Advances in Jute Composite: A Comprehensive Review

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Abstract:

The vision for changing the climatic impact of synthetic products by civil society can be replaced by nature-giving products. Though as textile technicians, we know that the textile industry is the second-largest waste producer in the world. In the composite sector, synthetic fibres are gaining huge profits due to their high strength and durability. It is a challenge for us to develop natural fibre composite to replace synthetic for the sake of the environment and sustainability. And Jute fibre is the best among natural fibres which can replace synthetic fibres for composite preparation. In this field, more studies are going on to enhance jute fibre as a reinforcing material with high strength and durability in various applications. This article comprehensively overviews jute fibre, its composition, mechanical properties, surface treatment, composite preparation with various resins and fibres, and applications in different sectors.

Keywords: *Application, chemical treatment, composite, jute, matrix, processes*

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1. Introduction

When metals, ceramics, and polymers failed to meet certain performance criteria, the use of composites grew in favour. The previous several decades have seen a dramatic increase in the use of composite materials across many different fields, including aerospace, transportation, infrastructure, and consumer goods. High toughness, damage tolerance, structural integrity, and handling of the reinforced material were achieved by using composite materials to produce structural elements that could endure mechanical and thermal stress (multi-directional). Environmentally friendly materials have been developed as more people become aware of their advantages for the benefit of the ecosystem. Fibre-reinforced polymers (FRP) are composite materials with a polymer matrix and high-strength fibres like glass, aramid, or carbon from synthetic fibres [1] or maybe from natural fibres like jute, sisal, coir, hemp, kenaf, flax etc., Combining a polymer with a high-performance fibre like this results in superior mechanical qualities. Synthetic fibres including carbon, glass, and aramid are often employed in composites due to their high stiffness and strength properties [2]. Issues with biodegradability, initial processing expense, recycle-ability, energy consumption, machine abrasion, health risks, etc., have resulted from the widespread use of these fibres [3]. Due to various drawbacks of these synthetic fibres, researchers set their goal to change from synthetic to natural fibre to adverse environmental impact. Natural fibre composites have the potential to replace synthetic fibre-reinforced composites as a result of their reduced cost and enhanced sustainability. An alternative to the ever-depleted petroleum resources is natural fibre-reinforced composites and also it gains increasing attention from researchers to society. There are numbers of advantages that simply attracts acceptance by manufacturers and scientists. These attractive features are lightweight, inexpensive, friendly processing; biodegradable, environmentally friendly, and non-toxicity absorbing CO_2 during their growth [4]. High specific modulus, low density, relatively high processing flexibility, and strong strength are only some of these fibres' fascinating physical and mechanical features. Studies of composites over time have repeatedly demonstrated that natural fibres such as coir, kenaf, flax, jute, hemp, and sisal outperform their synthetic equivalents [5]. Natural fibres, such as bio-fibres made from renewable resources, also have positive environmental effects due to their biodegradability and resource efficiency [3]. Natural fibres meeting these performance standards for the composites industry will gradually replace synthetic fibres. They can be modified and are considered to be excellent materials for use in automobiles, construction, and furniture production [6].

The popularity of NFCs is on the rise for several reasons. One of these is their potential to replace synthetic fibre-reinforced plastics, which they can do at a cheaper price and with greater sustainability. After decades of technological advancement of synthetic materials like carbon, aramid, and glass [5, 7], natural fibres like kenaf, coir, flax, jute, hemp, and sisal are still popular materials for composite preparation. It is crucial to improve compatibility between the (hydrophobic-thermoplastic or hydrophilic-thermoset) matrix and the reinforcements when utilising hydrophilic cellulose-based natural fibres as reinforcements in composite technology [8].

The composite material may take the shape of fibres, particles, or flakes; nonetheless, it is the fibres that serve as reinforcement and provide the bulk of the composite's strength and stiffness. In contrast, the matrix safeguards the reinforcement against chemical and physical damage while still maintaining its orientation [9]. The matrices also ensure that a load is distributed uniformly over the reinforcing bars. In the beginning, textile-reinforced composites were exclusively produced from high-performance fibres or artificial fibres, but the high initial raw material and processing costs slowed their development [10]. Thus, natural fibres entered the market. Naturally occurring fibres were used because they improved properties such as flexural limit during splitting, durability, ductility, and break resistance over unreinforced matrices [11].

There are several reasons for jute to be considered as sustainable alternative to synthetic fibers in the preparation and application of composites. These are listed as:

Jute is a natural fiber that is biodegradable, which reduces environmental contamination and waste. In contrast to synthetic fibers, which are synthesized from petroleum-based materials that are not renewable, jute is a renewable resource [12]. The absorption of carbon dioxide by jute plants during growth is a contributing factor to carbon sequestration. Rural communities are afforded employment opportunities through the cultivation and processing of jute. Jute production fosters sustainable livelihoods by supporting local economies. Jute fibers are lightweight, which reduces energy requirements and material consumption. Jute fibers are well-suited for composite applications due to their high tensile strength [13]. The energy consumption of buildings is reduced by the thermal insulation provided by jute fibers. Jute fibers are compostable, which minimizes the environmental impact of end-of-life disposal and reduces waste. The demand for virgin materials is diminished by the ability to recycle jute fibers.

2. Jute fibre short preface

In green composites, jute is the most often utilised reinforcing fibre made from natural materials. Because it is harvested from corchorus plants, jute is classified as a bast fibre and goes by the scientific name corchorus capsularis [14]. Nearly 30–40 species of Capsularis are classified as jute, all of which are in the family Tiliaceae. The most frequent species are the white jute (Corchorus capsularis) and the tossa jute (Corchorus olitorius) [14]. Jute is the most widely produced natural fibre in the world right now, and it also happens to be one of the cheapest. Modern jute growers have found greater success in Bangladesh, India, China, Nepal, Thailand, Indonesia, and Brazil [15], despite the plant's ancient links to the Mediterranean. In terms of both usage and production, jute is second only to cotton among the world's most significant vegetable fibres. The majority of the world's jute comes from India and Bangladesh, where over 3.3 million tonnes are harvested year [16]. Due to growing fuel costs, dwindling fossil fuel sources, and global warming, jute fibres have become more popular as reinforcement in the production of composite materials in recent years.

2.1. Chemical composition

Both the physical structure and chemical content of fibres are influenced by environmental factors, phases, and the degradation process. In addition to water, the primary components of plant cell walls are lignin, cellulose, and hemicellulose, with trace amounts of protein and starch [17]. The three main components of jute fibre are cellulose, hemicellulose, and lignin varying throughout different jute grades [18]. Plant cells and cell walls form the plant's stems; these cells could also be found in the plant's leaves or roots. Enzymes like cellulose may trigger it. Therefore, cellulose predominates among fibres and contributes to strength.

Table 1 - Physical properties of jute fibre

Sr. No.	Properties	Jute Fibre
1	Cellulose (%)	60-65
2	Hemi-cellulose (%)	20-22
3	Lignin (%)	20-24
4	Waxes (%)	0.5
5	Pectin (%)	0.2
6	Moisture content (%)	1.1
7	Density (g/cm^3)	1.45
8	Fibre diameter (μm)	110-120
9	Water absorption (%)	12
10	Tensile strength (MPa)	393-773
11	Young's modulus (MPa)	19500
12	Elongation at break (%)	1.16-1.18
13	Microfibrillar angle (^{o})	8.1
14	Aspect ratio (L/D)	355-375

2.2. Surface treatment

Jute is hydrophilic, and adhesion between the fibres may be strengthened by physical and chemical treatment. Physical alterations include plasma, steam, ionising radiation, and so on, while chemical treatments include alkali, acetylation, and the use of maleated coupling agents such as maleic-anhydride grafted PP, silane coupling agents, etc. [18]. During the chemical treatment procedure, the hydroxyl (OH) groups on the surface of the jute fibre react with the chemical agents. Alkali (NaOH, KOH, or LiOH) is used as the first step in cleaning cellulose fibres by removing partial hemicellulose, lignin, wax, and other surface contaminants [19]. The treatment is more successful when more NaOH is used and it is soaked for longer. When compared to virgin jute yarn, the treated variety had superior mechanical properties [20]. Jute fibre's thermal conductivity was improved by alkali treatment on its surface [21]. Silane treatment increased fracture toughness at high temperatures but had little impact at lower temperatures. Surface treatment also has an impact on the composite's thermal characteristics [22]. Jute fibre composites using a fluorocarbon, hydrocarbon, or hybrid fluorocarbon surface treatment showed improved mechanical characteristics [23].

3. Composites made with jute fibre

Composites may be processed in the same ways as plastics. Both thermoset and thermoplastic composites fall under this category. Thermoset composites reinforced with natural jute fibre were fabricated using open mould techniques including hand lay-up as well as closed mould methods like resin transfer and compression moulding. Unsaturated polyesters, epoxies, and phenols are the most popular thermosets [24]. The most prevalent thermoplastic matrices are polypropylenes, polyethylene, and elastomers [25]. Researchers have suggested a variety of approaches for fabricating jute fibre composites. Injection moulding, manual lay-up with compression moulding, and vacuum-assisted resin transfer moulding are some more ways to create eco-friendly composites [26].

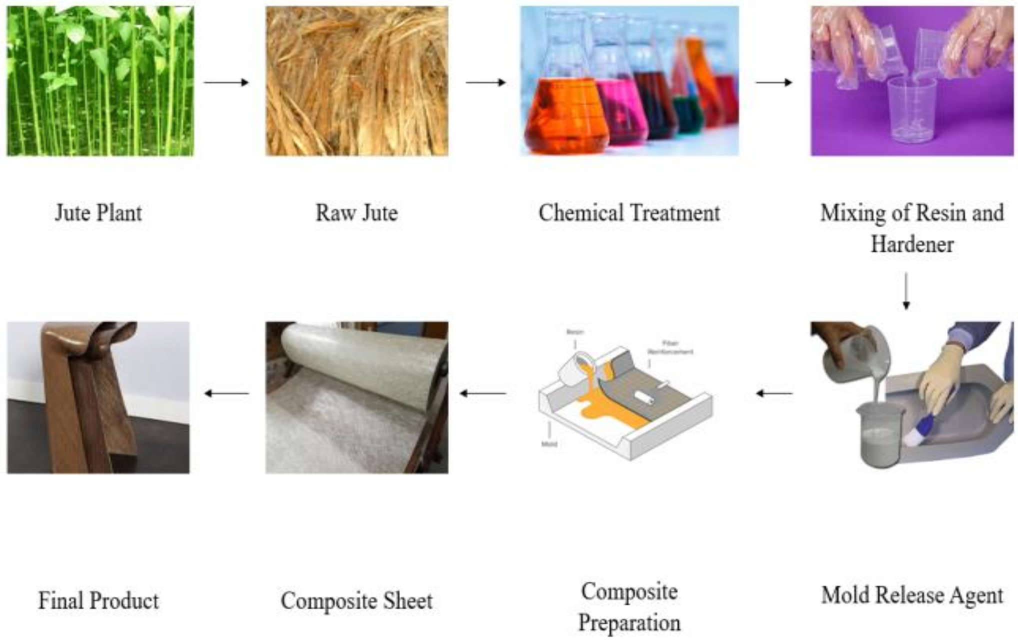

Figure.1: Jute plant to final composite application

3.1. Composites of thermoplastics reinforced with jute fibre

The temperature at which natural fibres deteriorate will limit the matrix determination. Most natural fibre composites are not thermally stable over 200°C [27], while some may withstand greater temperatures for shorter amounts of time under certain circumstances. Due to this restriction, not all thermoplastics may be employed as a matrix. Thermoplastics that may be mollified below the aforementioned temperature, such as polypropylene, polystyrene, polyethylene, and polyolefin, among others, can be employed as a matrix. Although many thermoplastic polymers can be utilised as a matrix, polyethylene and polypropylene are most frequently used in conjunction with jute fibre [28]. Polypropylene matrix is one of the most often used thermoplastics with jute fibres because it is inexpensive, has a low thermal expansion, and can be recycled. According to a tensile test and deflection temperature, the tensile strength of polypropylene by 19.7 percent when 40 percent jute fibre was added to the mix [29]. The composite made from jute and glass fibres reinforced with polypropylene had superior mechanical qualities than that made only from polypropylene, although the reinforcement only improved the composite's mechanical properties to a certain extent [30].

3.2. Composites of thermosets reinforced with jute fibre

In terms of thermoset, unsaturated polyester, epoxy resin, phenol–formaldehyde, etc. are the polymers that are most frequently utilised as a matrix [31]. The tensile strength of the jute-epoxy combination was found to be more than that of the jute-polyester combination, while the flexural strength was found to be greater for the latter. Creating items using jute and polyester was shown to be much faster than creating them with jute and epoxy [32]. Most studies conducted under actual operating conditions found that increasing the jute fibre volume% in the matrix increased the moisture diffusion rate into the composites [33]. Epoxy composites generated at 100 °C exhibited the highest tensile and flexural strengths, according to research on the impact of curing temperature on the mechanical parameters of jute fibre/epoxy-based composites [34].

Tensile, flexural, and inter-laminar shear strengths were all improved by the treatments, with the fluorocarbon treatment being the most effective. The shrinking of the fibres during the alkali treatment influenced the fibre structure and, by extension, the characteristics of the composite [35], even if the rough surface morphology brought on by the treatment did not increase interfacial adhesion. Seki used a manual lay-up approach to create a jute/epoxy composite. The mechanical characteristics of oligomeric siloxane-treated alkali-treated jute fibres were evaluated using tensile, flexure, and short beam shear tests [36]. Using a wettability and single-fibre pull-out test in an epoxy matrix, it was discovered that treating the surface of jute fibres with alkali, organo-silane, epoxy dispersions, and their mixtures enhanced the adhesion strength [37].

The tensile and flexural strength of a jute/epoxy composite using a hand lay-up method was evaluated after being subjected to salty, mineral, and sub-freezing water [38]. The flexural and tensile characteristics of the jute-epoxy composite were higher than those of the jute-polyester composite [32].

There have been several academic investigations on composites made from jute using polyester as resin. It is analysed the tensile, compressive, flexural, impact, and in-plane shear strengths and hardness of a hand-laid-up composite of untreated jute cloth and polyester [39]. Scientists discovered that composites made of jute and polyester was significantly more durable than their wooden counterparts. Hand-laid-up polyester laminates reinforced with woven jute fibres were created and their behaviour under uniaxial, multiaxial (tension/torsion), and fatigue loading was studied [40].

3.3. Composites made of jute and bio-based resin

Composites made of jute fibres reinforcing a biodegradable polymer matrix are known as "jute fibre-reinforced biodegradable polymers" [41]. Polylactic acid (PLA), polyvinyl alcohol (PVA), and poly hydroxy-butyrate (PHB) are just a few examples of biodegradable polymers now on the market [42]. Some research examined how water, enzymes, and soil affected the degradation behaviour of composites reinforced with natural fibres. Serving ware, composting bags, and films made from composites of PLA films and woven jute fibre in mat form have been offered as a renewable and degradable solution [43]. The results of the investigation suggest that PLLA-based Woven jute fibre composites may be superior to their synthetic counterparts. The one-way composites made from jute-spun yarn and PLA were manufactured via compression moulding. Jute composites use soy protein concentrate, soy protein isolate, soy resin made from soymilk, and bio-based epoxy resin, a petroleum-free substitute for epoxy resin. By using a film stacking technique, developed 40% weight/weight jute mat/PLA film composites [44]. Tensile testing, impact tests, and electron microscopy all proved that the fracture was brittle. The effect of alkali treatment on the mechanical characteristics of jute/PLA composites was investigated [45].

3.4. Hybrid composites using jute fibre

Natural fibre hybrid composites may either be (a) completely natural or (b) a blend of natural and synthetic fibres. The matrix material for these composites was unsaturated polyester, while the reinforcing fibres were natural (Jute, bamboo, and Kenaf). Mechanical experiments show that kenaf/unsaturated composites have a lower tensile modulus than bamboo/unsaturated polyester composites and jute/unsaturated composites [46]. Composites made of Jute fibre and epoxy, as well as composites made of woven glass fibre, was developed. The percentage of glass fibre used in the composite's construction has been found to increase its tensile strength. Jute/glass woven composites have greater flexural and impact strength than jute woven composites [47]. Concerns about the increased tendency of natural fibres to absorb moisture are warranted, especially for things that come into close contact with the environment. It was shown that when water absorption increased, flexural and compression strengths dropped. Hybrid composites made from natural and synthetic fibres have better mechanical properties [48] because their moisture absorption is reduced. These days, natural fibres (NFs) like sisal and jute are often used in conjunction with glass fibre composites. For this reason, researchers have been experimenting with and developing epoxy composites reinforced with a combination of glass fibre and sisal or jute. The results show that tensile strain is where sisal and glass fibre-reinforced plastic (GFRP) composites shine, but the flexural load is where jute composites shine. When compared to GFRP, the performance of these NF composites is subpar [49]. Flexural stiffness, tensile strength, compressive strength, moisture absorption, and mechanical characteristics are all improved in hybrid jute, which includes ranging from 0% to 6% $TiO2$ by weight [50]. Polymer epoxy with added jute had better mechanical qualities but still lagged behind epoxy with glass fibre reinforcement [51]. For sound absorption, jute low-density fibre-reinforced plastic performed better than high-density jute and even better than glass fibre composite [52].

Hand-laid-up hybrid composites of untreated woven jute with glass cloth reinforcement were investigated for their tensile, flexural, and interlaminar shear characteristics [53]. By combining jute, mercerized jute, and high-toughness man-made cellulose fibres with a polypropylene (PP) matrix, was able to generate a hybrid composite [54]. A combination of 25% jute and 75% synthetic cellulose yielded the right balance of qualities. The mechanical properties of hybrid composites made from sisal, jute, glass fibre, and polyester were studied [55].

4. Application of Jute Composites

Several sectors, including building, transportation, and furniture design, make use of natural fibre composites because of their adaptability [56]. Future applications for jute fibre-reinforced composites may be found in the automobile industry, the footwear manufacturing sector, the construction industry, the home and garden furniture industry, and the toy industry [57]. Several major American automakers have begun using natural fibres like jute, hemp, and flex to create a wide range of external and interior components [58].

However, the use of jute fibre as a reinforcing component in polymer matrix composites has resulted in exciting new possibilities for these kinds of building supplies. False ceilings, jute/polymer corrugated sheets, roof tiles, furniture, and other uses are some further examples. Consumers like jute fibre composites for their superior quality and minimal environmental impact [59]. Scientists are investigating ways to improve jute fibre for its potential future use.

5. Limitation of Jute Composites

In spite of the benefits of jute fibers in composites, there are numerous constraints:

1. Jute fibers are hydrophilic, allowing them to absorb moisture from the environment [60]. This can result in the following:

a. Swelling and degradation
b. Reduced mechanical properties

1. Enhanced susceptibility to the proliferation of mold and fungi
2. Jute fibers have a relatively low thermal stability, which can result in [61]:

a. Discoloration
b. Degradation

3. Decreased mechanical properties after contact with water
4. Utilization in high-temperature applications is restricted
5. The variability of jute fibers can be observed in the following factors:

a. Fiber length and diameter
b. Fiber strength and stiffness
c. Fiber surface texture and chemistry

6. Certain matrices may not be completely compatible with jute fibers, resulting in:

a. Decreased mechanical properties
b. Poor interfacial bondin
c. Increased potential for delamination

7. Jute fibers necessitate additional processing stages, including decortication and retting, which can result in a rise in costs [62].
8. Jute fibers may not be broadly available, and supply chains may be restricted, resulting in:

a. Increased costs
b. Reduced reliability
c. Limited scalability

6. Conclusion

In this article, we'll look at the many issues that have been associated with the overutilization of synthetic composites. To safeguard the environment from the dangers posed by synthetic composites, their production must be halted and discouraged. Jute fibre is increasingly being employed as the reinforcing phase in polymer matrix composites, which has broadened its potential applications beyond its traditional uses in rope, hessian fabric, carpet, wallmats, bags, etc. Outside of the textile business, jute fibres might be used in the construction and transportation industries, as well as in the toy and furniture industries. Although further research is required to fully use the potential of such composite materials, jute has shown promise as a reinforcing material for sustainable and environmentally friendly applications whether used as a single or hybrid fibre. Polymer composites reinforced with jute fibre will require further research before they can be sold commercially.

Conflict of Interest There are no conflicts of interest to declare.

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