Different Natural Fiber Reinforced Composites and Its Potential Industrial and Domestic Applications: A Review

Satish Babu Boppana, K. Palani Kumar, A. Ponshanmugakumar, and Samuel Dayanand

Abstract In recent years, considerable attention has been paid to the development and use of natural fibres since they are eco-friendly, renewable and reasonably economical. Natural fibres can be suitably used as a substitute for synthetic materials since they are lesser in weight and can conserve energy. They are available in abundance and incur low costs during harvesting. They happen to be budding materials, and when reinforced with a suitable matrix, they can substitute metal-based materials/composites that are presently used in aerospace and automotive industries. On the other hand, synthetic fibers are known to generate toxic byproducts and pose issues in recycling. However, natural fibers are prone to degradation when they are exposed to the external environment. The fibers pose a challenge while mixing with the polymer matrix. Surface modification of fibers is effectively carried out to overcome the weak interfacing bonding between the polymer and fibers. With the ever-growing environmental concern and excessive usage of petroleum-based reserves, the world is looking to develop composites that are compatible with the environment. In order to have a healthier impact on the environment, industries are often craving to use eco-friendly materials. The present paper focuses on the research work carried out by various investigators for synthesizing bio fiber-based composites aimed at using them in a variety of engineering fields.

Keywords Bio-fibers · Natural fibers · Applications · Natural fiber Composites · Renewable · Biodegradable · Polymers

S. B. Boppana (✉)
Department of Mechanical Engineering, School of Engineering, Presidency University, Bangalore, India

K. Palani Kumar · A. Ponshanmugakumar
Department of Mechanical Engineering, Sri Sai Ram Institute of Technology, Chennai 600044, India

S. Dayanand
Department of Mechanical Engineering, Government Engineering College, Gangavathi 583227, India

K. Palanikumar et al. (eds.), *Bio-Fiber Reinforced Composite Materials*,
Composites Science and Technology,
https://doi.org/10.1007/978-981-16-8899-7_4

1 Introduction

Over the past few years, owing to the rigorous consumer's consciousness focusing on new products being manufactured, there has been a dramatic shift towards recycling and green manufacturing.

The composite material first used in early days of human history was related to clay reinforced with straw. The material was developed roughly around 3000 years ago. The composite would be termed as natural fiber composite, but with the development of technologies related to manufacturing while concentrating on better strength, metals, ceramics and synthetic fibers were found to gradually replace the traditional material using clay and straw.

Nowadays, the practice of using composites synthesized through natural fibers has become very popular in almost all fields concerned with engineering. This may be because the materials processed using bio fibers exhibit nearly the same characteristics as conventional materials. Few features that excel for the bio fibre-based composites would be properties related to lightweight, lesser cost of materials, and more importantly, their environmentally friendly aspect. Day by day, consumers are more inclined to think over products manufactured through an environmentally friendly process. It was during this change in approach that led to the development of composite materials. Traditional methods were supposed to be adopted during the synthesis of new composite materials more sustainably. In Fig. 1, classification of bio-composites are explained.

There is a need for sustainable usage of bio-composites to overcome the ecological imbalance due to the petroleum-related synthetic-based resources. Artificial fibers related to polymer-based composites have to be substituted by fibers available in biodegradable and natural form. The various types of natural fibre reinforcement methods are listed in Fig. 2.

Table 1 explains the international standards based on bio-based, biodegradable and compostable standards. A thorough study about the applications of composites reinforced with various natural fibers in various engineering fields is carried out since bio fibers are available abundantly and can be renewed; they also happen to be non-toxic and relatively cheap. Table 2 gives the broad classification of natural fibers.

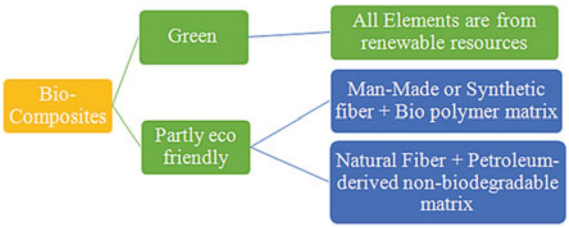


Fig. 1 Classification of bio-composites

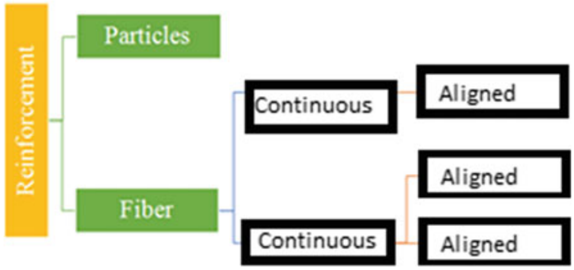


Fig. 2 Types of natural fibre reinforcement

Table 1 Bio-based, biodegradable, and compostable standards from the International Organization for Standardization (ISO)

Label	ISO Standard	Description
Bio-based	16620:2015	Describes the general ideas and calculation procedures for using the radiocarbon method to determine the amount of bio-based material in plastic products
Biodegradable	14852: 2018	Specifies a method for determining the degree of aerobic biodegradability of plastic materials by measuring the amount of carbon dioxide released
Compostable	17088:2012	Specifies the methods and requirements for identifying and labelling plastics and plastic-based products

Table 2 Natural fibre classification

Natural fibre	Cellulose/Lignocellulose	Bast Seed Fruit Stalk Grass / Reed Leaf Wood	Hemp, Flax, Jute, Ramie, Kenaf Cotton, Kapok Coir Wheat, Maize, Oat, Rice Bamboo, Corn Abaca, Banana, Pineapple, Sisal Hardwood, Softwood (e.g., Eucalyptus)
	Animal	Wool / Hair	Cashmere, Horsehair
	Mineral	-	Asbestos, Ceramic fibres

2 Natural Fibre Reinforced Composites Have a Variety of Applications

2.1 Coir Fiber-Strengthened Composite

The coir-based composites are extensively used in the aerospace industry and automotive industry. The wings, tails and propellors in the aircraft are the specific areas substituted by these composites. Particleboards [1], materials related to packaging [2] and mortar prepared by cement sand [3] have been associated with the use of

Fig. 3 Application of coir fibre in automobile

coir-based composites. Decks, panels, and slabs related to lightweight component members in structural fields also indicate the use of the above-mentioned composites. Figure 3 represents the thermal insulation provided by using coir related composites in areas like cushioning of seats in automotive sectors [4, 5]. Researchers have also been successful in designing water and other liquid storage tanks [6]. Considering the research carried out in finding hardness, flame retardancy and tensile properties of polypropylene composites reinforced with coir fiber, an optimal panel design was prepared for applications in interiors of automotive applications [7] through a suitable weight proportion mixture of coir fiber, polypropylene powder and maleic anhydride grafted polypropylene.

2.2 Kenaf Fibre-Fortified Composite

Polylactic acid thermoplastic, polypropylene and epoxy resin-based matrix materials fortified with kenaf fiber are used in bearings, tooling and some automotive parts. Pultrusion and compression moulding methods are often used to synthesize these kinds of composites. The kenaf fibers have tensile strength and Young's modulus in the range of 223–1191 MPa and 11-60GPa [8]. Hybrid kenaf/glass fiber-reinforced polymer composites showed enhanced mechanical properties with rain erosion resistance and found suitable for aircraft application [9].

Presently, kenaf is used in the production of paper. Kenaf is found to have superior properties in terms of toughness and improved aspect ratio compared to other fibers. Kenaf fibers are also used in product applications such as summer forage, potting media and animal bedding [10].

Owing to its lightweight, kenaf-based composites have reduced emissions and fuel consumption when used in automotive sectors. The composites are also used in Lexus package shelves. Figure 4 reveals the kenaf fiber based applications in automotive sectors. The exterior and interior parts of automotive structural members can be effectively manufactured. The beams of the bumper and parts related to front end modules in automotive vehicles can be effectively used with the help of twisted kenaf hybrid material [11].

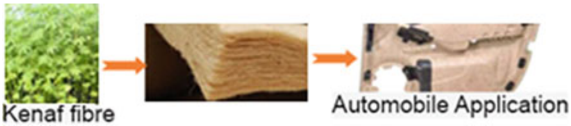


Fig. 4 Application of kenaf fibre in automobile

Fig. 5 Ramie fibre application in packaging and Insulation

2.3 Ramie Fibre-Strengthened Composites

Ramie fibers are used as sewing thread, handkerchiefs, weaving canvas, fabrics related to parachutes. The body armour and some applications in the civil field are also linked to the usage of ramie fiber since it has nearly the same specific stiffness as that of glass fiber. It has also used in the making of blouses, skirts, shirts and papers, and banknotes.

The specific applications involve ramie-based fabric centric epoxy composite bulletproof material. The conventional material used is heavier than the epoxy composite since it comprises steel and ceramics. Socket prosthesis was also achieved by using the fiber as mentioned earlier in epoxy matrix. Aluminium sheets were inserted with ramie fiber in the epoxy matrix to synthesize laminated composites in another application. Compared to aluminium, the tensile strength of the composite is relatively improved than that of aluminium. Ramie whiskers in nano form can also be used to prepare polymer-based electrolytes using polyoxyethylene [12]. Further, short ramie fiber reinforced soy protein-based polymer composites can be used in packaging and skins of appliances, whereas the long fibre-based composites can be effectively used in transportation and structural uses [13]. Figure 5 represents some applications in packaging related areas.

2.4 Flax Fibre-Fortified Composite

Researchers have worked on the possibility of using epoxy reinforced flax composite in the form of tube as concrete confinement. The compressive strength of the composite in the axial direction was superior when compared with the unconfined concrete. The other benefit would owe to its light weight-related framework. Tube made with flax reinforced composite covered the concrete as bridge pier [14]. Flax based composites with vegetable oil-based epoxy resin could be used in construction and automotive sectors (Fig. 6).

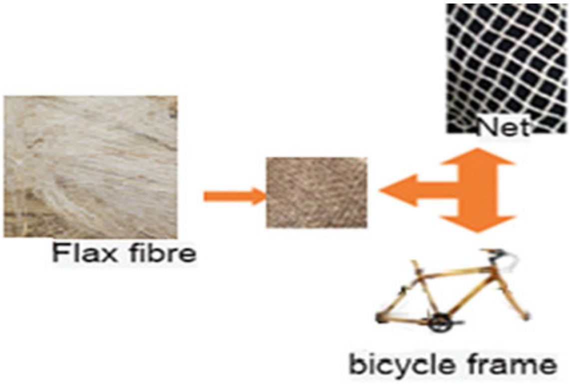


Fig. 6 Flax fibre application

Naturally available phenolic resin-like tannin strengthened with flax offers considerable benefits by lowering the ecological footprint of lighter weight applications in the automotive field corresponding to panels and trims of body and crash elements [15]. Gopalan et al. [16] suggest that flax woven epoxy-based composite can also be used in applications related to interiors of car, rail, panels of aircraft and equipment related to sports. Composites with flax fibers are used in frames of windows, decking, fencing, frame of bicycle, fork and snowboarding. Polypropylene based flax fiber composites are used in floor trays of cars. The interior door lining panels of few luxury cars also involve the use of flax fibre-based composites [17].

2.5 *Jute Fibre-Strengthened Composite*

Composite boards prepared from jute-coir are often superior when compared to plywood boards and can be used as backing for sleeper berths in railway coaches and fishing boats. Even the interiors of building, windows and doors have potential applications using board processed using jute. Gon et al. [18] emphasised the idea of using jute-based composites in backrest and backings of seats of vehicles. El-Sayed et al. [19] fabricated jute-based polymer composites for bearing applications.

Toilet blocks were successfully developed with the help of jute fiber reinforced plastic (FRP). Door shutters were sandwiched by FRP and synthesized within a short period that find importance during the aftermath of disaster relief. Other potential applications of jute-based composites were related to making doors using jute and FRP. The principal materials to support them could be foam using polyurethane and polystyrene. They can be used in construction fields like schools, offices and labs. Resin-jute based materials were also used to develop packaging resources for commodities like tea and fruits [18]. Gopinath et al. [20] highlighted the use of polyester-based jute composites in paperweights, false ceilings, shower, partition panels, tiles on roof, lampshades and bath units. Jute and phenolic based composite found a potential application to replace steel material used in slipway primarily used

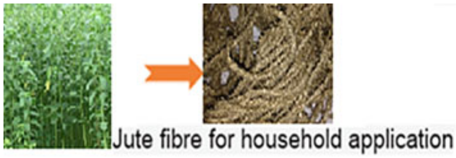


Fig. 7 Jute fibre applications

for launching lifeboats since they were found to reduce the coefficient of friction. Figure 7 represents application of jute fiber in making ropes.

2.6 Sisal Fiber-Strengthened Composite

Sisal fibers possess good strength of around 640 MPa, hence they are used in making ropes, carpets and mats. The fibers have low density with good modulus and hence can be potential candidates for applications in wall hangings and purses.

Swift [21] developed sisal/cement composites for structural applications. They were suitable for cladding walls that consisted of adobe structures which were resistant to earthquake. Water ducts, bins for storing grains were few other applications of the composites. Medhi et al. [22] reported the mechanical behaviour of sisal reinforced polymer composite and highlighted the potential to be used in industrial and automotive sectors. The other possible applications of the composite include laminates and construction-related material.

Researchers [23] have worked on cement-based long sisal fiber composite for their use in panels as structural members and were found to be resistant against impact and blast. The masonry walls which were not reinforced could be strengthened by using the composite. Sisal fiber reinforced resin-based composite was used to prepare brake pads that could possibly substitute pads using asbestos [24]. Glove box and door panels of cars were prepared by using sisal reinforced polymer composites, while the sisal/flax fibre-reinforced polyurethane-based composite was used in panels of door trim. The interior door lining of few cars was also substituted by sisal and flax-based composites [17]. Figure 8 represents the use of fiber in construction field.

Fig. 8 Sisal fibre applications

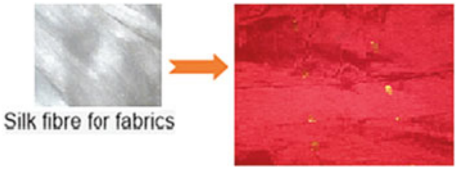


Fig. 9 Silk fibre applications

2.7 Silk Fiber-Fortified Composite

Silk fibers are of prime importance as natural fibers since it is found to be biocompatible and possess high toughness. They are used in clinical fields in the form of braided suture threads in surgical operations. The support structure for cartilage in medical fields also composes of silk fiber. The other fields related to the use of silk fibers is in the textile industry. Since silk fiber is relatively costlier than most other natural fibers, the waste obtained from the silk manufacturing industry is used as a supporting material for polymer-based composites. The polymer composites have the potential to be used in structural applications. The fibers are suitable as an alternative for glass fibers used as fortifying elements in applications like structures of turbine and aerospace sectors [25]. Epoxy resin reinforced with silk was used as a composite in the form of square tube energy-absorbers to check the crashworthiness of passenger vehicles [26]. The composites were found to be useful in energy absorbing applications. Figure 9 represents the use of silk fibers in making fabrics.

Since silk fibre is having superior resistance against fatigue, the composite involving silk fibers can reduce the propagation of the crack. Silk fibers have made bowstrings, fishing nets and wound dressings. Silk fibers exhibit piezoelectric behaviour and hence could also be used as potential candidates for preparing devices in optical fields.

2.8 Banana Fibre-Reinforced Composite

Banana fibers mixed with polyvinyl alcohol composite films were suggested as a food packaging material since the swelling of the films reduced with the increasing content of banana fiber in the blend [27]. Ramesh et al. [28] highlighted the importance of the synthesized banana fiber and epoxy resin-based composite as a substitute for fibre-reinforced polymer matrix composites since the natural fiber composite was able to endure higher loads. Researchers have opined the application of banana and cotton fibre-based composite in manufacturing of materials requiring lesser strengths. Banana fibers reinforced in polymer matrix could be satisfactorily used in building applications [29]. Venkateshwaran et al. [30] reported the potential application of banana fibre-based polymer composite in automotive and machinery fields since the fibers considered possessed high tensile modulus, relatively low density, and high tensile strength.

Banana fibers have been used in the manufacturing of ropes. Since it has natural buoyancy, the fiber can be effectively used in the preparation of shipping cables. The other desirable property of the fiber is its resistance towards seawater. Fishing nets, decorative papers, cordage, cables in wall drilling operations and wall furnishings also use banana fibers. Postcards, socks, note books, paper boards and tea bags are few other applications of banana fibers [31].

Soybean associated polyester and epoxy matrix reinforced with banana fibers have potential applications in transportation and automotive fields [31]. Hockey equipment was another potential application of banana fibre-related hybrid composites that effectively endured higher loads and could substitute the glass fibre-based composites [32]. Fibers of banana are used in the preparation of medium weight and lightweight composites. The composites are apt for agro-based industries.

2.9 Bamboo Fiber-Fortified Composite

Bamboo based composites are extensively used in designing interiors involving panels and furniture. Their use is limited in automotive fields, but they are found to have potential applications in structural and aerospace applications. Composites with bamboo can be used in making ply bamboo and medium density boards. Bamboo based composites have been found to have applications in the aircraft and vehicle interiors; helmets used by bicyclists and decks prepared for leisure activities are some other examples where the composites are widely used [33]. Bamboo fibre-reinforced in resin have also got probable applications in architectural fields [34].

Wood interiors were replaced with bamboo-based composite owing to the strength of bamboo and found to be ten times stronger than materials made up of wood. The other desirable properties of the composite were low flame speed, low maintenance and longevity.

The car-like dashboard, door panels, floor mats and cloth seats were also manufactured using bamboo composites. Spring chairs and stools as other applications of the said composite in furniture [35]. Figure 10 depicts the use of bamboo fiber in making door panels.

Fig. 10 Bamboo fibre applications

Fig. 11 Bagasse fibre applications

2.10 Bagasse Fibre-Strengthened Composite

Sugar cane bagasse is primarily used in fuels, enzymes and feedstocks. Bagasse is known to have low densities, and hence, structures of low weight, false ceilings, particle boards are some applications where bagasse fibers are used as reinforcement materials. Bagasse of sugarcane, oil palm and phenol–formaldehyde hybrid composites were prepared for making thermal insulation boards.

The other applications were in the construction field involving the preparation of cement panels using carbon nanotubes and fibers of sugar cane bagasse. The flexural strength of the panels was found to have higher flexural strength when compared with unreinforced cement panels. Panels of bagasse-based composites were found to have potential applications in lightweight structures due to the economic benefits [36]. Xiong [37] observed the competitive advantages of composites involving bagasse that do not require high mechanical properties like sound insulators. Composites synthesized through bagasse could be used as conductive materials for applications in the packaging industry. Heavy metals could also be absorbed by using composites prepared through bagasse.

Anti-static and anti-bacterial material in packing applications is some potential applications of conductive composites synthesized using polyaniline conducting polymer and bagasse. The process involved using dodecylbenzene sulfonic acid and ammonium persulfate during polymerization [38]. Figure 11 represents the use of bagasse in making thin sheets.

2.11 Cotton Fibre-Reinforced Composites

Cotton fibers are known for its absorbency and ability to blend effortlessly with any fiber. They offer superior strength with durability. In thermo-acoustic insulations, polymer composites reinforced with insulating cotton fibers are widely used.

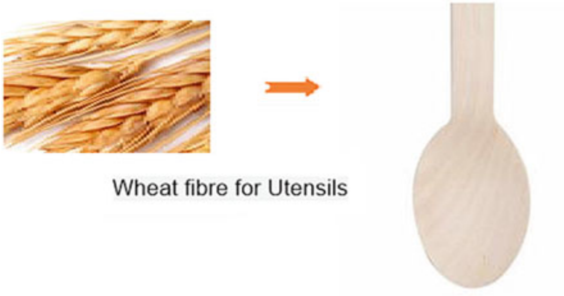


Fig. 12 Wheat fibre applications

Recently, they have found potential applications in the automotive industries owing to their inherent strength. Cotton fibre-reinforced polyester composites were used as bearings involved with water cooling [39].

Unsaturated polyester and cotton fiber composite was suggested for packaging applications due to their improved mechanical properties compared with coir and cotton-based unsaturated polyester composite [40]. Composite plates prepared from polyester-based resin and cotton fibers were investigated for use in structural parts like panels and doors and found satisfactory [41].

2.12 Wheat Fiber Strengthened Composite

Elmessiry and Deeb [42] prepared wheat straw composite with resin and protein colloid blues for applications in the flat board while hybrid composites involving wheat straw and flax fibers were opted for potential applications as shafts having round cross-sections. In Fig. 12, wheat fibre application is illustrated.

Further, wheat straw modified with caprolactam and polyethylene were used to prepare composites using melt blend technique. The composites offered higher mechanical properties since the modified wheat straw was found to have more excellent compatibility with the polyethylene. The modified wheat fibres would function as “biological steel” while forming bio composites [43].

2.13 Abaca Fibre-Reinforced Composite

Abaca fibers is regarded as one of the strongest available natural fibers. Presently, it is used in ropes and twines. The fibre-reinforced composite material could have potential applications in the airframe of crewless aerial vehicle. The fibre is also used in textile industries, handicraft, gift boxes, packaging materials, decorative accessories, wall coverings, foot wear, tea bags, coffee filters, surgical masks, caps and orthopedic materials [44].

The composites used as under floorings in cars had the reinforcement of abaca fibers. Since the fibres had high flexural strengths and exhibited high resistance against rotting, the exterior parts meant for the vehicle could pass the required rigorous necessities related to the vehicle's components [45].

Thermosetting plastic and abaca-based composites prepared through hand lay-up technique were suggested for applications in chemical vessels, tanks and pipes; however, since the fibers are associated with absorption of water, there are few drawbacks of using the composite [46]. If they are suitably addressed, they would have potential applications in the transport field, and the fibres could be selected as possible reinforcement for materials in wind turbines and transport industries [45, 47].

Sinha et al. [48] discussed utilising polypropylene-based abaca fibre composites in industrial and constructional applications; since the composites offered lesser transverse thermal conductivity, they could be used as thermal insulators in refrigeration components.

2.14 Oil Palm Fibre Reinforced Composites

Oil palm empty fruit bunch fibers have found applications in plywood and particleboard; oil palm frond fibers have been used in paper, pulp, biodegradable film, downdraft gasifier and fibreboard, while the oil palm trunk fibers have been used for making furniture. Thermoplastics and thermoset based oil palm fibre have extensive applications in the field of automobile components. Components of car-like rear parcel shell, splash shield, bumpers, plastic pellets and spare wheel could be made by technologies offered by Malaysian Palm Oil Board through an extrusion process. Oil palm fibers, when mixed with polyols, could produce lighter weight products like roof insulators and packaging materials [48] as shown in Fig. 13.

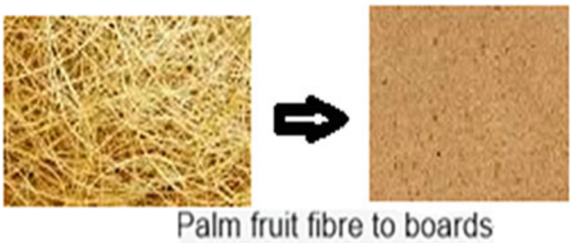
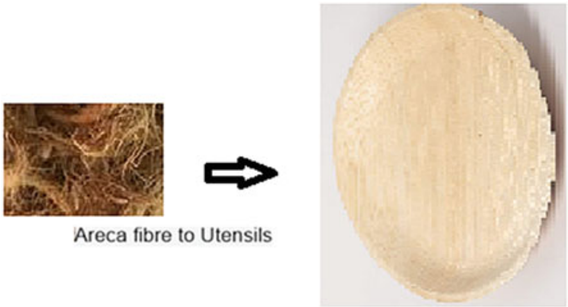


Fig. 13 Palm fibre applications

Fig. 14 Areca fibre applications



2.15 Areca Fibre Reinforced Composites

Areca fibers are generally inexpensive and generally found in abundance. The fibres are hard and the cellular structure of the fibers are much similar to coir fibers. The composite is suitable for preparing lightweight materials with potential applications in office furniture, automotive body building and partition panels [49]. Some of the applications of fibre reinforced composites are also found in the field of electrical insulation.

The areca/betel nut fibre reinforced composites finds more significant advantages in the latest development of composite materials such as electrical insulation, automobile bodybuilding and light load applications. The composites that used treated fibers were superior to glass fibre reinforced polyester and had nearly the same mechanical properties as that of the glass-reinforced polyester. In applications related to low-cost housing and packaging, areca fibre with maize powder strengthened composites were found to be useful. The fibre of areca sheath was also used in automobiles' interiors, storage of grains, partition of boards, suitcases, and post-boxes [50]. The laminate prepared by using areca fibre could be used to manufacture items like packaging box and pen stand [51]. The flower pot stand frame was prepared using a combination of areca sheath, jute fibre, glass fabrics, and epoxy resin and had shown lesser deformation [52]. Areca fibers also are used in making utensils (Fig. 14).

2.16 Okra Fibre-Based Composite

Okra fibre reinforced composites could be used in various parts of automobile. The polyester-based composites with okra fibre have insulation property, hence finding potential applications in the electrical industry [53, 54].

The bast fibers of okra which contribute to around 10 to 25% of the weight of the plant, are usually strong and comparable to the fibers of hemp and jute. The fibers are generally shiny and bright; the bast fibers from the stem are investigated for their ability to act as load-bearing members in the composites. Since the hybrid composite made from okra fibers have less weight, they are suitable for materials

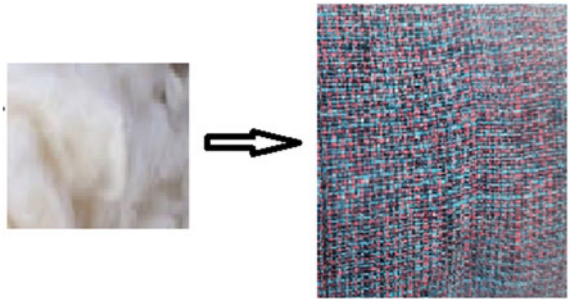


Fig. 15 Kapok fibre application in making fabrics

in architectural and building sectors. Walkway paths, architectural landscaping and panels for partition are few other areas where the composite can be used since they absorb minimum water. The composite has better sound-absorbing efficiency and resistance against shatter when compared to glass fibre reinforced composite. The composite prepared from okra and polylactic acid was able to compost completely after forty days in soil. This may reduce waste associated with construction and help in the sustainability concept [54]. Onyedum et al. [55] investigated banana and okra fibre-based composite in bumpers of automotive cars.

2.17 Kapok Fibre-Reinforced Composites

The kapok fiber happens to be one of the lightest natural fiber available. It is lighter than cotton fiber. It is generally called silk cotton since it lustres similar to silk. Venkata Reddy et al. [56] synthesized polyester-based hybrid composites involving sisal, kapok and glass fabrics and suggested the use of the composites in structural applications like automotive interior parts.

Composite was prepared by Liu et al. [57] using kapok fibre and hollow polyester and evaluated for sound-absorbing properties at low frequencies. In contrast, Lyu et al. [58] used polyε-caprolactone as matrix and kapok fibers as reinforcements and composites were prepared using a suitable flame retardant through hot pressing method. The composite was found to be suitable for applications in building materials. The kapok fibre-based polyester composites were found to be resistant to chemical attacks [59]. In Fig. 15, kapok fibre application is represented.

2.18 Milkweed Fibre-Reinforced Composites

The stem of the milkweed plant is often used for making natural rubber, while the seeds could be used to manufacture oil. The fiber had potential applications in the field of textiles. The milkweed floss has been used as filling material in jackets due to a completely hollow center. Due to the milkweed floss's low density, the composites reinforced with milkweed floss were preferable for developing light weight composites [60]. The fibers of the milkweed plant could be used for reinforcing cement-based composite structures. A higher amount of fibers per unit weight could be added due to the low density of fibers, thus aiding in manufacturing composite structures with lightweight is explained [61].

2.19 Pineapple Leaf Fiber Composites

Pineapple leaf fiber is generally white in colour and is smooth. The fiber is of medium length and possess high tensile strength. The fiber is also known to have higher stiffness, but it is hydrophilic due to the higher content of cellulose. Due to the incredible mechanical properties of fibers, they could be used in preparing polymer composites, biodegradable plastic composites and low-density polyethylene composites.

The fibers are abundantly used in industrial applications due to the ease of availability. Threads are made from these fibers for textile fabrics. Baggage, cabinets, sports item, automobiles and mats are a few other areas where the fibers are used. The belt, transmission cloth, conveyor belt cord, airbag tying cords, and transmission cloth are other machinery parts prepared using palm leaf fibers subjected to surface modification. Biopolymer's coating, cosmetics and medicine are few other applications of using the fiber [62]. Jamaluddin et al. [63] studied the effect of addition of palm leaf fiber in tapioca biopolymer and opined about its potential application as a renewable and biodegradable polymer.

2.20 Nettle Fibre-Reinforced Composites

Nettle is an herbaceous plant of the Urticaceae family. The entire plant could be used for various purposes like medicine, textile production, fodder, cosmetic and medicine [64]. Fiber from nettle plant is used in producing threads and ropes, while the leaves are used as vegetables. Sandeep Kumar et al. [65] worked on epoxy-based bauhinia vahlii and nettle fibre-reinforced composite and concluded that they could be used in products subjected to moderate tribological resistance. The composite could also be used in products having reasonable mechanical strength.

Nataraj et al. [66] investigated on dynamic and mechanical properties of nettle based polyester composites to check for the appropriateness of the synthesized composite for structural applications like machine tools. Since the machine tools operate at high speeds, high damping is preferred. The synthesized composites had offered good damping ratio. The composite could be used in potential applications involving automobile and aerospace applications.

The fiber was considered for applications in gear wheels, dashboard panels of automotive/aircraft. The nettle-based composites were suggested for applications in machine tool structures like micro lathe bed [67].

2.21 Elephant Grass Fibre-Reinforced Composites

Elephant grass is yellowish in colour and generally grows in dense clumps in rich soil. Studies were carried out to find the potential application of grass in the production of biogas. Polyester resin reinforced with elephant grass was used to prepare composite through hand layup technique. Since the density of the grass fiber was less, the fibers find potential applications for making light weight structures [68].

Ramaiah et al. [69] synthesized composite using elephant grass fiber and polyester resin using hand lay-up technique. The processed composites were found to be light in weight and had good thermal insulating properties. Further, on comparing with pure resin, the thermal conductivity and specific heat capacity of the glass fibre-reinforced composite was always less. They were also economical; they could be used in air-conditioners, interior parts of automobiles and electronic packages.

2.22 Luffa Fibre-Reinforced Composites

Luffa cylindrica, also known as luffa sponge, is known to have potential applications in packaging, sound absorption, and vibration isolation. The fibers of luffa possess good sound absorption coefficient and hence exhibit better acoustic properties. The fruit can be used in making composite materials since it is able to offer decent adhesion with the matrix due to its surface morphology. Luffa based natural composites could be used in cars, airplanes and yachts due to their ability to isolate vibrations and sound. Numerous researches had also projected using the luffa-based composites in printed circuit boards and building applications [70]. Doors, fiberboard and house panels were also some potential applications of luffa fiber composites [71]. Figure 16 shows luffa fibers.

2.23 Rice Fibre-Reinforced Composites

Rice husks are agricultural residues that are available in huge quantities during the milling process of rice. In rural areas, it is used as a fuel. However, in the recent times, composites were manufactured from agricultural wastes like rice husk. The ash obtained from rice husk was mixed with cement to produce cement-based composite.

Recycled polypropylene pellets and rice husk-based composites were formed in filaments for 3D printing applications by Maria et al. [72]. Automotive bumper was

Fig. 16 Luffa fibre

Fig. 17 Rice husk fibre applications

manufactured by using epoxy-based rice straw fiber composite through filament winding method [73]. In Fig. 17, the rice husk fibre application in automobile application is represented. Composites manufactured with rice husk could be used as substitute for wood. If the rice husk is properly blended with polymers, they could be used for manufacturing plastic toys [74].

2.24 Roselle (Hibiscus Sabdariffa) Fibre-Based Composites

Hibiscus sabdariffa is a shrub pertaining to Malvaceae family. Fibers obtained from the stem were examined for applications in particle boards, textile industries, paper products and composite materials [75]. In Fig. 18, one of the roselle fibre application is represented. Karakoti et al. [76] opined that the fiber from the plant could be used in the manufacturing of polymer-based composite, particularly in light weight applications like sports goods, panels relating to interiors of automobiles and biomedical fields.

Fig. 18 Roselle fibre applications

Fig. 19 Maize fibre applications

2.25 Maize Fibre-Reinforced Composites

Maize (Corn) is a staple food in different parts of the world. Corn fiber is a byproduct of the corn wet-milling industry. N H Sari and S Suteja [77] prepared Cornhusk fibre reinforced polyester resin composites and communicated about its application in exterior windows, decking, siding, and doors. Modified maize stalk fibers were used as reinforcements in natural rubber and revealed about its possible use in the production of shoe sole [78]. The application of maize fiber in fabric is shown in Fig. 19.

3 Challenges in Using Natural Fibers

Natural fibers used in composites are found to absorb water and offer weak interfacial adhesion with polymer matrix. They are subjected to degradation when exposed to the external environment through mechanical, biological and fire means. Organisms might attack cellulose and convert to digestible units. Hence, the interface between the fibers and matrix will weaken and offer lesser strength in composites. Sometimes, oxidation and reduction reactions occur through enzymes.

Degradation due to water is a major challenge with the natural fibre-based composites since they are found to be hydrophilic. They are easily able to absorb water in the external environment due to ice, sea and sources like dew. Swelling is seen in the reinforced composites when the fibers absorb water due to the presence of hemicelluloses. However, it is also observed that the composites also shrink when they dry up. The interface between the fiber and matrix weakens when the fibers tend to absorb water due to the presence of hydroxyl groups. Ultraviolet radiations degrade fibers when lignin content present in the fiber is exposed to radiations. Wind, snow and dust also degrade the composite through the formation of cracks through mechanical means. Resistance against fire is also found to be poor when the composites are used for structural applications. Due to the thermal degradation, change of odour and colour is also noticed in the biofibre reinforced composites [79].

4 Conclusion

Considering the challenges in processing bio fiber composites, surface modification is effectively carried out to improve fibre surface properties, and researchers have successfully improved the compatibility between the fiber and matrix. Several properties that were once considered as challenging were improved during the modification of fibers. Silane treatment was used to modify some of the natural fibers and could effectively enhance the strength and Youngs modulus of the fibers. In order to reduce the absorption water, coupling agents were used during the synthesis of the above said composites. For processing natural fibers, enzyme technology is used significantly since it is considered to be environment friendly and cost-effective.

One of the exceptional features of synthesizing bio fibre-reinforced composites is due to the fact that the mechanical properties could be custom made to such an extent that it would rightly suit a specific application. The fiber orientation and placement could be changed easily to exhibit either highly anisotropic or isotropic property based on the end application.

As discussed earlier, natural fibers have been considered a substitute for non-recyclable fibers since they are renewable, cheap, and easily recyclable. The other advantages of using natural fibers would be owing to its high toughness, low densities and CO_2 neutrality.

Further, the expense incurred in processing a bio fibre-based composite is quite less compared to conventional materials used. The longing for making green products is one more reason to deliberate on using the bio fibre-based composites in almost all fields of engineering. The day-to-day improvements in technology related to synthesizing bio fibre-based composites will also lead to improved product and material features. The composites would become further diverse and venture markets that were once considered unexplored and could be used in almost all fields of engineering.

References

1. Zhang L, Hu Y (2014) Novel lignocellulosic hybrid particleboard composites made from rice straws and coir fibers. Mater Des 55:19–26
2. Speaking R, Jawaid M, Ariffin H, Salit MS (2018) Effects of surface treatments on tensile, thermal and fibre-matrix bond strength of coir and pineapple leaf fibres with polylactic acid. J Bionic Eng 15(6):1035–1046

3. Andiç-Çakir O, Sarikanat M, Tüfekçi HB, Demirci C, Erdogan ÜH (2014) Physical and mechanical properties of randomly oriented coir fiber–cementitious composites. Compos B Eng 61:49–54
4. Sakthivel M, Ramesh S (2013) Mechanical properties of natural fiber (banana, coir, sisal) polymer composites. Sci Park 1(1):1–6
5. Dong Y, Ghataura A, Takagi H, Haroosh HJ, Nakagaito AN, Lau K-T (2014) Polylactic acid (PLA) biocomposites reinforced with coir fibres: evaluation of mechanical performance and multifunctional properties. Compos Appl Sci Manuf 63:76–84
6. Yousif B, Ku H (2012) Suitability of using coir fiber/polymeric composite for the design of liquid storage tanks. Mater Des 36:847–853
7. Ayrilmis N, Jarusombuti S, Fueangvivat V, Bauchongkol P, White RH (2011) Coir fiber reinforced polypropylene composite panel for automotive interior applications. Fibers Polym 12(7):919
8. Rajak DK, Pagar DD, Menezes PL, Linul E (2019) Fiber-reinforced polymer composites: Manufacturing, properties, and applications. Polymers 11(10):1667
9. Arockiam, N.J.; Jawaid, M.; Saba, N. Sustainable biocomposites for aircraft components. In Sustainable Composites for Aerospace Applications; Woodhead Publishing: Sawston, UK; Cambridge, UK, 2018; pp 109–123
10. Akil H, Omar MF, Mazuki AM, Safiee SZ, Ishak ZM, Bakar AA (2011 Sep 1) Kenaf fiber reinforced composites: A review. Mater Des 32(8–9):4107–4121
11. Hassan F, Zulkifli R, Ghazali MJ, Azhari CH (2017) Kenaf fiber composite in automotive industry: an overview. International Journal on Advanced Science, Engineering and Information Technology. 7(1):315–321
12. Du Y, Yan N, Kortschot MT (2015 Jan) The use of ramie fibers as reinforcements in composites. Biofiber Reinforcements in Composite Materials. 1:104–137
13. Netravali A.N. (2004) Ramie Fiber Reinforced Natural Plastics. In: Wallenberger F.T., Weston N.E. (eds) Natural Fibers, Plastics and Composites. Springer, Boston, MA. https://doi.org/10.1007/978-1-4419-9050-1_18
14. Yan L, Chow N, Jayaraman K (2014 Jan) Flax fibre and its composites–A review. Compos B Eng 1(56):296–317
15. Zhu J, Zhu H, Njuguna J, Abhyankar H (2013 Nov) Recent development of flax fibres and their reinforced composites based on different polymeric matrices. Materials 6(11):5171–5198
16. Gopalan V, Suthenthiraveerappa V, Annamalai AR, Manivannan S, Pragasam V, Chinnaiyan P, Mannayee G, Jen C-P (2021) Dynamic Characteristics of Woven Flax/Epoxy Laminated Composite Plate. Polymers 13:209. https://doi.org/10.3390/polym13020209
17. Mohammed L, Ansari MN, Pua G, Jawaid M, Islam MS. A review on natural fiber reinforced polymer composite and its applications. International Journal of Polymer Science. 2015
18. Gon D, Das K, Paul P, Maity S (2012) Jute composites as wood substitute. International Journal of Textile Science. 1(6):84–93
19. El-Sayed AA, El-Sherbiny MG, Abo-El-Ezz AS, Aggag GA (1995 Apr 1) Friction and wear properties of polymeric composite materials for bearing applications. Wear 184(1):45–53
20. Gopinath A, Kumar MS, Elayaperumal A (2014 Jan) Experimental investigations on mechanical properties of jute fibre-reinforced composites with polyester and epoxy resin matrices. Procedia Engineering. 1(97):2052–2063
21. Swift DG. Sisal-cement composites and their potential for rural Africa. In: Marshall IH, editor. Composite structures 3, Elsevier Applied Science Publisher. London/New York: p. 774–87
22. Medhi A, AitTahar K, Bibi M (2008 Apr 18) Studies of sisal fiber-containing composites. Journal of Natural Fibers. 5(1):36–46
23. de Andrade SF, Zhu D, Mobasher B, Soranakom C, Toledo Filho RD (2010 Jan 15) High speed tensile behavior of sisal fibre-cement composites. Mater Sci Eng, A 527(3):544–552
24. Xin X, Xu CG, Qing LF (2007) Friction properties of sisal fibre reinforced resin brake composites. Wear 262(5–6):736–741
25. Hamidi YK, Yalcinkaya MA, Guloglu GE, Pishvar M, Amirkhosravi M, Altan MC (2018 Nov) Silk as a natural reinforcement: processing and properties of silk/epoxy composite laminates. Materials 11(11):2135

26. Oshkovr SA, Eshkoor RA, Taher ST, Ariffin AK, Azhari CH (2012 Jul 1) Crashworthiness characteristics investigation of silk/epoxy composite square tubes. Compos Struct 94(8):2337–2342
27. Sathasivam K, Mas Haris MR, Noorsal K (2010 Sep 30) The preparation and characterization of esterified banana trunk fibers/poly (vinyl alcohol) blend film. Polym-Plast Technol Eng 49(13):1378–1384
28. Ramesh M, Atreya TS, Aswin US, Eashwar H, Deepa C (2014 Jan) Processing and mechanical property evaluation of banana fiber reinforced polymer composites. Procedia Engineering. 1(97):563–572
29. Pothan LA, Thomas S, Neelakantan NR (1997 May) Short banana fiber reinforced polyester composites: mechanical, failure and aging characteristics. J Reinf Plast Compos 16(8):744–765
30. Venkateshwaran N, Elayaperumal A (2010 Aug) Banana fiber reinforced polymer composites-a review. J Reinf Plast Compos 29(15):2387–2396
31. Vigneswaran C, Pavithra V, Gayathri V, Mythili K. Banana fiber: scope and value-added product development. Journal of Textile and Apparel, Technology and Management. 2015 May 19;9(2).
32. Al Rashid A, Khalid MY, Imran R, Ali U, Koc M (2020 Jan) Utilization of Banana Fiber-Reinforced Hybrid Composites in the Sports Industry. Materials 13(14):3167
33. Shah AU, Sultan MT, Jawaid M, Cardona F, Talib AR (2016 Sep 1) A review on the tensile properties of bamboo fiber reinforced polymer composites. BioResources 11(4):10654–10676
34. Biswas S (2012 Sep) Mechanical properties of bamboo-epoxy composites a structural application. Adv Mater Res 1(3):221
35. Suhail SS, Khalil HA, Nadirah WW, Jawaid M. Bamboo based biocomposites material, design and applications. In Materials science-advanced topics 2013 Jun 10. Intech Open
36. Devadiga DG, Bhat KS, Mahesha GT (2020 Jan 1) Sugarcane bagasse fibre-reinforced composites: Recent advances and applications. Cogent Engineering. 7(1):1823159
37. Xiong W (2018 Aug) Bagasse composites: A review of material preparation, attributes, and affecting factors. J Thermoplast Compos Mater 31(8):1112–1146
38. Youssef AM, El-Samahy MA, Rehim MH (2012 Aug 1) Preparation of conductive paper composites based on natural cellulosic fibers for packaging applications. Carbohyd Polym 89(4):1027–1032
39. - Cotton reinforced polymer composites, Editor(s): Navin Chand, Mohammed Fahim, In Woodhead Publishing Series in Composites Science and Engineering, Tribology of Natural Fiber Polymer Composites, Woodhead Publishing, 2008, Pages 129–161, ISBN 9781845693930, https://doi.org/10.1533/9781845695057.129
40. Balaji V (2017) Mechanical characterization of coir fiber and cotton fibre-reinforced unsaturated polyester composites for packaging applications. Journal of Applied Packaging Research. 9(2):2
41. Raftoyiannis, "Experimental Testing of Composite Panels Reinforced with Cotton Fibers," Open Journal of Composite Materials, Vol. 2 No. 2, 2012, pp. 31–39. https://doi.org/10.4236/ojcm.2012.22005
42. Elmessiry M, Deeb E (2016) Analysis of the wheat straw/flax fibre-reinforced polymer hybrid composites. J. App. Mech. Eng. 5:1–5
43. Zhang W, Chen J, Bekele LD, Liu Y, Duns GJ, Jin L (2016 Apr 4) Physical and mechanical properties of modified wheat straw-filled polyethylene composites. BioResources 11(2):4472–4484
44. Punyamurthy R, Sampathkumar D, Bennehalli B, Gouda RP, Srinivasa CV (2015 Jun 1) Influence of fiber content and effect of chemical pre-treatments on mechanical characterization of natural abaca epoxy composites. Indian J Sci Technol 8(11):53236
45. Delano JA (2018 Dec 2) A review on abaca fibre-reinforced composites. Compos Interfaces 25(12):1039–1066
46. Tumolva TP, Kubouchi M, Aoki S. Development of furan-based green composites. Proceedings of the international committee on composite materials (ICCM17); 2009 July 27–31; Edinburgh, Scotland.

47. Sinha AK, Bhattacharya S, Narang HK (2020 Nov) Abaca fibre reinforced polymer composites: a review. J Mater Sci 25:1–9
48. Abdul Khalil HPS, Jawaid M, Hassan A, Paridah MT, A. Zaidon (August 22nd, 2012) Oil Palm Biomass Fibres and Recent Advancement in Oil Palm Biomass Fibres Based Hybrid Biocomposites. Composites and Their Applications, Ning Hu, IntechOpen,. https://doi.org/10.5772/48235
49. Venkateshappa SC, Bennehalli B, Kenchappa MG, Ranganagowda RP (2010 Jul 15) Flexural behaviour of areca fibers composites. BioResources 5(3):1846–1858
50. Ashok RB, Srinivasa CV, Basavaraju B (2018 May 1) A review on the mechanical properties of areca fibre-reinforced composites. Science and Technology of Materials. 30(2):120–130
51. Heckadka SS, Kini MV, Ballambat RP, Beloor SS, Udupi SR, Kini UA (2014 Nov) Flexural strength analysis of starch-based biodegradable composite using areca frond fibre reinforcement. International Journal of Manufacturing Engineering. 13:2014
52. Jothibasu S, Mohanamurugan S, Vijay R, Lenin Singaravelu D, Vinod A, Sanjay MR (2020 Mar) Investigation on the mechanical behavior of areca sheath fibers/jute fibers/glass fabrics reinforced hybrid composite for light weight applications. J Ind Text 49(8):1036–1060
53. Srinivasababu N (2015) An overview of okra fibre reinforced polymer composites. IOP Conf Ser 626 Mater Sci Eng 83:012003. doi:https://doi.org/10.1088/1757-899X/83/1/012003
54. Khan GM, Yilmaz ND, Yilmaz K. Okra fibers: Potential material for green biocomposites. In Green biocomposites 2017 (pp. 261–284). Springer, Cham.
55. Onyedum O, Aduloju SC, Sheidu SO, Metu CS, Owolabi OB (2015) Comparative mechanical analysis of okra fiber and banana fiber composite used in manufacturing automotive car bumpers. American Journal of Engineering, Technology and Society. 2(6):193–199
56. Venkata Reddy G, Venkata Naidu S, Shobha RT (2008 Nov) Impact properties of kapok based unsaturated polyester hybrid composites. J Reinf Plast Compos 27(16–17):1789–1804
57. Liu X, Yan X, Li L, Zhang H (2015 Jul 4) Sound-absorption properties of kapok fiber nonwoven fabrics at low frequency. Journal of Natural Fibers. 12(4):311–322
58. Liu L, Tian Y, Lu J, Xiong X, Guo J (2020 Jan) Flame-Retardant and Sound-Absorption Properties of Composites Based on Kapok Fiber. Materials 13(12):2845
59. Mahesha GT, Subrahmanya BK, Padmaraja NH. Biodegradable natural fibre-reinforced polymer matrix composites: Technical updates. AIP Conference Proceedings 2019 Oct 25 (Vol. 2166, No. 1, p. 020001). AIP Publishing LLC.
60. Reddy N, Yang Y (2010) Non-traditional lightweight polypropylene composites reinforced with milkweed floss. Polym Int 59(7):884–890. https://doi.org/10.1002/pi.2798
61. Hassanzadeh S, Hasani H (2017 Feb) A review on milkweed fiber properties as a high-potential raw material in textile applications. J Ind Text 46(6):1412–1436
62. Asim M, Abdan K, Jawaid M, Nasir M, Dashtizadeh Z, Ishak MR, Hoque ME (2015 May) A review on pineapple leaves fibre and its composites. International Journal of Polymer Science. 6:2015
63. Jaafar J, Siregar JP, Oumer AN, Hamdan MH, Tezara C, Salit MS (2018 Jul 5) Experimental investigation on performance of short pineapple leaf fiber reinforced tapioca biopolymer composites. BioResources 13(3):6341–6355
64. Bedros E, Baley C. Investigation of the use of stinging nettle fibres (UrticaDioica) for polymer reinforcement: Study of single fibre tensile properties. In13th European Conference on Composite Materials 2008 Jun 2.
65. Kumar S, Mer KK, Gangil B, Patel VK (2020 Aug 1) Synergistic effect of hybrid Himalayan Nettle/Bauhinia-vahlii fibers on physico-mechanical and sliding wear properties of epoxy composites. Defence Technology. 16(4):762–776
66. Mahendra Kumar N, Thyla PR, Mohanram PV, Sabareeswaran A, Manas RB, Srivatsan S (2015 Dec 1) Mechanical and dynamic properties of nettle-polyester composite. Mater Express 5(6):505–517
67. Pokhriyal M, Prasad L, Rakesh PK, Raturi HP (2018 Jan 1) Influence of fiber loading on physical and mechanical properties of Himalayan nettle fabric reinforced polyester composite. Materials Today: Proceedings. 5(9):16973–16982

68. Rao KM, Prasad AR, Babu MR, Rao KM, Gupta AV (2007 May) Tensile properties of elephant grass fiber reinforced polyester composites. J Mater Sci 42(9):3266–3272
69. Ramaiah K, Prasad AR, Reddy KH (2012 Dec) Thermophysical properties of elephant grass fiber-reinforced polyester composites. Mater Lett 15(89):156–158
70. Alhijazi M, Safaei B, Zeeshan Q, Ismael M, Eyvazian A, Qin Z (2020 Jan) Recent Developments in Luffa Natural Fiber Composites. Sustainability 12(18):7683
71. Parida C, Dash SK, Das SC. Effect of fiber treatment and fiber loading on mechanical properties of luffa-resorcinol composites. Indian Journal of Materials Science. 2015;2015.
72. Morales MA, Atencio Martinez CL, Maranon A, Hernandez C, Michaud V, Porras A (2021 Jan) Development and Characterization of Rice Husk and Recycled Polypropylene Composite Filaments for 3D Printing. Polymers 13(7):1067
73. Saidah A, Susilowati SE. Design of composite material of rice straw fiber reinforced epoxy for automotive bumper. In2017 International Conference on Computing, Engineering, and Design (ICCED) 2017 Nov 23 (pp. 1–4). IEEE.
74. Bisht N, Gope PC, Rani N (2020 Dec 9) Rice husk as a fibre in composites: A review. J Mech Behav Mater 29(1):147–162
75. Akubueze EU, Ezeanyanaso CS, Muniru OS, Nwaeche FC, Tumbi MI, Igwe CC, Elemo GN (2019 Feb) Extraction and characterization of bastFibres from Roselle (Hibiscus Sabdariffa) stem for industrial application. Journal of Materials Science Research and Reviews. 9:1–7
76. Karakoti A, Biswas S, Aseer JR, Sindhu N, Sanjay MR. Characterization of microfiber isolated from Hibiscus sabdariffa var. altissima fiber by steam explosion. Journal of Natural Fibers. 2018 May 22.
77. Sari NH, Suteja S. Corn husk Fibers Reinforced Polyester Composites: Tensile Strength Properties, Water Absorption Behavior, and Morphology. In IOP Conference Series: Materials Science and Engineering 2020 (Vol. 722, No. 1, p. 012035). IOP Publishing.
78. Chigondo F, Shoko P, Nyamunda BC, Moyo M (2013) Maize stalk as reinforcement in natural rubber composites. Int J Sci Technol Res 2(6):263–271
79. Kumar R, Ul Haq MI, Raina A, Anand A (2019) Industrial applications of natural fibre-reinforced polymer composites–challenges and opportunities. Int J Sustain Eng 12(3):212–220