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Natural fiber reinforced polymer-based composites: importance of jute fiber

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Abstract

Natural fiber-reinforced polymer composites have become widely used in the last few years. Environmental concerns have forced academics to focus on developing "green composites," which has led to an increase in the usage of jute fiber as reinforcement. This review article seeks to give a thorough analysis of the most effective and widely used natural fiber-reinforced polymer composites (NFPC). It also provides a summary of distinct qualities and their uses in various sectors. The jute fiber composites involving basic types of polymer-based composites and their mechanical properties were reported. The uses of NFPCs were constrained by a variety of shortcomings, including higher water absorption, less fire resistance, and lower mechanical properties. The applications of NFPCs in the building, packaging, automobile, aerospace and sports industries were also investigated. As a result of their low cost, low density, rigidity, accessibility and low production energy, jute fiber-reinforced composites offer an advantage.

Keywords: Natural fiber; Classification; Jute fiber; Polymer composite; Mechanical properties; Applications

1. Introduction

The word "composite" first appeared around 1500 B.C. Early Egyptians and Mesopotamians used a mixture of mud and straw to build strong structures. Straw was utilized to offer strength while creating composite items. Engineers, architects, and manufacturers tried to create more complex uses for composite materials in a variety of industries during the ancient time. The chemical revolution began to alter composite material development as early as 1870 to 1890. Modern composite materials benefited much from the advancements in plastics. Plastic materials like vinyl, polystyrene, phenolic, and polyester were developed and reinforced in the early 1900s. The first plastic Bakelite was created in 1907 using synthetic components, and it performed better than other composite materials. In contrast, high stiffness and strength cannot be provided by plastic for structural applications. For structural developments, plastics, therefore, require more strengthening. In 1935, Owens Corning introduced the first glass fiber-reinforced polymer (FRP) technology. A very strong structure is developed when fiberglass and a plastic polymer are bonded. Unsaturated polyester resins (UPR) were first mentioned in 1936. Several resin solutions with better performance were developed starting in 1938 **[1-3]**.

Natural fiber composite materials are considered the most innovative composite materials due to their sustainability, affordability, renewability, lightweight, and biodegradable feature. In comparison to synthetic fiber, natural fiber offers better qualities and from 1990, it began to take the place of synthetic fiber. It is useful as a reinforced material because of its thermoplastic and thermosetting properties. Thermosetting resins, such as epoxy, unsaturated polyester resins, and polyester are widely used to create composite materials because of their better performance. Typically, bio-polymer is used as the matrix phase of a composite, while natural fibers are used as the enhancement phase. Natural polymers including PLA and PVA, are employed as matrix materials in bio-composites **[1, 3-6].**

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Jute, hemp, coir, sisal, bamboo etc. are some of the natural fibers that are biodegradable and recyclable. The least expensive of these is jute, which has already been shown to be an excellent reinforcement material in thermoplastic and thermosetting matrices. Low thermal conductivity, high tensile strength, moderate fire and heat resistance are just a few of the benefits that jute fiber naturally possesses **[7, 8].** Traditional products including hessian cloth, carpets, curtains, bags, packaging, and handicrafts are also made from jute. Jute fiber composites are also used in different sectors like automobile, aerospace, toys, building construction etc. **[9].** Jute fiber undergoes several treatments to change the fiber surfaces, which enhances the mechanical properties of the composite materials. In many different applications, including packing, car parts, roof tiles, and home decor, food packaging, the treated jute fiber showed better performance. They have superior toughness and longer fatigue life in the composites **[10, 11].**

Jute fiber-reinforced epoxy composites showed better tensile and compressive strength. The hybridization of 50% banana fiber with jute fiber composites reinforced with an epoxy coating improved the mechanical and thermal properties **[12, 13].** In one investigation, gamma radiation and UV radiation were used to enhance various mechanical qualities. Due to the generation of free radicals and the degree of cross-linking, composites containing 38% jute demonstrated improved tensile and bending strength. Before receiving gamma radiation, UV radiation was given considerably increased tensile and bending strength **[14].**

This paper reviews natural fiber and its classification, jute-based reinforced composites, their mechanical properties and applications. This paper aims to describe the types of natural fiber, especially jute fiber composites with various forms, their physical and mechanical properties, and their application to different requirements.

2. Natural Fiber

The simplest meaning of a natural fiber is one that is not artificial. Natural fiber can be found in both plants and animals. Natural fibers, such as jute, oil palm, flex, and sisal, are derived from both renewable and non-renewable sources. Natural fiber gained acceptable attention in the last few decades. Both the environment and human cultivation have benefited from it. Natural fibers have several advantages over synthetic ones, including low density, renewability, biodegradability, and non-toxicity. Natural fibers' low density is extremely advantageous to the automotive sector. A study found that using 65% hemp fibers in place of 30% glass fibers saves a net amount of energy of 50,000MJ (3 tons of emissions) **[4, 15, 16].**

2.1. Classification of Natural Fibers

Fibers are a class of hair-like materials that are continuous filaments or are indiscrete elongated pieces, similar to pieces of thread. They may be spun into rope, thread, or filaments. they can be matted into sheets to create goods like paper or felt. Natural fibers come from a variety of sources, including plants, animals, and minerals. Natural fibers can be categorized based on the origins listed below **[17, 18].**

2.1.1. Plant Fibers

Cellulose makes up the majority of plant fibers, frequently with other substances like lignin. Cotton, coir, jute, flax, ramie, sisal, and other materials are some examples. Seed fiber, leaf fiber, fruit fiber, and bast fiber are other subcategories of this fiber. Seed fiber is collected from the seed and seed case, for example, cotton and kapok. Seed fiber is also known as cellulose-based fiber. Most frequently, the fiber is spun into yarn or thread to create textiles. Leaf fiber is collected from the cell of the leaves like sisal and agave. Ropes are manufactured using leaf fibers. They are the hardest fibers, which is probably a result of their higher lignin content. Fruit fibers are those that are collected from fruits, such as coir fiber. The fruit's wasted portion is rich in cellulose and lignin. Bast fibers come from the skin or bast that surrounds the stem of a particular plant, such as jute or banana. Phloem fiber is the other name for bast fibers. Compared to other fibers, these fibers have a higher tensile strength.

2.1.2. Animal Fibers

After plant fibers, animal fibers are the most commonly used natural fibers. Protein-rich animal fiber can serve as potential reinforcement in composite materials. Alpaca, angora, mohair, wool, and silk are a few examples. Animal fibers included feathers, silk, and hair or wool from animals. Animal hair such as sheep wool, goat hair, alpaca hair, horse's hair, etc. is collected from hairy mammals. With a variety of diameters, it is a multipurpose fiber that may be used to produce textiles, household fabrics, and apparel. The protein fibroin makes up silk fiber, which is stronger than any natural fiber available. When making cocoons, fiber is gathered from the dried saliva of bugs or other insects. Animal fibers that come from birds are known as avian fibers. In general, feathers and feathers fiber are avian fibers.

2.1.3. Mineral Fibers

Mineral fibers are either naturally occurring fibers or fibers that have undergone minor modifications. These can be divided into three categories: metal fiber, asbestos, and ceramic fiber. The only naturally occurring mineral fiber is asbestos. Asbestos offers strength, fireproofing, chemical resistance, and heat resistance. Because of their beneficial properties, asbestos fibers are frequently used in industrial and commercial applications. One of the filament fibers with the smallest dimensions used in textile and other industries is ceramic fiber. It is capable of withstanding heat.

2.2. Jute as Natural Fiber

The most popular natural fiber used as reinforcement in green composites is jute. Jute (*Corchorus capsularis*) is a type of bast fiber from the Tiliaceae family. It is one of the naturally occurring fibers with cheap production costs. The best jute is now produced in Bangladesh, India, China, Nepal, Thailand, Indonesia, and Brazil. Jute fiber is produced globally in quantities ranging from 2300x103 to 2850x103 tons. Jute is brittle and can grow to a height of 2-3.5 m. The various types of jute fiber are shown in Figure 1 along with a digital representation of the jute plant. Jute's primary chemical components are lignin, protein, starch, cellulose and hemicellulose. For different jute grades, the chemical composition ranges from 61% to 73% of cellulose, 13.6%-23% of hemicellulose, and 12% to 23% of lignin. Pectin, wax, and lipids are also found in small amounts. Chemical compositions are impacted by climatic conditions, phases, and degradation processes. Table 1 displays the jute fiber's chemical composition.

Jute Plant | Jute Fiber | Jute Yarn | Jute Fabric

Figure 1 Digital images of Jute Plant, Jute Fiber, Jute Yarn and Jute Fabric

Because of the accessibility and characteristics of jute fiber, it is widely used in making composite materials among all fibers. Jute textile is available, portable and eco-friendly. Jute has a high lignin content (up to 12–16%) but a low resistance to moisture, acids, and UV light. Jute is less abrasive in behavior, has better dimensional stability and is harmless. Jute does not release poisonous gases because it is made of cellulose. Jute produces strong, long-lasting composites that are simpler to handle and restore nutrients to the earth **[8, 19-21].**

Table 1 Chemical composition of jute fibers [21-23]

Cellulose (%)	Hemicellulose (%)	Lignin (%)	Pectin (%)	Wax (%)
61.0-63.0	13.0	5.0-13.0	-	0.5
61.0-71.5	13.6-20.4	12.0-13.0	-	0.5
61.0-74.5	13.6-20.6	12.0-13.0	2.3	1.7

2.3. Types of Jute Fiber Composites

2.3.1. Jute Fiber-basedd Thermoplastic Composite

Polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC) matrix resin are commonly used thermoplastics with jute fibers. Due to the affordability, minimal thermal expansion, and capacity for recycling, the polypropylene (PP) matrix is frequently used. Jute/polylactic acid (PLA) and jute/poly L-lactic acid (PLLA) are polymer-based composites. Jute/polylactic (PLA) is the most efficient bio-composite out of all of these polymer-based composites. Using the tubular braiding process, jute yarns (both treated and untreated) were employed to create long-fiber reinforced unidirectional thermoplastic jute/PLA and jute/PP composites. Jute/PLA composites' maximum tensile strength and modulus increased with higher fiber volume percentages, and jute/PP composites' tensile and bending qualities were enhanced **[24].** Chemical solutions were used to treat jute/PP composites with varying fiber conditions. When treated fiber was compared to untreated fiber, no noticeable differences were seen. Jute-reinforced composites

(1 m in length and 50% weight) demonstrated superior tensile strength in this procedure **[25]**. The mechanical properties of the jute-polypropylene composite are displayed in Table 2.

Table 2 Mechanical Properties of Jute-Polypropylene Composites [26, 27]

Fiber Content	Chemical Treatment	Processing	Tensile Strength (MPa)	Flexural Strength (MPa)	Flexural Strength (MPa)	Impact Strength (j/m)
15	2% Silane	Injection Molding	37	2200	-	-
30	0.5% MAPP, 5 min	Compression Molding	31.27	59.18	-	65.96

2.3.2. Jute Fiber-Based Thermoset Composite

The jute epoxy composites offered superior mechanical (flexural and tensile) properties as compared to the jute-polyester composites. Jute-epoxy composites' mechanical characteristics have been extensively researched. We looked into three different kinds of laminated jute/epoxy resin composites: woven, non-woven, and carded silver. According to the study, compared to non-woven composites, silver-reinforced composites had the maximum rigidity. Non-woven reinforced composite has the lowest values in terms of strength. A jute/epoxy composite that had been alkali-treated (with NaOH) was created, and its water absorption and thickness swelling were studied (TS). The aquatic environment increased at both properties **[28-30].**

2.3.3. Jute Fiber-Based Hybrid Composite

Jute and E-glass fiber reinforced epoxy hybrid composites by hand layup method show maximum tensile, flexural, and impact strength compared to other composites. Woven jute-glass reinforced unsaturated polyester hybrid composites made by hot press compression molding technic were studied. Post-radiation treatment (γ-irradiation) on composites showed improvement in their tensile, bending and impact properties. The oil palm jute-reinforced epoxy hybrid composites were investigated. physical properties like water absorption, thickness swelling, and density tests were enquired which show improved mechanical properties **[20, 31, 32].**

2.3.4. Jute Bio-Based Resin Composites

For bio-based composites, biodegradable polymers like polylactic acid (PLA), polyvinyl alcohol (PVA), polyhydroxy butyrate (PHB), epoxy resin based on soybean oil, etc. have been utilized. Jute fiber combined with bio polyester PLA is considered the best for commercial application. Jute mat fiber reinforced bio polyester PLA composite show improved tensile and impact strength. In another study, jute-reinforced soy-based resin green composites were prepared by compression molding. The result found better degradation and water absorption property **[33, 34].**

2.4. Mechanical Properties of Jute Fiber Composites

2.4.1. Tensile Strength

Various researchers investigated the effect of the tensile strength of jute fiber-based polymer composites. Jute fiber reinforced polypropylene matrix composites with jute fiber (size 2mm and 10% by weight) give better tensile strength. Aging coated and uncoated short jute fiber reinforced PLA composites were investigated. The result found that the tensile strength was decreased effectively **[35, 36].**

2.4.2. Flexural Strength

Flexural strength is the amount of pressure a material can bear before giving way under a flexural load. The maximum pressure that is present is represented by the materials' yielding. Jute/e-glass polymer composite show better flexural stiffness, tensile, and impact strength. Jute/PLA composites with 40% fiber content show maximum flexural strength **[37, 38].**

2.4.3. Compressive Strength

The compressive strength of a material refers to its capacity to endure load. Jute fiber-reinforced epoxy composite exhibits better interfacial adhesion stress between jute fiber and epoxy resin. Additionally, there was an increase in compressive strength with a maximum range. The shafts fabricated E-glass jute epoxy hybrid composites have shown good mechanical strength in both compression and flexural loading than E-glass /banana hybrid epoxy composites **[12, 39].**

2.4.4. Water Absorption

The ability of jute fiber composite to absorb water affects its mechanical properties. Water absorption qualities of jute and banana fiber epoxy hybrid composites were found reduction with a 50/50 weight ratio of jute and banana fibers. Because of less water absorption, hybrid composites show better mechanical properties. Chemically modification reduced the overall water uptake of the jute fibers with filler red mud. The flexural strength of the composites with modified fibers increases significantly compared to untreated fibers **[13, 40].**

2.4.5. Impact Strength

Jute/E-glass reinforced hybrid composites show better flexural and impact strength and also improved impact resistance. Jute/epoxy polymer composite was studied in terms of tensile, flexural, and impact strength with various ranges of NaOH. At 7% NaOH, it showed maximum impact strength **[41, 42].**

2.5. Applications of Jute Fiber Composites

2.5.1. Building Interior and Construction

A novel option for the application of structural materials is provided by jute fiber-reinforced polymer composites. The use of composites as building materials has overtaken many traditional ones. Considering the embedded energy, composites offer a compelling alternative to metals. Other important properties such as impact resistance, corrosion resistance, and thermal & acoustic insulation - claim its position as an ideal building material. Composites reinforced with jute fiber are used in place of wood. Jute composite is used to create interior designs such as doors, door frames, false ceilings, furniture, etc. Comparing doors made of typical materials like wood and metal to those made of sandwich composites offers a distinct benefit **[43, 44].**

2.5.2. Packaging Industry

Packaging is typically divided into three categories: rigid packaging, semi-rigid packaging, and flexible packaging. Through the transformation of flexible jute materials into rigid/semi-rigid sheets, jute is primarily utilized as a packaging material. Jute can be used in place of plywood and wood. Jute composite materials are mostly utilized for wrapping, hard packaging, and paper goods in the packaging sector.

Sonali Bag — Jute Bag — Jute Paper Bag

Figure 2 Application of Jute in the Packaging Industry

Figure 2 displays a variety of jute-based composite packaging items. In place of synthetic fiber, jute-reinforced polymer polymers (PP, PE, and PLA) are utilized as composites in the packaging sector. Because of its salt resilience, the jute polymer sheet can be utilized to construct huts in coastal areas. A biopolymer (biodegradable) blander and jute cellulose were used to create a bio-plastic bag. Bio-plastic bags, also known as jute poly bags or Sonali bags are being used in place of plastic bags since they are recyclable, environmentally beneficial, and biodegradable. The item could be used to package clothing, food, and dairy milk **[43, 45, 46].**

2.5.3. Automobile Industry

Jute fiber-reinforced polymer composites have a variety of qualities that make them useful in a wide range of applications, including light-weightness, strength-to-weight ratio, corrosion resistance, high strength, stiffness, durability, and flexibility. Composites and hybrid bio-composites are used by the automotive industry in both interior and exterior applications such as molded door skin, insulation, headlining, carpets, door pad, etc. Jute mat is one of the composites created from non-woven jute fibers. Jute mat may be molded to create car door panels. Manufacturers may want to use jute fiber composite mats for products that need the same qualities as wood but cannot be made from wood components. In applications like door/ceiling panels and panels separating the engine and passenger compartment, jute fiber's hollow tubular structure offers better insulation against noise and heat. Jute fiber and PP or other thermoplastics are used to make these panels. The 100GSM jute fiber-based composite was discovered to be a particularly desirable material for headlining. Glass fiber-based composites can be replaced by jute fiber-based composites because it has the potential to be lighter, cheaper, and more environmentally friendly. Jute fibers work well with polypropylene fibers, improving the composite's rigidity and mechanical qualities **[9, 43, 47, 48]**. Figure 3 demonstrates products made from jute composite.

2.5.4. Aerospace

About 50% of the components used in the aerospace industry are comprised of composite materials. Natural fiber composites are being used 20%–30% more frequently in the aerospace industry. Typically, green fiber composites are more amazing and suitable materials due to their physical characteristics, reliability, durability, environmental friendliness, low cost, high strength, and improved stiffness-to-density ratio (e.g., adhesives). Typically, thermoset composites like epoxy resin are used to create natural fiber sandwich composites. Composite contributes to improved aircraft performance and fuel efficiency. Pilots' cabin doors, door shutters, and passenger seats can all be made of a jute fiber-reinforced polyester/epoxy composite with red mud. Due to its ability to lower aircraft weight, jute composite materials are also used in helicopters, military fighter aircraft, small and large transport aircraft cockpits, satellite launch vehicles, and missiles **[49, 50].**

Figure 3 Application in Automobile Industry

2.5.5. Sports

Composite materials are used to build sporting equipment because of their thermal stability, increased friction and abrasion resistance, vibration attenuation, high design freedom, high strength, low cost, and ease of availability. Skis, surfboards, windsurfers, tennis racquets, slats, badminton, fishing rods, golf clubs, golf club heads, swords, climbing ropes, various lines, etc. are some examples of possible application areas. Composite materials improve the mechanical qualities of that equipment by 30% to 50%. Surfboards, windsurfing, and climbing ropes all make use of jute fiber-reinforced polymer composites **[51, 52].**

3. Conclusion

Natural fiber-based polymer composites have gained popularity in the field of research and academic work in recent decades because of their properties. Natural fibers of all kinds, including jute, bamboo, coir, and many more, have been used in a variety of industries due to their unique physical and mechanical characteristics. Due to their low price, lightweight, easy availability, eco-friendliness, biodegradability, and high flexural strength, jute fiber composites beat steel, wood, and synthetic fiber composites as alternative materials. Jute fiber's characteristics can be enhanced by blending with glass and other natural fibers. Gamma radiation was successfully implied by many researchers to improve the valuable mechanical qualities of jute fiber. Jute fiber composites are used in a variety of industries, including building construction, automotive, aircraft, packaging materials, sports, the medical field, construction, the toy business, and furniture. Future research on natural fibers, notably jute fiber-based polymer composites, is left open-ended by this work. New ways are needed to discover to improve the physical and mechanical properties of jute fiber for further application in different fields.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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