ETHIOPIAN JOURNAL OF TEXTILE AND APPAREL
EJTEX
ETHIOPIAN INSTITUE OF TEXTILE AND FASHION TECHNOLOGY BAHIR DAR UNIVERSITY, ETHIOPIA

SUSTAINABLE BUILDING SOLUTIONS: HARNESSING JUTE FIBER COMPOSITES

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ISSN: (Print) (Online) Journal homepage: https://journals.bdu.edu.et/index.php/ejta

To cite this article: Dawit Tessema Ebissa (2026), SUSTAINABLE BUILDING SOLUTIONS: HARNESSING JUTE FIBER COMPOSITES, 62-93

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ABSTRACT

Jute fiber is a natural, biodegradable fiber derived from the jute plant. It is commonly used in the production of gunny sacks, carpets, ropes, and various eco-friendly packaging materials. Its eco-friendly nature, high lignin content, and ease of cultivation make jute a popular choice for sustainable textile and industrial applications, contributing to environmental conservation by reducing reliance on synthetic fibers. Jute fiber composites are increasingly utilized across various industries due to their biodegradable, lightweight, and cost-effective nature. Common applications include packaging materials, geotextiles for erosion control, automotive components such as door panels and interior parts, building and construction materials like wall panels and insulation, and furniture manufacturing. Their eco-friendly properties also make them suitable for sustainable product development in sectors aiming to reduce environmental impact, while ongoing research continues to expand their potential uses in sports equipment, medical devices, and industrial applications. Jute fiber composites are increasingly being utilized in building and infrastructure applications due to their eco-friendly, biodegradable, and cost-effective properties. They are commonly used in the manufacture of lightweight panels, roofing materials, door and window frames, and insulation boards, offering improved strength-to-weight ratios and durability. Additionally, jute composites serve as reinforcement materials in concrete and plaster composites, enhancing tensile strength and crack resistance. Their sustainable nature makes them suitable for eco-conscious construction practices, promoting greener building solutions while reducing reliance on non-renewable materials. The future looks bright for jute fiber composites in building and infrastructure. As the demand for sustainable materials increases, more innovations are likely to emerge.

Keywords: Jute fiber, buildings and infrastructure, Jute fiber composites, Construction materials, strength-to-weight ratios.

INTRODUCTION

Fiber is a thin, discrete reinforcement material manufactured in different shapes and sizes from different materials such as steel, plastic, glass, carbon, and natural materials (1). Fibers are a class of hair-like materials that are made as continuous filaments. They can be spun into filaments, thread, or rope. They can be used as a component of composite materials (2). They can also be matted into sheets to make products. Fibers are the basic building blocks of textiles, consisting of long, thin strands of natural or synthetic material that can be spun into yarns or threads for making fabrics. They are of two types (Figure 1): natural fiber and human-made or synthetic fiber.

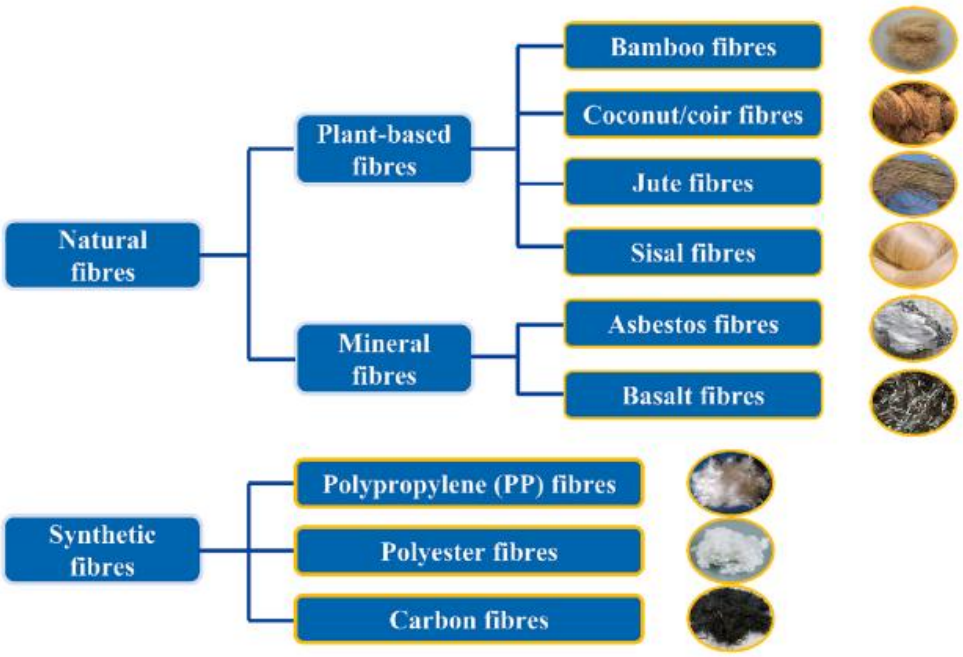


Figure 1 Natural and Synthetic Fibers (3)

Natural fibers are fibers obtained from plants, animals, or minerals that are used to produce textiles and other materials. Examples include plant-based fibers like cotton, linen (from flax), jute, bamboo, and hemp; animal-based fibers such as wool, silk, and alpaca; and mineral fibers like asbestos. These fibers are biodegradable, renewable, and environmentally friendly, making them popular choices in sustainable textile manufacturing, while Synthetic fibers are man-made fibers produced through chemical processes, typically derived from petrochemicals like petroleum and natural gas. They are created by extruding polymer solutions through spinnerets to form fibers, which are then processed into textiles. Common synthetic fibers include polyester, nylon, acrylic, and spandex, known for their durability, elasticity, resistance to moisture and chemicals, and versatility in various applications such as clothing, upholstery, and industrial uses. Figure 1 shows the classification of human-made fibers

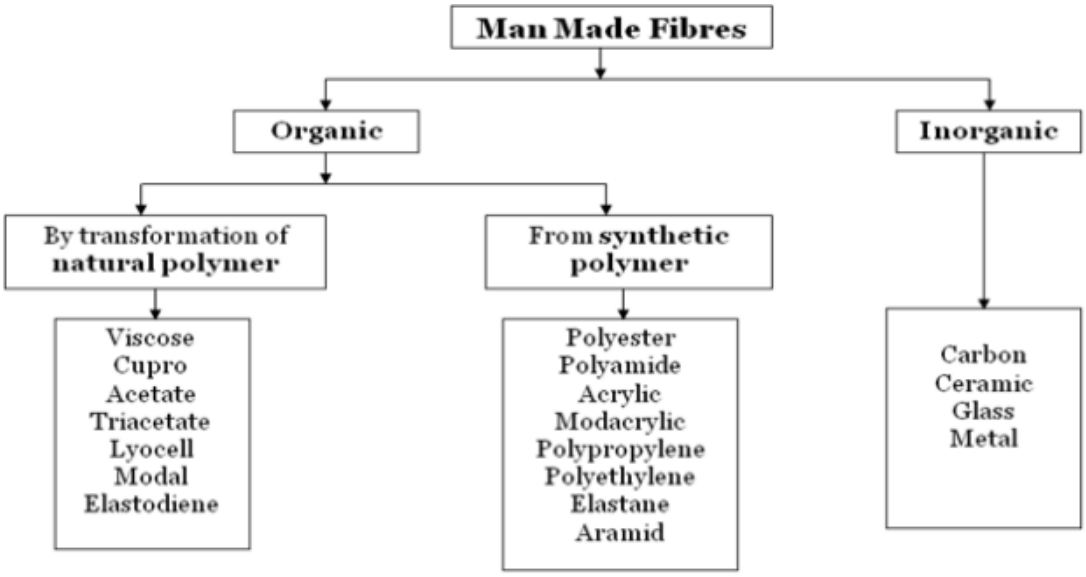


Figure 2 Classification of human-made fibers (4)

The development of major and durable fibers, in addition to aligned polymers such as thermosets and thermoplastics, provides the foundation of advanced material for composites (5). Glass fibers are by far the most extensively utilized of the fibers shown in Figure 2. Carbon fibers have attracted increasing attention due to the demands posed by ever-larger HKT blades and the lowering cost of carbon fibers (6). Aramid, polyethylene, and cellulose are three more potentially interesting fibers. All of these materials have intermediate material properties and significantly low density (7).

1.1 Glass fiber

Since the Si and O atoms are linked to a crystalline structure without crystallographic order. SiO2, Al2O3, and minor amounts of other oxides make up the majority of the glass. Glass fibers come in a diversity of chemical compositions, each with its own set of applications (8). The most common glass fiber used in composites is E-type. Molten glass is used to create glass fibers by assembling bundles consisting of a large number of fibers with diameters ranging from 10 to 20µm (9).

1.2 Carbon fiber

Carbon fibers are made of highly refined carbon, which develops a hexagonal graphitic lattice. Strong covalent forces hold the atoms inside the hexagonal plane together, while weaker bonds hold the hexagonal planes together (10). Carbon fibers in their entirety have a significant level of graphite plane alignment, which varies based on the type of fiber and its manufacturing procedure. Polyacrylonitrile (PAN) fibers are the first and most frequently used. Those fabrics are metabolized, extended, and then heat-treated at temperatures ranging from 1500 to 2500oC (11). The second process begins with natural tar, which has a random mixture of graphite units. Several stages of production culminate in the development of fibers by spinnerets, which make sure that the graphite planes are aligned and thus that the fibers have the desired properties (12,13).

1.3 Basalt fiber

Aromatic polyamide fibers, also known as basalt fibers, are mechanically strong. They absorb water quickly (14). When compared to basalt fibers, E-glass has poor mechanical properties, as shown in Table 1. Basalt fiber is 15-20% stiffer than E-glass. Carbon fibers are more cost-prohibitive than basalt fibers. Basalt has also been studied as a hydrokinetic turbine blade material (15,16). More research must be conducted before basalt fiber may be employed as a component of HKT blades because of its incredible ability to absorb water (17).

Table 1 Comparison of mechanical properties between basalt fiber and other fibers (18–20)

	Diameter (µm)	Dencity (gcm^{-1})	Tensile Strength (Mpa)	Modulus of Elasticity (Gpa)	Elongation at Break (%)	Price ($USDkg^{-1}$)
Basalt Fiber	6-21	2.65-3.00	3000-4840	79.3-93.1	3.1	2.5-3.5
E-glass fiber	6-21	2.55-2.62	3100-3800	72.5-75.5	4.7	0.75-1.2
Carbon Fiber	5-15	1.44	2900-3400	70-140	2.8-3.6	30

1.4 Natural fibers

Natural fibers have recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials. These natural fibers are low-cost with low density, are biodegradable, and have high specific properties. However, certain drawbacks, such as incompatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing, and poor moisture resistance, greatly reduce the potential of natural fibers to be used as reinforcement in polymers (21). Figure 3 shows the classification of natural fibers.

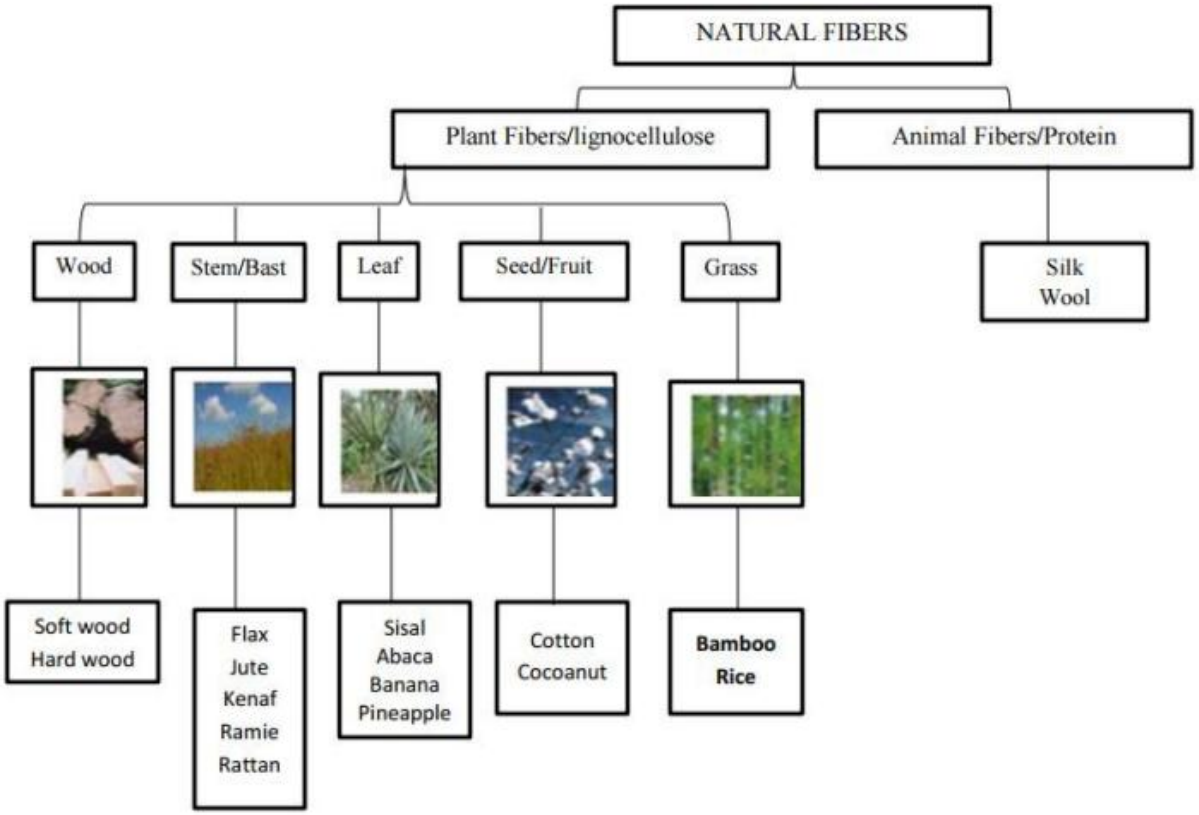


Figure 3 Classification of natural fibers (22)

Natural fibers can be made from plant, animal, and mineral sources. Natural fibers can be classified according to their origin.

- Animal fibers: - generally comprise proteins; examples include silk, wool, angora, mohair, and alpaca.
- Animal hair (wool or hairs): Fiber or wool taken from animals or hairy mammals like sheep wool, goat hair (cashmere, mohair), alpaca hair, horse hair, etc.
- Silk fiber: Fiber collected from the dried saliva of bugs or insects during the preparation of cocoons. Examples include silk from silk worms.
- Avian fiber: Fibers from birds, e.g., feathers and feather fiber.
- Mineral fibers: Are naturally occurring fibers or slightly modified fiber procured from minerals and non-metallic inorganic fibers.
- Plant fibers: are comprised mainly of cellulose; examples include cotton, jute, flax, ramie, sisal, and hemp. Cellulose fibers are used in the manufacture of paper and cloth. This fiber can be further categorized into the following:-
  - Seed fiber: Fibers collected from seeds or seed cases, like cotton and kapok.

- Leaf fiber: Fibers collected from leaves. E.g., sisal and agave.
- Baste fiber or skin fiber: Fibers are collected from the skin or baste surrounding the stem of the plant. Some examples are flax, jute, kenaf, industrial hemp, ramie, rattan, soybean fiber, and even vine fibers and banana fibers.
- Fruit fiber: Fibers are collected from the fruit of the plant, e.g., coconut (coir) fiber.
- Stalk fiber: Fibers that are the stalks of the plant. E.g., straws of wheat, rice, barley, and other crops, including bamboo and grass. Wood from a tree is also such a fiber(4).

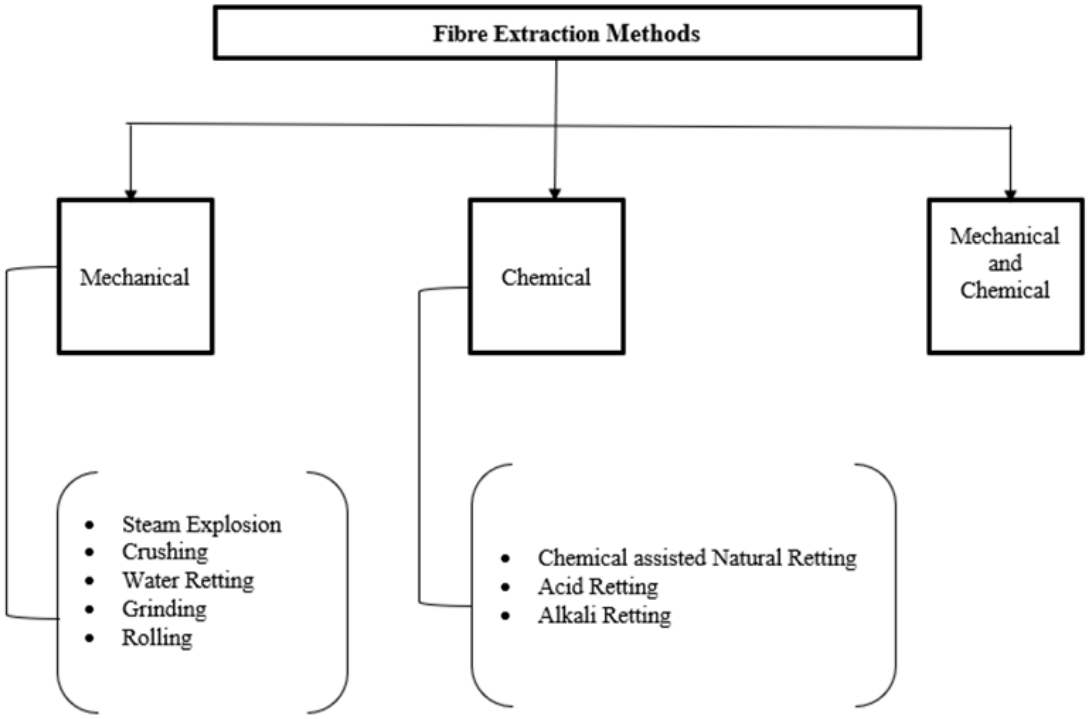
People are looking more and more for building materials that do less harm to the planet. This big shift is putting natural fibers like jute front and center. They are a smart choice for new buildings and fixing old ones.

Choosing natural fibers for building makes a lot of sense for both the Earth and our wallets. These materials help cut down on pollution. They also use less energy to make than common choices.

- Environmental Benefits: Natural fibers mean a smaller carbon footprint. They break down over time, which is good for waste management. Plus, they need less energy to produce, which is a win for the environment.
- Economic Advantages: They are often cheaper to get and can create local jobs. Using local resources means less shipping, too, saving money and fuel. This helps boost local economies.
- Performance Characteristics: Natural fibers offer great insulation against heat and cold. They also absorb sound well, making spaces quieter. Their natural flexibility can add to building resilience.

1.5 Natural Fiber Extraction Methods

As illustrated in Figure 4, different extraction methods were used depending on their use. Those processes are categorized as chemical, mechanical, and chemical and mechanical combinations (23).



The fibers extracted with steam explosion are rigid and dark, and also, single fibers are not effectively separated from the fiber bundles. Fiber cell walls are broken, and the fiber becomes brittle. The crushed cell walls stuck on the bamboo fiber surfaces have low shear resistance. The fiber collected by crushing has small fibers, and it becomes powdered with mechanical over-

processing (23).

Natural fibers in an amorphous matrix of lignin and hemicelluloses are complex in form and are typically lignocellulose composed of helically bound cellulose microfibrils. There are chemical methods available that can enhance the fiber-matrix interfacial adhesion(24–26). Of these methods, chemical-assisted natural retting methods are not desirable due to the high moisture content of the extracted fiber, even if it can remove more lignin than alkali and acid retting (27). In general, due to the need to get long fibers and improve the interfacial adhesion between the fibers and the matrix, the study of alkali and acid retting methods is important.

1.6 Matrix materials

Polymer resins, mainly thermosets, are used to make polymeric composites with fibers. Both of these are elastic with a low stiffness of less than 4 GPa. Their primary function is to ligate the fibers to produce a structurally effective composite (5). Toughness and, in particular, failure stress is low for thermosets (5-8%) but high for thermoplastics (50-100%), and also the matrices promote strength and hardness in the composites, primarily through energy absorption at the interface. Glass fibers are combined with thermosetting polyester in composite wind turbine blades, a material, using processing technology borrowed from the boating industry (28). The thermosets undergo an irrevocable gelling, causing the composites to shrink and create internal tensions. Thermoplastics for rotor blade composites are still in development, but hold high potential for improving sustainability. They have stiffness values ranging from 1-3 GPa and densities ranging from 0.9-1.4 g/cm^3 (29). The possibility of reusing thermoplastic polymers has piqued interest, as well as research; however, no clear technique for recycling thermoplastic polymer composites has been developed. Thermoplastics go through a rapid melting and solidification process during processing. Internal tensions should be considered because thermoplastics have relatively high melting points and processing temperatures, and improved thermoplastics often have higher melting points. Stress distribution, regardless of its origin, harms material properties.

1.7 Composite materials

The fibers and matrix are mixed to make the composite. The fibers, matrix, and interface set in place between these two components govern the composite properties (30,31).

The properties of reinforcement fiber and resin, as well as their placement within the composite, are all significant. The relative quantities are by far the most essential traits, which are commonly expressed by the volume fraction of fiber and the orientation of the fibers. E_c, the composite stiffness, is controlled and calculated as

$$E_c = \eta V_f E_f + V_m E_m \quad (2.1)$$

where V is the volume fraction, η is an orientation factor for the fibers, f is the fiber index, and m is the matrix (32). For a porosity-free composite, $V_f + V_m = 1$. For parallel fibres, the orientation factor is 1; The orientation factor for a randomly oriented fiber arrangement in two dimensions (in a plane, commonly referred to as a fiber-mat) is 1/3 (33,34).

Composites are the most commonly employed materials in the construction of HKT blades. Composites have various advantages over metals, including superior fatigue properties, a high stiffness-to-weight ratio, the ability to construct structures with complicated curvature, and a reduction in inertial loads (35). Moreover, the capacity to exert strength in a preferred direction, which for a horizontal axis turbine is radial. When using hydrofoils in the making of a tidal stream turbine, high stiffness is essential to minimize blade deformation, which would modify the blade's hydrodynamic performance and for structural integrity, affecting the turbine's power production. Furthermore, Carbon fibers are less affected by fouling (36,37). After six years of testing in seawater, the Kobold prototype turbine blades made of carbon fiber and epoxy resin maintained their structural integrity (38). Recently, mechanical degradation behaviors of fiber-reinforced matrix (composite) materials used in maritime environments have been reported (39,40). More research and testing are needed to investigate the effect of salty water uptake on composite mechanical properties.

1.8 Hybrid composites

The strength and failure processes of hybrid composite materials have been investigated (41). The majority of studies discovered that incorporating glass fibers into carbon fiber composites improved the strain-to-failure and impact properties of the carbon fibers. Investigations with the model of probabilistic fiber bundles and the micromechanical multi-fiber model have also been conducted (42). Hybrid composites consisting of synthetic and natural fibers are a smart choice for suitably strong composites because they combine the advantages of natural fibers with the high mechanical performance of synthetic fibers (43).

1.9 Material mechanics of composite materials

The consistency and quality of the materials are fundamental. Pore structure on the production line can result in deformations such as fiber rupture, interface bursting, and resin cracking, which can lead to micro buckling through trans-laminar crack propagation and delamination (44). These failure processes significantly impact the mechanics of composite materials, and the quality of the available materials restricts the mechanical properties and their fluctuations. From a materials standpoint, the initial damage and its progression determine these properties (45).

1. Jute Fiber

As shown in Figure 5, the jute plant, also called Corchorus spp., is a type of flowering plant that grows in warm areas. It can live for a long time or just one year. Its strong and long fibers are mainly used to make burlap, hessian, and gunny sacks, so it is an important crop in places like India, Bangladesh, and Thailand. This plant thrives best in hot, humid weather and requires well-drained, fertile soil. Farmers typically harvest it after about 4 to 6 months, when the plants are fully grown (46). To get the fibers, people soak the outside bark of the plant's stalks in water. This process is called retting, and it helps separate the fibers. Once the fibers are loosened, they are taken out, cleaned, and turned into yarn. Growing jute is good for the environment because it breaks down easily and needs fewer chemicals compared to man-made fibers. This helps promote sustainable farming and creates eco-friendly materials. Jute fiber is derived from the stem of the jute plant and is a natural material that is environmentally friendly because it breaks down easily. It is strong, long-lasting, and inexpensive, which is why it's commonly used to make bags, sacks, carpets, and other textiles. This makes jute a crucial ingredient in the production of environmentally friendly materials. Since it is easy to grow and gentle on the planet, jute is a popular alternative to synthetic fibers, which helps promote environmental safety. The fiber is composed of cellulose, hemicellulose, lignin, and pectin, with cellulose being the primary component that lends it strength and flexibility (47). The fibers are shaped like long tubes, and inside their walls, they have tiny structures called microfibrils that help them stay strong and durable. The center of the fiber is empty, which makes it lightweight and ideal for textiles, packaging, and special fabrics for outdoor use. The tiny structure of the fiber, which has layers, affects how it feels and what it can be used for. Factors that can alter the properties of jute fiber include the type and genetics of the jute plant, its growth environment, such as the type of soil, weather, and rainfall, as well as farming methods, including when it's harvested and how it’s processed after harvesting. The steps taken after harvesting, such as drying and cleaning, also play a role in determining the quality of the fiber, influencing its cleanliness and flexibility. Lastly, outside conditions like pollution and how it’s stored can also harm the fiber over time (48).

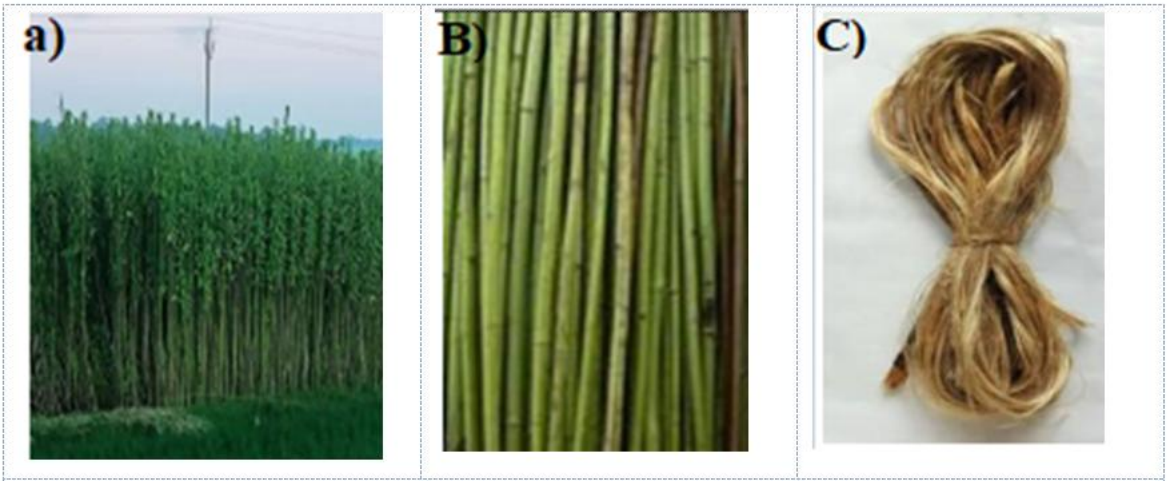


Figure 5. Jute description(49) a)Jute Plant b)Jute Stem c) Jute Fiber

2.1. Jute Fiber: Properties and Advantages

Jute is a type of fiber derived from a specific plant. It is taken from the stem of the jute plant. For many years, people have been using it for various purposes, such as making ropes and bags. Nowadays, scientists are combining jute with other materials to create new, very strong products. These new products are known as composites. You can think of them like a team where jute provides the strength while the other materials keep everything together. This combination makes them ideal for large construction projects. Jute fiber is unique due to its natural strength. It is a great choice for making tough composites. This is why jute is a popular selection for eco-friendly building constructions (49,50).

- **Physical Properties:** As shown in Table 2, Jute has very good tensile strength, meaning it can handle a lot of pulling force without breaking. It stretches very little, keeping its shape well. Its natural stiffness also adds to its strength in composite materials.
- **Chemical Composition:** This fiber is mostly cellulose, which gives it its strong structure. It also contains hemicellulose and lignin, which help bind the fibers together naturally. These parts work together to create a tough material.
- **Sustainability Profile:** Jute grows quickly and needs very little water, pesticides, or fertilizers. As it grows, it absorbs a significant amount of carbon dioxide from the air. This makes jute one of the most environmentally friendly fibers available.
- **Comparison with other fibers:** Jute holds its own against other natural fibers like flax or hemp. It's also often a more affordable and environmentally friendly choice compared to synthetic options like glass or carbon fiber. You get good strength without the environmental baggage.

Table 2 Tensile Properties of Jute Fiber (51)

Jute Fiber/Fabric Type	Resin	Treatment	Percentage of Fiber in Composites	Tensile Strength, MPa	Tensile Modulus, GPa	Tensile Elongation
Fiber length 5–6 mm	Polyester	5% NaOH	18% wt.	9.24	0.811	1.14 mm
		10% NaOH		7.92	-	-
	Epoxy	5% NaOH		12.46	1.064	1.17 mm
		10% NaOH		10.5	-	-
Bi-directional jute fiber mat	Epoxy	Untreated	12% wt.	71.67	0.96	-
			24% wt.	88.87	3.03	-
			36% wt.	97.99	3.81	-
			48% wt.	110	4.45	-
Woven fabric	Epoxy	Untreated	25% wt.	26.53	6.32	-
Main and cross-directional woven textile	Epoxy	Heat treatment		189.479		
Continuous jute fibers (5 layers)	Polyester	Dry	50% wt.	34.87	1.989	-
		Wet—water		35.23	2.23	-

Jute Fiber/Fabric Type	Resin	Treatment	Percentage of Fiber in Composites	Tensile Strength, MPa	Tensile Modulus, GPa	Tensile Elongation
Raw jute fiber reed	Un-saturated polyester	30% jute batching oil in water emulsion	25% wt.	80 ± 13.39	3.68 ± 0.48	4.5 ± 0.55%
			35% wt.	106 ± 16.30	4.83 ± 0.63	5.2 ± 0.83%
			44% wt.	122 ± 31.11	5.56 ± 0.67	4.8 ± 0.54%
Jute silver			25% wt.	71 ± 11.93	3.24 ± 0.65	4.8 ± 0.59%
			35% wt.	89 ± 9.74	4.46 ± 0.45	5.4 ± 0.48%
			44% wt.	109 ± 16	4.89 ± 0.55	4.7 ± 0.54%
Long jute fibers	Epoxy	Untreated	70% wt.	419	-	-
Plain weave jute fabrics	Polypropylene	0.4% NaOH	30% wt.	16.73	-	-
			40% wt.	22.31	-	-
			45% wt.	24.21	-	-
			50% wt.	21.55	-	-
			60% wt.	20.15	-	-
			65% wt.	18.50	-	-
Unidirectional jute fiber	Epoxy	Untreated	8% wt.	45.28 ± 0.45	3.18 ± 0.40	-
			10% wt.	54.35 ± 4.88	5.66 ± 0.65	-
			12% wt.	78.38 ± 1.01	9.9 ± 1.61	-
		Chemically treated	8% wt.	51.25 ± 4.88	11.9 ± 0.55	-
			10% wt.	67.97 ± 2.99	12.38 ± 1.38	-
			12% wt.	84.46 ± 4.99	13 ± 0.67	-
Bi-axial woven jute fabric	Epoxy	Untreated	44.3 ± 2.2% vol.	52.1	5.184	1.6%
Woven jute fiber plies	Polyester	Untreated	20% vol. Uni	42.236	3.973	0.011 m/m
			20% vol. Multi	21.685	-	0.529 m/m

2.2. Jute Fiber Composites: **Properties and Advantages**

Jute fiber is a natural material. It's known for its high tensile strength, meaning it's hard to pull apart. It also has good stiffness and breaks down naturally, which is great for the planet. To make a composite, we process jute into strands or woven mats. Then we combine it with a matrix material. Common choices for construction are polymers, like plastics. Other matrices include cement and geopolymers, which are special types of concrete. The jute acts like the steel bars in concrete, giving the material its backbone. As shown in Table 3&4, jute fiber composites, when combined with polymers or resins, typically exhibit enhanced mechanical strength, biodegradability, lightweight nature, good thermal and acoustic insulation, and resistance to environmental degradation, making them suitable for sustainable construction applications such as panels, insulation materials, and decorative elements (52,53).

- **Sustainability**: Jute's status as a renewable resource underscores its eco-friendliness, as it grows quickly and requires minimal chemical inputs, making it a sustainable choice for environmentally conscious consumers and industries aiming to reduce their ecological footprint.
- **Strength**: Jute composites are highly valued for their impressive tensile strength, which enables their effective use in structural applications such as packaging, automotive components, and building materials, contributing to lightweight yet durable solutions.
- **Cost-Effective**: Natural fibers such as jute, hemp, and coir are often more cost-effective than synthetic fibers, making them an economical choice for construction projects. Their lower production and processing costs contribute to reduced overall expenses, especially in large-scale applications, while also offering environmental benefits due to their biodegradability and renewable nature.

- **Biodegradable**: Jute composites are environmentally friendly because they are biodegradable, meaning they naturally decompose over time without leaving harmful residues, unlike synthetic materials that can persist in the environment and contribute to pollution.
- **Strength and Durability:** Jute fibers are renowned for their impressive tensile strength, which significantly enhances the strength and durability of composite materials. When combined with appropriate resins, these fibers form robust, resilient composites capable of enduring substantial mechanical stress, making them suitable for various structural applications and contributing to sustainable material development.
- **Lightweight Nature:** Jute fiber composites are valued for their lightweight nature, which contributes to reduced structural loads and enhances energy efficiency, making them ideal for various applications such as packaging, automotive parts, and construction materials, while also offering economic benefits through lower transportation costs.
- **Thermal Insulation:** Jute composites are known for their excellent thermal insulation properties, which can significantly reduce energy consumption in buildings by minimizing heat transfer, thereby lowering the need for heating in winter and cooling in summer. This eco-friendly and biodegradable material not only contributes to energy efficiency but also offers a sustainable alternative to traditional insulation materials, aligning with green building initiatives.
- **Moisture Resistance:** Moisture resistance in jute composites is crucial for their durability and performance, and can be significantly improved through careful resin selection—such as using waterproof or moisture-resistant resins—and optimized manufacturing processes like proper curing and sealing techniques, which prevent water ingress, reduce degradation, and maintain long-term structural integrity of the composites.

Table 3 Mechanical Properties of Jute-Polyethylene Composite(53)

Fiber content	Chemical treatment	Processing	Tensile strength (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Impact strength (j/m)
300 g/m2	60 W oxygen plasma, 15 min	Hydraulic molding	-	45.6±1.8	1244.5±18.5	-
30% (wt.)	1% MAPE, 5 min	Melt mixing	40.14	47.97 ± 1.3	-	65.69

Table 4 Tensile strength of jute fiber reinforced polyester composites (54)

SI No	Thickness (mm)	fvf (%)	Ultimate Load (kN)	Tensile Strength (MPa)
1	1.8	8.30	1.05	23.33
2	2.5	12.00	1.41	22.56
3	2.8	16.07	1.80	25.71
4	2.9	20.68	2.09	28.82
5	3.4	22.05	3.27	38.47
6	2.9	08.62	0.86	11.86
7	3.2	15.62	2.47	30.87
8	3.7	20.27	2.75	29.72
9	4.1	24.39	4.10	39.04
10	5.6	22.32	4.66	33.28

1. Jute Fiber Composites in Building and Infrastructure

The building industry is always looking for new and eco-friendly materials to keep up with the increasing demand while reducing harm to the

environment. Many common building materials depend on fossil fuels for making and delivering them, which causes a lot of carbon pollution. Jute, a natural fiber from the jute plant, is becoming more popular for its possible uses in construction and infrastructure. This strong, affordable, and eco-friendly fiber is being added to composite materials that can serve as a great substitute for regular building materials. This article looks into the various ways jute fiber composites can be used in construction and infrastructure, discussing their features, benefits, and the problems they may face. Jute fiber is a renewable resource that offers a hopeful option. Its natural qualities and ability to break down in the environment make it an appealing choice for making composite materials that can be used in different construction projects. Jute is often called the "golden fiber" of Bangladesh, and it is moving beyond its traditional use in textiles to become a key part of eco-friendly innovation in the construction field. As the need for green and budget-friendly building options increases worldwide, jute fiber composites provide a strong alternative to traditional materials like concrete, steel, and synthetic fibers (55). Their unique traits, such as being biodegradable, incredibly strong, and renewable, make them an important part of the future of sustainable building. The flexibility of jute, along with improvements in how composites are made, is creating new opportunities in architecture and infrastructure. From boosting the strength of buildings to producing light and long-lasting materials, jute fiber composites have the potential to solve important issues in the industry, like environmental effects, costs of materials, and safety for workers. This study looks into the many ways these natural fiber composites can be used, considering how they might change the way we build and take care of our structures. Some countries are already using jute composites in their building projects. For example, in India, scientists have created jute-reinforced concrete that shows promising strength and quality. Jute fiber composites are made by mixing jute fibers with other substances like resins or plastics. This mixture forms a light and strong material that can be used in many ways. Jute fiber composites are a great replacement for traditional building materials. Their eco-friendliness, strength, and affordability make them a smart option for the future of construction. Jute fiber composites are becoming more popular in the building industry as they not only help the environment but also bring many benefits over traditional materials. Even though there are few detailed studies available yet, some projects are looking into using jute composites in specific areas. For instance, researchers in India are studying the potential of jute fiber-reinforced concrete for building roads. These early projects offer useful information about the possibilities and challenges of using jute composites in real life (53). Figure 6 illustrates different applications of Jute Composite fiber for building and infrastructure.

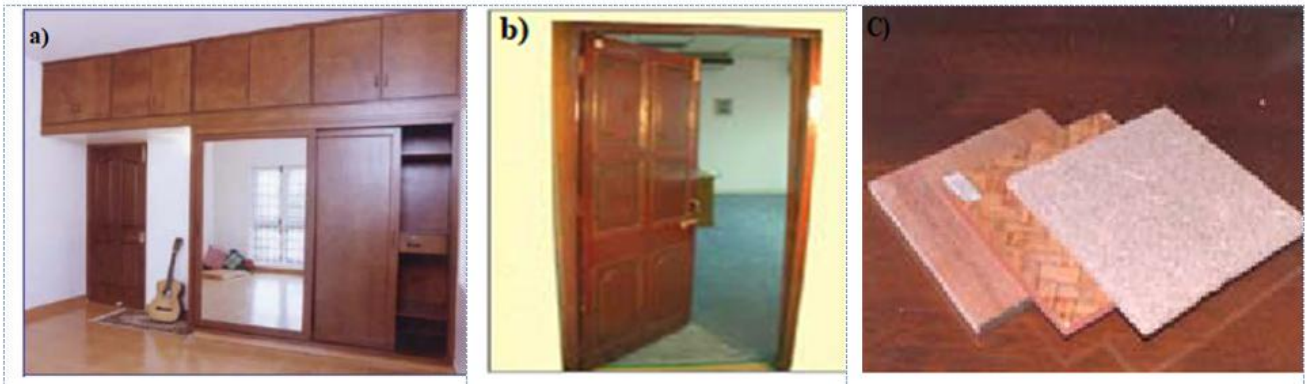


Figure 6 a) Jute-coir Composite Boards b) Jute composite door c) Jute composite particle board (56)

3.1. Jute fiber composites in construction

Jute composites aren't just used for buildings; they're also being used in big projects. They can help improve roads, prevent soil erosion, and create better utility systems. This shows that they have a lot of potential. The construction industry is at an important point, facing a lot of pressure to lower its impact on the environment while also trying to keep up with the needs of a growing world population. Traditional building materials often use a lot of energy and are not renewable, which results in a lot of carbon emissions and waste. Because of this, people are looking for new, sustainable options. Jute, which is a natural and biodegradable fiber that grows plentifully, is becoming a top choice for these new materials. Its special qualities, when made into composite materials, provide a great solution for building practices that are good for the environment and efficient. This article looks at how jute fiber composites can change the construction industry by discussing their benefits, uses, challenges, and what the future might hold (57). Jute is a flexible and renewable material, making it a great choice for creating new composite structures. Unlike synthetic fibers that come from petroleum products, jute is grown in many local areas, which helps the economy and reduces the emissions from transporting materials. Turning raw jute into parts that can be used in construction involves different technologies, but the main idea is the same: using the natural strength and flexibility of jute to make materials that are strong and good for the environment. Jute fiber composites are being used in many ways in construction, from insulation panels and roof tiles to structural pieces and decorative finishes. They have the potential to replace traditional materials like concrete, steel, and plastic, which are not as sustainable. As research continues, using jute-based materials is expected to be very important in shaping the future of eco-friendly building and sustainable infrastructure. The uses of jute fiber composites in building construction are many and include (51):

Wall Panels: Wall panels are versatile construction elements that can be designed for lightweight durability, making them ideal for both interior and exterior applications. They can be manufactured from various materials such as fiber cement, PVC, aluminum, or composite materials, providing options for different aesthetic and functional needs. These panels not only enhance the visual appeal of a space but also offer advantages like easy installation, maintenance, and improved insulation properties, contributing to energy efficiency and overall sustainability in building design. Figure 7 illustrates the Jute Fiber Panel Antimold Jute Fiber Panel Composite Plate Fiber Formaldehyde-Free Decorative Wall Panel. Wall panels crafted from jute fiber offer an eco-friendly and sustainable interior design solution, combining natural aesthetics with durability and sound insulation properties. Jute, a biodegradable and renewable material, provides a textured, rustic appearance that enhances interior spaces with a warm, organic feel. These panels are lightweight, easy to install, and can be treated or finished to improve moisture resistance and longevity. Ideal for environmentally conscious projects, jute fiber wall panels also contribute to improve indoor air quality by reducing airborne pollutants, making them a popular choice for modern, sustainable architecture.

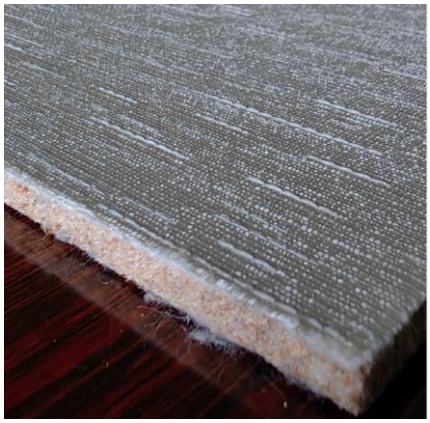


Figure 7 Jute Fiber Panel Antimold Jute Fiber Panel Composite Plate Fiber Formaldehyde-Free Dcorative Wall Panel.

- **Roofing Materials**: Jute composites are increasingly being explored for roofing materials due to their eco-friendly, biodegradable, and cost-effective properties, offering good insulation and structural strength. Their use in roofing systems can improve thermal performance, reduce environmental impact, and provide a sustainable alternative to traditional materials like asphalt shingles or concrete, especially in applications where lightweight and insulation are priorities. However, considerations such as moisture resistance, durability, and long-term performance need to be addressed through proper treatment and manufacturing processes to ensure their viability in roofing applications.
- **Flooring**: Flooring materials such as hardwood, laminate, vinyl, and tile are popular choices for their durability and aesthetic appeal, providing versatile options to suit various design styles and functional needs. These materials can enhance the visual appeal of a space while offering robustness against wear and tear, making them suitable for residential, commercial, and industrial applications.
- **Reinforcement**: Reinforcing concrete with jute fibers enhances its tensile strength and crack resistance by improving the material's toughness and flexibility, leading to more durable and resilient structures, especially in environments prone to cracking or stress.
- **Exterior Cladding:** Jute composites as exterior cladding materials offer a sustainable and aesthetically pleasing alternative, combining natural appeal with functional benefits like improved insulation and lightweight installation, which can reduce labor and structural support costs, making them an eco-friendly choice for modern building designs.
- **Roofing Materials:** Jute fiber composites present a promising sustainable alternative for roofing materials, leveraging their biodegradability, strength, and cost-effectiveness to reduce environmental impact compared to traditional roofing options. Their integration can enhance the durability and insulation properties of roofing systems while promoting eco-friendly construction practices.
- **Internal Wall Panels:** Jute fiber composites are a sustainable and eco-friendly material option for internal wall panels, offering benefits such as improved sound insulation and thermal performance due to their natural fibrous structure, which helps in reducing noise transmission and maintaining indoor temperature stability. Their biodegradability and low environmental impact make them an attractive choice for eco-conscious construction projects, while their durability and ease of processing can contribute to cost-effective and aesthetically versatile interior solutions.
- **Formwork:** Jute fiber reinforced composites present a sustainable and cost-effective alternative for formwork materials in concrete construction, leveraging their biodegradability, lightweight nature, and mechanical strength to reduce environmental impact and construction costs while maintaining structural integrity.
- **Structural Elements:** Jute fiber composites can be employed in load-bearing structural components, but their suitability hinges on factors such as the composite's mechanical properties, environmental conditions, and specific design requirements. While they offer advantages like biodegradability and cost-effectiveness, their relatively lower strength and durability compared to synthetic composites may limit their use to applications with moderate load demands or where sustainability is prioritized. Proper assessment and testing are essential to ensure safety and performance in structural applications.

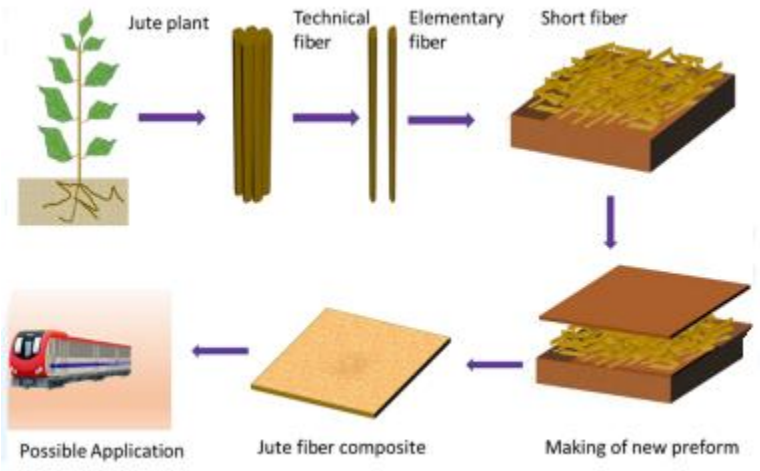


Figure 8 Jute Fiber composite and their Possible Applications (58)

3.2 Jute Fiber Composite Applications in Infrastructure Development

Jute is a natural fiber that comes from the jute plant, and it is famous for being biodegradable. This is really important today because pollution and waste problems are major issues. The construction industry is changing a lot because it needs to focus more on sustainable building practices. One of the new ideas being looked at is using jute fiber composites. These materials are not only affordable and light but also good for the environment. They are becoming popular substitutes for regular building materials in different construction projects. There is a growing need for eco-friendly options, and industries are looking for materials that work well and are less harmful to the environment. Jute fiber composites are a great match for this need. They are created by mixing jute fibers with different substances, resulting in a strong and long-lasting material that has a smaller negative impact on nature compared to common materials like steel or concrete. One of the best uses for jute fiber composites is making railway sleepers. These have traditionally been made from wood or concrete, but jute composites provide a green alternative. They are very strong for their weight, which helps support heavy trains without making the railway too heavy overall. They also resist water and decay, which are common problems with traditional materials. By using jute fiber composites for railway sleepers, companies can rely less on non-renewable resources and help create more eco-friendly railway systems (59).

Jute composites are being looked at more often for building bridges. Bridges have special needs because they have to deal with bad weather and heavy traffic all the time. Jute fiber composites are very strong and can handle stress, which makes them great for parts of bridges like the flooring. Because they are light, they are easier to transport and set up, and they reduce the need for heavy machines, which further lessens the environmental impact during construction. Road barriers are another place where jute fiber composites can work well. Regular safety barriers, like those made from concrete or metal, can be heavy and complicated to install or maintain. Jute fiber composites can be designed to be strong yet much lighter. This makes them easier to handle and set up, which also lowers shipping costs. Plus, since jute is biodegradable, if a barrier gets old or damaged, it can break down naturally, which helps decrease waste in landfills. The move towards using jute fiber composites in building infrastructure shows a larger goal of encouraging environmentally friendly methods in civil engineering. By stepping away from usual materials, the construction industry is not just meeting current needs but is also setting up a path for a better future (60). Because jute fiber composites are affordable, strong, and good for the environment, they show how new ideas can change the way we build things. Jute fiber composites are becoming a game-changer in the building industry, especially for infrastructure development. Their adaptability and eco-friendliness match the industry's move toward responsible practices. As more studies and innovations happen, these materials are expected to become even more

important in creating a greener, more sustainable future. Besides regular building, there is a growing interest in using jute fiber composites for infrastructure because they are good for the environment, inexpensive, and light. This makes them perfect for things like railroad ties, bridges, and road barriers. Their ability to break down naturally and their strong qualities provide eco-friendly solutions, cutting down on the use of traditional materials like steel and concrete, and supporting green practices in civil engineering projects (61).

- **Road Construction:** Incorporating jute fiber reinforcement into road construction materials offers a promising solution to improve strength and durability, especially in regions with heavy traffic or seismic activity, by enhancing the structural integrity and lifespan of roads.
- **Bridge Construction:** Jute fiber composites are currently in the research and development phase as potential materials for bridge construction, including decks and structural components, due to their biodegradable, lightweight, and sustainable properties, which could offer an eco-friendly alternative to traditional materials.
- **Railway Track Reinforcement:** The investigation into using jute fiber composites for railway track reinforcement offers a sustainable and cost-effective solution to enhance track stability and minimize maintenance expenses. Jute fibers, being biodegradable, lightweight, and strong, can improve the mechanical properties of reinforcement materials, potentially leading to better load distribution and resistance to wear and tear. Incorporating such eco-friendly composites aligns with environmental sustainability goals while providing durable support for railway infrastructure. Continued research and testing are essential to optimize the composite formulations and ensure their long-term performance under real-world railway conditions.
- **Sewer Pipes:** Jute composites present a promising sustainable alternative for sewer pipes, especially in regions with limited access to synthetic materials, due to their biodegradability, low environmental impact, and potential for cost-effectiveness. Their natural fiber composition can enhance the durability and strength required for sewer infrastructure while reducing reliance on non-renewable resources, contributing to eco-friendly urban development. However, further research into their long-term performance, resistance to chemical corrosion, and suitability for various soil conditions is essential to ensure their viability as a practical replacement for conventional sewer pipes.

3.3 Jute Composite in Reinforced Concrete (JRC)

Jute fiber composites are not just for decoration. They are showing how useful they are in making buildings tougher and longer-lasting. These materials can hold heavy weights and make places safer. Jute composites are getting more attention in construction because they break down naturally, are cheap, and have great strength, making them a green choice compared to regular synthetic composites. These eco-friendly materials mix jute fibers with plastic materials like epoxy, polyester, or thermoplastics, giving them good strength and resistance to damage. They are used in different areas like car parts, building materials, and furniture, where it's important to be environmentally friendly and save money. Research is ongoing to improve their strength, ability to resist moisture, and how well they stick together, so they can be used in tougher construction situations. Concrete is a common material widely used in building because it is strong and lasts a long time. However, concrete can easily break, which causes problems when it faces different types of stress that can lead to cracks or failures. To solve this problem, new ways to strengthen concrete are being looked into more these days. One of these methods involves adding natural fibers, especially jute. This article talks about Jute Composite in Reinforced Concrete (JCRC), its advantages, and how it can be used in modern buildings. Jute fibers come from the jute plant and are known for being strong and able to break down naturally, making them a good choice for improving traditional concrete mixes. When you add jute fibers to concrete, you get Jute Reinforced Concrete (JRC) (62).

Figure 9 A cross-section of a concrete structure reinforced with Fiber Reinforced Polymer (FRP) rebar

Table 5 Determining various parameters of jute fiber reinforced cementitious composites (63).

This mix not only makes concrete stronger but also helps the environment by using a resource that can be renewed. One big benefit of JRC is that it helps stop cracks from spreading. Regular concrete can form tiny cracks when under pressure, which can grow and cause big structural problems. Jute fibers add strength to the concrete mix, helping keep those small cracks from getting worse. This is important for keeping buildings strong, especially in places that feel earthquakes or have a lot of traffic. Another important feature of JRC is its flexibility. Regular concrete is very stiff, which can be a disadvantage in some situations where flexibility is needed. When jute fibers are used, the concrete becomes more flexible and ductile. This means it can absorb and spread energy better during events like earthquakes or heavy loads. The better flexibility of JRC makes it a good choice for many construction projects, including houses and bridges. Sustainability is becoming a key concern in the construction world. Jute, being a natural fiber that can be grown again, helps lower the carbon emissions linked with making normal concrete. Using JRC allows builders to take advantage of environmental gains by using biodegradable materials in their work. Plus, by using leftover agricultural materials like jute it helps support local farmers and encourages environmentally friendly methods (64). We can't ignore how cost-effective JRC is. Jute is much cheaper than synthetic fibers, making it a budget-friendly option for improving concrete. This low cost, along with its many advantages, makes JRC a smart choice for construction companies looking to boost performance while staying within their budgets. JCRC can be used for more than just traditional building materials. Its special features make it good for various construction projects, such as sidewalks, precast parts, and structures meant to hold water. The flexibility of JRC also means it's a good choice for upgrading old buildings to make them stronger and last longer. Jute Composite in Reinforced Concrete (JCRC) marks an important step forward in construction materials. By adding jute fibers, concrete can be made to resist cracking, become more flexible, and support eco-friendly building methods. As the construction industry progresses, innovations like JRC will be vital for creating safer, tougher, and more environmentally friendly structures. Choosing options like this not only makes our buildings stronger but also helps create a sustainable future. Mixing jute fibers into concrete to make Jute Reinforced Concrete (JRC) boosts its performance by making it more resistant to cracks and more flexible, leading to buildings that last longer and are more reliable. This green reinforcement lowers the chances of cracks while offering a better choice than synthetic fibers, promoting eco-friendly construction methods. Adding jute fibers can enhance the durability and safety of concrete buildings, especially in areas that often experience cracking or earthquakes (65).

S/N	Raw material	Mix proportion	Studied properties	Strength increment
1	Cement, Sand, Water, Aggregate and Jute fiber.	1:1.56:3.02, w/c ratio 0.35, 0.45 & 0.55.volume content 0.2, 0.6, & 1.2%.	C-S and S-T-S	C-S = Increase 35.1 N/mm^2 with 0.2% fiber content & w/c ratio 0.55. S-T-S = Increase 3.5 N/mm^2 with 0.2% fiber content & w/c ratio 0.55.
2	Cement, Sand, Water, Aggregate and Jute fiber	1:1.24:3.45 w/c ratio 0.48. volume content 0.1, 0.25 & 0.5%.	C-S and S-T-S	C-S = Increased by 22.51, 29.56 & 26.15% with 0.25% fiber content.S-T-S = Increased by 14.09, 26.23 & 25.48% with 0.25% fiber content.
3	Cement, Sand, Water, Aggregate, and Jute fiber	1:1.5:3 w/c ratio 0.5. Weight content = 0.50%.	F-S	F-S = Increase by 50% with 0.50% fiber content.
4	Cement, Sand, Water, Aggregate and Jute fiber	M25, 1:1:2 w/c ratio 0.32%, volume content 0.5, 1.0 & 1.5%.	C-S	C-S = Enhanced with 0.5% fiber content.
5	Cement, Sand, Water, Aggregate and Jute fiber	1:1.41:2.38 w/c ratio 0.45. Weight content 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6 & 1.8%.	C-S	C-S = Increased 8.8 N/mm^2 & 44.44 N/mm^2 with 0.4% fiber content.
6	Cement, Sand, Water, Brick chips and Jute fiber	1:1.5:3 & 1:2:4 w/c ratio 0.55 & 0.60.volume content 0, 0.1, 0.25, 0.50 & 0.75%.	C-S, F-S, and S-T-S	C-S (1:1.5:3 w/c ratio 0.55) = Increase 15%. C-S (1:2:4 w/c ratio 0.60) = Increase 10%. F-S (1:1.5:3 w/c ratio 0.55) = Increase 22%. F-S (1:2:4 w/c ratio 0.60) = Increase 14%. S-T-S (1:1.5:3 w/c ratio 0.55) = Increase 35%. With 0.10% fiber content.
7	Cement, Sand, Water, Aggregate and Jute fiber	M20 1:1.95:3 w/c ratio 0.50 & M25 1:1.9:3.3 w/c ratio 0.4. volume content 0, 0.75, 1.5 & 2.25%.	C-S	C-S = Enhanced with 0.75 & 1.5% fiber content.
8	Cement, Sand, Water, Aggregate and Jute fiber	1:1.5:3 w/c ratio 0.45,volume content 0.5%, 1.0, 1.5 & 2%.	C-S and S-T-S	C-S & S-T-S = Enhanced gradually with % of fiber content increased.
9	Cement, Sand, Water, Aggregate and Jute fiber	1:1.5:3 w/c ratio 0.55,volume content 0.2, 0.3, & 0.4%.	C-S and Ultrasonic-pulse velocity (U-P-V)	C-S = Increased with 0.2% fiber content.U-P-V = Enhanced with 0.4% fiber content.
10	Cement, Sand, Water, Aggregate, coconut fiber, and Jute fiber	M20 1:1.5:3 w/c ratio 0.5. Weight content 0. 5, 1, 1.5 & 2%,	C-S and F-S	F-S = Increased by 40 & 26% with 0.5 & 1% fiber content.
11	Cement, Sand, Water, Aggregate, and Jute fiber	M20 1:1.5:3 w/c ratio 0.5. Weight content 0.5, 1.0 & 2%.	C-S, F-S, and S-T-S	C-S = Increased by 4.93%. F-S = Increased by 9.43%. S-T-S = Increased by 6.23%.
12	Cement, Sand, Water, Brick chips, and Jute yarn	1:1.5:3 w/c ratio 0.55.volume content 0, 0.10, 0.25, 0.50 & 0.75%.	C-S, F-S and S-T-S	C-S (1:1.5:3 w/c ratio 0.55) = Increased by 33% with 0.10% yarn content.F-S (1:1.5:3 w/c ratio 0.55) = Increased by 23% with 0.10% yarn content.S-T-S (1:1.5:3 w/c ratio 0.55), (1:2:4 w/c ratio 0.55) = Increased by 38% with 0.1 & 0.25% yarn content.
13	Cement, Sand, Water, Aggregate, and Jute fiber	1:1.5:3 w/c ratio 0.55,weight content mixing amount of 0.5–0.6 kg/m^3	C-S and F-S	C-S = Increased by 20.44%. F-S = Increased by 53.47%. With 30 mm fiber length, 0.5–0.6 kg/m^3 fiber content.

As shown in the Figure 10, diverse past considers were carried out to guarantee the application of jute fiber composite for the reinforcement of concrete. These things about approving that Concrete with jute fiber is a significant step towards the economic improvement in Bangladesh, where jute is widely developed. Within the experimental examinations conducted within the consideration, it was found that the expansion of jute fiber contributes to improved comes about for mechanical properties of concrete composites for a specific length and amount of fiber. More particularly, compressive, flexural, and malleable qualities are found to upgrade essentially for volume substance of 0.1 and 0.25 % and the fiber cut length of 10 and 15 mm. In any case, with bigger fiber length and substance, the mechanical properties were found to influence antagonistically. At last, it can be expressed that the

most extreme increase is observed for pliable quality, which is 35 % with reference to the plain concrete. So JFRCC can be created with locally manufactured jute in Bangladesh. The slightest taken a toll on jute, it being a renewable asset, the diminished weight of the JFRCC, and the natural compatibility would clearly demonstrate the financial reasonability of JFRCC. Based on the bits of knowledge picked up from the test comes about and examinations of the JFRCC, the joining of jute fiber in making FRC composite would be one of the promising procedures to improve the execution of concrete (66).

Figure 10 Jute fiber reinforced Composite concrete specimen after compression failure (66).

3.4 Jute Composites in Load-Bearing Components

Advanced methods are making jute materials strong enough to be used in crucial parts of buildings. They can now support heavy weights. These techniques help transform jute into dependable building materials. As the construction field changes, finding materials that are light, strong, and good for the environment is becoming really important. Jute composites are one of the exciting options that are coming up in this search. Jute has usually been known for making fabrics, but now it is being recognized as a good material for carrying weight in buildings, thanks to new manufacturing techniques that strengthen it. Jute, often called the "golden fiber," is a natural and eco-friendly material that comes from the jute plant. It has great environmental advantages; it can be renewed, needs very few chemicals to grow, and it can capture carbon dioxide while it is growing. However, the real innovation comes from making jute composites that can hold up a lot of weight, which makes them a great choice for many building uses. Recent improvements in composite technology have allowed scientists and engineers to change jute fibers by combining them with other materials to create composites that are both strong and lightweight. Techniques like treating the fibers, adding resin, and using mixed materials are helping jute be used in load-bearing situations. These new methods not only make jute stronger but also help it resist water and weather damage, which makes it last longer and be more reliable for building. A big advantage of jute composites is that they can be changed to fit specific needs (63). This means architects and designers can adjust the material's features to meet various building requirements, which is key for anything that has to support weight. For example, jute composites can be made to improve flexibility, so they can be used for beams, columns, and floors in buildings. Using jute composites in construction fits well with the increasing need for eco-friendly building materials. As cities grow and the effects of climate change become clearer, there is a strong need for alternatives to traditional concrete and steel. Jute composites offer a way to reduce carbon emissions, which supports green building projects and certifications. Research from different countries has shown that jute composites can be used in real-life situations. Test projects have successfully shown that they can handle the stresses of weight-bearing parts in homes and businesses. As more studies confirm how well they work, the construction industry might begin to use jute composites more regularly in building. The demand for jute composites is predicted to keep rising as more people learn about eco-friendly materials. Construction companies, seeking new methods to lessen their impact on the environment while

keeping buildings strong, will likely start using jute composites. They are not just effective but also look good. The natural look and feel of jute can give buildings a special charm, aligning with the modern trend of using materials from nature. Jute composites show a breakthrough in construction materials. With continued research and improvements to their features, jute composites are set to become common in making strong building parts. This change not only supports eco-friendliness but also changes what can be done in today's architecture, hinting at a future where natural beauty and strong innovation work hand in hand (67).

1. Non-Structural and Aesthetic Applications of Jute Composites

Jute, which is often called the "golden fiber," is a popular material used in many industries because it is good for the environment, strong, and flexible. While many talks about jute composites highlight their strength, it is also important to look at how they can be used for things that are not structural and their visual appeal. These aspects of jute composites bring important advantages in terms of design and usability, making indoor and outdoor areas more beautiful while showcasing the natural appeal of the fiber. One of the coolest things about jute composites is how they can change plain spaces into attractive places. Designers and architects have started to include jute as an important part of creating beautiful products like wall panels, furniture, and decorations. The rich texture and natural colors of jute can add warmth and a natural feel to both homes and businesses. By using jute composites, designers can create a special atmosphere that reflects sustainability and nature. In interior design, jute composites are being used in many different ways. Jute fiber wall coverings not only help insulate but also act as bold features that add depth and personality to rooms. This use is especially popular in areas that want a rustic or bohemian look. Also, furniture made from jute, like chairs or tables, can bring an earthy vibe to a room while still being practical and strong. This furniture usually highlights the natural patterns in jute, making it a standout element in modern design. Outside, jute composites are also becoming popular in landscaping and outdoor design. Furniture made from jute can fit in perfectly with natural surroundings and encourage a lifestyle that cares for the environment. Jute can also be used to make outdoor decorations like planters, rugs, and hammocks, creating a connected outdoor living area that focuses on sustainability. These decorative items add a touch of natural elegance to porches, patios, and gardens while ensuring they are environmentally friendly. Another major benefit of jute composites is how well they perform in different weather conditions. Jute resists moisture and decay, making it a great option for outdoor use, ensuring it lasts even in tough environments. This strength makes it perfect for decorative items that need to last a long time. When treated with eco-friendly coatings, jute composites can hold up against rain and sunlight without losing their appeal (59).

Jute composites are very flexible, which allows for creative design ideas that fit different styles and tastes. No matter if the design is classic, contemporary, or a mix of styles, jute can work with many design styles, making it popular with builders and creatives. Its ability to combine well with materials like wood, metal, and clay leads to unique pieces that can create exciting differences and visual interest. The way jute composites can be used for both looks and function shows how adaptable this material is and how it can improve the look and usefulness of spaces. By adding jute to design features, we can appreciate the beauty of this natural fiber while supporting eco-friendly practices. As more architects and designers start to use jute, we can look forward to seeing more and more creative items that will enrich our environment, both inside our homes and outside (68).

4.1. Jute Composites for Interior Design and Fit-outs

Using jute composites in buildings adds a natural beauty and great performance. They can make any room feel welcoming. Since they are light, they are also easy to handle. As the world of design keeps changing, there is a growing need for new materials that look good and work well. One material that is becoming popular in interior design is jute composites. These are made from the natural fibers of the jute plant and combine traditional elegance with modern flexibility, making them a great choice for today’s interiors. One amazing thing about jute composites is how beautiful they are. The natural fibers have a warm, earthy color that brings comfort and texture to any space. This feature helps designers use jute composites easily in different styles, whether they are rustic, modern, or simple. Using jute composites can create a cozy and inviting vibe in both homes and businesses. Besides

looking good, jute composites have impressive strength and durability. They can be used for many different things, like wall panels or flooring. Unlike man-made materials, jute composites are also better for the environment, providing a sustainable option that lowers a building's carbon footprint. Jute composites can be used in many ways inside a space. Their lightweight makes them very easy to manage and install, which is important during renovations (56). As shown in the Figure 11, they can be made into feature walls, sound-absorbing panels, or furniture details, offering designers a lot of creative options. In places like offices, shops, and restaurants, jute composites enhance both look and the overall feel of the space. Furniture made from jute composites can reflect a brand's style, while decorative pieces can make stark industrial settings more inviting for customers. Recently, more people have realized how indoor air quality affects health and comfort. Because jute composites are natural materials, they can help with this problem. Unlike many synthetic options, jute composites usually don't contain harmful chemicals, which means they have a lower risk of releasing unwanted gases and can improve the indoor atmosphere. They also have great sound-absorbing properties, making spaces quieter and more pleasant. The movement towards more sustainable practices in interior design is changing how we choose materials. Jute is a fast-growing resource that doesn't need many chemicals and can break down naturally. When designers use jute composites, they not only add a natural charm to their work but also make decisions that are good for the environment. This thoughtful choice helps achieve the broader aim of building sustainable spaces that can help future generations. Using jute composites in interior design provides many options that combine beauty, practicality, and eco-friendliness. These flexible materials can change rooms, making them both more welcoming and better for the planet. As more people learn about sustainable design, jute composites become an excellent option for anyone wanting to enjoy natural beauty while ensuring good performance and health advantages in their designs. Whether you are updating homes or modernizing businesses, think about how jute composites can enhance your spaces (69).

Figure 11 (a) Jute composite door; (b) Jute composite furniture; (c) Bamboo-jute composite door (53)

4.2 Jute Composites in Architectural Facades and Cladding

Jute composites can be used to make buildings look nicer on the outside. They give a fresh and natural vibe to walls and coverings. These materials are not just attractive; they also help protect buildings. As being eco-friendly becomes more important in today's building designs, jute composites have started to be seen as a great option for building walls and coverings. These creative materials make structures look better and have several benefits that fit with greener building plans. Since there is a growing focus on lowering carbon emissions, jute composites offer a great natural option compared to regular building materials. Jute is a strong and long-lasting natural fiber that is now being made into composite materials that are great for construction. When used in walls and coverings, jute composites bring a unique style that mixes rustic and modern looks. The fibers are often mixed with eco-friendly resins, which lets designers create everything from natural textures to bright colors. This flexibility means jute composites can match different architectural styles, making them a perfect choice for both modern and traditional buildings. One of the biggest benefits of jute composites is that they are sustainable. Jute can be grown again and again, and it needs very few chemicals to grow, making it a green choice. Making jute composites has a smaller environmental footprint than common materials like plastic or metal. By using jute composites for building walls, architects and

builders can support eco-friendly construction practices and lessen the harm to the environment. Besides looking good, jute composites are made to last. If treated well, they can withstand weather changes, pests, and mold, so walls and coverings stay in good shape over time. This strength helps protect buildings from bad weather and cuts down on the costs of maintenance (70). By blocking moisture and temperature changes, jute composites help make a building last longer—a key factor in today's fast-paced construction world. Jute composites also provide great insulation. Their natural fibers are good at reducing noise, which is helpful in busy cities. This is becoming more important as urban areas get more crowded and noisy, creating a need for materials that help keep indoor spaces calm. Also, jute composites help keep buildings warm or cool inside, improving energy efficiency. Buildings with jute coverings can lower their heating and cooling costs, which fits well with the worldwide move toward more sustainable building methods. As the building industry looks for new ideas that mix style, usefulness, and being eco-friendly, jute composites stand out as an excellent option for building walls and coverings. They bring a fresh, natural style that can enhance the look of any building while also offering protection and durability. Using jute composites in building design helps create a better future that cares about the environment. More and more projects are starting to use these materials, showing that jute composites are not simply a fad but a strong, practical, and smart choice for modern construction. When architects and builders choose these natural materials, they create a space that values both new ideas and taking care of our planet (71). **Figure 12** shows Jute Fiber Composites - First Class Material, Moisture Proof & Environmentally Friendly | Ideal for Outdoor Usage.

Figure 12 Jute Fiber Composites **(**https://www.tradeindia.com/products/7-mm-afc-jute-fiber-flat-sheet-cladding-c7574224.html**)**

4.3 Jute Composites in Geotechnical Engineering

In places where the ground needs support, jute composites are proving to be very helpful. They are great at making the soil stronger and preventing it from washing away. This is superb for the health of the land. Recently, people have been paying more attention to using jute composites in geotechnical engineering. This new method takes advantage of jute's natural traits, as it is a biodegradable and eco-friendly fiber, to improve soil stability and reduce erosion in different areas. With rising worries about using the environment wisely and taking care of land, jute composites are becoming a smart option to improve soil health and aid building projects. Soil erosion is a big issue in many places, especially where there is a lot of rain, flooding, or activities that weaken the land. When soil washes away, it not only makes farming harder but also risks the safety of buildings that are on or close to weak areas. Here's where jute composites shine; their natural fiber structure effectively strengthens the soil, making it tougher while lowering the chances of erosion. Jute fibers are tough, flexible, and very good at soaking up moisture, allowing them to stick well to soil particles. When jute is mixed into the soil, it forms a composite material that improves the soil's physical properties. This mixture boosts the soil's strength and ability to resist sliding, making it better able to handle both natural events and human

activity. Research in the field has shown that using jute composites can greatly better soil stability, especially for embankments, retaining walls, and slopes (72).

Jute composites act as effective geotextiles, which are fabrics that let water pass through while helping to stabilize soil and prevent erosion. These geotextiles can be used in various projects, like road building, drainage systems, and reclaiming land. By using jute geotextiles, designers can take a more eco-friendly approach to managing soil and stopping erosion. One of the biggest advantages of jute composites is that they are good for the environment. Unlike man-made materials, which can take hundreds of years to break down and may release harmful chemicals into the soil, jute is a natural resource that degrades easily. When jute composites are used to strengthen the soil, they help create a healthier environment by cutting down on plastic waste and encouraging sustainable methods in building and land care. Also, growing jute helps local economies and creates jobs, especially in developing areas, which benefits both communities and nature (73).

Jute composites can be mixed with other materials to improve their features. For example, when jute fibers are combined with natural plastics or other materials that break down easily, the result is composites that work better for specific engineering tasks related to soil. This ability to adapt lets engineers create solutions that address the specific problems that different types of soil and environments present. Using jute composites in geotechnical engineering has many benefits for the health and stability of soil. These natural fibers not only help prevent erosion and soil damage but also support important sustainability efforts in today's engineering. As more people look for environmentally friendly building methods, jute composites become a strong option, helping with land management and protecting the environment. The future of keeping soil stable is closely linked with new, sustainable materials like jute, which can help create healthier ecosystems and stronger structures (74).

Figure 13 Jute fiber for soil conservation(https://gabionindia.com/products/gti-jute-geotextile)

4.5 Jute Composites for Utilities and Transportation

Beyond just using soil, jute composites are now being used in pipes, roads, and train tracks. They are light and do not rust, making them great for these purposes. This helps create more environmentally friendly public services. As more people want sustainable materials, jute composites are becoming a ground breaking option in different fields, especially in utilities and transportation. Because they are light and resistant to damage from the environment, jute composites are changing how we build our infrastructure. Jute was once mainly considered a natural fiber for textiles, but it is now expanding into new areas. The need for greener choices instead of regular materials, which often produce high carbon footprints, has made it possible for jute composites to be important in today's construction projects. From pipes used in public services to roads and train tracks, jute composites are proving to be a major improvement. One of the

greatest benefits of jute composites is that they are very light. This feature helps lower transportation costs and decreases the energy needed during the building steps of projects. For industries that depend on moving goods and heavy machines, using lighter materials can save a lot of money, making jute composites both a green option and a budget-friendly choice (75).

Jute composites resist rust and corrosion really well. This makes them particularly good for water-related projects and drainage systems. In areas where traditional materials like metal and concrete might break down over time due to moisture, jute composites last longer and are durable. This strength means less money spent on maintenance and fewer replacements needed, which is great for cities trying to save money and for contractors who care about the environment. When it comes to roads, jute composites are being added to asphalt to improve how it performs. Adding jute fibers helps create a stronger and more flexible surface that can handle different weather conditions and traffic. Plus, using jute fibers helps reduce the carbon footprint of road building because these natural fibers can replace some of the usual materials made from petroleum. On the environmental side, the advantages of jute composites are even clearer. Using plant-based materials lessens the need for fossil fuels and reduces the carbon emissions that come from regular building methods. As cities work toward their sustainability goals, jute composites are a smart way to support green initiatives. They can break down and return to the earth without leaving harmful waste, which aligns with the ideas of eco-friendly construction (76). The increasing use of jute composites in transportation and public services shows that leaders in different industries are changing how they choose materials. With discussions about climate change and being eco-friendly picking up speed, materials that support these important issues are becoming increasingly important. Using jute fibers helps meet sustainability targets and encourages creative ideas for building structures that work well and are good for the environment. Jute composites in public services and transportation is a positive change for creating more environmentally friendly services. These composites are light, strong, and can resist damage from weather, which helps in building a more sustainable future. The chances for these materials to change infrastructure are huge, and as the industry starts to use this new approach, we can expect more uses to show up in the next few years. Using jute composites is not just a fad; it's a move towards creating a better world for those who come after us (77).

4.6 Jute Composites for the Automotive Industry

In the automotive sector, natural fiber (jute) composites are widely employed in a variety of applications, including headliners, carpets, door pads, insulation, and molded door skins. Because of its many adaptable qualities, such as their high strength, shape, mass, stiffness, durability, flexibility, low cost, strength-to-weight ratio, and ease of structure creation, hybrid composite materials find extensive use. Composites and hybrid materials are used in numerous exterior and interior applications in the automotive industry. One type of non-woven jute fiber composite is jute mat. A mat that may be molded into imaginative designs, like a car door panel, is produced throughout the production process. When creating items that need the qualities of wood, manufacturers may think about utilizing a composite mat made of jute fiber. But has a shape that is impossible to create using a typical wood product. Natural fiber composites are finding more and more uses as a cost-effective and environmentally friendly alternative to pricey synthetic fibers like carbon, aramid, glass, etc. To create "green" vehicle structural components, an LCA analysis of substituting jute fibers for glass fibers as reinforcement of composite materials was conducted. Regarding the composite materials used to create an off-road vehicles (buggy) structural frontal bonnet, the buggy case study showed that jute fiber composite offers the best option for improving the enclosures' environmental performance, which in turn improves the vehicle's overall environmental performance (53). The items that are manufactured from jute composite materials are displayed in the Figure 14.

Figure 14 (a) Car headlining; (b) Seat cover; (c) Carpet padding; (d) Car pane (53)

4,7 Jute Composites for Ship and Fishing Boats

Jute composites are emerging as a sustainable and cost-effective material option for ship and fishing boat construction due to their biodegradability, lightweight properties, and good mechanical strength. Incorporating jute fibers into polymer matrices enhances the structural integrity while reducing the overall weight, leading to improved fuel efficiency and lower emissions. These composites also offer advantages such as resistance to corrosion, ease of manufacturing, and environmental benefits, making them a promising alternative to traditional materials like fiberglass and steel in maritime applications. However, challenges such as moisture absorption and long-term durability need to be addressed through advanced treatment techniques and composite design optimization. As a single or hybrid fiber, jute has shown promise as a reinforcing material for environmentally friendly and sustainable applications. The marine industry now uses laminated fiber-reinforced composite materials extensively; these materials are used in the construction of fast ferries, coast guard and naval patrol boats, fishing and work boats, pleasure boats, racing yachts, and offshore oil and gas. This is because composite materials offer numerous benefits over steel, aluminum, or wood, including high specific material qualities, flexural strength, and impact resistance, resistance to corrosion and rot, and ease of manufacturing intricate seamless shapes. In comparison to other lignocellulosic fibers used in shipbuilding, jute fiber reinforced composite is one of the more interesting natural fibers since it has a high impact strength in addition to moderate tensile and flexural capabilities. Unlike the wooden ones, they are not severely damaged. In contrast to wooden boats, which only endure three years, composite boats last twelve to fifteen years. The jute composite boats are depicted in Figure 15. Most of them can be repaired and reused in the event of unanticipated disasters like tsunamis.The Acehnese traditional boat Jalo Kayoh, which is primarily made of wood, provides an overview of the structural strength of fiberglass and jute. Glass and jute fibers are more robust than wood. Even though glass fiber exhibits greater stress than jute and jute fiber exhibits better strain (53,56).

Figure 15 Jute Fiber Composite Boat (53,56)

1. Challenges and Future Prospects of Jute Composites

Jute composites, derived from the natural fibers of the jute plant, have gained significant attention in recent years as environmentally friendly alternatives to synthetic materials in various industries. Their lightweight, biodegradability, and excellent tensile strength make them appealing for applications ranging from construction to automotive manufacturing. However, despite their promising attributes, jute composites face several challenges that need to be addressed for them to reach their full potential. One main problem with jute composites is that they can easily get wet. Jute fibers soak up water, which can weaken their strength and cause problems like mold and breakdown over time. This is a big worry in building projects, where being strong and lasting is really important. Researchers and engineers are working hard to find ways to make jute composites better at resisting moisture. New ideas like treating the surface of jute and adding water-repellent materials are looking promising in solving this problem. Another major issue is that the quality of jute fibers can vary a lot (78). Things like where the jute is grown, how it is processed, and how it is stored can all change the quality, which affects how strong the composites are. Scientists are looking into how to create standard methods for growing and processing jute to make sure the quality is the same everywhere. This would help companies make more dependable and consistent composite materials. Processing jute fibers into composites also has its challenges. The usual manufacturing methods that work for synthetic materials might not work well with jute because it has different qualities. This often means that new ways to process jute fibers need to be developed. More partnerships between scientists who study materials and manufacturers are happening to tackle these issues and help jute composites fit into current production systems more easily. Even with these challenges, the future for jute composites looks very positive. There is a worldwide push for eco-friendly and sustainable materials, which is creating a good chance for jute products to grow. As people become more aware of how their choices affect the environment, there is likely to be a bigger demand for natural and biodegradable materials, making jute composites a good alternative to plastics and other synthetic options (79). New research is also leading to fresh uses for jute composites. Besides construction and cars, areas like packaging and consumer goods are starting to look into how jute composites can be useful. Because they are light and can break down naturally, they are a great choice for cutting down on plastic waste. As technology improves, it's becoming more possible to create high-performing jute composites that can compete with regular materials in a lot of different uses. Additionally, it is really important to make jute production and composite making more economically helpful. If jute farming becomes more profitable, farmers will likely want to use more sustainable farming methods, making the jute supply chain stronger. This connection between eco-friendly farming and advanced material science could help jute composites become more popular, making them a key part of the green materials movement. The challenges with jute composites are big, but ongoing research and new ideas in the field offer hopeful solutions (80). As society continues to focus on sustainability, jute composites are set to have a big positive effect across various industries, helping both the environment and the economy along the way. The need for green and eco-friendly materials in building has greatly increased lately, with jute composites becoming a key area of innovation. Jute is a type of natural fiber that comes from the jute plant. It can be recycled and comes with several benefits for both the environment and industries. As researchers dig deeper into what jute composites can do, promising discoveries are on the way that could change how we build and widen the use of these materials in many areas. A major focus in jute composites is looking into mixed materials called hybrid composites. Hybrid composites mix jute fibers with other natural or man-made fibers to create a material that takes advantage of jute's strength and lightness while adding more durability and flexibility from the other fibers. For example, when jute is combined with fibers like bamboo or hemp, the resulting composites can be stronger, making them perfect for use in building structures. Scientists are also looking at using bio-resins and adhesives with jute fibers. Regular resin systems often have harmful chemicals that can impact air quality inside buildings and hurt the environment. By using bio-resins from renewable sources, jute composites can still have similar strength without

harming the earth. This makes jute more appealing as a green building material and supports global goals to lessen the reliance on fossil fuels. Current studies are looking into how jute composites might be used in new technologies, like smart building materials (81). Smart jute composites can be made to react to changes in the environment and can provide real-time information about things like temperature, humidity, and the condition of structures. This advancement opens new possibilities in construction, where keeping track of a building's health is important for safety and durability. As more industries use the Internet of Things (IoT), adding sensors to jute composites could set new standards for smart building materials. Besides their use in construction, jute composites are also being examined for their potential in packaging and consumer goods. With growing worries about plastic waste, jute composites could be great biodegradable options for various items, from packaging to furniture. Their lightweight and strength make them appealing for manufacturers who want to cut down on their carbon emissions while keeping their products strong. Looking forward, several research paths will influence the future of jute composites. It's important to look into how to produce these composites at a scale that meets commercial needs. New innovations in manufacturing, like automation and eco-friendly practices, can help make jute composites easier to produce and available to industries around the world. Additionally, studying the whole lifecycle of jute composites will be vital in proving how sustainable they are, helping promote their use in different areas (82).

2. Overcoming Current Limitations

The building industry is changing a lot, with more focus on being sustainable and using materials that are good for the environment. One of the new options that is becoming popular is jute composites. But even with all their benefits, they haven't been widely used in construction yet because there are some challenges. It's important to solve these problems so that jute composites can be used in all buildings, helping us move toward a greener future. Jute, a natural fiber, is really flexible and useful. It breaks down easily in the environment and can be grown again quickly, making it a great choice for builders who care about the planet. Jute composites are made by mixing jute fibers with different resins. They have nice strength, which allows them to be used in various construction projects like panels, bricks, and insulation. However, we need to address current challenges to make them more reliable and a common option in the field. One main issue with jute composites is that they can easily get damaged by water and other environmental factors. While traditional materials like concrete and steel are very strong, jute composites need special treatment to be just as durable. Scientists and engineers are working hard to develop jute composites that can resist moisture and harmful UV rays. By using better coatings and bonding agents, companies are making these composites last longer, which is important for builders who want materials that will stand the test of time (83). Another big problem is that not all jute composite products are made equally. The quality can vary because of the differences in raw jute fibers, which depend on farming conditions. To fix this, the industry is looking into ways to standardize how these composites are made and the materials used. Setting clear quality standards will help ensure that the products are reliable and build confidence among builders and architects. Also, a lot of people in construction don't know much about jute composites yet. Many workers still stick with traditional materials because they think they are more reliable, even though jute technology has improved a lot. It's crucial to teach people in the industry about the benefits and uses of jute composites. Organizing workshops, seminars, and working with key people in the building field can help these materials be accepted more widely. As more people talk about sustainability and being eco-friendly, highlighting the benefits of jute composites will connect with those wanting to lessen their impact on the environment. Additionally, as technology moves forward, new ways to process jute composites are being tested to make them even better. Using nanotechnology and mixing jute with other eco-friendly materials might improve its strength and add features like fire resistance and better heat protection. If the construction industry invests in research, it can unlock new possibilities that will make jute composites not just a backup option, but a top choice for building (84).

3. Conclusion

Research on natural fiber-based composite materials has grown due to their attractive properties. Jute fiber composites are a low-cost, lightweight, eco-friendly, and biodegradable alternative to synthetic fibers. They are used in various sectors, including textiles, automotive, structures, aerospace, sports, medical, packaging materials, toys, and furniture.

Surface treatments and hybridization with other natural fibers have improved the mechanical strength and interfacial adhesion of these composites. The automotive and aerospace industries are the most active users of jute fiber-based composites, manufacturing non-structural and semi-structural parts. Further research is needed to improve the mechanical strength of jute fiber polymer composites and commercialize them.

Jute fiber composites are gaining popularity in the construction and infrastructure sectors due to their sustainability and strength. These materials are biodegradable and have a lower environmental impact, making them a viable alternative to traditional building components. They enhance mechanical properties, making them suitable for various applications, including reinforcement in concrete, insulation, and prefabricated structures. Jute fiber composites are a game-changer for building and infrastructure, offering strong performance, low cost, and clear environmental benefits. Despite challenges like standardization, resin compatibility, and cost competitiveness, ongoing research and development efforts are expected to address these issues. The world of jute composites is ripe with opportunities for innovation and advancement, with ongoing exploration in hybrid composites, bio-resins, smart technologies, and sustainable end-use applications. Collaboration across disciplines is key to unlocking the full potential of this remarkable natural resource.

Availability of Data

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicting interests

The author declare no potential conflicts of interest concerning this article's research, authorship, and/or publication

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