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Biocomposite

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Abstract

Biocomposites composed of natural fibers derived from local and renewable resources provide great importance to sustainability, green chemistry, eco-friendly, and industrial ecology. Fabrication of biocomposites is guiding the manufacturing process for the next generation of biomaterials, products, and processes. Biocomposite materials are broadly classified as wood and non-wood fiber-reinforced composite materials. These composite materials were fabricated by various processing techniques including the extrusion process, injection molding, compression molding, hand layup, and resin transfer molding. Properties of composites like mechanical and thermal were analyzed for the selection into the variety of industrial applications. With the incorporation of natural fibers into the variety of polymeric matrices for the fabrication of composites produces many outstanding properties as mechanical and thermal. These outstanding properties of composites make it for wide applications in the field of the domestic sector, automotive, construction building material, railways, circuit boards, and aerospace over the past few decades.

Keywords- Composite, biocomposite, natural fibers, applications, properties.

Introduction

Composite materials have been used since ancient civilizations when chopped straw was added to brick to form building materials. In the present era, the development of biocomposites has attracted a lot of attention from researchers because of their significantly improved properties as compared to intrinsic polymers or conventional composites. A biocomposite is a type of composites materials having two or more distinct phases one is the matrix phase (resin) for example epoxy, polyester, polypropylene, polyethylene, etc and the other is the reinforcement phase (natural fibers) such as wood and nonwood fibers. These materials would combine and form an advanced composite material with enhanced properties as compared to an individual material component [1]. The matrix phase is generally formed by thermoset or thermoplastic resins such as polyester, epoxy, and vinyl ester polymers and reinforced phase using natural fibers. Generally, the natural fibers are lighter in weight, stiffer, and stronger as compared to the polymer matrix, which means that the reinforcing fibers behavior dominates over the mechanical behavior, while the polymer matrix component tends to control the durability and holds the fibers together, transfers the loads on them, and also protects it from the impact of environmental degradation and mechanical failure [2]. In addition, the main component of biocomposite is bio-fibers, the bio-fibers originate from biological resources such as crop fibers, recycled wood, wastepaper cellulose fibers, etc. Biocomposites attracted the interest of several researchers due to rapidly growing utilization and achieving great benefits in the area of many industrial applications such as automotive, construction, railways, aerospace, military applications, and food packaging [3, 4].

Currently, the entire world is facing a challenge of environmental concerns, sustainability, and cost. Hence, many researchers have focused on the latest biomaterial technology which shows a promising opportunity in biodegradation. These biocomposites based on bio-fibers are easily decomposed or composted after the expiry of their life without creating an environmental hazard which is impossible in the case of conventional synthetic composite materials. Also, the advantages of bio-fibers such as lightweight, high strength, and corrosion resistance as compared to synthetic composite materials make bio-fibers more attractive. In addition to these attractive properties, bio-fibers also have some drawbacks such as hygroscopic and anisotropic nature [5].

Composites based on natural fibers have lower weight, higher strength-to-weight ratio, and greater stiffness. However, there will be a problem with the properties of reinforced composite materials i.e. moisture absorption is generally high and impact strength is low. The performance of composite materials has been analyzed by various factors like matrix materials, type of fibers, fiber orientation, fiber application, manufacturing processes, etc. Apart from these factors, a new demand in the market arises which is based upon the end-use of biocomposites. Several classes of natural fibers have been reinforced with polymeric matrices for the development of composite material against synthetic fibers reinforced composites which gain special attention. The waste generated from agriculture can be used for the manufacturing of fiber-reinforced composites for commercial end-user applications in various markets. The polymeric matrix is one of the main components for improving the mechanical and chemical properties of the biocomposite product and most of them are petro-chemical based materials. Among the different biocomposites, natural fiber-reinforced biocomposites are used at a low cost and have multifunctional structural properties. The depletion of fossil fuel and petrochemical-based materials has provided the path to switch to renewable resources Therefore, many researchers are studying biocomposite based on natural resins which are taken from plants to synthesize matrix material for biocomposite.

The day-by-day increase in the special attention and importance of composites based on bio-fibers increased the number of publications in the particular subject area with a variety of different perspectives. The publications include articles, review papers, books, and book chapters that show the importance of the subject. Safak Yıldızhan et al.[5], Kurki Nagaraj Bharath et al.[6], Faruk et al.[7], Shinoja et al.[8], Hassan et al.[9], Venkateshwaran and Elayaperumal[10], John and Thomas[11], and many more reviewed composite materials with bio-fibers and matrices.

Classification of biocomposites

Biocomposite materials are mainly classified into two classes based on nonwood fibers and wood fibers, the main component of all these fibers are cellulose and lignin. Non-wood fibers like jute, hemp fiber, kenaf fiber, coir, flax, and sisal fibers have attracted more interest from the industry because all these fibers have excellent physical, mechanical, and thermal properties. Also, all these fibers are long and have high cellulose component, therefore, it provides high mechanical properties like tensile, modulus, and a high degree of crystallinity. But the natural fibers show some drawbacks due to having hydroxyl groups (OH), which attract more water molecules, thus, these fibers swell. Due to these results, voids form at the interface of the developed bio-composite, which affects the properties like mechanical and dimensional stability.

Table 1. Classification of biocomposites reinforced with natural fibers [12].

<table>
<tr><td rowspan="4">Reinforcing natural fibers</td><td>Nonwood fiber material</td><td>Straw type fiber</td><td>Bast type fiber</td><td>Leaf type fiber</td><td>Seeds/Fruit fiber</td><td>Grass type fibers</td></tr>
<tr><td>Examples</td><td>Rice husk, wheat straw, corn straw</td><td>Kenaf, Jute, Flax, and hemp fibers</td><td>Henequen, Sisal, and pineapple leaf fibers</td><td>Cotton, Coco-nut and coir, fiber</td><td>Switchgrass, elephant grass, and bamboo fiber</td></tr>
<tr><td>Wood fibers</td><td colspan="2">Recycled</td><td colspan="3">Non-recycled</td></tr>
<tr><td>Examples</td><td colspan="2">Newspaper, magazine fibers</td><td colspan="3">Soft and hardwoods</td></tr>
</table>

Natural fibers are mainly classified into different types such as straws, bast fiber, leaves, seeds, and grass fibers. These fibers are mostly utilized in the composites industry as flax fiber, hemp, jute, kenaf, sisal, and coir fibers. Straw fiber is an example of low-cost reinforcement for biocomposites and it is found in many parts of the world. On the other hand, the wood fibers having 60% of their total mass is wood component. Which contains softwood (long and flexible) components and hardwood fibers (shorter and stiffer) components and have a low degree of cellulose crystallinity. Wood fiber composites can be recycled or non-recycled. Therefore, most polymer matrices like polyethylene (PE), propylene (PP), and polyvinyl chloride (PVC) are widely utilized in the wooden composite industries.

Processing of biocomposite

Biocomposite materials reinforced with natural fiber have been manufactured by using the following processing techniques.

Extrusion

Extrusion is a continuous process that is used for the compounding of biocomposite material based on thermoplastic resin. A thermoplastic resin such as PE, or PP with bio-fiber is processed by using the extrusion technique. The extrusion technique is used to manufacture the products with a uniform cross-sectional profile by passing molten material through the required cross-section orifice (die). The advantages od this technique over other processing techniques like compression and thermoforming is its ability to develop very complex cross-sectional objects.

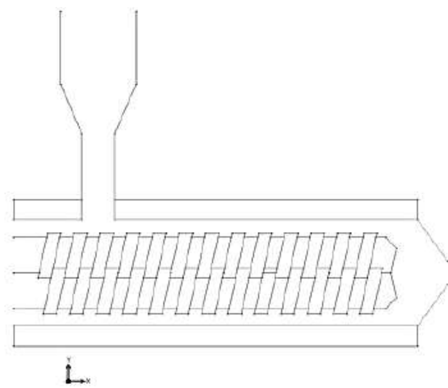

Figure 1. Twin screw extruder for the extrusion process.

Pultrusion

Pultrusion is also a continuous process for creating biocomposite reinforced with fiber with constant cross-section. The word Pultrusion is derived from the word portmanteau, which means "pull" and "extrusion". Pultrusion is opposite to extrusion, which pulls the material, extrusion pushes the material from the die.

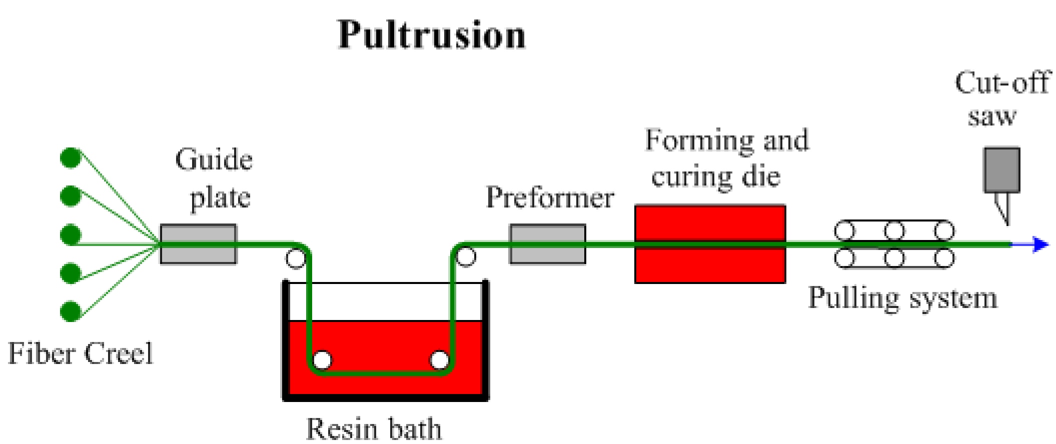

Figure 2. Pultrusion extruder.

Injection molding

The injection molding technique is used for the special purpose machine and it has three main units that are clamping unit, injection unit, and molding unit. This processing technique is used for creating products or components by injecting molten plastic materials inside the closed cavity (mold). This molding technique can be performed with common thermoplastics as well as thermoset polymers. Plastic materials used for the making part/component are fed into a heated barrel, soften, mixed, and injected into the mold, where they solidify and harden to the configuration of the mold cavity. This processing technique is used to develop a variety of products, parts/components, from smaller components to larger parts like car panels.

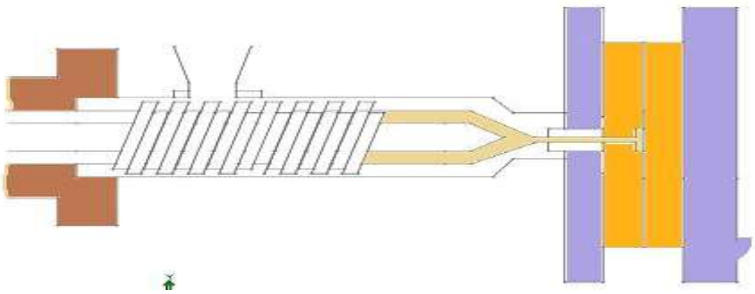

Figure 3. Injection molding process.

Hand layup

The hand layup is the manufacturing process for developing composite materials, in which final composite materials are formed by overlapping a specific number of different layers of fibers with a matrix. This method is usually made of polymeric materials, ceramic, fibers, and thermosets resin.

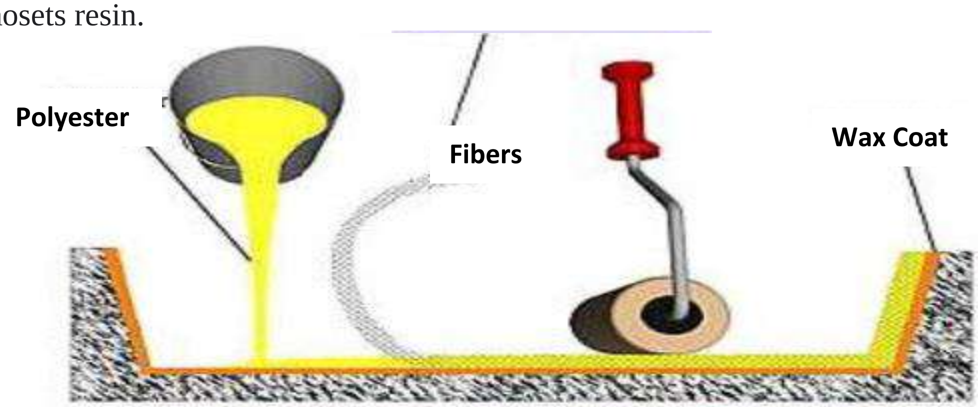

Figure 4. Hand Layup process

Compression molding

Compression molding is the manufacturing process of making sheets of fiber-reinforced composites, rubber, and plastics, in which preheated plastic, and rubber materials are placed into an open mold cavity. After that, the open mold is closed by applying pressure and compressed to have preheated plastic materials contact all areas of the mold cavity. The heat and pressure are controlled until the preheated materials have cured; the process of curing is also called vulcanization. In this processing technique, the plastics materials are used in the form of pellets, powder, preforms, or putty-like masses.

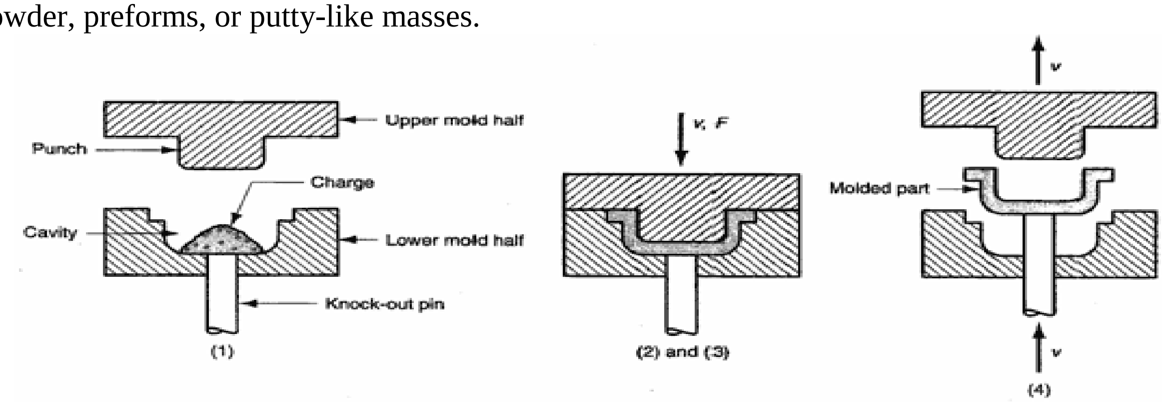

Figure 5. Compression molding process.

Filament winding

Filament winding is the manufacturing process generally used for fabricating open or closed structures. In this process winding filaments under tension over a rotating mandrel, and the mandrel rotates around the spindle axis. The most common filament made from glass and carbon fiber is impregnated with resin by passing through a bath and wound around the mandrel once the mandrel is fully covered to the desired thickness of resin, the mandrel is extracted or removed and leaves the hallow final object after that the resin is cured based on the resin curing characteristics. For making a few products like gas bottles, the mandrel is a main component/part of the finished product forming a liner to prevent gas leakage or as a barrier to protect composites from the fluid to be stored.

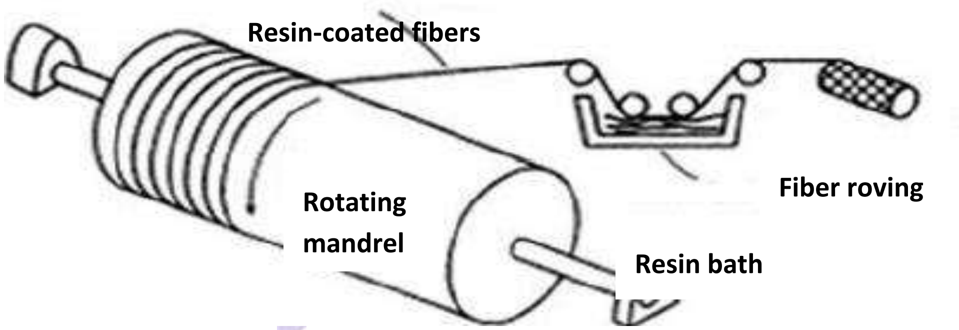

Figure 6. Filament winding.

Resin transfer molding

Resin transfer molding (RTM) is the technique for fabricating high-tech composites structure. This processing technique can fabricate composite components with higher strength, complex structure, dimensional accuracy, and excellent product quality which is used in aerospace applications. This technique used a closed mold which is made of aluminum and reinforced fiber like graphite is kept in the mold. After that, the mold is closed, heated, sealed placed under a vacuum. Heated plastic resin is injected into the mold to impregnate the fiber layup. The closed mold is heated at a sufficient temperature to cure the resin and fabricate the lightweight component with superior mechanical properties. With these improved properties composites, materials are widely used in a variety of structural and non-structural applications like aviation and aerospace.

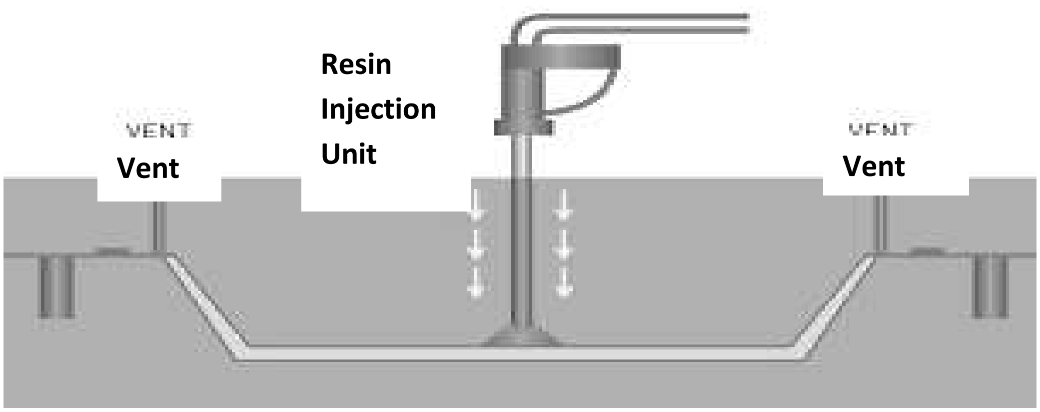

Figure 7. Resin transfer molding.

Mechanical properties of biocomposite

Mechanical properties are the most important parameter for selecting composite materials for different applications. The selection of suitable reinforcing fibers of required properties i.e. tensile strength, elongation at break, adhesion of fibers with matrix, dynamic and long-term behavior,compatibility of matrix and the fiber, price, and manufacturing cost. Fibers act as reinforcement and provide strength and stiffness in the fiber-reinforced composites, ultimately the properties of the composite are governed by the inherent properties of these fibers. Fibers carry the structural loads of the biocomposites, and matrix materials provide the rigidity of composites and make the shape and appearance of the final objects. Nowadays most objects manufactured with composite material have non-renewable petroleum. But, there are various investigations are done to study the uses of a renewable and sustainable matrix of composite materials development. Generally, thermoplastics and thermosets materials are used for biocomposites manufacturing like polystyrene (PS), PP, PE, PVC, epoxy, vinyl esters, polyester, and phenol-formaldehyde with natural fibers.

The mechanical properties of different polymer matrices reinforced with different fibers were investigated by many researchers. Cardanol-formaldehyde composites developed by compression molding with baggas fibers show 24.4 Mpa, 1.8 GPa tensile strength, and elastics modulus respectively [13]. PP biocomposites reinforced with bagasse powder prepared by injection molding show 35 Mpa, 2 GPa tensile strength, and elastics modulus respectively [14]. Polylactic acid (PLA) with corn fiber composites developed by injection molding shows 46 Mpa tensile strength [15]. PP composites with bamboo fiber manufactured by compression molding show a tensile strength of 37 Mpa and an elastics modulus of 4.34 GPa [16]. PLA composites flax prepared by compression molding shows 53 Mpa, 8.3 GPa, and 1.0 % tensile strength, elastics modulus, and elongation at break respectively [17]. Different polymer matrices reinforced with various types of fiber and their processing techniques with the industrial application are shown in Table 2.

Application of biocomposite

Biocomposite materials developed by combining matrix and reinforcement (natural fibers) such as wood fiber, and nonwood fiber like cotton, silk, sisal fiber, jute, flax, pineapple, kenaf, and many more recently corn and soya are increasingly replacing synthetic fibers. These biocomposite materials show superior physical, thermal, mechanical, and biodegradation. Due to the presence of these excellent properties, biocomposite materials have been significantly used in various areas like automotive, aerospace, military, navel, construction, and food packaging. Presently, the main markets for biocomposites are in the construction and automotive sectors. Composite material reinforced with hemp fiber work excellently where weight reduction, as well as improved stiffness, is important. In the case of consumer goods applications, Trifilon has made many hemp fiber biocomposites to replace conventional polymers or composites. Biocomposite with hemp fiber is used to develop products like suitcases, chili boxes, cell phone cases, and cosmetic packaging.

Automobile applications

The biocomposite materials used in automobiles for making the lighter weight car, have high resistance to heat, internal and external impact resistance, and enhanced economic fuel capacity. This shows further improvement in the manufacturing of middle and lower-price cars. This new investigation on biocomposite and higher mass production forced us to decrease the cost and also increase the demand in different sectors including automobiles. Akampumuza et al. (2017) investigate the application of biocomposite in the automobile industry and identify the concept of bio-concept cars [18]. In 2001, Toyota Motor brought a concept of a lightweight and eco-friendly (ES3) car that is made from polyester and hemp fiber parts like carpet, body panels of the car, and other exterior and interior components. The lightweight body parts of the car are made of natural fiber reinforced with a thermoset, and other parts in the interior and engine compartment are developed by bioplastics.

Marine applications

Many researchers/scientists investigate the biocomposite having potential marine applications due to its excellent thermo-mechanical properties and biodegradability. Because of these properties, biocomposites based on bio-fibers become an alternate use of synthetic fiber-reinforced composites. Dupont^{TM} made biocomposite incorporating Kevlar fiber, which is useful to provide an idea of many properties like stiffness, tensile strength, and lightweight. Composite made by Kevlar will be lighter, tougher, and carry out better performance under the condition of hydrodynamic fatigue loading [19].

Construction applications

Biocomposite materials have various applications in the field of construction. For example, the construction of walls and partitions inside the apartment, bamboo fiber panels fire doors made from corn or sunflower. Manufacturing of biocomposite such as roofing sheets, door panels, slabs, beams, pipe, and tanks are used in load-bearing applications. Moreover, biocomposites are working as in the repairing and rehabilitation of different structural components because of their excellent thermal as well as acoustic properties, natural fiber reinforced biocomposites are utilized as insulating and soundproofing materials [20].

Table 2. Manufacturing techniques of biocomposite with different matrix materials and different fiber reinforcement and its applications.

Used matrix materials	Reinforcing fibers	Processing techniques	End used applications	References
PP, PS, and epoxy resin	Sisal fiber	Compression molding, Hand lay-up method	Automobile body parts, roofing sheets etc.	[21, 22]
PLA, PP, and epoxy resin	Kenaf fiber	Compression molding, Pultrusion etc	Tooling, bearings, automotive parts	[23]
PE, PP, and PU matrix	Hemp fiber	RTM, compression molding	Furniture, automotive sector	[24]
PP, polyester, and epoxy	Flax fiber	RTM, spray/hand lay-up	Structural component, textile	[25]
PU, PE, and PP	Rice Husk	Compression/injection molding	Window/door frames, automotive structure	[26]
PP, Polyolefin, and, PLA	Ramie fiber	Extrusion molding and injection molding	Bulletproof vests, socket prosthesis, civil.	[27, 28]
PP, PE, and epoxy resin	Coir fiber	Extrusion molding and injection molding	structural components of the automobile, boards, panels, roofing sheets, insulation boards	[29, 30]
Polyester and PP	Jute fiber	Hand layup, compression molding, and injection molding	Ropes, roofing, door panels	[31]

Conclusions

Biocomposite materials are exploited by academicians and used by many industries to produce sustainable modules for future applications. Biocomposite materials are fabricated with available natural fibers with varying amounts (wt%). Their specific properties (thermo-mechanical) have been used as an alternative to synthetic fibers like glass, ceramic, and carbon fibers. Hence, biocomposites reinforced with natural fibers are considered for valid superior replacement over synthetic fiber composites due to their compostability, degradability, and solution to the waste disposal problem. Therefore, we conclude that biocomposites made by renewable resources play a significant role in the fabrication of many interiors and exterior automobile parts, marine components, sound-absorbing materials for construction, and many consumers application. Indeed, many researchers/scientists reported that the biocomposite reinforced with natural fibers shows excellent properties like mechanical strength, thermal stability, and self-degradability. Moreover, the improvisation in all these properties of biocomposite was found suitable with the addition of compatibilizing agents. In addition, the composites fabricated by renewable resources like cellulose, bacteria cellulose, rice husk, rice straw, lignocelluloses, and paper sludge possess various favorable properties against other organic/inorganic fillers. The greater contribution of these favorable properties is leading to get higher benefits in near future and generating new applications and opportunities for biocomposite in the 21st century.

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