challenges, this has initiated a need to study them for probable potentialities as alternative use in the field of material science and engineering development apart from their localized usage. Consequently, this paper intends at reviewing these two agricultural waste material compositions characteristically to identify their potential development as renewable composite materials. Sugarcane bagasse has a chemical composition within the range of 88.13%, while Coir fibre varies from 25% - 76% of silica content depending on the type of treatment. This is a good quality material for composite production. The compatibility of these cellulose reinforcing agents and their adhesive matrix can be linked to their high cellulose, lignin, and other fibre contents and these can be explored in developing a multiphased system with different properties from the original components while retaining the qualities of the material among other potentials. These two agricultural by-products are good sources of fuel for electricity generation and agents of pozzolanic and polymerization with polypropylene for flame retardation. To conclude, therefore, SB and CF are decent resources for composites production and renewable energy, with excellent biodegradable characteristics consequently controlling environmental degradation.*

KEYWORDS: sugarcane bagasse; coir fibre; materials development; metal matrix; innovative composites; waste valorization.

INTRODUCTION

Fibres with extraordinary characteristics have been principally answerable for the innovative developments in composite materials advancement as unparalleled to orthodox materials. The usage of fibre composites has increased over the years as a result of their elevated strength-to-weight ratio, which is key to countless engineering applications. [1][2][3]

Over the years, attempts have been made to use natural fibres in place of synthetic fibre in the reinforcement of composite materials due to their desirable properties foremost amongst them are biodegradability and good mechanical properties[4]; it worthy of note that in using agro-waste, the cost is reduced to the barest minimum and the environment is sanitized.

Natural fibres are lavishly accessible and ecologically gentle, an advantageous contrast to conventional fibres. Therefore, this review paper aims to study the dual agro-waste of sugarcane bagasse and coconut coir materials by probing through their distinctive structures to identify their potential in developing renewable multifarious materials and maximizing their eco-friendliness. [5],[6],[7].

Selected Fibres

Sugarcane Bagasse

The manufacturing of ethanol and sugar uses sugarcane as a feedstock. Six of the world's most competitive sugar producers are in Africa with Uganda leading the group, it is worthy of note that Uganda has the lowest sugar production cost in Africa at a rate of $140-$180 per hectare with an annual production increase of 3.76% per year; which counts for 5.78milion tonnes sugar produced in 2020. After sugarcane is milled for juice extraction, a residue of about 25% corresponding weight with a carbohydrate content of about 60% to 80% is obtained [8].

Fig.1. Sugarcane Bagasse. Source: [9].

In contrast to being wasted as agricultural waste or burned for energy in sugar and ethanol mills, these carbohydrates, if fermented, might considerably increase the production and sustainability of bioethanol [8],[10],[11],[12]. Both alternatives are toxic and unproductive in creating new materials and promoting green engineering [13],[12]. Sugarcane bagasse is the waste formed after extracting juice from sugarcane in the crushers and among the uses of this agro-waste is power generation. The ash obtained through precise burning of sugarcane bagasse is known as sugarcane bagasse ash, these ashes are not responsive because they are burned at elevated temperatures. under improper settings and the combination of ash from sugarcane bagasse with other constituents has been proven to enhance mechanical properties in the development of superior engineering material. [14],[15],[16].

The improvement of micro-structural and particular mechanical properties of some engineering materials is done using alloys some elements such as chromium, manganese, nickel, tungsten and several others by employing heat treatment which ordinarily climaxes in pricy materials, while cost and robustness are the key concerns in engineering material choice. Consequently, this work is set to examine the Prospects of sugarcane bagasse ash in metal matrix composite reinforcement to produce superior and cost-effective engineering material. An associated goal to the aforementioned of this study will be to advance the consideration of sugarcane bagasse reinforced metal matrix composite and expose a value-added and operational means of repositioning agro-waste such as sugarcane bagasse. The improvement in engineering material development has amplified the application of metals of specific properties for use in engineering mechanisms. To improve strength, hardness, wear, and corrosion resistance, ceramics reinforcement has been introduced to metal matrix composite [17],[18],[19],[20].

Coir Fibre

After the coconut fruit has been harvested, the mesocarp tissue or husk is used to make the versatile natural fibre known as coir. One coconut harvest takes place every 45 days. It is possible to extract around 10 kg of coir, the thickest and most durable of all commercially available natural fibres, from 1000 coconut fruits. Its low rate of breakdown is a technical value for producing long-lasting products. The two primary varieties of coir fibre are brown from aged coconut fruit and delicate white from raw green fruits. Because of their exceptional strength, these fibres have been used for generations to make rope. This is one of the natural fibres with the greatest lignin [21].

Fig. 2. Coir fibre. Source: [22].

This agricultural fibre has a diameter of 12 to 25 microns and can be up to 35 cm long. Coir has one of the highest lignin contents of all vegetable fibres, making it less flexible but stronger than cotton and unsuitable for dyeing. Coir is effectively resistant to microbial attack. When coir fibres are made, tons of leftover coir is created. The shells, in particular, were extensively utilized as a source of fuel for combustion, as a potential substitute for diesel oil, or as manure [23],[24],[25]. Excellent results have been obtained from recent research using coconut shells as reinforcement in the polymer matrix [26]. Therefore the husk could be employed in the composites-producing industry as another type of reinforcement.

Environmentally, a common solution to the erosion issue is coir, by collecting water and preventing the topsoil from drying out, it encourages the growth of new vegetation when woven into geotextiles and applied to regions that need erosion control. Coir geotextiles, unlike geosynthetic materials, provide strong soil support for up to three years, allowing for the establishment of natural flora. They also have a natural ability to store moisture and protect from solar radiation. [102],[103],[104].

The coir's fibre cells are structurally thin, hollow, and have cellulose-based thick walls. They are light in colour when young, but as they age, lignin is deposited on their walls, hardening and turning them yellow. Compared to fibres like flax and cotton, grown tan coir fibres have numerous lignin and a reduced amount of cellulose, making them robust but not as much of elastic. They are composed of thin strands that are 10-20 micrometres in diameter and less than 0.05 inches (1.3 mm) long. As the only natural fibre immune to harm from seawater, coir fibres are comparatively waterproof [27], [28],[29].

To limit heat transfer and increase energy conservation, roof sheets constructed of coir fibre cement mortar have been utilized in Thailand. In that study, a researcher noted that hot, humid countries like Thailand are better suited for natural fibre-based composite building materials. It is thought that a high humidity environment shortens the hydrophilic nature of the natural fibre.
Polyester composites were reinforced with coir fibre that had been treated with 2% alkali; the findings demonstrated enhanced strength under tension and a decrease in resistance above 2% concentration of sodium hydroxide solution [30],[31],[32]. By eliminating the hemicelluloses and lignin components, alkali-treated coir could be better wetted with polyester, which is what led to the improvement in mechanical qualities [33],[34].[35].

However, compared to regular coir fibres, one alkaline pretreatment on dark coir fibres has produced subpar outcomes. [21].

With increasing NaOH concentration for alkaline treatment, the composite's lower tensile strength was observed. The strength loss of the fibre had defeated the goal of increasing the adhesiveness between fibre and matrix through alkaline synthesis.

In addition to investigating the strength qualities, researchers have looked into the phenomena of fibre shrinking [36],[30].

The findings indicate that weight loss and shrinking are greatest in the 20% of alkaline-treated coir fibres. This is because the crystal structure of high NaOH concentrations absorbs a lot of water, causing the fibre to swell. Weight losses and structural shrinking were discovered after the water had been removed.[37]

On the characteristics of composites, the impact of lignin content was investigated. By using sodium chlorite, the content of lignin in coir fibre is reduced to half. [38]. Lignin elimination barely affects the samples' ability to absorb water but has no discernible impact on their mechanical qualities. A group of scholars claimed the leftover content of lignin is still adequate to envelop the fibre exterior, demonstrating that the surplus content of lignin has no impact on the qualities of the composite. [39],[40].

The physiomechanical characteristics of a polymer matrix reinforced coir fibre composite has undergone extensive research. The coir fibre's strength begins to deteriorate when more fibre is added to the polyester matrix. This demonstration shows the strength of the composite is not increased by the random arrangement of coir fibre in the matrix [41],[42].
A common analogy for natural fibre reinforced polymer (FRP) composites has been glass fibre reinforced plastic. Lower strength properties were mostly caused by a weakened interfacial strength of the reinforcement and matrix [43],[44],[45]. Crack spread and void development are made easier by the composite's inadequate bonding structure.

Coir fibre is one type of natural fibre that is a great affordable alternative adsorbent. The findings demonstrated a good ability for methylene blue adsorption [46].

Additionally, [47],[48], eliminate the presence of heavy metal ions like Ni(II), Zn(II), and Fe(II), by chemically altering the fibre, these oxidized coir fibres are effectively regenerating using alkali, having been made more effective in adsorbing metal ions and can be recycled at least three times.

Selected Fibres Characteristics

Sugarcane Bagasse

Numerous researchers have attempted different applications of sugarcane bagasse and other possible applications. According to [49];[50].

Additionally, organic fillers made from agricultural waste have attracted a lot of interest across many industries due to their Low densities providing several advantages, including biodegradability, low cost, and low energy use. As stated in table 1 below, many reports have been published on cellulose fillers reinforced composites as well as the chemical makeup of coir fibre.
The applicability of sugarcane bagasse depends on factors like its mineralogy, biochemical, and physicomechanical qualities [51],[107]. Composites have been demonstrated to

have impossible feats in mechanical and physical capabilities as multipurpose engineering materials that may be tested to meet any application requirement [52],[53],[54]. To develop a multiphase system with different properties from the original components while retaining the qualities of the material, the reinforcing agent and adhesive matrix should be compatible.[55],[56]. With a mean length of 1590µm, sugarcane bagasse has high cellulose, lignin, and fibre content and is longer than wheat straw [57].

Table 1. Sugarcane bagasse chemical composition

Cellulose	Hemicellulose	Lignin	Fat and Waxes	Ash	Source
50.4	28.5	14.9		2	[58].
35.46	31.25	23.7	-	-	[59].
50	25	25	0.6	5	[60],[61]
36	24.5	21.9	-	9.6	[62].
43	10.1	33.23	-	1	[63].
49.44	23.19	12.56	2-2.5	-	[64].
40	24.4	15	3.5	5-6	[65].
48.68	25.46	21.94	-	3.92	[66].
40 -43	28-30	9-11	3.5-5.5	2.4	[65].
55.7	-	20.5	-	1.85-3.7	[67].
40-46	24.5	19.5-20	-	0.6-2.4	[68].
69.4	21.1	4.4	-	-	[69].
41.8	28	21.8	-	1.1	[70].
55.2	16.8	25.3	-	7	[65].
56	6	29	-	-	[71].
36.32	24.7	18.14		-	[72]

Table 2: Sugarcane bagasse Physiomechanical properties

Properties	Value
Density (g/cm3)	1.2
Tensile Strength (MPa)	20 -290
Modulus of elasticity (GPa)	19.-27.1
Elongation Break (%)	1.1

Source: [73]

Coir Fibre Characteristics

To fulfil its primary function, the potential coir fibre available resources for the construction of metal matrix composites must retain some specific suited characteristics. This resource potential is strongly influenced by its outstanding characteristics, such as its biological, physical, mineralogical, and mechanical properties [51],[74]. The blend of more than one physical material gives rise to composite compounds According to [52],[106] Composites are multipurpose engineering materials that have unmatched physical and mechanical qualities and may be customized to meet the needs of a specific application.

To produce a multi-phase structure with various qualities of the base materials while retaining the unique characteristics of the material, the strengthening agent (coir fibre) and matrix must work in harmony [55],[105].

The advantages of coir fibres are their cost efficiency, rich lignin content, good density, accessibility, good plasticity and elasticity, among others [75],[76]. The creation of fibre-reinforced composites requires an understanding of this composition. The chemical, physio-mechanical, thermal, and microstructural are all covered in this review. The table below shows the chemical makeup of coir fibre; various changes across samples may be caused by geographic variations, varying climatic conditions, soil chemistry, etc.

Table 3. Coir fibre chemical composition

Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Source
37	0.20	42	1.25	[78].
32-43	0.15-0.25	40-45	-	[79].
37	0.15	42	-	[80].
36-43	0.20	41-45	1.8	[81].
36–43	0.20	41–45	1.8	[82].
45–50	–	30	–	[83].
37	–	42	–	[44]
43.4	0.25	45.8	3	[44], [84].
36–43	0.15–0.25	41–45	3–4	[85].
42.14	15–17	35.25	–	[86].
32–43	0.15–0.25	40–45	–	[87].
38–46	10–15	37–41	–	[88].
42.44	0.25	45.4	3	[89].
32–43	0.15–0.25	40–45	–	[90].
45.67	0.12–0.25	41–45	–	[75].
39.3	–	29.8	–	[91].
43.44	0.25	45.84	3	[81].

The features of the elements that constitute a composite and the interactions that surround them are what primarily determine its properties. Weight improvement through water absorption and density amongst other properties of a material are referred to as its physical property whereas properties comprising tensile, flexural, impact strengths etc. are mechanical. Table 2 below shows the evaluation of a few of the physiomechanical characteristics of coir fibres as acknowledged and evaluated by various scholars.

Table 4: Coir fibre PhysioMechanical properties.

Density (g/cm^3)	**Water absorption (%)**	**Modulus of Elasticity (GPa)**	**Tensile strength (MPa)**	**Elongation at break (%)**	**Source**
1.20	130-180	4-6	175	30	[92].
1.25	--	--	--	--	[78].
1.20	--	6	593	30	[79].
--	--	3-6	106-175	47	[44]
1.2	--	4-6	150-180	47	[93].
1.15-1.46	--	2.2—6	95 –230	15 –51.4	[94],[82].
1.24	--	6.4	139	28	[95].
1.2	--	2.74	286	20.8	[82].
1.3 -1.5	10	4 -6	105 -175	17 – 47	[86].
1.2	--	2	144	45	[87].
--	--	3.23	165.2	39.45	[96].
--	--	4 -6	144	15-40	[90].
1.15	--	4 -6	108 -252	15-40	[97].
1.37	--	3.19-3.23	158 -165	39-41	[96].
--	--	4 -5	250	20-40	[98].
--	--	3 -6	106 -175	47	[44]
--	--	4 -6	131 -175	47.2	[99].
1.3	--	3.11	144.6	32.3	[76].
1.17	93	8	95 -188	--	[100].
1.2	--	4 -6	593	30	[101].

In summation, the density of coir fibre is 1.15-1.45 g/cm3, with a water absorption capacity of 10-180%, a young's modulus of 2-6GPa, and tensile strength of 95-593MPa, and an elongation at break of 15-51.4%. The source, geographic location, procedures used to harvest the fibre, and pre-treatment could all affect the reported differential in features. The boundary relationship between the reinforcement agents and their matrix is strategic in terms of their overall performance characteristics. The leading limitations of coir fibres hover around high moisture content, and this can be measured through chemical treatment.

Table 5: Comparison between Cellulose content of SB and CF

Cellulose content of sugaecane bagasse in (%)	Coir fibre Cellulos content in (%)
50.4 [58].	37 [78].
35.46 [59].	32-43 [79].
50 [60],[61].	37 [80].
36 [62].	36-43 [81].
43 [63].	36-43 [82].
49.44 [64].	45-50 [83].
48.68 [66].	37 [44]
40 -43 [65].	43.4 [44], [84].
55.7 [67].	36-43 [85].
40-46 [68].	42.14 [86].
69.4 [69].	32-43 [87].
55.2-56 [65].	38-46 [88].
36.3 [72].	42.44 [89].
	32-43 [90]
	45.67 [75].
	39.3 [91].
	43.44 [81].

Table 6: Comparison of Hemicellulose content of SB and CF

Sugarcane bagasse Hemicellulose (%) content	Coir Fibre Hemicellulose (%) content
28.5 [58].	0.20 [78].
31.25 [59].	0.15-0.25 [79].
25 [60],[61].	0.15 [80].
24.5 [62].	0.20 [81].
10.1 [63].	0.20 ([82].
23.19 [64].	0.25 [44], [84]
24.4 [65].	0.15–0.25 [85].
25.46 [66].	15–17 [86].
28-30 [67].	0.15–0.25 [87].
24.5-28 [68].	10–15 [88].
21.1 [69].	0.25 [89].
6-16.8 [65]	0.15–0.25 [90].
24.7 [72].	0.12–0.25 [75].
	0.25 [81].

Table 7: Comparison of Lignin contents of SB and CF

Sugarcane Bagasse Lignin content in (%)	Coir Fibre Lignin content in (%)
14.9[58].	42 [78].
23.7 (Kordkheili et al,2012)	40-45 [79].
25 [60],[61].	42 [80].
21.9 [62].	41-45 [81].
33.23 [63].)	41-45[82].
12.56 [64].	30 [83].
21.94 [66].	42 [44].
9 -15 [65].	45.8 [84].
20.5 [67].	41-45 [85].
19.521.8 [68].	35.25 [86].
4.4 [69].	40-45 [87].
25.3-29 [65].	37-41 [88].
18.14 [72].	45.4 [89].
	40-45 [90].
	41-45 [75].
	29.8 [91].
	45.84 [81].

The main percentage of the massive quantity of biomass present in SB and CF is indicated in the percentages presence of cellulose, hemicellulose and lignin 35.46% -69.4%, 6-31.25% and 4.4-33.23% respectively for sugarcane bagasse, while Coir fibre possesses 32-50%, 0.2-17% and 29.8-45.84% correspondingly. It is important to note that the differential features may be altered by environmental and chemical activities such as geographic location, source, procedures used to harvest the fibre, and pre-treatment.

Potential of Sugarcane Bagasse and Coir Fibre in the Development Of Metal Matrix Composites.

Chemical and material products made from renewable resources are becoming increasingly important. The need for sustainable development, financial viability, and environmental friendliness are the key drivers. When disposed of, pollutants like sugarcane bagasse and coir fibre are harmful to the environment. It has been widely practised to recycle waste materials like coir fibre and sugarcane bagasse to reduce environmental hazards and turn them into high-value products. This is done by combining them with other elements to create composite materials that are more durable and have improved economic worth. Several uses of sugarcane bagasse and coir fibre have been discovered by investigating their constituents.

Coir fibre admixture has been successfully used in a variety of products, including household items, sanitary, and fishing equipment. It has also been used successfully as a cement mortar substitute in roof sheets to control heat transfer and conserve energy. Contrastingly, these two agro-wastes have been investigated and shown to have potential usage in applications requiring multifunctional mechanical properties.

Cellulose and lignin are prevalent in both, with SB possessing 69.4% and 33.23% respectively, and CF containing approximately 50% and 45.84% respectively, per weight. This is a crucial component in the filtration and treatment of water. According to some studies, coir fibre and sugarcane bagasse both can be utilized as a source of fuel and energy production. On a wet, as-fired basis, sugarcane bagasse has a heating value that varies from 12560.4 –16747.2 KJ/Kg. The energy content of coir fibre alone has been approximated to be between 7200 –7960 KJ/Kg, with the capacity to support sustainable global energy.

According to the review, the SB and CF wastes could be used for binder and reinforcing agent matrix. Materials with their kind qualities are in high demand in the manufacturing and automotive industries. When employed, the wastes provide stronger resistance to breaking under tension because of their superior mechanical characteristic. Impermeability and robustness are prime considerations in the development of metal matrix materials because they affect how much weight a material can bear without fracturing. With chemical synthesis, the silica contents of these wastes—about 80% in the case of sugarcane bagasse and 90% for coir fibre—can be used in chemical processes for applications like fillers in the plastics industry as well as catalysts and adsorbents in the fabrication of metal matrix composites.

Cellulose $(C_6H_{10}O_5)_n$ and hemicellulose $(C_5H_8O_4)_m$, which are biodegradable and non-toxic and can be utilized in toothpaste, cosmetics, explosive manufacture, and papermaking, have been discovered to be present in sugarcane bagasse chemical components.Coir fibre is appropriate for outdoor uses due to its high resistance to damage from seawater. Lignin components, which have several industrial usages as an adhesion, a reinforcement material or functional component of epoxy resins, a binding agent and similar laminated or composite wood products, and a soil conditioner are also included in the chemical properties composition of sugarcane bagasse and coir fibre ashes.

DISCUSSION

The quest to provide alternative solutions to the 21st-century environmental challenges, and promote eco-friendly materials as the better alternative in the development of metal matrix composite materials led to research into the sugarcane bagasse and coir fibre constituents. Numerous regions of the world produce and consume sugarcane and coconuts, but the byproducts left over after the food value has been removed make the final products harmful to the environment. Many studies have found and confirmed that utilising coir fibre and sugarcane bagasse will significantly improve our environment while also generating economic benefits from their wastes. Both coir fibre and sugarcane bagasse are non-toxic, biodegradable materials that are high in silica content. The materials can be reinforced and bound with matrix agents thanks to this characteristic, their uses in the creation of metal matrix composites are diverse.

CONCLUSION

Researchers are examining the characteristics of sugarcane bagasse and coir fibre to turn these materials into appealing composite goods because of the possible environmental harm that sugarcane bagasse and coir fibre could generate if not managed well throughout the year-round farming season. Researchers agree that coir fibre and sugarcane bagasse are agricultural waste that must be eliminated from the environment to prevent environmental deterioration, contamination, and climate change. From the surveyed literature, it can be inferred that coir fibre and sugarcane bagasse, as biodegradable, non-toxic renewable resources and agricultural wastes, have the potential to be effective in the development of composites. In the end, this will prevent environmental degradation and lessen the impact of climate change

References:

[1]. Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics?. *Composites science and technology*, *63*(9), 1259-1264.

[2]. Xiao, Y., Zhang, Z., Yao, P., Fan, K., Zhou, H., Gong, T., ... & Deng, M. (2018). Mechanical and tribological behaviors of copper metal matrix composites for brake pads used in high-speed trains. *Tribology International*, *119*, 585-592.

[3]. Lalmuan, S. K., Das, S., Chandrasekaran, M., & Tamang, S. K. (2017). Machining investigation on hybrid metal matrix composites-a review. *Materials Today: Proceedings*, *4*(8), 8167-8175.

[4]. Jayavani, et al, 2015); Adeniyi, A. G., Onifade, D. V., Ighalo, J. O., & Adeoye, A. S. (2019). A review of coir fiber reinforced polymer composites. *Composites Part B: Engineering*, *176*, 107305.

[5]. Sarath, M. V., Gharde, S. S., Ojjela, O., & Kandasubramanian, B. (2021). Fiber-Reinforced Composites for Restituting Automobile Leaf Spring Suspension System. In *Recent Advances in Layered Materials and Structures* (pp. 67-105). Springer, Singapore.

[6]. Manaba, B., & Hashe, V. T. (2021). A review of composite leaf springs for automotive vehicles. In *MATEC Web of Conferences* (Vol. 347). EDP Sciences.

[7]. Ramesh, M., Rajeshkumar, L., & Bhuvaneswari, V. (2021). Leaf fibres as reinforcements in green composites: A review on processing, properties and applications. *Emergent Materials*, 1-25.

[8]. Vargas Betancur, G. J., & Pereira Jr, N. (2010). Sugar cane bagasse as feedstock for second generation ethanol production: part I: diluted acid pretreatment optimization. *Electronic Journal of Biotechnology*, *13*(3), 10-11.

[9]. Prusty, J. K., Patro, S. K., & Basarkar, S. S. (2016). Concrete using agro-waste as fine aggregate for sustainable built environment–A review. *International Journal of Sustainable Built Environment*, *5*(2), 312-333.

[10]. Zhang, Y. H. P., & Lynd, L. R. (2004). Toward an aggregated understanding of enzymatic hydrolysis of cellulose: noncomplexed cellulase systems. *Biotechnology and bioengineering*, *88*(7), 797-824.

[11]. Himmel, M. E., Ding, S. Y., Johnson, D. K., Adney, W. S., Nimlos, M. R., Brady, J. W., & Foust, T. D. (2007). Biomass recalcitrance: engineering plants and enzymes for biofuels production. *science*, *315*(5813), 804-807.

[12]. Pauly, M., & Keegstra, K. (2008). Cell‐wall carbohydrates and their modification as a resource for biofuels. *The Plant Journal*, *54*(4), 559-568.

[13]. Rezende, C. A., De Lima, M. A., Maziero, P., deAzevedo, E. R., Garcia, W., & Polikarpov, I. (2011). Chemical and morphological characterization of sugarcane bagasse submitted to a delignification process for enhanced enzymatic digestibility. *Biotechnology for biofuels*, *4*(1), 1-19.

[14]. Bahurudeen, A., & Santhanam, M. (2014). Performance evaluation of sugarcane bagasse ash-based cement for durable concrete.

[15]. Bahurudeen, A., Wani, K., Basit, M. A., & Santhanam, M. (2016). Assesment of pozzolanic performance of sugarcane bagasse ash. *Journal of Materials in Civil Engineering*, *28*(2), 04015095.

[16]. Abdulkadir, T. S., Oyejobi, D. O., & Lawal, A. A. (2014). Evaluation of sugarcane bagasse ash as a replacement for cement in concrete works. *Acta Technica Corviniensis-Bulletin of Engineering*, *7*(3), 71.

[17]. Hodder, K. J., Izadi, H., McDonald, A. G., & Gerlich, A. P. (2012). Fabrication of aluminum–alumina metal matrix composites via cold gas dynamic spraying at low pressure followed by friction stir processing. *Materials Science and Engineering: A*, *556*, 114-121.

[18]. Mistry, J. M., & Gohil, P. P. (2018). Research review of diversified reinforcement on aluminum metal matrix composites: fabrication processes and mechanical characterization. *Science and Engineering of Composite Materials*, *25*(4), 633-647.

[19]. Grilo, J., Carneiro, V. H., Teixeira, J. C., & Puga, H. (2021). Manufacturing methodology on casting-based aluminium matrix composites: systematic review. *Metals*, *11*(3), 436.

[20]. Zhang, H., Ramesh, K. T., & Chin, E. S. C. (2008). A multi-axial constitutive model for metal matrix composites. *Journal of the Mechanics and Physics of Solids*, *56*(10), 2972-2983

[21]. Gu, H., 2009. Tensile behaviours of the coir fibre and related composites after NaOH treatment. Mater. Design 30, 39313934.

[22]. Liné Cowley, (2019, June 12) "Coir – the Natural Fiber from Coconut Husk" Eco World https://ecoworldonline.com/coir-the-natural-fiber-from-coconut-husk/

[23]. Wever, D.-A.Z., Heeres, H., Broekhuis, A.A., 2012. Characterization of Physic nut (Jatropha curcas L.) shells. Biomass Bioenergy 37, 177187

[24]. Queirós, C. S., Cardoso, S., Lourenço, A., Ferreira, J., Miranda, I., Lourenço, M. J. V., & Pereira, H. (2020). Characterization of walnut, almond, and pine nut shells regarding chemical composition and extract composition. *Biomass Conversion and Biorefinery*, *10*(1), 175-188.

[25]. Linan, L. Z., Cidreira, A. C. M., da Rocha, C. Q., de Menezes, F. F., de Moraes Rocha, G. J., & Paiva, A. E. M. (2021). Utilization of acai berry residual biomass for extraction of lignocellulosic byproducts. *Journal of Bioresources and Bioproducts*, *6*(4), 323-337.

[26]. Qaiss, A., Bouhfid, R., & Essabir, H. (2015). Characterization and use of coir, almond, apricot, argan, shells, and wood as reinforcement in the polymeric matrix in order to

valorize these products. In *Agricultural biomass based potential materials* (pp. 305-339). Springer, Cham.

[27]. Shekar, H. S., & Ramachandra, M. J. M. T. P. (2018). Green composites: a review. *Materials Today: Proceedings*, *5*(1), 2518-2526.

[28]. Balar, K. P., Mistri, P. S., & Rathod, H. A. AGRO WASTE: OPPORTUNITIES FOR DEVELOPMENT OF VALUE ADDED CIVIL ENGINEERING PRODUCTS.

[29]. Mukhopadhyay, S., Annamalai, D., & Srikanta, R. (2011). Coir fiber for heat insulation. *Journal of natural fibers*, *8*(1), 48-58.

[30]. Rout, J., Misra, M., Tripathy, S. S., Nayak, S. K., & Mohanty, A. K. (2001). The influence of fibre treatment on the performance of coir-polyester composites. *Composites Science and Technology*, *61*(9), 1303-1310.

[31]. Asasutjarit, C., Charoenvai, S., Hirunlabh, J., & Khedari, J. (2009). Materials and mechanical properties of pretreated coir-based green composites. *Composites Part B: Engineering*, *40*(7), 633-637.

[32]. Noorunnisa Khanam, P., Ramachandra Reddy, G., Raghu, K., & Venkata Naidu, S. (2010). Tensile, flexural, and compressive properties of coir/silk fiber-reinforced hybrid composites. *Journal of reinforced plastics and composites*, *29*(14), 2124-2127.

[33]. Arrakhiz, F. Z., El Achaby, M., Kakou, A. C., Vaudreuil, S., Benmoussa, K., Bouhfid, R., ... & Qaiss, A. (2012). Mechanical properties of high-density polyethylene reinforced with chemically modified coir fibers: impact of chemical treatments. *Materials & Design*, *37*, 379-383.

[34]. Mir, S. S., Hasan, S. M., Hossain, M. J., & Hasan, M. (2012). Chemical modification effect on the mechanical properties of coir fiber. *Engineering Journal*, *16*(2), 73-84.

[35]. Haque, M., Rahman, R., Islam, N., Huque, M., & Hasan, M. (2010). Mechanical properties of polypropylene composites reinforced with chemically treated coir and abaca fiber. *Journal of reinforced plastics and composites*, *29*(15), 2253-2261.

[36]. Rahman, M. M., & Khan, M. A. (2007). Surface treatment of coir (Cocos nucifera) fibers and its influence on the fibers' physico-mechanical properties. *Composites science and technology*, *67*(11-12), 2369-2376.

[37]. Ouajai, S., Hodzic, A., & Shanks, R. A. (2004). Morphological and grafting modification of natural cellulose fibers. *Journal of Applied Polymer Science*, *94*(6), 2456-2465.

[38]. Muensri, P., Kunanopparat, T., Menut, P., & Siriwattanayotin, S. (2011). Effect of lignin removal on the properties of coconut coir fiber/wheat gluten biocomposite. *Composites Part A: Applied Science and Manufacturing*, *42*(2), 173-179.

[39]. Hemsri, S., Grieco, K., Asandei, A. D., & Parnas, R. S. (2012). Wheat gluten composites reinforced with coconut fiber. *Composites Part A: Applied Science and Manufacturing*, *43*(7), 1160-1168.

[40]. Montaño-Leyva, B., da Silva, G. G. D., Gastaldi, E., Torres-Chávez, P., Gontard, N., & Angellier-Coussy, H. (2013). Biocomposites from wheat proteins and fibers: Structure/mechanical properties relationships. *Industrial Crops and Products*, *43*, 545-555.

[41]. Monteiro, S. N., Terrones, L. A. H., & D'almeida, J. R. M. (2008). Mechanical performance of coir fiber/polyester composites. *Polymer testing*, *27*(5), 591-595.

[42]. Verma, D., & Gope, P. C. (2015). The use of coir/coconut fibers as reinforcements in composites. In *Biofiber reinforcements in composite materials* (pp. 285-319). Woodhead Publishing.

[43]. Harish, S., Michael, D. P., Bensely, A., Lal, D. M., & Rajadurai, A. (2009). Mechanical property evaluation of natural fiber coir composite. *Materials characterization*, *60*(1), 44-49.

[44]. Verma D, Gope P, Shandilya A, Gupta A, Maheshwari M. Coir fibre reinforcement and application in polymer composites: A. Environ Sci 2013;4(2):263–76.

[45]. Biswas, S., Kindo, S., & Patnaik, A. (2011). Effect of fiber length on mechanical behavior of coir fiber reinforced epoxy composites. *Fibers and Polymers*, *12*(1), 73-78.

[46]. Etim, U. J., Umoren, S. A., & Eduok, U. M. (2016). Coconut coir dust as a low cost adsorbent for the removal of cationic dye from aqueous solution. *Journal of Saudi Chemical Society*, *20*, S67-S76.

[47]. Shukla, S. R., Pai, R. S., & Shendarkar, A. D. (2006). Adsorption of Ni (II), Zn (II) and Fe (II) on modified coir fibres. *Separation and purification technology*, *47*(3), 141-147.

[48]. Conrad, K., & Hansen, H. C. B. (2007). Sorption of zinc and lead on coir. *Bioresource Technology*, *98*(1), 89-97.

[49]. Onuegbu, G. C., Madufor, I. C., & Ogbobe, O. (2012). Studies on effect of maleated polyethylene compatibilizer on some mechanical properties of kola nut filled low density polyethylene. *Academic Research International*, *3*(1), 406.

[50]. Obasi, H. C., & Onuegbu, G. C. (2013). Biodegradability and mechanical properties of low density polyethylene/waste maize cob flour blends. *Int. J. Appl. Sci. Eng. Res*, *2*(3), 233-240.

[51]. Sultana, M. S., Hossain, M. I., Rahman, M. A., & Khan, M. H. (2014). Influence of rice husk ash and fly ash on properties of red clay. *Journal Of Scientific Research*, *6*(3), 421-430.

[52]. Doorvasan, M., Sathiyamurthy, S., Jayabal, S., & Chidambaram, K. (2014). Moisture content of rice husk particulate natural fiber polymer composites. *OSR Journal of Mechanical and Civil Engineering*, *24*, 17-21.

[53]. Das, G., & Biswas, S. (2016). Effect of fiber parameters on physical, mechanical and water absorption behaviour of coir fiber–epoxy composites. *Journal of Reinforced Plastics and Composites*, *35*(8), 644-653.

[54]. Bharathiraja, G., Jayabal, S., Kalyana Sundaram, S., Rajamuneeswaran, S., & Manjunath, B. H. (2016, March). Mechanical Behaviors of Rice Husk and Boiled Egg Shell Particles Impregnated Coir-Polyester Composites. In *Macromolecular Symposia* (Vol. 361, No. 1, pp. 136-140).

[55] Abraham, E., Deepa, B., Pothan, L. A., Jacob, M., Thomas, S., Cvelbar, U., & Anandjiwala, R. (2011). Extraction of nanocellulose fibrils from lignocellulosic fibres: A novel approach. *Carbohydrate Polymers*, *86*(4), 1468-1475.

[56]. Chandra, J., George, N., & Narayanankutty, S. K. (2016). Isolation and characterization of cellulose nanofibrils from arecanut husk fibre. *Carbohydrate polymers*, *142*, 158-166.

[57]. Aziz, S., Gale, J., Ebrahimpour, A., & Schoen, M. P. (2011, January). Passive control of a wind turbine blade using composite material. In *ASME International Mechanical Engineering Congress and Exposition* (Vol. 54945, pp. 467-476).

[58]. Huang, C., Zhao, C., Li, H., Xiong, L., Chen, X., Luo, M., & Chen, X. (2018). Comparison of different pretreatments on the synergistic effect of cellulase and xylanase during the enzymatic hydrolysis of sugarcane bagasse. *RSC advances*, *8*(54), 30725-30731.

[59]. Kordkheili, H. Y., Hiziroglu, S., & Farsi, M. (2012). Some of the physical and mechanical properties of cement composites manufactured from carbon nanotubes and bagasse fiber. *Materials & Design*, *33*, 395-398.

[60]. Huang, W., Gong, F., Fan, M., Zhai, Q., Hong, C., & Li, Q. (2012). Production of light olefins by catalytic conversion of lignocellulosic biomass with HZSM-5 zeolite impregnated with 6 wt.% lanthanum. *Bioresource Technology*, *121*, 248-255.

[61]. Peng, F., Ren, J. L., Xu, F., Bian, J., Peng, P., & Sun, R. C. (2010). Comparative studies on the physico-chemical properties of hemicelluloses obtained by DEAE-cellulose-52 chromatography from sugarcane bagasse. *Food research international*, *43*(3), 683-693.

[62]. Ahmed, N., Zeeshan, M., Iqbal, N., Farooq, M. Z., & Shah, S. A. (2018). Investigation on bio-oil yield and quality with scrap tire addition in sugarcane bagasse pyrolysis. *Journal of Cleaner Production*, *196*, 927-934.

[63]. Ibrahim, Q., & Kruse, A. (2020). Prehydrolysis and organosolv delignification process for the recovery of hemicellulose and lignin from beech wood. *Bioresource Technology Reports*, *11*, 100506.

[64]. Ramlee, N. A., Jawaid, M., Zainudin, E. S., & Yamani, S. A. K. (2019). Tensile, physical and morphological properties of oil palm empty fruit bunch/sugarcane bagasse fibre reinforced phenolic hybrid composites. *Journal of Materials Research and Technology*, *8*(4), 3466-3474.

[65]. Hajiha, H., & Sain, M. (2015). The use of sugarcane bagasse fibres as reinforcements in composites. In *Biofiber reinforcements in composite materials* (pp. 525-549). Woodhead Publishing.

[66]. Onésippe, C., Passe-Coutrin, N., Toro, F., Delvasto, S., Bilba, K., & Arsène, M. A. (2010). Sugar cane bagasse fibres reinforced cement composites: thermal considerations. *Composites Part A: Applied Science and Manufacturing*, *41*(4), 549-556.

[67]. Amin, H. A., Secundo, F., Amer, H., Mostafa, F. A., & Helmy, W. A. (2018). Improvement of Aspergillus flavus saponin hydrolase thermal stability and productivity via immobilization on a novel carrier based on sugarcane bagasse. *Biotechnology reports*, *17*, 55-62.

[68]. Yu, Q., Xu, C., Zhuang, X., Yuan, Z., He, M., & Zhou, G. (2015). Xylo-oligosaccharides and ethanol production from liquid hot water hydrolysate of sugarcane bagasse. *BioResources*, *10*(1), 30-40.

[69]. Habibi, Y., El-Zawawy, W. K., Ibrahim, M. M., & Dufresne, A. (2008). Processing and characterization of reinforced polyethylene composites made with lignocellulosic fibers from Egyptian agro-industrial residues. *Composites Science and Technology*, *68*(7-8), 1877-1885.

[70]. Bhatti, H. N., Sadaf, S., Naz, M., Iqbal, M., Safa, Y., Ain, H., ... & Nazir, A. (2021). Enhanced adsorption of Foron Black RD 3GRN dye onto sugarcane bagasse biomass and Na-alginate composite. *Desalination Water Treat*, *216*, 423-435.

[71]. Chantit, F., El Abbassi, F. E., & Kchikach, A. (2022). Investigation on the reuse of the sugar co-products (Bagasse, Molasses, and Ash) as industrial wastes in the production of Compressed earth blocks. *Materials Today: Proceedings*, *58*, 1530-1534.

[72]. Vilay, V., Mariatti, M., Taib, R. M., & Todo, M. (2008). Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber–reinforced unsaturated polyester composites. *Composites Science and Technology*, *68*(3-4), 631-638.

[73]. Jayamani, E., Rahman, M. R., Benhur, D. A., Bakri, M. K. B., Kakar, A., & Khan, A. (2020). Comparative study of fly ash/sugarcane fiber reinforced polymer composites properties. *BioResources*, *15*(3), 5514-5531.

[74]. Sultana, M., & Ahmed, A. N. (2022). Study on Sugarcane Bagasse Ash–Clay Mixture Properties to Develop Red Ceramic Materials. *Sugar Tech*, 1-8.

[75]. Sudhakara P, Jagadeesh D, Wang Y, Prasad CV, Devi AK, Balakrishnan G, Kim B, Song J. Fabrication of Borassus fruit lignocellulose fiber/PP composites and comparison with jute, sisal and coir fibers. Carbohydr Polym 2013;98(1): 1002–10

[76]. Saw SK, Sarkhel G, Choudhury A. Preparation and characterization of chemically modified Jute–Coir hybrid fiber reinforced epoxy novolac composites. J Appl Polym Sci 2012;125(4):3038–49.

[78]. Omrani, E., Menezes, P. L., & Rohatgi, P. K. (2016). State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world. *Engineering Science and Technology, an International Journal*, *19*(2), 717-736.

[79]. Duan, J., Wu, H., Fu, W., & Hao, M. (2018). Mechanical properties of hybrid sisal/coir fibers reinforced polylactide biocomposites. *Polymer Composites*, *39*, E188-E199.

[80]. Bongarde, U. S., & Khot, B. K. (2019). A review on coir fiber reinforced polymer composite. *International Research Journal of Engineering and Technology*, *6*(4), 793-95.

[81]. Adeniyi, A. G., Onifade, D. V., Ighalo, J. O., & Adeoye, A. S. (2019). A review of coir fibre reinforced polymer composites. *Composites Part B: Engineering*, *176*, 107305.

[82]. Sliseris, J., Yan, L., & Kasal, B. (2016). Numerical modelling of flax short fibre reinforced and flax fibre fabric reinforced polymer composites. *Composites part B: engineering*, *89*, 143-154.

[83]. Arifuzzaman Khan, G. M., Alam Shams, M. S., Kabir, M. R., Gafur, M. A., Terano, M., & Alam, M. S. (2013). Influence of chemical treatment on the properties of banana stem fiber and banana stem fiber/coir hybrid fiber reinforced maleic anhydride grafted polypropylene/low-density polyethylene composites. *Journal of applied polymer science*, *128*(2), 1020-1029.

[84]. Verma, D., Gope, P. C., Shandilya, A., Gupta, A., & Maheshwari, M. K. (2013). Coir fibre reinforcement and application in polymer composites. *J. Mater. Environ. Sci*, *4*(2), 263-276.

[85]. Zhang L, Hu Y. Novel lignocellulosic hybrid particleboard composites made from rice straws and coir fibers. Mater Des 2014;55:19–26.

[86]. Siakeng R, Jawaid M, Ariffin H, Salit MS. Effects of surface treatments on tensile, thermal and fibre-matrix bond strength of coir and pineapple leaf fibres with poly lactic acid. J Bionics Eng 2018;15(6):1035–46.

[87]. Yusoff RB, Takagi H, Nakagaito AN. Tensile and flexural properties of polylactic acid-based hybrid green composites reinforced by kenaf, bamboo and coir fibers. Ind Crops Prod 2016;94:562–73.

[88]. Pérez-Fonseca, A. A., Arellano, M., Rodrigue, D., González-Núñez, R., & Robledo-Ortíz, J. R. (2016). Effect of coupling agent content and water absorption on the mechanical properties of coir-agave fibers reinforced polyethylene hybrid composites. *Polymer Composites*, *37*(10), 3015-3024.

[89]. Khan A, Ahmad MA, Joshi S, Al Said SA. Abrasive wear behavior of chemically treated coir fibre filled epoxy polymer composites. Am J Mech Eng Autom 2014;1 (1):1–5

[90]. Zainudin E, Yan LH, Haniffah W, Jawaid M, Alothman OY. Effect of coir fiber loading on mechanical and morphological properties of oil palm fibers reinforced polypropylene composites. Polym Compos 2014;35(7):1418–25

[91]. Chollakup R, Smitthipong W, Kongtud W, Tantatherdtam R. Polyethylene green composites reinforced with cellulose fibers (coir and palm fibers): effect of fiber surface treatment and fiber content. J Adhes Sci Technol 2013;27(12):1290–300.

[92]. Anupama Sai Priya N. P. Veera Raju, P. N. E. Naveen 2014 Experimental Testing of Polymer Reinforced with Coconut Coir Fiber Composites. International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 12

[93]. Ticoalu, A., Aravinthan, T., & Cardona, F. (2010). A review of current development in natural fiber composites for structural and infrastructure applications. In *Proceedings of the southern region engineering conference (SREC 2010)* (pp. 113-117). Engineers Australia.

[94]. Yan L, Su S, Chouw N. Microstructure, flexural properties and durability of coir fibre reinforced concrete beams externally strengthened with flax FRP composites. Compos B Eng 2015;80:343–54.

[95]. Okpala, C. C., Chinwuko, E. C., & Ezeliora, C. (2021). Mechanical Properties and Applications of Coir Fiber Reinforced Composites. *International Research Journal of Engineering and Technology*, *8*(7).

[96]. Andiç-Çakir, Ö., Sarikanat, M., Tüfekçi, H. B., Demirci, C., & Erdoğan, Ü. H. (2014). Physical and mechanical properties of randomly oriented coir fiber–cementitious composites. *Composites Part B: Engineering*, *61*, 49-54.

[97]. Sanjay, M. R., Madhu, P., Jawaid, M., Senthamaraikannan, P., Senthil, S., & Pradeep, S. (2018). Characterization and properties of natural fiber polymer composites: A comprehensive review. *Journal of Cleaner Production*, *172*, 566-581.

[98] Tran LQN, Fuentes C, Dupont-Gillain C, Van Vuure A, Verpoest I. Understanding the interfacial compatibility and adhesion of natural coir fibre thermoplastic composites. Compos Sci Technol 2013;80:23–30.

[99]. Omiwale, T. F., Odusote, J. K., & Alabi, A. G. (2017). Tensile properties and hardness of coconut fiber and wood dust filler reinforced polyester hybrid composites. *Journal of Research Information in Civil Engineering*, *14*(1), 1134-1145.

[100]. Sen, M. T., & Reddy, H. J. (2011). Finite element simulation of Retrofitting of RCC beam using Coir fibre composite (Natural fibre). *International Journal of Innovation, Management and Technology*, *2*(2), 175.

[101]. Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011). A review on the tensile properties of natural fiber reinforced polymer composites. *Composites Part B: Engineering*, *42*(4), 856-873.
[102]. Ahmad M, Rajapaksha AU, Lim JE, Zhang M, Bolan N, Mohan D, Vithanage M, Lee SS, Ok YS. 2014. Biochar as a sorbent for contaminant management in soil and water: a review. Chemosphere. 99: 19–33. doi:10.1016/j.chemosphere.2013.10.071.
[103]. Yan L, Chouw N, Huang L, Kasal B. Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites. Constr Build Mater 2016;112:168–82
[104]. Loganathan, T. M., Sultan, M. T. H., Ahsan, Q., Shah, A. U. M., Jawaid, M., Talib, A., ... & Basri, A. A. (2021). Physico-mechanical and Flammability Properties of Cyrtostachys renda Fibers Reinforced Phenolic Resin Bio-composites. *Journal of Polymers and the Environment*, *29*(11), 3703-3720.
[105]. Li, X., Liu, Y., Verma,, J., & Wang, W. (2018). Study of almond shell characteristics. *Materials*, *11*(9), 1782.
[106]. Huang, Z., Wang, N., Zhang, Y., Hu, H., & Luo, Y. (2012). Effect of mechanical activation pretreatment on the properties of sugarcane bagasse/poly (vinyl chloride) composites. *Composites Part A: Applied Science and Manufacturing*, *43*(1), 114-120.
[107]. Deeepa, B, L. A. Pothan, R. Mavelil-Sam AND s. Thomas (2011): Structure, properties and recyclability of natural fiber reinforced polymer composites. Department of Chemistry, Bishop Moore College, Mavelikara and Department of Polymer science and Engineering, Mahatma Gandhi University Kottayam, Kerala, India.