Research Article

Bio-fiber reinforced polymer matrix composites: A Review

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Abstract

This research paper describes various composite materials reinforced with hybrid biofibers. Due to their low cost, availability, ease of production and high environmental friendliness, hybrid biofiber composites were chosen to study the reinforcing potential of various formulations using composites. Further research is being conducted worldwide to improve the thermal, tribological and mechanical properties of these engineered biocomposites, and their potential has been demonstrated in a wide range of applications. This review aims to provide an overview of the factors influencing the mechanical performance of natural hybrid biofiber-reinforced composites and the advances achieved through them.

1.0 Introduction

Natural bio composite materials are currently sweeping the field of material science and engineering, owing to the growing demand for more environmentally friendly materials to combat environmental deterioration, pollution, and rescue the planet. Hybrid composite materials are materials made from natural resources that contribute very little pollution to the environment [1]. Plant fibres are one of the most common and abundant natural reinforcement materials used in the manufacture of those composites. Composites made of biopolymers or synthetic polymers reinforced with plant fibres have the best features, such as light weight, biodegradability, and renewability [2].

The reinforcing is principally responsible for the composite material's high strength and stiffness [11]. Epoxy is a popular material for making composites with natural fibre reinforcing. However, epoxies can have low impact strength, fracture toughness, and fatigue crack propagation resistance [12]. Epoxies can be reinforced with various materials such as glass fibre, natural fibre, glass powder, fly ash, and hybridised with carbon fillers, MnO_2, ZnO, egg shell, zinc powder, and so on to strengthen their toughness and strength. It's a type of matrix that gives the composite better physical and mechanical qualities, allowing it to be used in high-performance transportation systems, aerospace industries, and vehicle parts, as well as in the field of artificial organ transplantation in bio-medical science [3].

2.0 Common natural fibers in composite material manufacturing

In the manufacturing of composites, both animal and plant fibres are used as reinforcing agents. Animal fibres are mostly made up of protein, whereas plant fibres are mostly made up of cellulose. The steam explosion method is used to modify wool fibres, and these fibres are treated at varied steam pressures. Because of the increased explosion pressure, the fibres' attraction for water, mechanical characteristics, and propensity to dissolve in caustic solution decrease after a steam explosion [4]. The steam explosion process is also used to separate nanocelluloses from pineapple leaf fibres. The isolated nanofibers have a width of 5-60 nm. After each stage of purification, the cellulose content of the fibre increases while the hemicellulose and lignin content declines. The separated nanocellulose might find new applications in the field of biomedical sciences and in medical implantation [5].

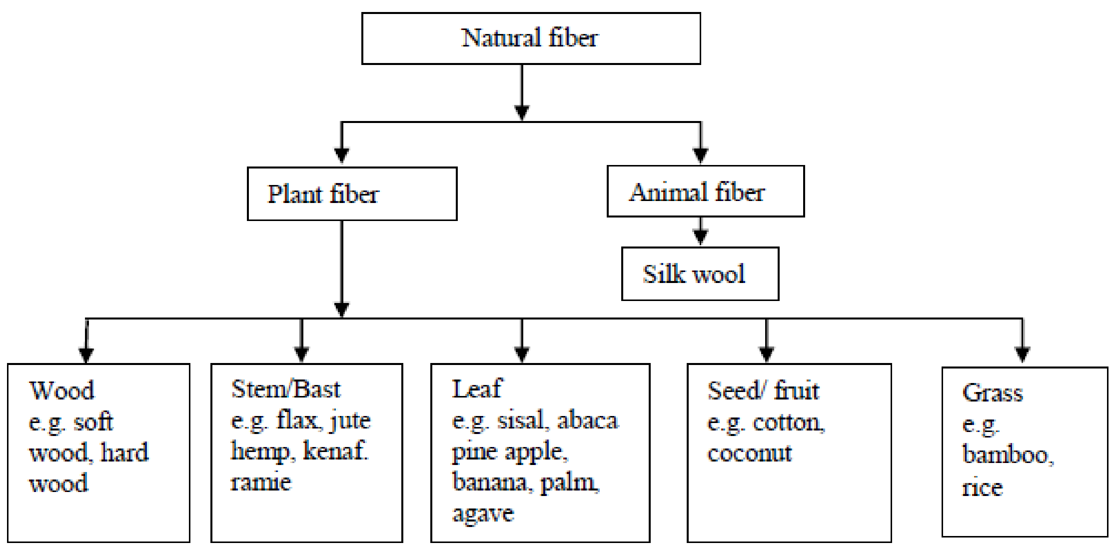

Fig 1 common bio fibers

The FTIR spectrum of nanocellulose isolated from sugarcane bagasse and cellulose is similar, which is considerably different from that of sugarcane bagasse [6]. A good reinforcing element in polymer matrix composites is homogeneous nanocellulose fibril derived from diverse lignocellulosic fibres [7]. The tribological characteristics of these composites are substantially influenced by natural fibres. Fiber treatment can greatly improve tribological properties by ensuring good interfacial adhesion between fibres and matrix [8]. When bamboo fibres are exposed to water or kept in humid circumstances, they absorb moisture. However, composites constructed from these fibres have superior thermal characteristics, making bamboo fibre superior to other natural plant fibres [9]. Banana nanofibers recovered by steam explosion have better thermal characteristics than untreated fibres, making them ideal for use as reinforcing elements in bio composites [1]. Agave fibre is made up of bundles of lignified microfibers, and their application improves the composite's resistance. These fibres have a higher adhesion to the matrix than other fibres [10].

Advantages	Disadvantages
• Low density and high specific strength and stiffness • Fibres are a renewable resource, for which production requires little energy, involves CO_2 absorption, whilst returning oxygen to the environment • Fibres can be produced at lower cost than synthetic fibre • Low hazard manufacturing processes • Low emission of toxic fumes when subjected to heat and during incineration at end of life • Less abrasive damage to processing equipment compared with that for synthetic fibre composites	• Lower durability than for synthetic fibre composites, but can be improved considerably with treatment • High moisture absorption, which results in swelling • Lower strength, in particular impact strength compared to synthetic fibre composites • Greater variability of properties • Lower processing temperatures limiting matrix options

Table 1 Advantages and Disadvantages [2–5]

3.0 Natural Fibre-Reinforced Bio-Composites

Bio-based composites can be characterised as either partly environmentally friendly or environmentally friendly (Figure 1). All of the ingredients of a green composite are sourced from renewable resources, potentially lowering carbon dioxide emissions and reducing reliance on petroleum-derived products. While partly eco-friendly, one of the ingredients, fibre or matrix, is not derived from renewable resources [30].

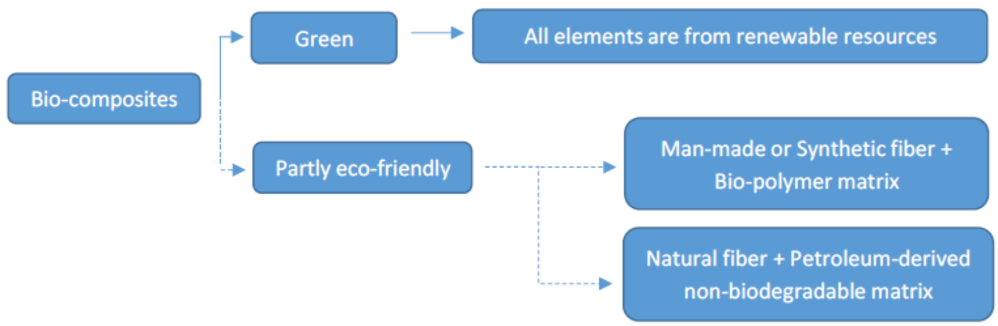

Figure 1. Classification of bio-composites [31-33]

The length, size, and orientation of natural fibre reinforcement can all be separated. This can take the form of a fibre or a particle. The length-to-diameter (l/d) ratio of the fibre determines whether it is continuous or discontinuous (i.e., chopped). The woven or non-woven fiber-reinforced phase arrangement is the most common classification. A woven fabric is defined by a consistent pattern of continuous interlacing of perpendicular strands. Yarns are constructions made up of a number of interwoven threads. The twist angle is responsible for fibre cohesion and yarn strength up to a degree, after which the maximum fibre strength declines due to increased obliquity [14]. Furthermore, increasing the fibre twist angle is linked to a reduction in fibre-resin bond strength, reduced permeability, and, as a result, inferior mechanical properties [15]. The fibre architecture can have more than one dimension when continuous fibres are employed [16]. The twist angle and amount of alignment of continuous-filament yarns play a significant effect in determining the maximum applied load in the one-dimensional design. Unidirectional composites, as a result, are weaker in the transverse directions [13, 15]. Given these characteristics, anisotropic structures can have at least 3 to 4 times better mechanical properties than their isotropic counterparts given a certain state of stress [17].

4.0 Treatment of Natural Fibers

In recent years, a number of treatments have been developed to increase interfacial bonding and improve the mechanical and water resistance capabilities of natural fibres [18]. The most important disadvantage of these natural fibres is that they are hydrophilic, which results in a brittle interfacial interaction between fibre and matrix in polymer composites [19]. The fate of natural fibres as enforcement materials is determined by various physical imperfections and the hydroxyl groups present on the fibre surface [20]. Several investigations on the surface modification and treatments of natural fibres to attain the necessary properties have been conducted [21, 22]. The orientation and type of fibres, however, have an impact on the mechanical performance of a composite material.

5.0 Matrix selection

A fibre-reinforced composite's matrix is a crucial component. It shields the surface of the fibres from mechanical wear and transfers load to the fibres by acting as a barrier against harsh conditions. Polymeric matrices are currently the most commonly utilised in NFCs because they are light weight and can be produced at low temperatures. For natural fibre matrices, both thermoplastic and thermoset polymers have been employed [23]. The temperature at which natural fibres deteriorate limits matrix selection. Most natural fibres used for reinforcement in natural fibre composites are thermally unstable over 2000C, while they can be treated at higher temperatures for a short amount of time in specific circumstances [24]. Only thermoplastics that soften below this temperature, such as polyethylene (PE), polyolefin, polyvinyl chloride, and polystyrene, as well as thermosets (which can be cured below this temperature), can be used as a matrix [25]. It should be emphasised, however, that the thermoplastics listed are the most commonly used thermoplastics in the plastics sector, considerably outnumbering the use of any other thermoplastic matrices.

5.0 Mechanical properties of the composites

There are many factors which affect the mechanical properties of the composites fabricated with natural fiber reinforcement. Some of these factors and their effects are tabulated below:

Factors	Effects
Moisture absorption	Poor interfacial boding between fiber and hydrophobic matrix polymer.
Fiber alignment	Aligned natural fiber composites exhibit best tensile, flexural and impact properties.
Fiber treatment	Mechanical properties of the composite get improved but lower concentration of NaOH gives better tensile strength and hardness.
Fiber distribution	Flexural strength increases with longitudinal fiber distribution in banana fiber reinforced epoxy composites. While in jute fiber reinforced composites, it increases with transverse fiber distribution.
Use of additives	Addition of silica or rubber nanoparticle increases the interlaminar fracture energy of the epoxy matrix composite.

Table 2 Factors and their effects [26,27,28,29,30]

5.1Tensile property

Epoxy composites reinforced with NaOH treated fibre have a higher tensile strength than those reinforced with untreated fibre because the cementing material present in the fibres, lignin and hemicellulose, is removed during the NaOH treatment, resulting in an increase in the surface area of the fibre. As a result, there is improved adhesion between the fibre and the matrix, which boosts the composite's tensile strength. Another cause for the composite's increased tensile strength could be the greater crystallinity of the NaOH-treated fiber[3]. Only up to a specific limit of fibre loading does the composite's tensile property rise and it steadily reduces after that. [13]

5.2 Flexural property and Impact property

When compared to virgin epoxy, natural bio composites have a better flexural performance. Bamboo fibre composites have better flexural properties than jute fibre composites. It changes depending on the NaOH concentration used in fibre treatment. A lower concentration of NaOH (5%) yields a better result than a higher concentration of NaOH (10%) [29]. The impact strength of a material is the amount of energy absorbed by it before it fractures under a shock load. Unlike tensile or flexural strength, impact strength of an epoxy composite grows steadily with increased fibre loading rather than dropping suddenly [3].

6.0 Conclusion

Natural fibres are particularly compatible with epoxy matrix, according to this article review, because both the fibre and the matrix cling to each other very well, producing a strong link between them. They have the potential to replace synthetic fibres in composite manufacture since they exhibit comparable or better physical and mechanical qualities in a wide range of applications. These composites' different mechanical qualities make them excellent for low-load applications such as window panels, decorative objects, cushioning pads, fishing rods, internal sections of aeroplanes, lampshades, food trays, and interior panelling, among others. These composites can be used to replace the most often utilised materials in particular applications, improving the product's overall quality. Natural fibre composites offer a wide range of uses, including weight bearing and outdoor applications such vehicle exterior underfloor panelling, sports equipment, and marine structures. More research is needed to broaden their application range, which includes improving moisture resistance and fire resistance. Overall, natural fibre composites are gaining popularity at a quick pace, and their use appears to have a bright future ahead of it.

References

[1] B. Deepa, Eldho Abraham, Bibin Mathew Charian, Alexander Bismarck, Jonny J. Blaker, Laly A. Pothan, Alcides Lopes Leao, Sivoney Ferreira De Souza and M. Kottaisamy. (2011) "Structure, morphology and thermal characteristics of banana nanofibersobtained by steam explosion." *Bio resource Technology*102: 1988-1997.

[2] Savita Dixit, RiteshGoel, Akash Dubey, Prince Raj Shivhare, and TanmayBhalavi. (2017) "Natural Fibre Reinforced Polymer Composite Materials - A Review *Polymers from Renewable Resources* 8(2): 71-78

[3] Girisha. C, Sanjeevamurthy, GuntiRangasrinivas and Manu.S. (2012) "Mechanical Performance Of Natural Fiber-Reinforced Epoxy- Hybrid Composites" *International Journal of Engineering Research and Applications (IJERA)* Vol. 2, Issue 5: 615-619.

[4] Weilin Xu, GuizhenKe, Jihong Wu and Xungai Wang. (2006) "Modification of wool fiber using steam explosion"*European Polymer Journal* 42:2168-2173.

[5] Bibin Mathew Charian, Alcides Lopes Leao, Sivoney Ferreira De Souza, Sabu Thomas, Laly A. Pothan and M. Kottaisamy. (2010) "Isolation of nano-cellulose from pineapple leaf fibers by steam explosion" *Carbohydrate Polymers* 81: 720-725.

[6] Arup Mandal and DebabrataChakrabarty. (2011)"Isolation of nanocellulose from waste sugarcane bagasse (SCB) and its characterization" *Carbohydrate Polymers*86: 1291-1299.

[7] E. Abraham, B. Deepa, L. A. Pothan, M. Jacob, S. Thomas, U. Cvelbar and R. Anandjiwala. (2011) "Extraction of nanocellulose fibrils from lingo-cellulosic fibers: A novel Approach" *Carbohydrate Polymers*86:1468-1475.

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

[9] Parnia Zakikhani, R. Zahari, M.T.H Sultan and D.L Majid. (2014)"Extraction and preparation of bamboo fiber reinforced composites" *Materials and Design*63: 820-828.

[10] Ridha Ben Cheikh, Sami Ben Brahim, Mohamed Baklouti and Béchir Hadj Sassi "The Agave Fibers in Composite Materials" *EcoleNationaled'Ingenieurs de Tunis :Le Belvédère, Tunis (TUNISIA*) BP 37.

[11] Noor AfizahRosli, Ishak Ahmad, and Ibrahim Abdullah; "Isolation and characterization of cellulose nanocrystals from Agave Angustifoliafibre".

[12] Jianing Gao, Junting Li, Brian C. Benicewicz, Su Zhao, Henrik Hillborg and Linda S. Schadler. (2012) "The Mechanical Properties of Epoxy Composites Filled with Rubbery Copolymer Grafted SiO2" *Polymers* 4:187-210.

[13]. AL-Oqla, F.M.; Salit, M.S. Material selection of natural fiber composites. In Materials Selection for Natural Fiber Composites; Elsevier: Amsterdam, The Netherlands, 2017; pp. 107–168.

[14]. Bar, M.; Alagirusamy, R.; Das, A. Advances in Natural Fibre Reinforced Thermoplastic Composite Manufacturing: Effect of Interface and Hybrid Yarn Structure on Composite Properties. In Advances in Natural Fibre Composites; Springer International Publishing: Cham, Switzerland, 2018; pp. 99–117.

[15]. Shah, D.U.; Schubel, P.J.; Clifford, M.J. Modelling the effect of yarn twist on the tensile strength of unidirectional plant fibre yarn composites. J. Compos. Mater. 2013, 47, 425–436.

[16]. Mallick, P. Fiber-Reinforced Composites; Dekker Mechanical Engineering; CRC Press: Boca Raton, FL, USA, 2007; Volume 20072757, ISBN 978-0-8493-4205-9.

[17]. Goutianos, S.; Peijs, T.; Nystrom, B.; Skrifvars, M. Development of Flax Fibre based Textile Reinforcements for Composite Applications. Appl. Compos. Mater. 2006, 13, 199–215.

[18]. H. Ku, H. Wang, N. Pattarachaiyakoop, and M. Trada,Compos. B, 42, 856 (2011). Matrix selection

[19]. H. Essabir, M.E. Achaby, E.M. Hilali, R. Bouhfid, and A. Qaiss, J. Bionic. Eng., 12, 129 (2015).

[20]. E. Terpakova, L. Kidalova, A. E.stokova, J. Cigasova, and N. Stevulova, Proc.. Eng., 42, 931 (2012).

[21]. M.S. Meon, M.F. Othman, H. Husain, M.F. Remeli, and M.S.M. Syawal, Proc. Eng., 41, 1587 (2012).

[22]. D. Puglia, M. Monti, C. Santulli, F. Sarasini, I.M. De Rosa, and J.M. Kenny, Fiber Polym., 14, 423 (2013).

[23] Holbery J, Houston D. Natural-fiber-reinforced polymer composites in automotive applications. JOM 2006;58(11):80–6.

[24] Summerscales J, Dissanayake NPJ, Virk AS, Hall W. A review of bast fibres and their composites. Part 1 – fibres as reinforcements. Composites Part A 2010;41(10):1329–35.

[25] dos Santos PA, Giriolli JC, Amarasekera J, Moraes G. Natural fibers plastic composites for automotive applications. In: 8th Annual automotive composites conference and exhibition (ACCE 2008). Troy, MI: SPE Automotive & Composites Division; 2008. p. 492–500.

[26] K. L Pickering, M.G Aruan Efendy and T. M. Le (2016) "A review of recent developments in natural fiber composites and their mechanical performance" *Composites: Part A*83:98-112.

[27] Ajith Gopinath, Senthil Kumar. M and Elayaperumal A. (2014) "Experimental Investigations on Mechanical Properties of Jute Fiber Reinforced Composites with Polyester and Epoxy Resin Matrices" *Procedia Engineering*97: 2052 – 2063.

[28] Subhankar Biswas, Sweety Shahinur, Mahbub Hasan and Qumrul Ahsan. (2015) "Physical, Mechanical and Thermal Properties of Jute and Bamboo Fiber Reinforced Unidirectional Epoxy Composites" *Procedia Engineering*105: 933 – 939.

[29] A. J. Kinloch, A. C. Taylor, M. Techapaitoon, W. S. Teo and S. Sprenger. (2015) "Tough, natural-fibre composites based upon epoxy matrices"*J Mater Sci* 50:6947–6960.

[30] Mitra, B.C. Environment friendly composite materials. Def. Sci. J. **2014**, 64, 244–261.

[31] Mohanty, A.; Misra, M.; Drzal, L.; Selke, S.; Harte, B.; Hinrichsen, G. Natural Fibers, Biopolymers, and Biocomposites; Mohanty, A., Misra, M., Drzal, L., Eds.; CRC Press: Boca Raton, FL, USA, 2005; ISBN 978-0-8493-1741-5.

[32]. Dicker, M.P.M.; Duckworth, P.F.; Baker, A.B.; Francois, G.; Hazzard, M.K.;Weaver, P.M. Green composites: A review of material attributes and complementary applications. Compos. Part A Appl. Sci. Manuf. **2014**, 56, 280–289.

[33]. AL-Oqla, F.M.; Salit, M.S. Material selection of natural fiber composites. In Materials Selection for Natural Fiber Composites; Elsevier: Amsterdam, The Netherlands, 2017; pp. 107–168.