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Eco-friendly composites: Developing sustainable solutions for modern engineering

Mahboubeh Izadi [a] *, ***Leila Bazli*** [b]

[a] *Department of Chemistry and Biochemistry, Ohio University, Athens, OH, USA*

[b] *School of Science and Technology, The University of Georgia, 0171 Tbilisi, Georgia*

A B S T R A C T

Eco-Friendly Composites examines the development and application of sustainable composite materials in modern engineering. The primary aim of this initiative is to integrate natural fibers and bio-based polymers to create eco-friendly composites that ensure performance while minimizing their environmental impact. The focus lies in enhancing life cycle assessments, mechanical properties, and processing techniques to guarantee that these materials meet the demands of various industries, including construction, automotive, and aerospace. These composites offer lightweight and cost-effective alternatives to traditional materials, simultaneously reducing carbon footprints by incorporating renewable resources and minimizing waste. While preserving performance and cost-effectiveness, the research underscores that eco-friendly composites hold the potential to transform engineering practices and promote a more sustainable future.

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1. Introduction

In the past few years, a growing global awareness has inspired people to take steps to protect nature from numerous threats. These include air pollution, which exacerbates global warming, water contamination, and the erosion of natural resources [1]. Consequently, many individuals are pushing for a new kind of development and conduct through various regulations designed to increase the use of alternative fuels. This initiative has given rise to the idea of sustainable development [2-4]. Eco-friendly sustainable composites have been a popular trend for materials science innovation in recent years [5, 6].

New materials based on renewable resources are being developed due to the excessive consumption of petroleum-based products and the growing awareness of sustainable development. The latest environmental regulations have created innovative, environmentally friendly materials for various building, automotive, and packaging uses [6-9]. The main objective of sustainable development is to replace the current synthetic petroleum-based composites with natural resources and help achieve environmental goals such as lowering greenhouse gas emissions, reducing carbon emissions, and lessening the effects of climate change [6, 10]. Due to the increased demand for sustainable engineering solutions, eco-friendly composites are at the forefront of contemporary material innovation [11]. These cutting-edge materials combine excellent performance with a lower environmental effect, making them a possible substitute for more conventional counterparts like metals and non-renewable polymers [12, 13].

To solve issues throughout their whole lifecycle from manufacture to disposal eco-friendly composites are designed to reduce carbon emissions, use recycled or renewable feedstocks, and adhere to the principles of the circular economy [14, 15]. These materials are gradually replacing more traditional solutions in construction, automotive, and aerospace sectors because of their durability,

low weight, and potential to use less energy while in operation [16, 17]. However, obstacles, including energy-intensive production procedures, some composites' limited capacity for recycling, and the environmental costs of end-of-life management, must be overcome to achieve real sustainability [5, 6, 14].

This study investigates the creation of environmentally friendly composites to achieve sustainable engineering methods. It looks at life cycle analyses, new material developments, and strategies to increase resource efficiency and recyclability to meet global sustainability targets. While encouraging environmental stewardship, eco-friendly composites have the potential to transform contemporary engineering by tackling these issues.

* *Corresponding author: Mahboubeh Izadi, Email: mi397022@ohio.edu*

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2. Types of eco-friendly composites

Three categories of eco-friendly composites bio-based, recycled, and natural fiber are made of various cutting-edge materials intended to lessen their adverse environmental effects. A synopsis of each is provided below. In multiple applications, these composites enrich performance and cost-effectiveness and provide environmental advantages.

2.1. Bio-based composites

Biocomposite materials, which are made from plant fibers and other renewable resources, are gradually taking the place of conventional synthetic and non-biodegradable materials in a variety of lightweight applications. To create sustainable, eco-friendly biocomposites, natural fibers like flax, hemp, jute, sisal, wood, cotton, bamboo, silk, wool, feathers, and so forth are necessary [18].

These renewable plant and animal fibers are inexpensive, recyclable, biodegradable, and generate minimal non-recyclable trash. They also have a low carbon footprint. These materials can be used as fillers in the polymer matrix to produce ecologically friendly, sustainable biocomposites suitable for various bulk industrial, biomedical, and engineering uses [19].

Natural fillers develop the mechanical properties of green composites, such as strength and stiffness, while preserving their lightweight, thermally stable, and sustainable attributes. Because of their exceptional performance, renewability, affordability, and environmental sociability, natural fillers are critical in producing maintainable green composites, expressively contributing to a more maintainable and greener future [20].

Furthermore, advanced additive manufacturing, which offerings potential solutions for preparation, processing, and manufacturing, is made probable by these justifiable composites [21]. Additionally, adding additive manufacturing affects various engineering uses [22].

2.2. Recycled composites

Waste material processing is a laborious issue that requires a lot of resources, which reduces its profitability [23]. Several experimental studies have been conducted to determine whether it is feasible to produce wood-plastic composites (WPC) using both waste plastic and waste wood [24].

One crucial factor that should be considered while creating a new WPC is the potential to reuse the discarded WPC. Recycling generally results in material savings but degrades the material's mechanical, chemical, and physical qualities [25]. More studies should be conducted to determine whether recycling waste WPC as a raw material is feasible. The breakdown of old wood, particularly at high temperatures (about 200 ◦C), where toxic volatiles are released, is a important barrier to WPC recycling [26].

To produce WPC using three distinct waste materials, such as matrix and thermoplastics, cedar wood sawdust (SD) has been utilized as reinforcement. Specifically HDPE, PET, and PP [24]. As a waste by-product of woodworking activities like planning, routing, drilling, sanding, and sawing, SD is inexpensive, clean, and easily accessible. Using sawdust minimizes the amount of waste in landfills by giving regenerated wood fibers a new purpose [24]. SD is widely used as a filler with various polymers. Sawdust is an environmentally friendly method of reinforcing recycled polystyrene composite [27].

According to scientific research, natural fiber-reinforced composites, or NFCs, have gained international recognition for their environmentally beneficial and renewable qualities [28]. Compared to traditional materials, NFCs provide several advantages [29].

Natural fibers' high specific strength, stiffness, low density, and exceptional thermal insulation qualities make them valuable in various industries, including consumer goods, construction, automotive, and packaging [16, 30]. Since these fibers come from cellulose-based, botanical, and zoological sources, they are also sustainable resources that lessen reliance on non-renewable alternatives [31].

Since these natural fibers are often hydrophilic, they have difficulty adhering to hydrophobic materials, mainly at high temperatures [32]. However, this can be quickly resolved by applying several surface modification techniques to the fibers [33].

Examining these composites' properties, manufacturing methods, applications, and sustainability will raise public awareness and acceptance of these materials as viable and sustainable alternatives [34].

Researchers are investigating traditional natural fibers such as sisal, hemp, flax, jute, kenaf, abaca, pineapple leaf fiber, ramie coir, bamboo, bagasse, and wheat straw. These natural fibers have different chemical compositions, affecting their use [35]. The properties and applications of some of these natural fibers are presented in Fig. 1 and Table 1 shows images of some natural fibers.

3. Manufacturing processes

To solve the environmental issues related to conventional composite materials, eco-friendly composite production techniques are changing. These procedures use sustainable materials and methods to lower waste, energy use, and environmental effects. Below are these procedures:

3.1. Green manufacturing techniques

Various production techniques, such as extrusion, compression moulding, resin transfer moulding, extrusion, and thermoforming, (Fig. 2) are used to create green composites. Below, a few of these techniques will be discussed. The kind and process of material being treated, part's hardness, the complexity of its design, production resources, and funding needs are usually considered when selecting manufacturing procedures [70].

3.1.1. Pultrusion

Pultrusion is a process for creating composite profiles that involve impregnating the fiber with a thermosetting matrix and then drawing it through a heated die. In general, symmetric sectional profiles with notable volume rates can be produced by continuously using this fabrication technique. There are three primary zones in pultrusion, which are tugging, pressure, and heat transfer zones [71].

The final cross-sectional shape of the die is determined by the output of drawing the fiber tapes using a thermosetting polymer resin solution. Composites containing reinforcing elements composed of fibers such as glass or carbon or natural fibers like hemp, jute, and kenaf can be created using the pultrusion process [72, 73].

Depending on the die's geometry, the products are often shaped like bars or poles. The final harvests are cut to the appropriate distance, and the die also requires composite curing. This technique's primary advantage is that it may continuously generate mechanisms with a steady cross-sectional plan [74].

Fig. 1. Different types of natural fibers [36].

Table 1
Properties and applications of natural fibers

Natural fibers	Properties	Applications	References
Sisal (Agave sisalana)	1.5 to 2 meters tall, favorable sound and thermal insulation	Automotive industry, shipping, civil construction, elevator steel wire cables, agricultural twine	[37-41]
Hemp (Cannabis sativa)	1.2–4.5m in length and 2 cm in diameter, sustainability and biodegradability	Automotive, packaging, rope, textiles, garden mulch, building materials and animal bedding	[42-47]
Flax (Linum usitatissimum)	90 cm length and diameter of 12–16µm.	Furniture materials, textiles, bed sheets, linen, interior decoration accessories	[48-50]
Jute (Corchorus capsularis)	15–20 cm length, acoustic and thermal insulation	Textile products, packaging, construction, automobile	[51-53]
Kenaf (Hibiscus cannabinus)	biodegradability, noteworthy thermal stability	Automotive, construction, packaging, furniture, textiles, mats, paper pulp	[54-56]
Ramie (Boehmeria nivea)	1–2m height	Textiles, pulp, paper, agrochemicals	[49, 57, 58]
Bamboo (Bambusoideae)	Great mechanical strength, high resilience, and ability to absorb and release moisture	Making houses, bridges, traditional boats, packaging, athletic equipment, textiles and apparel	[59-63]
Banana Fiber	Noteworthy tensile strength, high moisture resistance, biodegradable, environmental sustainability,	Manufacturing of paper, textile products	[64, 65]
Pineapple Leaf (Ananas comosus)	Good mechanical properties,	Automotive, textile, mats, construction,	[66, 67]
Coconut Fiber (Cocos nucifera)	Resilience, strength, and damping	Agriculture, construction	[68, 69]

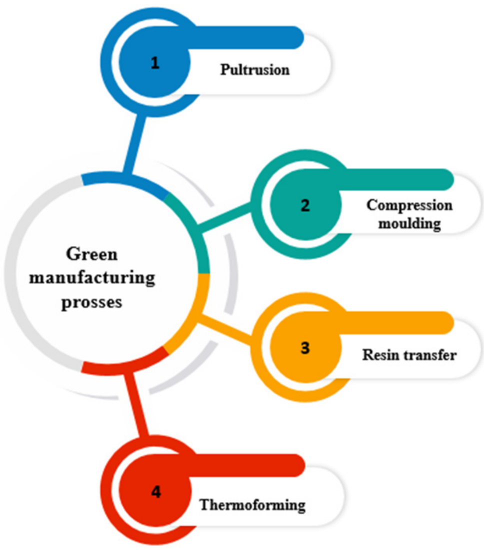

Fig. 2. Green manufacturing techniques of eco-friendly composites.

3.1.2. Compression moulding

A powerful press compresses a stack of pre-impregnated layers between a set of matched dies, and the stack is subsequently cured while under compression. This technique is known as compression moulding. This process produces tiny amounts of high-quality parts, like bicycle frames and crash helmets. This approach is very costly. Additionally, it is pretty challenging to create components with constantly dropping plies [75]. The mechanical properties of CNF/3D-polylactic acid composites produced by 3D printing and compression molding were compared in a new study by Ambone et al. [76]. CNF made from sisal fibers was used as reinforcement in the study. It was demonstrated that compression-molded composites outperformed 3D-printed composites in terms of tensile properties.

3.1.3. Molding with resin transfer

The resin transfer moulding process creates discontinuous lignocelluloses, woven rovings, and continuous mats. The primary benefit of this technology is its easy regulation of fiber orientation [77]. The long-term endurance of high-strength components created using this technology is an additional advantage. Wood strand panels with high performance for automotive applications were produced [78]. In a study by Gartner et al [79]. Using compression resin transfer moulding and resin transfer technology. When exposed to moisture, resin transfer-moulded composites of wood strands showed meaningly improved mechanical properties and dimension stability.

3.1.4. Thermoforming

Composite sheets are either pre-cut or roll-fed during thermoforming, depending on their total thickness [80]. A crimping frame is commonly utilized to prevent warping and twisting of pre-cut sheets. In either case, convection or radiation heaters are then used to preheat the sheets to their glass transition temperature [81].

Preheating is recommended before forming to reduce the amount of material shear as well as early fractures brought on by rapid cooling [81, 82]. As reported by Wang et al [83]. Woven bamboo fiber/polypropylene composites were made using the thermoforming technique. Using bamboo fibers that have been alkali-treated, the woven bamboo fiber/polypropylene composite has greater tensile strength than the unprocessed bamboo fiber composite.

3.2. Life cycle assessment (LCA)

Life cycle assessment, or LCA, is a technique for analysing the possible effects on ecosystems of a product or substance from the beginning of production to the conclusion of its life. Life cycle inventory (LCI) analysis is a crucial phase in the (LCA). Every input and output of the system boundaries must be measured and allocated to the various product stages and processes during the LCI. Emissions (air, soil, and water), waste, raw materials, and energy are typical inputs and outputs [84].

LCA has been used to evaluate various natural fiber composites' environmental characteristics and possible effects. According to most life cycle assessments, including natural fibers in composites instead of synthetic ones can lessen their negative environmental impact [85, 86].

These lead to decreased reliance on non-renewable energy and material sources, reduced emissions of pollutants and greenhouse gases (GHGs), improved energy recovery, and the biodegradability of components at the end of their helpful lives [87]. Analysing bio-based composites with different natural fiber reinforcing in a biosynthesized polymer matrix also maintains this tendency [85].

In a study by Carvalho et al [88]. Ramie and jute were evaluated from the perspectives of technical performance, cost, and the environment compared to E-glass and carbon fiber-reinforced epoxy composites (with aluminum as the standard material as a baseline). The manufacturing phase is the primary contributing phase and cycle time is a factor in the variations among the options in this phase.

More energy is needed for a longer cycle duration, significantly affecting the environment. With just minor differences, the effects of the various composite materials are somewhat similar. Still, the aluminum alternative has a much greater value because it is made from primary sources, even though it benefits from material recycling at the end of its useful life. From an LCA standpoint, ramie is the optimum material for the solution because it uses less material than jute and has a lesser impact.

3.3. Energy efficiency in production

NFCs have been widely used by several industries, including the automotive, construction, packaging, and aerospace sectors. These composites can lessen adverse environmental effects, increase energy efficiency, and promote sustainability [89, 90].

Furthermore, natural fiber composites can potentially lower the carbon footprints of numerous companies. Creating synthetic materials usually involves chemical synthesis, energy-intensive procedures, and major carbon emissions. In contrast, the production of NFCs usually uses less energy and emits less carbon emissions.

Natural fibers require less energy to grow and process than synthetic counterparts [91].

4. Applications in engineering

The versatility of eco-friendly composites makes them a valuable asset across multiple industries. Their distinctive properties, such as lightweight nature, durability, and sustainability, not only meet engineering demands but also contribute positively to environmental conservation efforts. Due to their distinctive properties, eco-friendly composites find numerous engineering applications. These applications span various industries, including construction, automotive, aerospace, and consumer products, highlighting their importance.

4.1. Construction and building materials

Due to the urgent need to reduce the built environment's carbon footprint to combat climate change, environmentally friendly engineered cementitious composites, or ECCs, have been produced continually for the last ten years [92]. ECCs are a cementitious material with many advantages over regular concrete, including excellent ductility, strain-hardening capabilities, and a distinct fiber composition [93, 94]. By removing the need for ongoing maintenance brought on by steel corrosion and concrete fracture in reinforced concrete components, these materials also hold great promise for reducing the carbon footprint of infrastructure [95]. It is essential to handle building materials and dispose of construction waste properly to maintain sustainability. Scientists are now developing and implementing natural fiber in the building industry because of many synthetic fibers' high embodied energy and carbon footprints (including carbon, glass, asbestos, and aramid). Nwankwo et al [96]. Provide a succinct evaluation of fiber-reinforced polymer (FRP) composites made of natural fiber and bio-polymer for strengthening concrete structures, addressing sustainability, cost-effectiveness, and durability. Additionally, the study found that concrete beams and columns can be reinforced with FRPs based on biopolymers. Additionally, the width of the FRP materials is significantly influenced by the composite materials employed as confinement.

Zhang et al [97]. Studied the application of superabsorbent polymers and nanomaterials to coarsen the pore structure and increase the impermeability of ECC. The results indicated that the long-term performance of the composite structure is improved by the major reduction in shrinkage deformation of ECC caused by the addition of SAP. Furthermore, they discovered that ECC outperformed mortar regarding mechanical integrity and surface erosion because of its high tensile strength after creating a methodical way to model microbiologically generated erosion and assess the sewage-simulated durability of engineered cementitious composites. Despite this, Hawileh et al [98]. Also, evidence of improved concrete workability was obtained when 1% nano-silica was used instead of some of the cement.

4.2. Automotive industry

New manufacturers use a lot of composite materials in order to decrease weight and increase range of battery-electric and hybrid vehicles[20, 99]. Fibers and resins are composite materials with advantages not found in their constituent parts alone. When adequately developed and constructed, a composite material can exhibit increased strength, fatigue life, toughness, corrosion resistance, damage resistance, stiffness, thermal insulation, and wear resistance. Furthermore, compared to traditionally manufactured metallic materials, composite materials have mechanical properties like modulus and specific strength (MPa/kg/m3) that are several times higher per unit density [100].

Crash-absorbing composite components, interior trim panels and bins for family cars made from natural fiber, storage systems for commercial trucks, A large panel for a bus or a medium-duty truck, as well as a whole truck cab, are just a few examples of how composites are finding their way into more accessible transportation modes [101]. The introduction of innovative biocomposites in the automotive sector results from the numerous obstacles contemporary companies have had to overcome to comply with environmental sustainability [99]. Thermoplastic-reinforced nanocellulose fibers have been successfully employed in automotive applications in recent years [102].

These fibers are an excellent alternative to synthetic carbon and glass fibers. Because of its many excellent qualities, including its low cost, aluminum-like tensile strength, design freedom, and low weight, nanocellulose can be used in various automotive applications [103]. According to research by Pervaiz et al.[104], Microfiber technology (MF technology) allows for the production of a variety of lightweight components for automotive applications when bio microfibers are distributed throughout the polymer matrix. They investigated the usage of carbon fiber-reinforced composite with cellulose microfiber, which reduced weight by 15–30% and made it appropriate for various end-use applications. Additionally, Meng et al [105]. Offered a thorough analysis of recycled carbon fiber that can be used for various automotive applications and explained how to effectively lower energy consumption in the transportation sector by adopting lightweight vehicles.

4.3. Aerospace applications

The use of composite materials in the transportation and aerospace has grown in recent years because of their superior mechanical qualities, low weight, and favorable fatigue behavior [17]. Composites make it possible to build lighter and more efficient aircraft, lowering fuel consumption. The main structural components of contemporary aircraft, such as the Airbus A350 and Boeing 787 Dreamliner, are made of high-performance composites like carbon fiber reinforced polymers (CFRP) [106]. They are gradually taking the place of traditional materials like steel and aluminum. Additionally, sandwiches composed of phenolic resins as a matrix system and glass fiber reinforced polymers (GFRP) find use in interior spaces because of their fire resistance and low weight to stiffness ratio [84].

The goal of using green polymer composites for interior components is to replace potentially hazardous materials like glass fibers and phenolic resins with non-renewable resources. Because of the reduced weight, this change improves fuel economy, lowers carbon emissions and emphasizes how crucial it is to maintain sufficient strength and adhere to strict safety regulations.

Hussain et al. created new 3D jute-reinforced natural fiber aluminum laminates (JuRALs) [107]. The compressive, tensile, and flexural strengths of fiber metal laminates (FMLs) composed of natural and synthetic fiber composites were evaluated by Mohammed et al [108]. The carbon and flax fiber reinforced aluminum alloy (CAFRALL) composite outperformed the CAKRALL composite in compressive and tensile strength. EMF was used by Glushchenkov et al [109] for a five-layer metal-polymer composite that was made of commercial aluminum that was 0.3 mm thick and had carbon fiber interlayers surrounded by two-way reinforced epoxy laminate. The findings demonstrated that increased strain values raise the electromagnetic field's energy level. A more excellent profile height (>30%) was attained using the EMF approach instead of traditional stretching without cracking [110].

4.4. Consumer products

NFCs are increasingly used by the packaging sector as sustainable packaging substitutes. They are used to produce biodegradable packaging materials such as trays, containers, and disposable silverware. These composites meet various packing requirements thanks to mechanical strength, moisture resistance, and thermal insulation. In the consumer goods sector, they emerge in toys, cookware, household appliances, and furniture, combining aesthetic appeal and environmental friendliness [111, 112].

Applications for NFCs are varied and include furniture and sporting goods production. They create skateboards, helmets, tennis rackets, and bicycle frames by balancing durability, vibration-damping capabilities, and lightweight design. In terms of furnishings, they combine organic textures with modern styles to form table tops, chair frames, and ornamental accents. These examples underline the potential and versatility of NFCs in various industries [112]. In recent years, the utilization of bamboo has been strengthened to exploit bamboo as a non-wood renewable fiber. Bamboo's fast-growing and renewable properties lead to an evolution in theoretical and applied research on bamboo-based products, particularly furniture. These products are made from 70% recycled bamboo fibers and 30% recycled high-density polyethylene (HDPE) and are very popular in the market. These bamboo composites have been designed with unique characteristics, maintaining their shape, termite resistance, high thermal stability, easy handling, and installation [113].

5. Future trends

Natural fibers are inherently prone to absorbing moisture, leading to dimensional changes, a deterioration in mechanical properties, and, ultimately, disintegration[114]. This problem is most noticeable in situations where exposure to moisture is likely, such as with outdoor building materials or automobile components. Surface treatments, chemical alterations, and the infusion of moisture-resistant matrix materials are some methods being investigated to reduce moisture absorption [115].

Standardization and quality control are essential for uniform performance, which supports material selection and market acceptance. Fiber characteristics, manufacturing methods, and composite qualities vary among fiber composites. These discrepancies make establishing uniform testing procedures and performance standards more difficult. Standardized testing processes, material standards, and quality control methods tailored to NFCs are being developed. This step will enable producers to produce reliable goods, increasing consumer trust and commercial acceptance [116]. Cost effectiveness and market acceptability are key factors in the broad use of fiber composites. Although there is a growing interest in sustainable materials, perceived performance constraints, a lack of information, and a preference for traditional solutions can all work against their acceptance. Fibers can be more expensive than standard materials because of fiber processing, surface treatment, and quality control costs. However, the cost-efficiency of these composites is set to improve, making them more competitive because of improvements in production methods, economies of scale, and increased awareness of environmental benefits [117].

6. Conclusion

Developing eco-friendly composites is an essential step towards realizing maintainable answers in modern engineering. These materials, often composed of natural fibers and recyclable matrices, decrease not only environmental effect but also offer viable mechanical properties compared to traditional composites. Combining eco-composites into industries such as automotive, aerospace, construction, and consumer products expressively lowers carbon footprints and improves resource efficiency. Furthermore, progresses in recycling technologies and additive manufacturing methods are decisive for scaling up the construction of these balanced materials. As the world moves towards a more circular economy, embracing eco-friendly composites will be important for meeting sustainability aims while maintaining economic viability. By leveraging cutting-edge technologies and modern engineering practices, the possible for eco-friendly composites to transform industries and contribute to a greener future is massive and promising.

Author contributions

Mahboubeh Izadi: Writing—Original Draft Preparation, Resources, Investigation. **Leila Bazli**: Writing—Original Draft Preparation, Conceptualization, Writing—Review and Editing:

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REFERENCES

[1] T.T. Nguyen, U. Grote, F. Neubacher, D.B. Rahut, M.H. Do, G.P. Paudel, Security risks from climate change and environmental degradation: implications for sustainable land use transformation in the Global South, Current Opinion in Environmental Sustainability 63 (2023) 101322 .

[2] L.J.R. Nunes, The Rising Threat of Atmospheric CO2: A Review on the Causes, Impacts, and Mitigation Strategies, Environments, 2023.

[3] S. Selmi, M. Habibi, L. Laperrière, S. Kelouwani, Characterisation of Natural Flax Fibers Honeycomb: Compression Damage Analysis Using Acoustic Emission, Journal of Natural Fibers 19(3) (2022) 1084-1093.

[4] I. Elfaleh, F. Abbassi, M. Habibi, F. Ahmad, M. Guedri, M. Nasri, C. Garnier, A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials, Results in Engineering 19 (2023) 101271 .

[5] Y. Zhou, P. Stanchev, E. Katsou, S. Awad, M. Fan, A circular economy use of recovered sludge cellulose in wood plastic composite production: Recycling and eco-efficiency assessment, Waste Management 99 (2019) 42-48 .

[6] M.M. Rahman, M. Maniruzzaman, M.S. Yeasmin, A state-of-the-art review focusing on the significant techniques for naturally available fibers as reinforcement in sustainable bio-composites: Extraction, processing, purification, modification, as well as characterization study, Results in Engineering 20 (2023) 101511 .

[7] S.G. Jebadurai, R.E. Raj, V. Sreenivasan, J. Binoj, Comprehensive characterization of natural cellulosic fiber from Coccinia grandis stem, Carbohydrate polymers 207 (2019) 675-683 .

[8] M. Marichelvam, P. Manimaran, A. Verma, M. Sanjay, S. Siengchin, K. Kandakodeeswaran, M. Geetha, A novel palm sheath and sugarcane bagasse fiber based hybrid composites for automotive applications: an experimental approach, Polymer Composites 42(1) (2021) 512-521.

[9] A.A. Firoozi, A.A. Firoozi, D.O. Oyejobi, S. Avudaiappan, E.S. Flores, Emerging trends in sustainable building materials: Technological innovations, enhanced performance, and future directions, Results in Engineering 24 (2024) 103521 .

[10] J. Binoj, R.E. Raj, V. Sreenivasan, G.R. Thusnavis, Morphological, physical, mechanical, chemical and thermal characterization of sustainable Indian Areca fruit husk fibers (Areca Catechu L.) as potential alternate for hazardous synthetic fibers, Journal of Bionic Engineering 13(1) (2016) 156-165 .

[11] A. Chermoshentseva, A. Pokrovskiy, L. Bokhoeva, The behavior of delaminations in composite materials-experimental results, IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2016, p. 012005.

[12] M. Bar, R. Alagirusamy, A. Das, Advances in natural fibre reinforced thermoplastic composite manufacturing: effect of interface and hybrid yarn structure on composite properties, Advances in Natural Fibre Composites: Raw Materials, Processing and Analysis, Springer, 2018, pp. 99-117.

[13] D.U. Shah, P.J. Schubel, M.J. Clifford, Modelling the effect of yarn twist on the tensile strength of unidirectional plant fibre yarn composites, Journal of Composite Materials 47(4) (2013) 425-436.

[14] A. Wąsik, B. Leszczyńska-Madej, M. Madej, Sustainability in the Manufacturing of Eco-Friendly Aluminum Matrix Composite Materials, Sustainability 16(2) (2024) 903 .

[15] A. Esparham, F. Ghalatian, The features of geopolymer concrete as a novel approach for utilization in green urban structures, Journal of Composites and Compounds 4(11) (2022) 89-96 .

[16] S. Pickering, Thermal methods for recycling waste composites, Management, recycling and reuse of waste composites, Elsevier2010, pp. 65-101.

[17] L. Bazli, M. Bazli, A review on the mechanical properties of synthetic and natural fiber-reinforced polymer composites and their application in the transportation industry, Journal of Composites and Compounds 3(9) (2021) 262-274 .

[18] M.K. Singh, S. Siengchin, S.M. Rangappa, Recent advances of sustainable composites in manufacturing sector, Journal of Applied Science, Engineering, Technology and Management 1(02) (2023) 01-02.

[19] O. Das, K. Babu, V. Shanmugam, K. Sykam, M. Tebyetekerwa, R.E. Neisiany, M. Försth, G. Sas, J. Gonzalez-Libreros, A.J. Capezza, M.S. Hedenqvist, F. Berto, S. Ramakrishna, Natural and industrial wastes for sustainable and renewable polymer composites, Renewable and Sustainable Energy Reviews 158 (2022) 112054 .

[20] F. Azamian, M. Hojjati, Advancements in Green Composites: Materials Science Innovations for a Sustainable Future, Journal of Composites and Compounds 5(17) (2023).

[21] C. Billings, R. Siddique, B. Sherwood, J. Hall, Y. Liu, Additive Manufacturing and Characterization of Sustainable Wood Fiber-Reinforced Green Composites, Journal of Composites Science 7(12) (2023) 489 .

[22] O. Koçar, N. Anaç, S.K. Palaniappan, M. Doğan, S. Siengchin, Effect of process parameters on the mechanical behavior of additively manufactured and FSW joined PLA wood sheets, Polymer Composites 45(2) (2024) 1568-1584 .

[23] Y.V. Vazquez, S.E. Barbosa, Process window for direct recycling of acrylonitrile-butadiene-styrene and high-impact polystyrene from electrical and electronic equipment waste, Waste management 59 (2017) 403-408 .

[24] Y.M. Lopez, J.B. Paes, D. Gustave, F.G. Gonçalves, F.C. Méndez, A.C.T. Nantet, Production of wood-plastic composites using cedrela odorata sawdust waste and recycled thermoplastics mixture from post-consumer products-A sustainable approach for cleaner production in Cuba, Journal of Cleaner Production 244 (2020) 118723 .

[25] N. Petchwattana, S. Covavisaruch, J. Sanetuntikul, Recycling of wood–plastic composites prepared from poly (vinyl chloride) and wood flour, Construction and Building Materials 28(1) (2012) 557-560 .

[26] P. Shahi, A.H. Behravesh, S.Y. Daryabari, M. Lotfi, Experimental investigation on reprocessing of extruded wood flour/HDPE composites, Polymer Composites 33(5) (2012) 753-763.

[27] A. Abdel-Hakim, T.M. El-Basheer, A.M. Abd El-Aziz, M. Afifi, Acoustic, ultrasonic, mechanical properties and biodegradability of sawdust/recycled expanded polystyrene eco-friendly composites, Polymer Testing 99 (2021) 107215 .

[28] L. Aggarwal, S. Sinha, M.S. Bhatti, V. Gupta, Mixer design optimization with fractured surface topography of mechanical properties of polymer biocomposites, Journal of the Taiwan Institute of Chemical Engineers 74 (2017) 272-280 .

[29] G. Smith, New developments in producing more functional and sustainable composites, Management, recycling and reuse of waste composites (2010) 425-439 .

[30] V. Thakur, A. Singha, M. Thakur, Biopolymers based green composites: mechanical, thermal and physico-chemical characterization, Journal of Polymers and the Environment 20 (2012) 412-421 .

[31] M.P. Dicker, P.F. Duckworth, A.B. Baker, G. Francois, M.K. Hazzard, P.M. Weaver, Green composites: A review of material attributes and complementary applications, Composites part A: applied science and manufacturing 56 (2014) 280-289 .

[32] M. Asim, K. Abdan, M. Jawaid, M. Nasir, Z. Dashtizadeh, M. Ishak, M.E. Hoque, A review on pineapple leaves fibre and its composites, International Journal of Polymer Science 2015(1) (2015) 950567 .

[33] P. Suwanruji, T. Tuechart, W. Smitthipong, R. Chollakup, Modification of pineapple leaf fiber surfaces with silane and isocyanate for reinforcing thermoplastic, Journal of Thermoplastic Composite Materials 30(10) (2017) 1344-1360.

[34] H.-y. Cheung, M.-p. Ho, K.-t. Lau, F. Cardona, D. Hui, Natural fibre-reinforced composites for bioengineering and environmental engineering applications, Composites Part B: Engineering 40(7) (2009) 655-663 .

[35] M. Ramesh, K. Palanikumar, K.H. Reddy, Plant fibre based bio-composites: Sustainable and renewable green materials, Renewable and Sustainable Energy Reviews 79 (2017) 558-584 .
[36] N. Gebremedhin, G.K. Rotich, Manufacturing of bathroom wall tile composites from recycled low-density polyethylene reinforced with pineapple leaf fiber, International Journal of Polymer Science 2020(1) (2020) 2732571.
[37] M. Mihai, M.T. Ton-That, Novel polylactide/triticale straw biocomposites: Processing, formulation, and properties, Polymer Engineering & Science 54(2) (2014) 446-458 .
[38] M. Ramesh, K. Palanikumar, K.H. Reddy, Mechanical property evaluation of sisal–jute–glass fiber reinforced polyester composites, Composites Part B: Engineering 48 (2013) 1-9 .
[39] U. Nirmal, J. Hashim, M.M. Ahmad, A review on tribological performance of natural fibre polymeric composites, Tribology International 83 (2015) 77-104 .
[40] M. Aslan, M. Tufan, T. Küçükömeroğlu, Tribological and mechanical performance of sisal-filled waste carbon and glass fibre hybrid composites, Composites Part B: Engineering 140 (2018) 241-249.
[41] J. Naveen, M. Jawaid, P. Amuthakkannan, M. Chandrasekar, Mechanical and physical properties of sisal and hybrid sisal fiber-reinforced polymer composites, Mechanical and physical testing of biocomposites, fibre-reinforced composites and hybrid composites, Elsevier2019, pp. 427-440.
[42] S. Réquilé, A. Le Duigou, A. Bourmaud, C. Baley, Peeling experiments for hemp retting characterization targeting biocomposites, Industrial Crops and Products 123 (2018) 573-580 .
[43] T. Väisänen, P. Batello, R. Lappalainen, L. Tomppo, Modification of hemp fibers (Cannabis Sativa L.) for composite applications, Industrial Crops and Products 111 (2018) 422-429 .
[44] N. Martin, N. Mouret, P. Davies, C. Baley, Influence of the degree of retting of flax fibers on the tensile properties of single fibers and short fiber/polypropylene composites, Industrial crops and products 49 (2013) 755-767.
[45] A. Bourmaud, D. Siniscalco, L. Foucat, C. Goudenhooft, X. Falourd, B. Pontoire, O. Arnould, J. Beaugrand, C. Baley, Evolution of flax cell wall ultrastructure and mechanical properties during the retting step, Carbohydrate Polymers 206 (2019) 48-56 .
[46] R. Bhoopathi, M. Ramesh, C. Deepa, Fabrication and property evaluation of banana-hemp-glass fiber reinforced composites, Procedia Engineering 97 (2014) 2032-2041 .
[47] H.N. Dhakal, S.O. Ismail, Z. Zhang, A. Barber, E. Welsh, J.-E. Maigret, J. Beaugrand, Development of sustainable biodegradable lignocellulosic hemp fiber/polycaprolactone biocomposites for light weight applications, Composites Part A: Applied Science and Manufacturing 113 (2018) 350-358.
[48] K. Charlet, J.-P. Jernot, J. Breard, M. Gomina, Scattering of morphological and mechanical properties of flax fibres, Industrial Crops and Products 32(3) (2010) 220-224.
[49] L.G. Angelini, S. Tavarini, Ramie [Boehmeria nivea (L.) Gaud.] as a potential new fibre crop for the Mediterranean region: Growth, crop yield and fibre quality in a long-term field experiment in Central Italy, Industrial Crops and Products 51 (2013) 138-144 .
[50] M. Ramesh, Flax (Linum usitatissimum L.) fibre reinforced polymer composite materials: A review on preparation, properties and prospects, Progress in Materials Science 102 (2019) 109-166.4.
[51] M.S. Rahman, Jute–a versatile natural fibre. Cultivation, extraction and processing, Industrial applications of natural fibres: structure, properties and technical applications 1 (2010) .
[52] I. Kong, J.B. Shang, K.Y. Tshai, Study of properties of coconut fibre reinforced poly (vinyl alcohol) as biodegradable composites, ARPN J Eng Appl Sci 11(1) (2016) 135-143.
[53] J.I.P. Singh, S. Singh, V. Dhawan, Effect of curing temperature on mechanical properties of natural fiber reinforced polymer composites, Journal of natural fibers 15(5) (2018) 687-696.
[54] H. Anuar, A. Zuraida, Improvement in mechanical properties of reinforced thermoplastic elastomer composite with kenaf bast fibre, Composites Part B: Engineering 42(3) (2011) 462-465 .
[55] A. Atiqah, M. Maleque, M. Jawaid, M. Iqbal, Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications, Composites Part B: Engineering 56 (2014) 68-73 .
[56] E. Kipriotis, X. Heping, T. Vafeiadakis, M. Kiprioti, E. Alexopoulou, Ramie and kenaf as feed crops, Industrial Crops and Products 68 (2015) 126-130 .
[57] T. Sen, H.J. Reddy, Application of sisal, bamboo, coir and jute natural composites in structural upgradation, International journal of innovation, management and technology 2(3) (2011) 186.
[58] A.R. Bunsell, Introduction to the science of fibers, Handbook of properties of textile and technical fibres, Elsevier2018, pp. 1-20.
[59] P. Zakikhani, R. Zahari, M. Sultan, D. Majid, Extraction and preparation of bamboo fibre-reinforced composites, Materials & Design 63 (2014) 820-828 .
[60] G. Wang, F. Chen, Development of bamboo fiber-based composites, Advanced high strength natural fibre composites in construction, Elsevier2017, pp. 235-255.
[61] L. Osorio, E. Trujillo, A.W. Van Vuure, I. Verpoest, Morphological aspects and mechanical properties of single bamboo fibers and flexural characterization of bamboo/epoxy composites, Journal of reinforced plastics and composites 30(5) (2011) 396-408 .
[62] K. Bharath, P. Madhu, T.Y. Gowda, M. Sanjay, V. Kushvaha, S. Siengchin, Alkaline effect on characterization of discarded waste of Moringa oleifera fiber as a potential eco-friendly reinforcement for biocomposites, Journal of Polymers and the Environment 28 (2020) 2823-2836.
[63] P. Madhu, M. Sanjay, P. Senthamaraikannan, S. Pradeep, S. Siengchin, M. Jawaid, M. Kathiresan, Effect of various chemical treatments of Prosopis juliflora fibers as composite reinforcement: Physicochemical, thermal, mechanical, and morphological properties, Journal of Natural Fibers 17(6) (2020) 833-844.
[64] M.S. Hossain, M.B. Mobarak, F.K. Rony, S. Sultana, M. Mahmud, S. Ahmed, Fabrication and characterization of banana fiber reinforced unsaturated polyester resin based composites, Nano Hybrids and Composites 29 (2020) 84-92.
[65] S.M. Rangappa, M. Puttegowda, J. Parameswaranpillai, S. Siengchin, S.M. Gorbatyuk, Advances in Bio-Based Fiber: Moving Towards a Green Society, Woodhead Publishing2021.
[66] N. Kengkhetkit, T. Amornsakchai, Utilisation of pineapple leaf waste for plastic reinforcement: 1. A novel extraction method for short pineapple leaf fiber, Industrial Crops and Products 40 (2012) 55-61.
[67] W.A. Laftah, W.A.W.A. Rahaman, Chemical pulping of waste pineapple leaves fiber for kraft paper production, Journal of Materials Research and Technology 4(3) (2015) 254-261.
[68] F.M. Al-Oqla, S. Sapuan, Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry, Journal of cleaner production 66 (2014) 347-354.
[69] J.C. Dos Santos, R.L. Siqueira, L.M.G. Vieira, R.T.S. Freire, V. Mano, T.H. Panzera, Effects of sodium carbonate on the performance of epoxy and polyester coir-reinforced composites, Polymer Testing 67 (2018) 533-544.
[70] S.D.S. Kopparthy, A.N. Netravali, Green composites for structural applications, Composites Part C: Open Access 6 (2021) 100169 .
[71] M. Asyraf, M. Ishak, S. Sapuan, N. Yidris, R. Ilyas, M. Rafidah, M. Razman, Potential application of green composites for cross arm component in transmission tower: A brief review, International Journal of Polymer Science 2020(1) (2020) 8878300 .
[72] A. Fairuz, S. Sapuan, E. Zainudin, C. Jaafar, Pultrusion process of natural fibre-reinforced polymer composites, Manufacturing of natural fibre reinforced polymer composites (2015) 217-231.
[73] E. Medeiros Santos, F.J. Humberto Tommasini Vieira Ramos, P.H. Poubel Mendonça da Silveira, S. Neves Monteiro, A. Vieira Gomes, Chemical, thermal, and microstructural characterization of polyethylene terephthalate composites reinforced with steel slag geopolymer waste, Journal of Composites and Compounds 3(8) (2021) 164-170.
[74] P. Lehtiniemi, K. Dufva, T. Berg, M. Skrifvars, P. Järvelä, Natural fiber-based reinforcements in epoxy composites processed by filament winding, Journal of reinforced plastics and composites 30(23) (2011) 1947-1955 .
[75] S. Ahmad, Preparation of eco-friendly natural hair fiber reinforced polymeric composite (FRPC) material by using of polypropylene and fly ash: a review, International Journal of Scientific & Engineering Research 5(11) (2014) 969-972.
[76] T. Ambone, A. Torris, K. Shanmuganathan, Enhancing the mechanical properties of 3D printed polylactic acid using nanocellulose, Polymer Engineering & Science 60(8) (2020) 1842-1855 .
[77] K. Liu, X. Zhang, H. Takagi, Z. Yang, D. Wang, Effect of chemical treatments on transverse thermal conductivity of unidirectional abaca fiber/epoxy composite, Composites Part A: Applied Science and Manufacturing 66 (2014) 227-236 .
[78] M. Feldmann, A.K. Bledzki, Bio-based polyamides reinforced with cellulosic fibres–processing and properties, Composites Science and Technology 100 (2014) 113-120 .
[79] B. Gartner, V. Yadama, L. Smith, Resin transfer molding of wood strand composite panels, Forests 13(2) (2022) 278.
[80] W. Klein Peter, Fundamentals of Plastics Thermoforming, Morgan & Claypool, Ohio Uniwersity (2009).
[81] M. Zampaloni, F. Pourboghrat, S. Yankovich, B. Rodgers, J. Moore, L. Drzal, A. Mohanty, M. Misra, Kenaf natural fiber reinforced polypropylene composites: A discussion on manufacturing problems and solutions, Composites Part A: Applied Science and Manufacturing 38(6) (2007) 1569-1580 .
[82] L.-T. Lim, R. Auras, M. Rubino, Processing technologies for poly (lactic acid), Progress in polymer science 33(8) (2008) 820-852 .
[83] B.-J. Wang, W.-B. Young, The natural fiber reinforced thermoplastic composite made of woven bamboo fiber and polypropylene, Fibers and Polymers 23(1) (2022) 155-163 .
[84] J. Bachmann, C. Hidalgo, S. Bricout, Environmental analysis of innovative sustainable composites with potential use in aviation sector—A life cycle assessment review, Science China Technological Sciences 60 (2017) 1301-1317 .
[85] S.A. Miller, W.V. Srubar III, S.L. Billington, M.D. Lepech, Integrating durability-based service-life predictions with environmental impact assessments of natural fiber–reinforced composite materials, Resources, Conservation and Recycling 99 (2015) 72-83 .

[86] S.A. Miller, S.L. Billington, M.D. Lepech, Influence of carbon feedstock on potentially net beneficial environmental impacts of bio-based composites, Journal of Cleaner Production 132 (2016) 266-278 .
[87] V. Dornburg, I. Lewandowski, M. Patel, Comparing the land requirements, energy savings, and greenhouse gas emissions reduction of biobased polymers and bioenergy: An analysis and system extension of life-cycle assessment studies, Journal of industrial Ecology 7(3-4) (2003) 93-116.
[88] H. Carvalho, A. Raposo, I. Ribeiro, J. Kaufmann, U. Götze, P. Peças, E. Henriques, Application of Life Cycle Engineering approach to assess the pertinence of using natural fibers in composites–the rocker case study, Procedia CIRP 48 (2016) 364-369 .
[89] G. Cristaldi, A. Latteri, G. Recca, G. Cicala, Composites based on natural fibre fabrics, Woven fabric engineering 17 (2010) 317-342.
[90] K.N. Keya, N.A. Kona, F.A. Koly, K.M. Maraz, M.N. Islam, R.A. Khan, Natural fiber reinforced polymer composites: history, types, advantages and applications, Materials Engineering Research 1(2) (2019) 69-85 .
[91] V.K. Thakur, A. Singha, Mechanical and water absorption properties of natural fibers/polymer biocomposites, Polymer-Plastics Technology and Engineering 49(7) (2010) 694-700 .
[92] D. Wang, X. Zhou, Y. Meng, Z. Chen, Durability of concrete containing fly ash and silica fume against combined freezing-thawing and sulfate attack, Construction and Building Materials 147 (2017) 398-406 .
[93] Q. Zhang, V.C. Li, Development of durable spray-applied fire-resistive Engineered Cementitious Composites (SFR-ECC), Cement and Concrete Composites 60 (2015) 10-16 .
[94] E.D. Shumuye, J. Liu, W. Li, Z. Wang, Eco-friendly, high-ductility slag/fly-ash-based engineered cementitious composite (ECC) reinforced with PE fibers, Polymers 14(9) (2022) 1760 .
[95] J. Luo, Z. Cai, K. Yu, W. Zhu, Z. Lu, Temperature impact on the micro-structures and mechanical properties of high-strength engineered cementitious composites, Construction and Building Materials 226 (2019) 686-698 .
[96] C.O. Nwankwo, J. Mahachi, D.O. Olukanni, I. Musonda, Natural fibres and biopolymers in FRP composites for strengthening concrete structures: A mixed review, Construction and Building Materials 363 (2023) 129661 .
[97] M. Zhang, X. Zhu, B. Liu, J. Shi, O. Gencel, T. Ozbakkaloglu, Mechanical property and durability of engineered cementitious composites (ECC) with nano-material and superabsorbent polymers, Powder Technology 409 (2022) 117839 .
[98] R.A. Hawileh, A. Al Rashed, H.H. Mhanna, J.A. Abdalla, Properties of concrete with partial replacement of cement with different percentages of micro silica and nano silica, Materials Today: Proceedings (2023) .
[99] S.H. Kim, C.H. Park, Direct impregnation of thermoplastic melt into flax textile reinforcement for semi-structural composite parts, Industrial Crops and Products 95 (2017) 651-663.
[100] J.P. Carey, Introduction to braided composites, Handbook of Advances in Braided Composite Materials, Elsevier2024, pp. 1-21.
[101] K. Friedrich, A.A. Almajid, Manufacturing aspects of advanced polymer composites for automotive applications, Applied Composite Materials 20 (2013) 107-128 .
[102] J. Yan, J. Hu, R. Yang, Z. Zhang, W. Zhao, Innovative nanofibrillated cellulose from rice straw as dietary fiber for enhanced health benefits prepared by a green and scale production method, ACS Sustainable Chemistry & Engineering 6(3) (2018) 3481-3492.
[103] D. Trache, M.H. Hussin, M.M. Haafiz, V.K. Thakur, Recent progress in cellulose nanocrystals: sources and production, Nanoscale 9(5) (2017) 1763-1786 .
[104] M. Pervaiz, S. Panthapulakkal, M. Sain, J. Tjong, Emerging trends in automotive lightweighting through novel composite materials, Materials sciences and Applications 7(01) (2016) 26.
[105] F. Meng, J. McKechnie, S.J. Pickering, An assessment of financial viability of recycled carbon fibre in automotive applications, Composites Part A: Applied Science and Manufacturing 109 (2018) 207-220 .
[106] M. Norkhairunnisa, T. Chai Hua, S.M. Sapuan, R.A. Ilyas, Evolution of Aerospace Composite Materials, in: N. Mazlan, S.M. Sapuan, R.A. Ilyas (Eds.), Advanced Composites in Aerospace Engineering Applications, Springer International Publishing, Cham, 2022, pp. 367-385.
[107] M. Hussain, A. Imad, A. Saouab, T. Kanit, Y. Nawab, C. Herbelot, M. Kashif, Properties and characterization of novel 3D jute reinforced natural fibre aluminium laminates, Journal of Composite Materials 55(14) (2021) 1879-1891.
[108] I. Mohammed, M.T.H. Sultan, M. Jawaid, A.H. Ariffin, S. Saadon, Mechanical properties of fibre-metal laminates made of natural/synthetic fibre composites, BioResources 13(1) (2018) 2022-2034.
[109] V. Glushchenkov, D. Chernikov, Y. Erisov, I. Petrov, S. Alexandrov, L.H. Lang, Electro-magnetic forming of fiber metal laminates, Key Engineering Materials 794 (2019) 107-112 .
[110] M.H. Shahavi, N. Ayrilmis, Advancements in Energy Storage: Exploring the Impact of Graphene Composites, Journal of Composites and Compounds 5(16) (2023) 208-209 .
[111] L. Mohammed, M.N. Ansari, G. Pua, M. Jawaid, M.S. Islam, A review on natural fiber reinforced polymer composite and its applications, International journal of polymer science 2015(1) (2015) 243947.
[112] S. Nagaraja, P.B. Anand, M.I. Ammarullah, Synergistic advances in natural fibre composites: a comprehensive review of the eco-friendly bio-composite development, its characterization and diverse applications, RSC advances 14(25) (2024) 17594-17611.
[113] M. Shahruzzaman, S. Biswas, M.M. Islam, M.S. Islam, M.S. Rahman, P. Haque, M.M. Rahman, Furniture: Eco-Friendly Polymer Composites Applications, Encyclopedia of Polymer Applications, 1st ed.; Mishra, M., Ed (2019) 1517-1547.
[114] M. Yusuf, S. Eskandarinezhad, An overview of materials, processing, and applications for wearable electronics, Journal of Composites and Compounds 3(9) (2021) 275-290 .
[115] T. Väisänen, O. Das, L. Tomppo, A review on new bio-based constituents for natural fiber-polymer composites, Journal of Cleaner Production 149 (2017) 582-596 .
[116] S. Nagaraja, P. Bindiganavile Anand, R.N. Mahadeva Naik, S. Gunashekaran, Effect of aging on the biopolymer composites: mechanisms, modes and characterization, Polymer Composites 43(7) (2022) 4115-4125 .
[117] K.L. Pickering, M.A. Efendy, T.M. Le, A review of recent developments in natural fibre composites and their mechanical performance, Composites Part A: Applied Science and Manufacturing 83 (2016) 98-112 .