Review

Kurki Nagaraj Bharath* and Satyappa Basavarajappa

Applications of biocomposite materials based on natural fibers from renewable resources: a review

Abstract: Biocomposites (natural fiber composites) from local and renewable resources offer significant sustainability; industrial ecology, eco-efficiency, and green chemistry are guiding the development of the next generation of materials, products, and processes. Considerable growth has been seen in the use of biocomposites in the domestic sector, building materials, aerospace industry, circuit boards, and automotive applications over the past decade, but application in other sectors until now has been limited. Nevertheless, with suitable development, the potential exists for biocomposites to enter new markets and thus stimulate an increase in demand. Many types of natural fibers have been investigated with polymer matrices to produce composite materials that are competitive with synthetic fiber composites which require special attention. The agricultural wastes can be used to prepare fiber-reinforced polymer composites for commercial use and have marketing appeal. The growing global environmental and social concern, high percentage of exhaustion of petroleum resources, and new environmental regulations have forced the search for new composites, compatible with the environment. Many references to the current status of research work on the applications of biocomposites are cited in this review.

Keywords: agriculture waste; applications; biocomposites; natural fibers.

DOI 10.1515/secm-2014-0088
Received March 23, 2014; accepted July 11, 2014; previously published online May 13, 2015

1 Cellulose-based fibers

There has been rapid growth in the use of novel materials based on natural fibers with growing environmental consciousness and with high performance at reasonable costs in recent years. Natural fibers are an alternative resource to artificial fibers like glass fiber, carbon fiber as reinforcement for polymeric materials to manufacture low-cost, renewable and eco- friendly composites due to their specific properties, advantages in health issues and recyclability [1].

1.1 Classification of natural fibers

Cellulose is a polysaccharide, which is found abundant in the plant kingdom and is common in all natural fibrous materials. In general, all natural fibers are single-cell materials [2]. Classification of natural fibers, its origin and world annual production are as shown in Table 1.

The classification of natural fibers is shown in Figure 1. At the present level of technology, nonwood fibers such as hemp, kenaf, flax, and sisal have achieved commercial success in the design of biocomposites in automotive applications. Cellulose and lignin are the principal components in all the natural reinforcing fibers that are lign-cellulosic, and contents of cellulose and lignin vary from one natural fiber to another [3].

1.2 Chemical composition of natural fibers

The properties of natural fibers depend mainly on the nature of the plant, locality in which it is grown, age of the plant, and the extraction method used. Table 2 shows chemical composition of several natural fibers [4], which helps to know the chemical and physical composition, such as structure of fibers, cellulose content, angle of fibrils, cross-section and by the degree of polymerization [5].

1.3 Mechanical and structural properties of natural fibers

Table 3 shows the mechanical properties of different types of potential natural fibers for composite

***Corresponding author: Kurki Nagaraj Bharath,** Mechanical Department, G.M. Institute of Technology, Davangere, Karnataka, India, e-mail: kn.bharath@gmail.com
Satyappa Basavarajappa: Department of Studies in Mechanical Engineering, University BDT College of Engineering, Davangere, Karnataka, India

Table 1: Classification of natural fibers, origin, world annual production and cost [2].

Fiber type (plant)	Botanical name	Origin	Production (10^3 ton)
Abaca	*Musa textilis*	Leaf	91
Bagasse	*Saccharum officinarum* L.	Stem	102,000
Banana	*Musa uluguruensis* Warb.	Leaf	200
Bamboo	*Gigantochloa scortechinii* *Dendrocalamus apus*	Stem	10,000
Coir	*Cocos nucifera* L.	Fruit	650
Cotton	*Gossypium spp.*	Seed	19,010
Flax	*Linum usitatissimum*	Stem	830
Hemp	*Cannabis sativa* L.	Stem	214
Jute	*Corchorus capsularis, Corchorus olitorius*	Stem	2850
Kapok	*Ceiba pentandra*	Seed	123
Kenaf	*Hibiscus cannabinus*	Stem	970
Phormium	*Phormium tenax*	Leaf	-
Pineapple	*Ananas comosus* Merr.	Leaf	-
Ramie	*Boehmeria nivea* Gaud	Stem	100
Sisal	*Agave sisalana*	Leaf	318.8

applications [6], and this reveals that plant-based natural fibers can very well be used as reinforcement in polymer composites by replacing more expensive and non-renewable synthetic fibers such as glass. Table 4 shows the characteristic values for cellulose content, spiral angle, and cell size.

2 Natural fiber-reinforced composites (biocomposites)

Several natural fibers, namely oil palm, banana, sisal, jute, wheat, flax straw, sugarcane, cotton, silk, bamboo, and coconut which are abundantly available, have proved to be good and effective reinforcement in the thermoset and thermoplastic matrices [8]. Natural fiber composites have been used for a variety of structural applications because they have high specific strength and modulus against metals [9]. These applications range from household to more sensitive and specialized areas such as

Table 2: Chemical composition of several natural fibers [4].

Type of fiber	Chemical composition (%)		
	Cellulose	Hemi-cellulose	Lignin
Jute	61–63	13	5–13
Banana	60–65	6–8	5–10
Coir	43	<1	45
Flax	70–72	14	4–5
Mesta	60	15	10
Pineapple leaf	80	–	12
Sisal	60–67	10–15	8–12
Wood	45–50	23	27
Sun hemp	70–78	18–19	4–5
Ramie	80–85	3–4	0.5

Table 3: Mechanical properties of different types of potential natural fibers for composite applications [6].

Natural fibers	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (GPa)
Jute	200–800	1.16–8	10–55
Banana	529–914	3	27–32
Coir	106–175	14.21–49	4–6
Flax	300–150	1.3–10	24–80
Kenaf	295–119	3.5	2.86
Pineapple leaf	170–162	2.4	60–82
Sisal	80–840	2–25	9–38
Hemp	310–900	1.6–6	30–70
Ramie	348–938	1.2–8	44–128

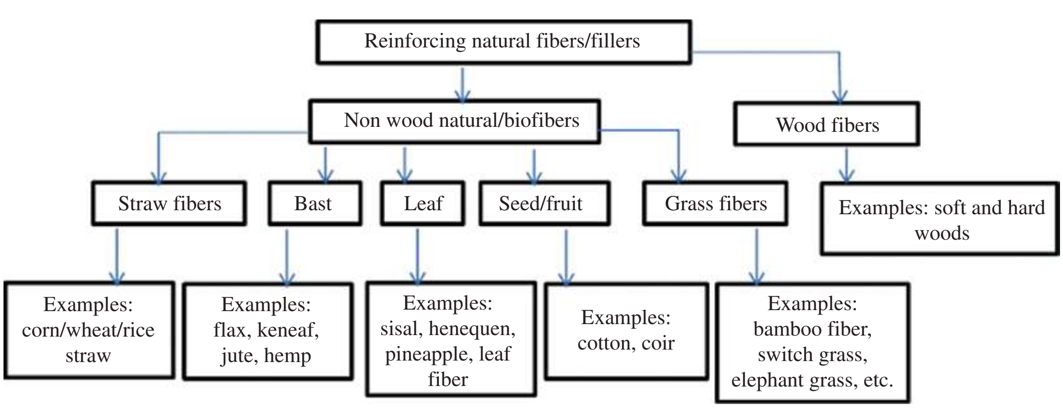

Figure 1: Classification of natural fibers [3].

Table 4: Structure parameters of different cellulose-based natural fibers [7].

Fiber	Cellulose content (wt%)	Spiral angle (°)	Cross-sectional area A 1022 (mm^2)	Cell length L (mm)	L/D ratio (D is the cell diameter) (-)
Jute	61	8.0	0.12	2.3	110
Coir	43	45.0	1.20	3.3	35
Flax	71	10.0	0.12	20.0	1687
Sisal	67	20.0	1.10	2.2	100
Hemp	78	6.2	0.06	23.0	960
Ramie	83	7.5	0.03	154.0	3500

spacecraft and aircraft [10]. The use of natural fibers in composite materials is predicted to be a growth market. The driving arguments for the use of natural fibers is competitive pricing, coupled with the increasing awareness of environmental issues such as "renewable resources", "recycling", and "carbon dioxide emission reduction" etc. Natural fibers could effectively meet the challenges of each of these areas. Figure 2 shows how the compatibilizing agent works in the lignocellulosic filler (biofiber)-polyolefin (polymer) composite system which forms biocomposite materials [11].

2.1 Natural fiber composite applications

The use of natural fibers for composites has increased immensely. There are six basic types of natural fibers, which are classified as follows: bast fibers (jute, flax, hemp, ramie, and kenaf), leaf fibers (abaca, sisal, and pineapple), seed fibers (coir, cotton, and kapok), core fibers (kenaf, hemp, and jute), grass and reed fibers (wheat, corn, and rice), and all other types (wood and roots) [12]. The investigation of the suitability of natural fiber composites has shown more interest in structural and infrastructure applications where moderate strength, lower cost, and environmentally friendly properties are required [13]. Figure 3 shows the interior components of an E-Class car which are made of various natural fiber composite [14]. In Germany, the major car manufactures such as Mercedes, Volkswagen, Audi and Ford uses natural fiber composites for various interior and exterior applications. Figure 4 shows car door inner trim panels that are precast using mats of 60% natural fiber in a Baypreg® polyurethane resin (Courtesy of Bayer Polymers) [15].

2.2 Coir fiber-reinforced composite applications

An attempt has been made using coir – polyester composites to fabricate helmets, roofing and post-boxes as shown in Figure 5. Figure 6 shows the coir fiber from which biocomposites are prepared. These components have been exposed to indoor and outdoor weathering for many 6 years and no degradation has been observed [16]. Coir reinforced bio-composite concrete panels have good durability, due to the fact that the composite walls were not affected by the acid or sulphate environment. Hence, these coir reinforced concrete panels can be used as molded concrete slabs for light weight loading structures [17]. It was found that, coir particles with sepiolite as binder has high thermal decomposition which helps in the electrical conductivity of the samples and this points out possible applications in electrical and sensor devices [18]. Figure 7 shows the chair made of coir composites. Coir fibers are used in the majorly in domestic sector for making a wide variety of floor-furnishing materials, for mattress/sofa bed and in gardening, while in the automotive sector it is used as a support for seats and seat coversas shown in Figure 8 [19, 20].

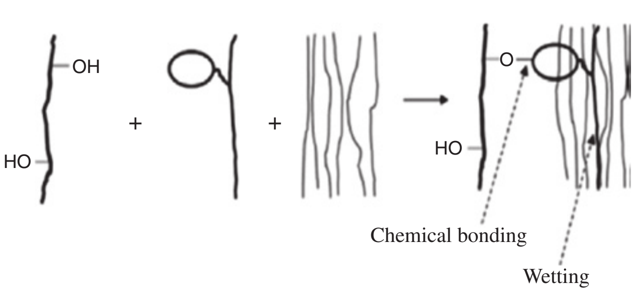

Figure 2: The function of the compatibilizing agent in the lignocellulosic filler-polyolefin composite system [11].

Figure 3: The interior components made of a natural fiber composite for an E-class car [14].

Figure 4: These modern door inner trim panels are molded using mats of 60% natural fiber in a Baypreg polyurethane resin (Courtesy of Bayer Polymers) [15].

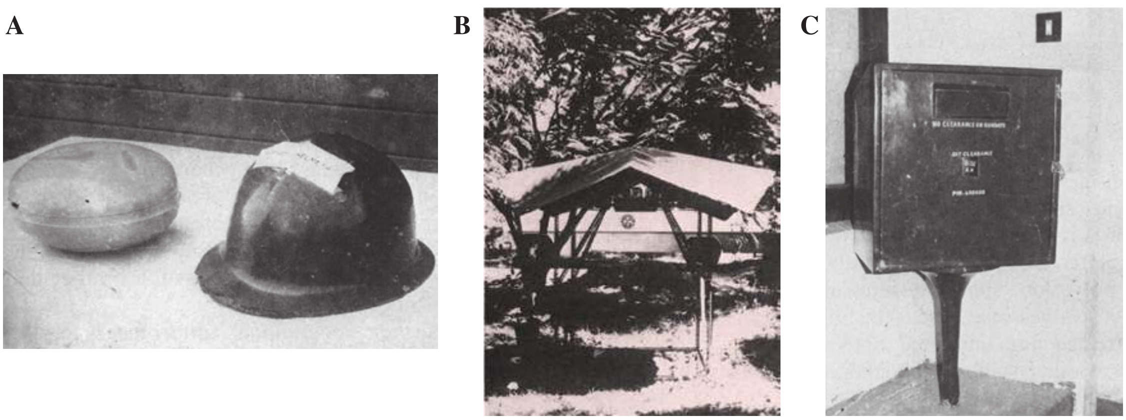

Figure 5: Components made of coir-polyester composites: (A) helmet, (B) roofing, and (C) post-box [16].

2.3 Kenaf fiber-reinforced composite applications

Figure 9 shows kenaf plants and Table 5 gives details of the physical and mechanical properties of Kenaf fiber. Kenaf fiber-reinforced composite is an alternative biocomposite material used particularly in applications such as building and construction, as it is lightweight and has low cost [22]. Kenaf composite panels are made using a one-step steam-injection pressing method and

Figure 6: Coir fiber.

Figure 7: Chair made of coir composites [19].

Figure 8: (A) Floor-furnishing materials, (B) gardening articles, and (C) door which are made using coir fiber.

Figure 9: Kenaf plants [21].

Table 5: Physical and mechanical properties of kenaf fiber [22].

Diameter (μm)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Length of fiber (mm)
140	223	15	5.7	8–12

a two-step pressing method (the particle board is steam pressed first, followed by overlaying) [23]. A study on a hybrid of kenaf/glass fiber composites was carried out to check the mechanical properties of those composites. The results indicate some mechanical properties of hybrid composites and show their potential application in some car structural parts such as bumper beams [24].

2.4 Roselle fiber-reinforced composite applications

Roselle fiber is shown in Figure 10, and Figure 11 shows (A) spur gear and (B) gib-cotter joint made by roselle fiber/polyester. Due to the environmental expectations, and their low weight-high strength, low density, low cost, and high specific properties, roselle fiber-reinforced composites have very good inferences in several applications [4].

2.5 Ramie fiber-reinforced composite applications

Figure 12 shows a static comfort test of socket prosthesis [25]. Ramie fiber composites has greater potential to be

Figure 10: Roselle fiber [4].

further industrialized as a substitute material for socket prosthesis because it is locally available, biomechanically applicable, as lightweight as possible, comfortable, and psychosocially suitable [25].

2.6 Flax fiber-reinforced composite applications

Flax fiber composites show almost the same specific performance as that of glass fiber-reinforced composites. This study reveals that in future natural fibers will compete with glass fiber-reinforced composites to get high-performance composite materials for industrial applications [26]. Flax fiber composites are also used in the development of eco-friendly brake friction composites as these composites stabilize the friction coefficient and also increase the wear rate at high temperature [27].

Flax fiber composites are used in manufacturing of low cost structural components viz cellular beams and panels based on renewable resources for load bearing applications and this result in a great asset for current and future structural applications [28]. These composites are used as raw materials for particle board, which is a partial substitute of wood [29].

Figure 13 shows the flax mat and foam as new flax fiber composite structures which are manufactured so as to be used a substitute for conventional wood structures in buildings. A detailed study on stress-strain analysis were made to know the mechanical properties, which further helps in processing and manufacturing of roof for a house [30].

2.7 Chicken feather fiber-reinforced composite applications

Porous fiber mats such as chicken feathers reinforced with polymer composites provide flow channels for various applications including house roof manufacturing [30]. A very interesting research study was carried out using these composites showing that these can be used in the development of printed circuit boards (PCBs). Because of the good essential properties such as mechanical, flame retardancy, thermal, and peel strength, it was found that these composites are promising for PCB applications [31].

Figure 12: Static comfort test of socket prosthesis [25].

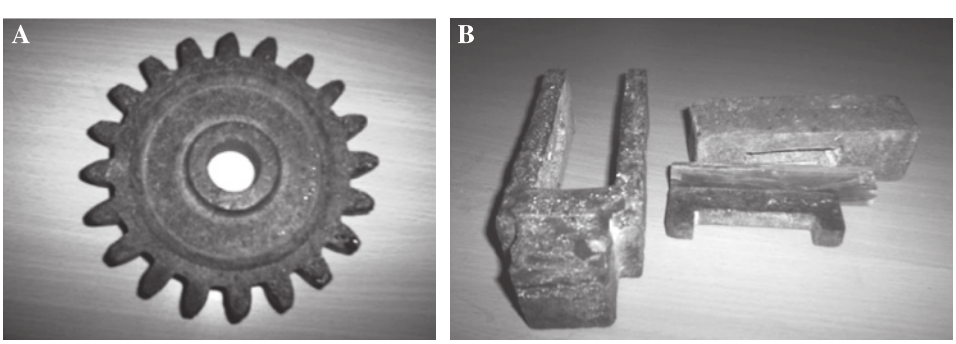

Figure 11: (A) Spur gear and (B) gib-cotter joint fabricated by roselle fiber/polyester [4].

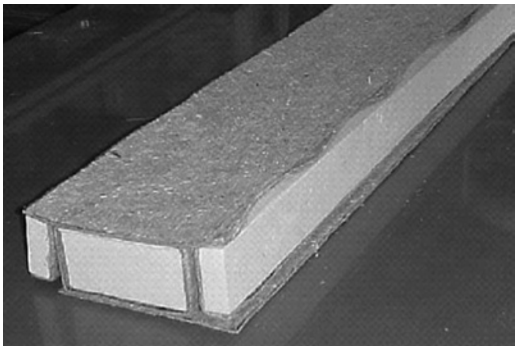

Figure 13: A lay-up of flax mat and foam before bagging [30].

2.8 Recycled waste paper fiber-reinforced composite applications

Figure 14 shows paper wrapped on foam core ready to be assembled in the preform. Composites made up of a soy oil-based resin and recycled paper in the form of paper sheets from cardboard boxes are used in the manufacturing of composite structures. Earlier recycled paper were tested using composite sheets and structural unit beams made from these recycled paper composites resulted in the required stiffness and strength which is used in construction of roof [32].

Fire retardant treated waste paper board shows that there is a possibility to make composites with very good incombustible properties which are suitable to be used as interior finishing material or as insulation board [33].

2.9 Jute fiber-reinforced composite applications

Jute fiber-reinforced composite materials have found their application in trenchless restoration of underground pipes, so the reinforcements composed of inside jute mats and outside glass fiber were recommended for the shape of the reinforcement for the impending work of trenchless restoration of underground pipes [34]. The growth of natural fiber nonwoven composites for the application of car interiors for noise control is intense. As natural fiber composites are noise-absorbing materials, renewable and biodegradable nonwovens were developed for the automotive interiors to reduce noise. The other applications suggested for the developed nonwovens include the acoustic wall coverings for auditoriums, theatres, generator room, and floor mats [35].

Mechanical characterization of untreated woven jute and glass fabric reinforced with isothalic polyester hybrid composites was studied. This hybrid approach had enhanced the mechanical properties and durability of the composites. These hybrid composites may find the applications in moderate load carrying structures such as cabinets, machine covers, seat backings, bumpers, luggage shelves, and many more [36]. The study on natural fiber such as sisal (Chopped) and jute (textile) along with industrial waste like red mud and fly ash reinforced composites had gained its significance as a potential wood substitute material as they are of low cost and energy effective which can be used in building applications [37].

Figure 15 shows a car made from jute fiber-reinforced composites. Research work was carried out to develop, manufacture, and assemble a small prototype car whose body panels were made of these composites and hybrid composites [38].

Figure 14: Paper wrapped on foam core ready to be assembled in the preform [32].

2.10 Hemp fiber-reinforced composite applications

Hemp-based natural fiber-reinforced thermoplastic material was studied to know the environmental performance quantifying carbon storage potential and CO_2 emissions, and it is being compared with commercially available glass fiber-reinforced composites. Table 6 gives details about the annual potential savings in CO_2 emissions and non-renewable resources compared with glass fiber composites in auto sector applications [39].

Hybrid glass fiber and natural fiber composites were studied to check the properties and performance of these composites for curved pipe application. There was a noticeable reduction in cost of about 20% and weight reduction of 23% when composites were made using hemp mats for commercial pipe construction, as shown in Figure 16 [40].

Figure 15: A car made from jute fiber-reinforced composite and hybrid composites [38].

Table 6: Annual potential savings in CO_2 emissions and non-renewable resources by replacing 50% glass fiber composites with natural fibers in auto sector applications [39].

	Savings	
	Emission resources Carbon dioxide (million ton)	**Crude oil (million m³)**
Materials/manufacturing	1.01	0.39
Weight reduction (by saving fuel)	2.06	0.8
Total	3.07	1.19
% of total Canadian fossil fuel emissions	0.5	–
% of total Canadian oil consumption	–	1.0
% of total US industrial emissions	4.3	–

2.11 Sisal fiber-reinforced composite applications

Sisal/glass hybrid-reinforced polymer composites and sisal/silk fiber hybrid composites were tested for chemical resistance, and it was suggested that they can be used in making water and chemical storage tanks [41, 42]. Various

Figure 16: Fittings build with hybrid glass/hemp lay-up [40].

properties of sisal/kapok fabrics reinforced hybrid polyester composites were studied, and it was recommended that these composites can be used primarily for low-cost housing and automotive interior component applications [43].

This work concentrates on the progress of biocomposites materials in the field of orthopedics (medical) applications. An effort is done to replace the conventional materials such as titanium, cobalt chrome, stainless steel and zirconium in orthopedics applications. These bio-materials can be used for both internal fixation and external fixation on fractured bone [44]. Natural fiber (sisal)-reinforced polypropylene composites were processed by compression molding, and it was found that these composites have the potential to replace glass fiber composites in several applications where they do not need very high load carrying applications [45].

2.12 Borassus fruit fiber-reinforced composite applications

Borassus fruit fiber-reinforced epoxy composites treated with 5% alkali were found to be very promising materials to replace synthetic fibers in the structural, low load carrying applications and in automotive applications such as two wheeler bumpers [46].

2.13 Curaua fiber-reinforced composite applications

Curaua fibers composites can yield economic, environmental, and social benefits in the automotive industry. This study has shown that curaua fiber can replace glass fiber and is a small step towards the sustainability of the whole automobile industry [47].

2.14 Silk fiber-reinforced composite applications

The mechanical behavior of silk fiber composites was studied. And their ultimate strength, elongation at break, and Young's modulus were examined by carrying out a uniaxial tensile test on a single fiber. Silk fiber-reinforced composites have become a promising biomaterial for engineering and biomedical application [48].

The crashworthiness characteristics of woven natural silk-reinforced epoxy composites tubes were studied and the energy absorption response of triggered and non-triggered woven natural silk-reinforced epoxy composite rectangular tubes was investigated by carrying out the axial quasi-static crushing test. The four-piece triggering mechanism does not lead to perfect progressive failure; nevertheless, this triggering mechanism increases the crashworthiness characteristics of composite tubes and changes the category of failure from catastrophic to progressive [49].

2.15 Banana fiber-reinforced composite applications

Banana pseudostem fiber-reinforced epoxy composites are used in designing and fabrication of a multipurpose table as shown in Figure 17. Banana fiber is used as a raw material to produce a reinforced composite for household furniture applications, and this composite may replace wood, plastic, and conventional metallic, non-metallic materials to some extent [50].

Natural woven banana fabric-reinforced epoxy composites were used to design and fabricate a household telephone stand as shown in Figure 18. As banana fiber is a waste product, it is used as an alternative and new material for household furniture applications at low cost [51].

2.16 Oil palm fiber-reinforced composite applications

As there is shortage of wood as a raw material, it has forced us to find alternative and new local raw materials for wood based industries. Oil palm fiber reinforced composites appears to be most feasible alternative and are been used as substitute for raw materials to produce ply wood for interior and exterior household usages [52]. These composites were also used as solid fuel briquettes where in physical performance; it shows good dimension stability after exposed to ambient conditions [53].

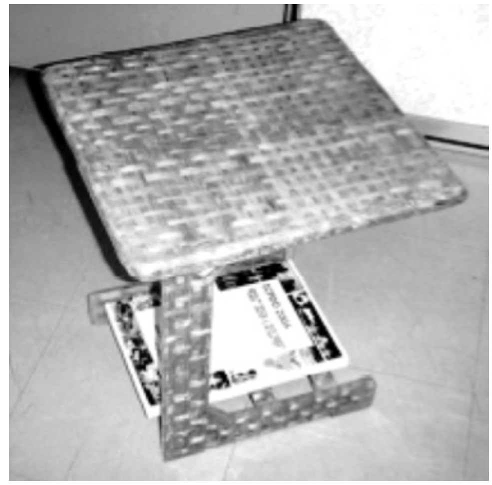

Figure 17: A banana pseudostem fiber epoxy composite multipurpose table [50].

Figure 18: Actual banana woven fabric composite telephone stand [51].

2.17 Areca (betel nut) fiber-reinforced composite applications

Areca fiber-reinforced phenol formaldehyde composites were tested for various properties; they are very promising materials for packing and for other structural applications [54]. An experimental work was carried out on the biodegradable and swelling properties of areca fiber/maize powder-reinforced phenol formaldehyde composites, which gave 40% better result compared to conventional wood-based particle board and suggested that they can be used for packing purpose and domestic applications [55].

2.18 Rice husk-reinforced composite applications

Rice husk-reinforced high-density polyethylene composites are fabricated by the injection molding process and thus stress on hollow and solid window frames was analyzed. These composites are suitable for the manufacture of window frames, where hollow design has less warpage on cooling and inherently requires low material and operation cost [56].

2.19 Bamboo fiber-reinforced composite applications

The strength properties of bamboo fiber-reinforced composites are evaluated under various environmental conditions. And as bamboo fibers are available in plenty and are very low cost materials, they are usually used in building, packaging, automobile, storage devices, and construction industries for manufacturing of panels, ceilings, and partition boards [57].

2.20 Bagasse fiber-reinforced composite applications

Sugarcane bagasse fiber-reinforced polymer composites were fabricated, and the effect of maleic anhydride and press temperature on their mechanical properties, such as static bending, modulus of elasticity, and internal bond, and physical properties, such as thickness swelling, water, and steam absorption, was studied. Based on the findings of this study, it is stated that bagasse fiber composites have potential to be used in the manufacturing of medium-density fiberboard [58].

3 Conclusion

There is a need to rectify in the view of the opportunities they offer for new applications with value addition. Whereas high specific strength and lightweight were often the dominant criteria to be achieved and there is an increasing emphasis on other criteria such as environmental durability, embedded energy, fire resistance. Furthermore, biocomposites offer opportunities for environmental gains, reduced energy consumption, insulation and sound absorption properties. With more and more realization on conversation of nature and natural resources, scarcity of wood emerges large for the construction and housing sector and developing suitable wood substitutes. From the point of view of wood substitution, natural fiber composites would enjoy wider acceptance and Value-added novel applications of natural fiber composites would also ensure international market for cheaper substitutes. The efforts put to develop biocomposites materials with enhanced performance for global applications are in process.

References

[1] Fiore V, Valenza A, Di Bella G. *Compos. Sci. Technol.* 2011, 71, 1138–1144.
[2] Mwaikambo LY. *African J. Sci. Technol.* 2006, 7, 120–133.
[3] Mohanty AK, Misra M, Drzal LT. *J. Polym. Environ.* 2002, 10, 19–26.
[4] Thiruchitrambalam M, Athijayamani A, Sathiyamurthy S, Syed Abu Thaheer A. *J. Nat. Fibers.* 2010, 7, 307–323.
[5] Maries I, Neelakantan NR, Oommen Z, Joseph K, Thomas S. *J. Appl. Polym. Sci.* 2005, 96, 1699–1709.
[6] Cheung H-Y, Ho M-P, Lau K-T, Cardona F, Hui D. *Composites Part B.* 2009, 40, 655–663.
[7] Bledzki AK, Gassan J. *Prog. Polym. Sci.* 1999, 24, 221–274.
[8] Siva I, Winowlin Jappes JT, Suresha B. *Polym. Compos.* 2012, 33, 723–732.
[9] Netravali AN, Chabba S. *Mater Today* 2003, 6, 22–29.
[10] Hassan A, Salema AA, Ani FN, Bakar AA. *Polym. Compos.* 2010, 31, 2079–2101.
[11] Majeed K, Jawaid M, Hassan A, Abu Bakara A, Abdul Khalild HPS, Salemae AA, Inuwaa I. *Mater. Des.* 2013, 46, 391–410.
[12] Faruk O, Bledzki AK, Fink H-P, Sain M. *Progress Polym. Sci.* 2012, 37, 1552–1596.
[13] Ticoalu A, Aravinthan T, Cardona F. *Southern Region Engineering Conference*, Toowoomba, Australia, 11–12 November 2010, pp. 1–5.
[14] Sindhuphak A. *KMITL Sci. Tech. J.* 2007, 7, 160–170.
[15] Marsh G. *Mater. Today* 2003, 6, 36–43.
[16] Satyanarayana KG, Sukumaran K, Mukherjee PS, Pavithran C, Pillai SGK. *Cem. Concr. Compos.* 1990, 12, 117–136.
[17] Saravanan R, Sivaraja M. *Eur. J. Sci. Res.* 2012, 81, 220–230.
[18] Bispo TS, Barin GB, Gimenez IF, Barreto LS. *Mater. Charact.* 2011, 62, 143–147.
[19] Satyanarayana KG, Guimaraes JL, Wypych F. *Composites Part A* 2007, 38, 1694–1709.
[20] Wieldman GA, Costa CZ, Nahuz MA. Int. Conference on *ISNaPol*, 2000, pp. 488–492.

[21] Akil HM, Omar MF, Mazuki AAM. *Mater. Des.* 2011, 32, 4107–4121.
[22] Ozturk S. *J. Compos. Mater.* 2010, 44, 2265–2288.
[23] Thiruchitrambalam M, Alavudeen A, Venkateshwaran N. *Rev. Adv. Mater. Sci.* 2012, 32, 106–112.
[24] Davoodi MM, Sapuan SM, Ahmad D, Ali A, Khalina A, Jonoobi M. *Mater. Des.* 2010, 31, 4927–4932.
[25] Irawan AP, Soemardi TP, Widjajalaksmi K, Reksoprodjo AHS. *Int. J. Mech. Mater. Eng.* 2011, 6, 46–50.
[26] Baley C, Busnel F, Grohens Y. *Composites Part A* 2006, 37, 1626–1637.
[27] Fu Z, Suo B, Yun R, Lu Y, Wang H, Qi S, Jiang S, Lu Y, Matejka V. *J. Reinf. Plast. Compos.* 2012, 31, 681–689.
[28] Burgueno R. *Composites Part A* 2004, 35, 645–656.
[29] Papadopoulos AN, Hague JRB. *Ind. Crops Prod.* 2003, 17, 143–147.
[30] Dweib MA, Hu B, Donnell AO, Shenton HW, Wool RP. *Compos. Struct.* 2004, 63, 147–157.
[31] Zhan M, Wool RP. *Composites Part A* 2013, 47, 22–30.
[32] Dweib MA, Hu B, Shenton HW, III. *Compos. Struct.* 2006, 74, 379–388.
[33] Yang H-S, Kim D-J, Kim H-J. *J. Fire Sci.* 2002, 20, 505–517.
[34] Yu HN, Kim SS, Hwang IU, Lee DG. *Compos. Struct.* 2008, 86, 285–290.
[35] Thilagavathi G, Pradeep E, Kannaian T, Sasikala L. *J. Ind. Text.* 2010, 39, 267–278.
[36] Ahmed KS, Vijayarangan S, Rajput C. *J. Reinf. Plast. Compos.* 2006, 25, 1549–1569.
[37] Saxena M, Morchhale RK, Asokan P, Prasad BK. *J. Compos. Mater.* 2008, 42, 367–384.
[38] Jawaid M, Abdul Khalil HPS. *Carbohydr. Polym.* 2011, 86, 1–18.
[39] Pervaiz M, Sain MM. *Resour. Conserv. Recycl.* 2003, 39, 325–340.
[40] Cicala G, Cristaldi G, Recca G, Ziegmannb G, El-Sabbaghb A, Dickert M. *Mater. Des.* 2009, 30, 2538–2542.
[41] John K, Venkata Naidu S. *J. Reinf. Plast. Compos.* 2007, 26, 373–376.
[42] Raghu K, Noorunnisa Khanam P, Venkata Naidu S. *J. Reinf. Plast. Compos.* 2010, 29, 343–345.
[43] Venkata Reddy G, Venkata Naidu S, Shobha Rani T, Subha MCS. *J. Reinf. Plast. Compos.* 2009, 28, 1485–1494.
[44] Chandramohan D, Marimuthu K. *Eur. J. Sci. Res.* 2011, 54, 384–406.
[45] Wambua P, Ivens J, Verpoest I. *Compos. Sci. Technol.* 2003, 63, 1259–1264.
[46] Boopathi L, Sampath PS, Mylsamy K. *Eur. J. Sci. Res.* 2012, 79, 353–361.
[47] Zah R, Hischier R, Leao AL, Braun I. *J. Cleaner Prod.* 2007, 15, 1032–1040.
[48] Cheung H-Y, Lau K-T, Ho M-P, Mosallam A. *J. Compos. Mater.* 2009, 43, 2521–2531.
[49] Eshkoor RA, Oshkovr SA, Sulong AB, Zulkifli R, Ariffin AK, Azhari CH. *Mater. Des.* 2013, 47, 248–257.
[50] Sapuan SM, Harun N, Abbas KA. *J. Trop. Agr.* 2007, 45, 66–68.
[51] Sapuan SM, Maleque MA. *Mater. Des.* 2005, 26, 65–71.
[52] Abdul Khalil HPS, Nurul Fazita MR, Bhat AH, Jawaid M, Nik Fuad NA. *Mater. Des.* 2010, 31, 417–424.
[53] Yuhazri MY, Sihombing H, Yahaya SH, Said MR, Nirmal U, Lau S, Tom PP. *Global Eng. Technol. Rev.* 2012, 12, 6–11.
[54] Swamy RP, Mohan Kumar GC, Vrushabhendrappa Y, Joseph V. *J. Reinf. Plast. Compos.* 2004, 23, 1373–1382.
[55] Bharath KN, Swamy RP, Mohan Kumar GC. *Int. J. Agr. Sci.* 2010, 2, 1–4.
[56] Rahman WAWA, Sin LT, Rahmat AR. *J. Mater. Process. Technol.* 2008, 197, 22–30.
[57] Mishra SC. *J. Reinf. Plast. Compos.* 2009, 28, 2183–2188.
[58] Ashori A, Nourbakhsh A, Karegarfard A. *J. Compos. Mater.* 2009, 43, 1927–1934.