iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: I Month of publication: January 2025

DOI: https://doi.org/10.22214/ijraset.2025.65971

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue I Jan 2025- Available at www.ijraset.com

Future Prospects of Biodegradable Natural Fiber Composites: Innovations and Enhanced Performance in Roofing and Packaging Applications

Syed Rashedul Haque
Department of Industrial Production Engineering, Military Institute of Science and Technology (MIST), Mirpur Cantonment, Dhaka 1216

Abstract: This paper explores advancements in sustainable composite materials, focusing on biodegradable fibers, recycling innovations, and enhanced performance for packaging and roofing applications. With growing environmental concerns industries are shifting toward materials that reduce ecological footprints without compromising performance. Biodegradable fibers derived from natural sources such as hemp, jute, and flax have gained attention for their potential to replace synthetic fibers in composite manufacturing. These natural fibers offer environmental benefits including reduced carbon emissions, energy savings, and easier disposal. However, challenges remain in optimizing their mechanical properties to match conventional materials. Recycling innovations also play a critical role in achieving sustainability goals in composite manufacturing. Recent advancements in chemical and mechanical recycling processes allow the reuse of composite waste, reducing landfill dependency and resource depletion. Enhanced recycling methods improve material recovery and retain quality extending product life cycles. This research examines how these processes can be effectively applied in packaging and roofing, two sectors with high material demand and waste output. The study assesses the performance of sustainable composites in terms of durability, thermal stability, and resistance to environmental factors, critical for both packaging and roofing. Through a combination of experimental testing and case studies, this thesis demonstrates that sustainable composites can offer viable alternatives to traditional materials supporting a transition to greener construction and packaging solutions. This paper contributes valuable insights into the practical applications of biodegradable and recyclable composites paving the way for more sustainable material choices in industrial sectors.
Keywords: Biodegradable fibers; Natural Fiber; Composites; Roofing; Packaging.

I. INTRODUCTION

A crucial component of product packaging is packaging. In order to preserve the product's quality for a predetermined amount of time, its design should shield it from the elements and mechanical harm. Additionally, it serves to draw customers to products by displaying product information. Packaging is categorized according to a number of factors including application, level of packaging, kind of packaging, and material type [1]. There are three levels of packaging: primary, secondary, and tertiary, depending on the level. The product is in direct touch with the primary package. From a protective perspective, secondary packaging strengthens the primary package by covering it. Transporting bulk products and providing protection while doing so are two uses for tertiary packaging. Paper and board, glass, plastic, and metal are the categories into which packaging can be divided based on its raw materials. Packaging can be widely categorized according to its application in the following industries: food, drinks, pharmaceuticals, personal care, household, electronics, and industrial. Packaging types are generally divided into two categories: flexible and rigid kinds of packing. The packaging sector is expanding steadily due to the rising demand for goods. According to newly released data, the worldwide packaging market has grown steadily with a value of over 8% since 2015 and is valued at over 900 billion. Packaging is the biggest end-user sector for plastic products. It accounts for around 40% of the world's total plastic consumption. Typically, every minute three million bottles and bags are shipped all over the world [2].

Plastic packaging uses a lot of energy during production and is not renewable, making it extremely unsustainable for the environment. Additionally, it releases greenhouse gases, hazardous material in the environment for the duration of the packaging's lifecycle.

In Recycling rates in emerging nations are currently reaching their maximum to address environmental issues. Publicly available reports indicate that the problem of microplastic pollution in soils worldwide is even more severe than that of microplastic pollution in our oceans. More than 10% of the 600 Mt of packaging waste produced in 2015 was recycled, less than 13% was burned, and over 75% ended up in the environment.

More than 60% of plastic manufactured ends up in open spaces and causes pollution, according to a recently released survey. If current waste and production trends have been adhered to, over 10,000 Mt of plastic garbage will end up in landfills or the open environment by 2050 due to poor management. Microplastics in soil have a number of detrimental effects, such as altering the behavior of earthworms and other soil animals and spreading sickness [3].

The production of packaging and the burning of plastic release a lot of carbon dioxide and other toxic pollutants into the atmosphere. Polluting gases and hazardous substances like sulfur dioxide and nitrous oxide can be released during incineration. Packaging waste accounts for about 70% of all marine trash.

Tourism along the seaside is also impacted. Marine life consumes or entangles plastic debris, leading to fatalities and serious injuries. According to reports, several ocean-dwelling species, including fish, sea turtles, and other marine life, include plastic as a result of plastic pollution in the ocean. Sustainable initiatives in the packaging industry are necessary to lessen the negative effects on the environment [4].

One of the primary advantages of NFCs is their effective thermal insulation properties, which help maintain temperature stability within buildings and reduce energy costs associated with heating and cooling. Natural fibers have inherently low thermal conductivity due to their cellular structure, which traps air and minimizes heat transfer. This makes them particularly useful in climates where maintaining indoor temperatures is a challenge. In addition, recent advancements in treatment techniques have enhanced the durability of NFCs, addressing common issues such as moisture absorption, UV degradation, and susceptibility to biological decay.

These improvements allow NFCs to compete with synthetic materials in terms of longevity while retaining their sustainable appeal. With these benefits, natural fiber composites are increasingly being used in roofing, wall insulation, and other applications within green building practices. However, to fully leverage their potential, it is essential to assess their durability and thermal performance under various environmental conditions.

This paper will comprehensively explore the potential of biodegradable composites as a sustainable alternative to traditional packaging materials, with a specific focus on the context of Bangladesh. The research will critically examine the technical properties of natural fiber composites, their environmental implications, and their practical applications across various sectors, particularly in packaging and military logistics.

By investigating the intersection of material science, environmental sustainability, and practical engineering, the study aims to provide a holistic analysis of how biodegradable composites can address the critical challenges of waste management, resource efficiency, and environmental protection. The methodology will involve a detailed examination of locally available natural fibers, their composite potential, manufacturing processes, performance characteristics, and potential scalability within Bangladesh's unique environmental and industrial landscape

II. BIODEGRADABLE FIBER REINFORCED COMPOSITES

Natural fiber composites (NFCs) are composite materials reinforced with natural fibers like jute, hemp, flax, bamboo, coconut (coir), and sisal, which are bound within a polymer or resin matrix. These materials are increasingly popular due to their sustainability, lightweight nature, and favorable mechanical properties making them an environmentally friendly alternative to synthetic fiber composites (e.g., fiberglass and carbon fiber composites). Two main fabrication methods are used to produce fiber-reinforced composites [6].

They are:

1) *Compression Molding:* This method entails setting a previously weighted fiber and matrix mixture in a heated mold while exerting pressure. The thickness and density of the composite can be precisely controlled via compression molding.
2) *Injection Molding:* To create intricate shapes, a blend of fibers and molten polymer is pumped into a mold. Regarding mass-producing components with precise geometric specifications, injection molding is more beneficial than compression molding.

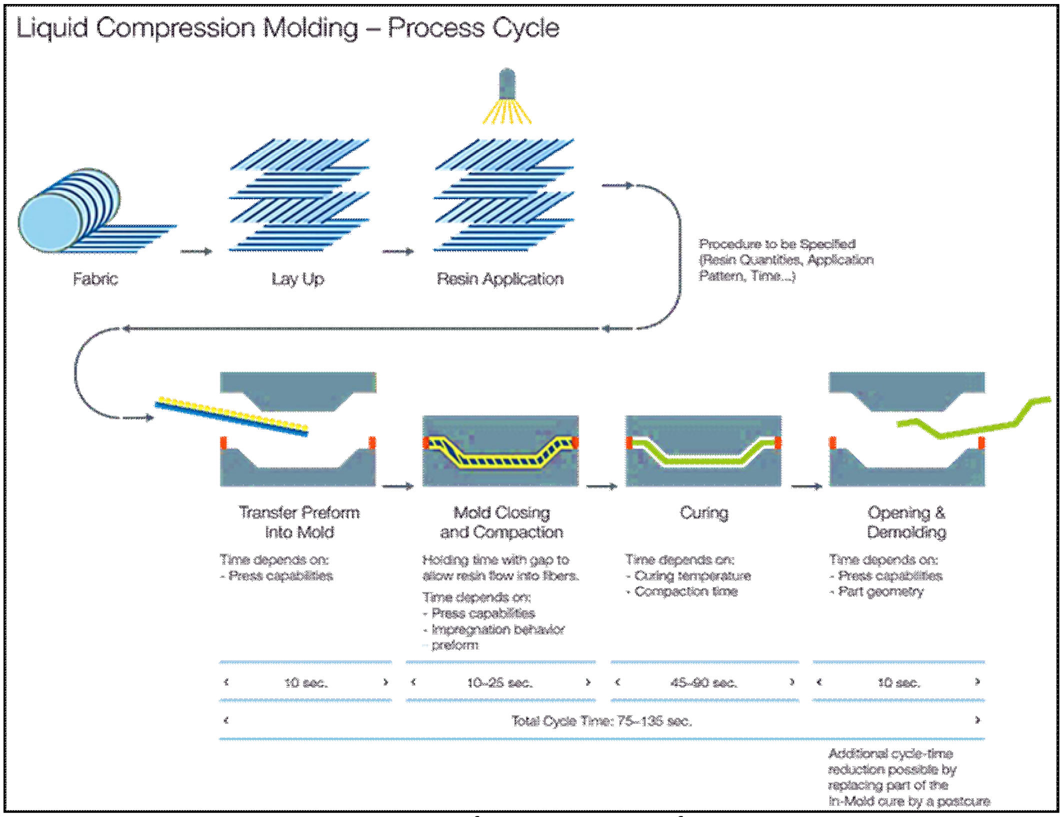

Fig. 1 Manufacturing Process of NFCs

Some of the most common natural fibers used for composite materials include:

a) *Jute:* Known for its flexibility, low cost, and availability. Used in packaging and automotive interiors.
b) *Flax:* The plant from which linen is derived is flax. Because of their intermediate mechanical qualities, biodegradability, and lightweight nature, they are widely used in packaging and automotive composites.
c) *Hemp:* Known for its lightweight nature and high tensile strength; hemp can be used as reinforcement in composites. Research indicates that hemp-PLA composites have superior mechanical qualities compared to PLA alone.
d) *Bamboo*: Bamboo fiber is a cellulosic fiber that has been regenerated from bamboo. Alkaline hydrolysis and multi-phase bleaching are the processes used to turn bamboo stems and leaves into starchy pulp. Bamboo fiber is created by additional chemical processes, which makes it a great reinforcement material for biodegradable composites.
e) *Coconut (Coir):* Offers good durability and sound absorption, often used for insulation and upholstery applications.


Flax Fiber


Coconut Fiber


Jute Fiber

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue I Jan 2025- Available at www.ijraset.com

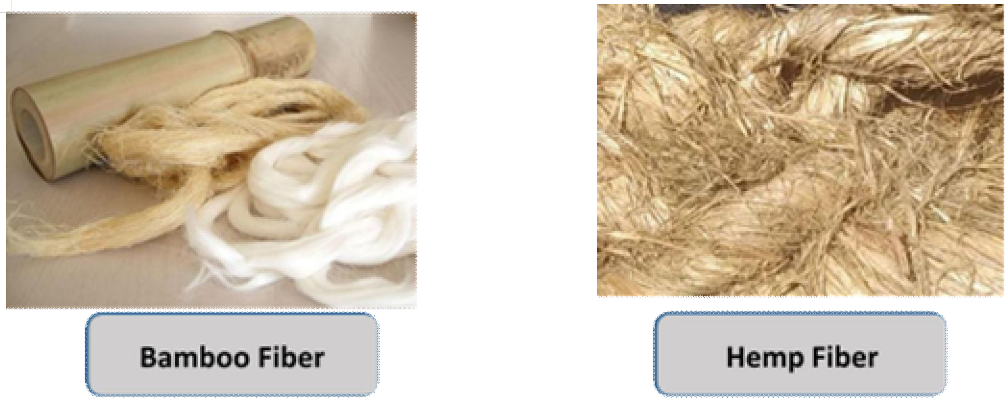

Figure 2. Various Types of Natural Fibers

III.KEY CHARACTERISTICS OF BIODEGRADABLE FIBER REINFORCED COMPOSITES

Natural fibers such as bamboo, jute, and coconut are valued for their high strength-to-weight ratios, which make them suitable for lightweight construction applications [7]. Some of the key characteristics are given below:

1) Biodegradability: The fiber and polymer matrix are both selected for their capacity to decompose naturally, including by microbial action, into non-toxic residues such CO_2, water, and biomass. Because they don't linger in the environment like traditional plastics do, this feature makes these composites eco-friendly [8].
2) Enhanced Mechanical Properties: The composite obtains better mechanical properties by using natural fibers to reinforce the biodegradable polymer. Characteristics like stiffness, impact resistance, and tensile strength in comparison to utilizing just the polymer. This makes the material appropriate for uses including packaging, agriculture, and car interiors where both strength and biodegradability are needed [9].
3) Sustainability: Biodegradable polymers can be made from renewable resources (e.g. corn starch for PLA), and the natural fibers utilized in these composites are frequently renewable. This lessens the material's total environmental effect and dependence on petroleum-based resources.
4) Packaging Uses: In environmentally friendly packaging, biodegradable Fiber-reinforced composites can be utilized for food containers, disposable trays, cutlery, and other products that gain strength yet don't contribute to long-term pollution because they decompose after being disposed of [10].
5) Thermal Insulation: Natural fibers exhibit excellent thermal insulation properties, which can significantly reduce energy consumption in buildings. Natural fiber composites are composed of a natural fiber matrix bonded with a polymer or other binding agents to enhance structural integrity. This combination creates a material that is not only sustainable but also has a lower carbon footprint compared to conventional roofing materials such as concrete, asphalt, or metal. Furthermore, natural fiber composites are abundant and economically viable in many regions, making them an attractive option for local construction projects that prioritize sustainable sourcing [11].

IV. FACTORS AFFECTING THE THERMAL PERFORMANCE OF NATURAL FIBER COMPOSITES

A. Thermal Stability

1) *Fiber Type:* Compared to manufactured fibers (such as carbon or glass), natural fibers have a lower inherent thermal stability. While more heat-resistant fibers like ramie and bamboo may tolerate temperatures up to 300°C before degrading, common natural fibers like flax, hemp, jute, sisal, and cotton normally have thermal stability up to about 200–250°C [12].
2) *Composite Matrix:* Thermal performance is also significantly influenced by the kind of polymer matrix that is utilized such as epoxy, polyester, polypropylene, or biodegradable polymers. For example, compared to thermoplastic matrices like polypropylene, thermoset matrices like epoxy often offer greater temperature stability.
3) *Processing Conditions:* Processing at high temperatures may have an impact on the composite's ultimate thermal characteristics. For instance, how well the composite maintains its strength and stability at high temperatures can be influenced by the curing temperature and duration throughout the manufacturing process [13].

B. Decomposition Temperature

1) *Breakdown Temperature:* Both the fiber and the matrix affect the breakdown temperature of natural fiber composites. At temperatures ranging from 180°C to 300°C, natural fibers start to break down. The type of fiber and any treatments used, such as chemical treatments to strengthen the link between the fiber and matrix, may affect this, though [14].
2) *Fiber Surface Treatments:* By strengthening the adherence between the fibers and matrix, surface treatments such as alkali (NaOH) treatments can improve the thermal characteristics and perhaps increase the composite's overall performance. The thermal stability may still be much less than that of composites made of synthetic fibers, though [15].

C. Thermal Conductivity

1) *Insulation Properties:* Natural fibers are suitable for applications needing thermal insulation since they have a lower heat conductivity than metals or glass fibers (such as in-vehicle interiors or building materials). This characteristic is advantageous since it indicates that NFCs do not readily transmit heat, providing some matrix protection and aiding in insulation applications.
2) *Thermal Conductivity Range:* The fiber type, matrix, and fiber volume percentage all affect the thermal conductivity of natural fiber composites, which typically fall between 0.10 and 0.30 W/m·K. This attribute is greatly influenced by the matrix material; thermoplastic matrices, like polypropylene, often offer lower thermal conductivity than thermoset matrices, like epoxy [16].

D. Heat Deflection Temperature (HDT)

The temperature at which a polymer composite deforms under a given load is known as HDT. Both the fiber and the matrix have an impact on the HDT for natural fiber composites.

Natural fiber-based NFCs with thermoplastic matrices (such polyethylene or polypropylene) typically have lower HDT values (between 60 and 120°C). However, depending on the fiber type and content, composites manufactured with thermoset matrices (such as epoxy or phenolic) typically have higher HDT values (150–200°C or more) [17].

E. Fire Resistance

Because natural fibers are flammable, natural fiber composites often have lower fire resistance than synthetic composites. However, by applying fire-retardant coatings or treatments to the fibers or matrix, fire resistance can be increased. Although surface treatments, including flame-retardant chemicals, can greatly lessen NFCs' flammability, they cannot eliminate the risk of fire, particularly in high-heat settings. Composites containing both natural and synthetic fibers, such as glass fibers may provide improved fire resistance [18].

F. Expansion and Shrinkage

1) *Coefficients of thermal expansion:* When compared to synthetic fiber composites, natural fiber composites often have greater coefficients of thermal expansion (CTE). Accordingly, natural fibers are more likely to expand and contract in response to temperature fluctuations, which could lead to dimensional instability in harsh environments.
2) *Fiber-Matrix Compatibility:* The overall thermal expansion behavior of NFCs is also influenced by the matrix material's coefficient of thermal expansion. Internal stresses resulting from a mismatch between the fiber and matrix CTE may compromise the composite's structural soundness [19].

TABLE I
THERMAL PERFORMANCES OF NFCS

Fiber Type	Thermal Conductivity	Thermal Degradation (TGA)	Glass Transition Temperature (Tg)	Heat Deflection Temperature (HDT)
Jute	0.1 – 0.2 W/m·K	250°C – 300°C	60°C – 80°C	50°C – 70°C
Hemp	0.15 – 0.25 W/m·K	250°C – 350°C	50°C – 100°C	60°C – 90°C
Bamboo	0.1 – 0.2 W/m·K	200°C – 300°C	40°C – 70°C	50°C – 80°C
Flax	0.15 – 0.25 W/m·K	250°C – 350°C	60°C – 100°C	70°C – 90°C

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue I Jan 2025- Available at www.ijraset.com

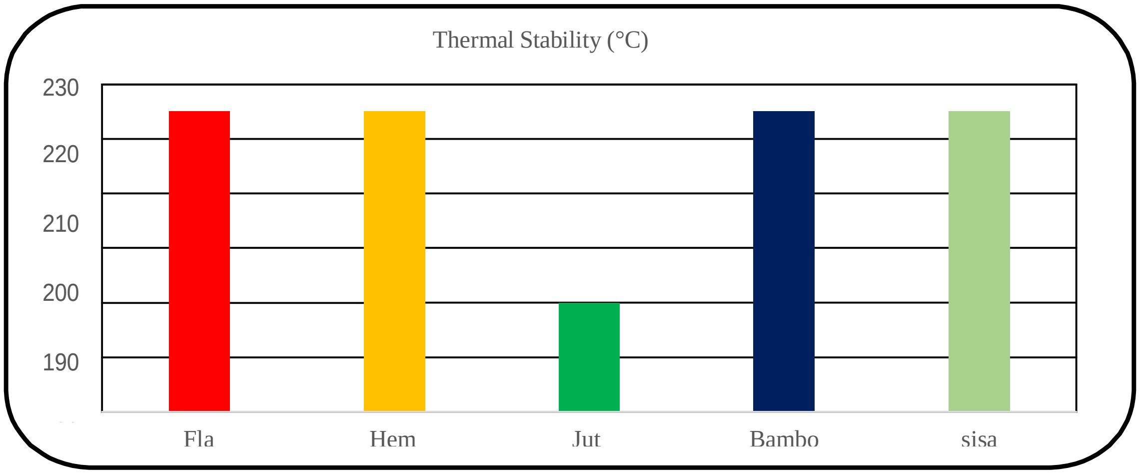

Fig. 3 Thermal Stability of NFCs

G. Durability Performance

The longevity of Natural fiber composites' (NFCs') performance is a major determinant of its potential for use in a variety of industries, especially consumer items, buildings, and automobiles. Usually, a polymer matrix bonded with natural fibers like flax, hemp, jute, sisal, or bamboo makes up these composites [20]. Although they have benefits including sustainability, biodegradability, and affordability, a number of variables, such as the fiber type, matrix material, manufacturing process, and environmental conditions, can affect how long they last. An outline of the key elements of NFC durability performance is provided below:

1) Mechanical Durability

- *Tensile Strength:* When compared to synthetic fiber composites (such as glass or carbon fiber), natural fiber composites often have lower tensile strengths. The type of fiber, matrix compatibility, and fiber-matrix interface quality all have a significant impact on how well natural fibers function under tension [21].
- *Flexural Strength and Impact Resistance:* Generally speaking, NFCs are less impact-resistant than synthetic composites. The main cause of this is that natural fibers are generally fragile and can break easily under unexpected stresses.
- *Fatigue Resistance:* When compared to synthetic composites, NFCs often exhibit lower fatigue resistance. Under cyclic loading, the fibers are more prone to slow deterioration, particularly in damp or humid environments.

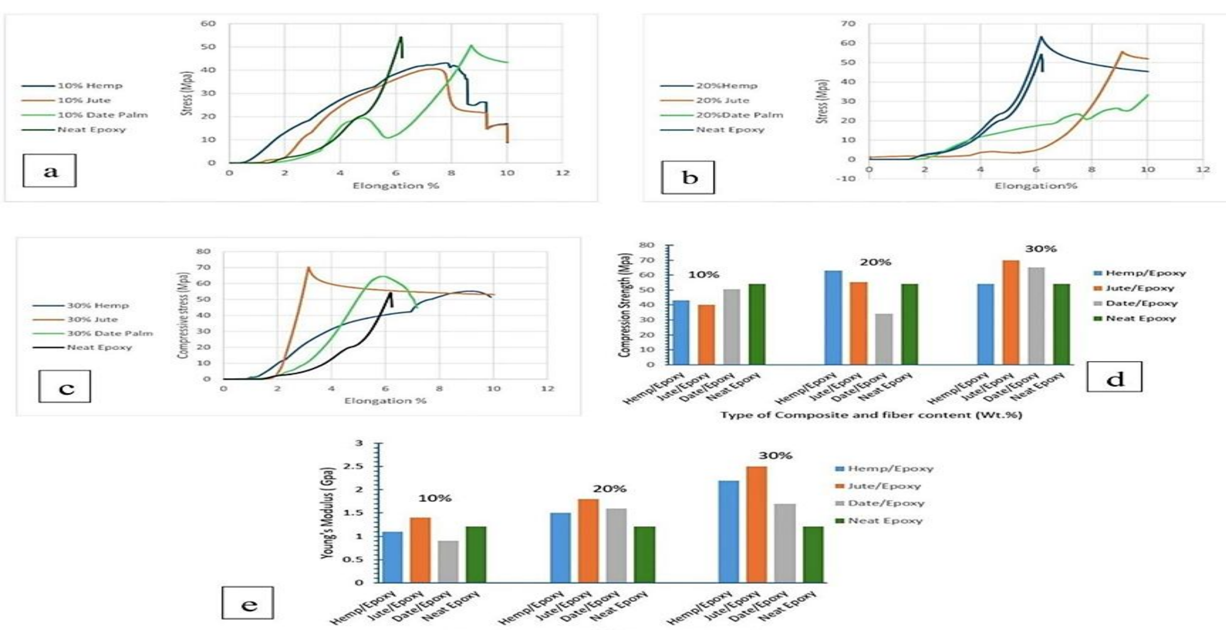

Fig. 4 Durability Performance of NFCs

2) Environmental Durability

- *Absorption of moisture*: Being hygroscopic—that is, able to absorb moisture from the surroundings, is one of the main disadvantages of natural fibers. Natural fibers can swell when exposed to high humidity or wet circumstances, which lowers their mechanical qualities including strength and stiffness. Mold or mildew can grow as a result of water absorption over time, further deteriorating the material [22].
- *UV degradation:* Ultraviolet (UV) light can weaken the structure of natural fibers and cause them to lose their flexibility and strength. The natural fibers themselves are susceptible to photodegradation, even though UV stabilizers can be added to the matrix.
- *Stability of temperature:* Most natural fibers begin to break down at temperatures between 200 and 300°C, making them less thermally stable than synthetic fibers. Although the degradation temperature varies depending on the fiber type, certain polymer matrices or modifications such as fiber surface treatments might enhance thermal performance [23].

TABLE III
ENVIRONMENTAL PERFORMANCE OF NFCS

Fiber Type	Moisture Absorption	UV Resistance	Biodegradability	Weather Resistance
Jute	High (20%–30%)	Poor to Moderate	Fully biodegradable	Moderate (susceptible to rot)
Hemp	Moderate (8%–10%)	Moderate	Fully biodegradable	Good (better than jute)
Bamboo	Moderate (15%–20%)	Good	Fully biodegradable	Good (durable outdoors)
Flax	Low to Moderate (6%–8%)	Moderate	Fully biodegradable	Good (better than jute)

V. FEASIBILITY OF NATURAL FIBER COMPOSITES AS ROOFING MATERIALS

The feasibility of using natural fiber composites (NFCs) as roofing materials depends on various factors including material properties, manufacturing processes, cost-effectiveness, and performance under real-world conditions. While natural fiber composites offer several environmental, aesthetic, and functional benefits, their wide-scale adoption in roofing applications still faces a few significant challenges. This feasibility analysis looks at both the advantages and the challenges to assess the potential of NFCs as viable roofing materials [24].

A. Material Properties

1) *Sustainability and Renewability:* Compared to conventional roofing materials like asphalt or synthetic polymers, natural fibers like hemp, jute, flax, bamboo, and sisal are biodegradable, renewable, and have a significantly smaller environmental impact. Because of this, NFCs have an advantage in areas where environmentally responsible building is valued highly.
2) *Thermal Insulation:* NFCs often have low heat conductivity, which helps buildings use less energy. By keeping interiors cooler in hot weather or minimizing heat loss in cold climates, they can aid in maintaining a pleasant indoor temperature.
3) *Light Weight:* Compared to traditional roofing materials like concrete or metal, NFCs are lighter, making them easier to handle and install. This lowers labor costs and may also result in decreased transportation costs.
4) *Acoustic Insulation:* In both residential and commercial structures, NFCs can offer some soundproofing advantages by lowering noise from outside sources like wind and rain.

B. Challenges

1) *Moisture Sensitivity:* Natural fibers absorb moisture because they are hygroscopic. If the material is not properly treated and is exposed to rain or excessive humidity, it may swell, degrade, or mold. For roofing materials that must endure a variety of weather conditions, this is a crucial problem.

2) *Fire Resistance:* Unless treated with fire retardants, natural fibers are flammable. This may restrict their use in high-risk fire zones. To improve their safety, sufficient fireproofing measures (such as flame-retardant coatings) would be required.
3) *UV Degradation:* Natural fibers can become brittle and weaker over time due to prolonged exposure to UV rays. For long-term durability, natural fiber composites may require stabilizers or UV- resistant coatings.

C. Manufacturing Process

1) Cost-Effectiveness: Compared to synthetic substitutes like fiberglass or carbon composites, natural fibers are typically less expensive to produce and treat. They can be sourced locally and are easily accessible in many areas, which lowers the cost of raw materials and shipping.
2) Processing Ease: Conventional manufacturing techniques can be used to transform natural fibers into composite panels, shingles, or tiles. Roofing materials can be created by modifying processes such as extrusion, injection molding, and compression molding.

D. Problems

1) Process Consistency: The unpredictability of natural fibers is one of the difficulties in employing them. In contrast to synthetic fibers, the characteristics of natural fibers might vary based on the source (e.g., plant age, harvesting techniques, and climate), potentially leading to a final product of variable quality.
2) Surface Treatments and Resins: Natural fiber composites may require chemical or heat treatments to increase their strength, fire resistance, and moisture resistance to increase durability. This raises the complexity and cost of manufacturing.
3) Composite Matrix: The final performance of the composite is significantly influenced by the matrix material, which can be synthetic or bio-based resin. The overall integrity of the roofing material may be jeopardized if the matrix is incompatible with the fibers or if it deteriorates over time.

E. Performance in Roofing Applications

1) Benefits

Environmental Impact: By lowering the need for petroleum-based roofing materials, NFCs can assist in achieving sustainability targets for buildings as green building techniques gain popularity. The opportunity to help achieve LEED (Leadership in Energy and Environmental Design) certifications is another benefit they provide.

Thermal Insulation: Because NFCs have a low thermal conductivity, they can serve as natural insulators, increasing a building's energy efficiency by assisting in temperature regulation, which lowers heating and cooling expenses.

Aesthetic Appeal: Natural fiber composites can have a rustic, organic appearance that complements eco-friendly or specific architectural designs. They can also be given different textures and finishes to resemble more conventional materials like slate, bamboo, or wood.

2) Problems.

Durability in Extreme Conditions: The ability of natural fiber composites to withstand severe weather conditions is their biggest obstacle as roofing materials. NFCs might not perform as well or last as long as more conventional roofing materials like metal or clay tiles in areas with a lot of rain, strong winds, or extremely high temperatures.

Structural Strength: When compared to traditional roofing materials, NFCs often have inferior mechanical strength. Without further strengthening or hybridization with stronger materials, they might not be appropriate for regions that encounter high winds or large snow loads.

Moisture Control: NFCs may collect moisture if appropriate waterproofing measures are not taken, which could result in deterioration, the growth of mold, and a shorter lifespan. This is especially problematic in places with high humidity or a lot of rain.

F. Cost Feasibility

1) Benefits.

Lower Material Costs: Compared to synthetic materials like metal or fiberglass, natural fibers like hemp, jute, and bamboo are usually less expensive. The cost of raw materials is cheaper in some areas due to the widespread availability of these commodities, which could result in a lower beginning cost.

Energy Efficiency: Over time, NFCs' thermal insulation can result in energy savings, particularly in regions with notable temperature swings. Some of the initial installation costs may be covered by lower energy demand for buildings' heating and cooling.

2) Problems

Costs of Processing and Treatment: Although natural fibers are cheap, extra treatment expenses (such as those for fire retardants, moisture resistance, or UV protection) may raise the finished product's total cost. For instance, applying protective coatings to increase durability may result in higher production costs.

Maintenance Costs: Compared to conventional roofing materials, NFC roofing materials would need greater upkeep. Regular maintenance or replacement may be required if the roofing material is improperly treated or if exposure to the outdoors causes it to deteriorate.

VI. APPLICATIONS OF COMPOSITE MATERIALS IN ROOFING

Natural fiber composites (NFCs) as roofing materials present an exciting potential for sustainable construction practices. The use of these materials, derived from renewable resources like hemp, flax, sisal, bamboo, and jute, can address several key concerns in the building industry, including environmental sustainability, energy efficiency, and cost-effectiveness. However, their successful integration into mainstream roofing applications requires addressing challenges related to durability, moisture resistance, and fire safety [25].

A. *Eco-friendly and residential housing*

1) *Green and Sustainable Roofs:* Eco-friendly residential developments and green building designs can benefit greatly from NFCs. They are perfect for homes seeking to satisfy sustainability criteria like LEED (Leadership in Energy and Environmental Design) certifications because of their minimal carbon footprint and biodegradability.
2) *Passive Houses:* Natural fiber composites can be used as roofing materials in energy-efficient dwellings (like passive houses), which can aid with insulation and lower heating and cooling expenses.
3) *Affordable Accommodations:* NFCs provide an inexpensive substitute for traditional materials like concrete tiles or metal roofing sheets in places where cost-effectiveness is essential, like rural areas or developing nations. NFCs are accessible in remote locations because of their low weight, which also lowers shipping expenses.

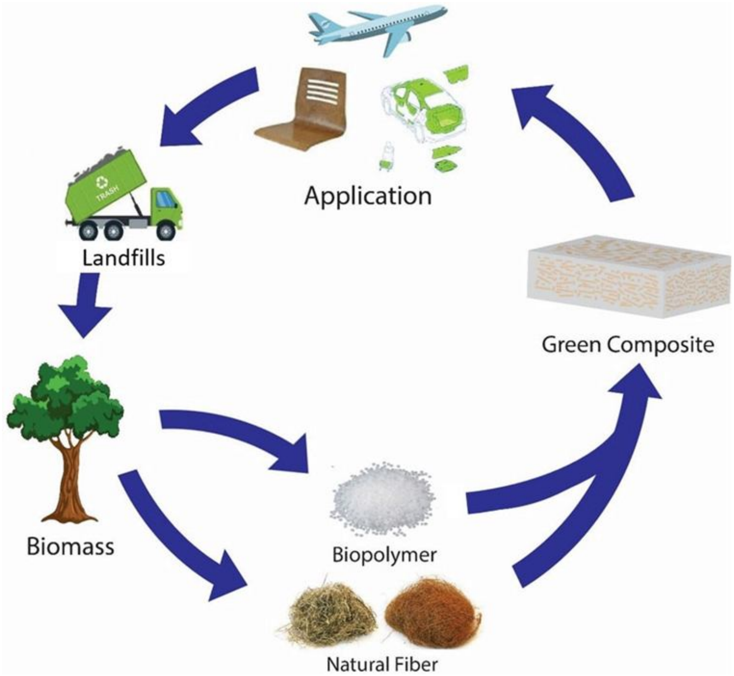

Fig. 4 Applications of NFCs

VII. AGRICULTURAL AND INDUSTRIAL BUILDINGS

A. Farm Sheds & Agricultural Structures

Barns, greenhouses, and other agricultural buildings can be constructed in rural locations using NFCs, particularly those composed of bamboo or hemp.

Durable, lightweight, and reasonably priced materials are needed for these buildings. NFCs can be utilized to make reasonably priced roofing panels that provide rudimentary weather protection.

B. Warehouses and Storage

NFC-based roofs can offer sufficient thermal insulation and soundproofing for employees and stored goods in agricultural or light industrial storage while having a minimal negative environmental impact.

C. Green Roofs

Green roofing systems, also known as vegetative roofs, are made of soil, vegetation, and natural fibers that serve as the substrate and support structure.

NFCs can be incorporated into these systems. Green roofs improve air quality, lessen stormwater runoff, and reduce urban heat islands, among other ecological advantages. NFCs provide lightweight, moisture-resistant panels that promote plant development, making them a good choice for bolstering these systems. NFCs can also be utilized in pre-manufactured, readily built modular green roofing panels that are made from recycled or low-impact materials. This can drastically cut down on labor expenses and installation time for green roofs [26].

VIII. COMMERCIAL AND URBAN CONSTRUCTION

1) *Sustainable Office Buildings:* Corporate offices, particularly those constructed with sustainability objectives in mind, are a suitable location for NFCs. NFCs' visual appeal can support biophilic designs that bring the outside indoors, enhancing employee well-being and supporting green building principles.
2) *Eco-Tourism and Hotels:* To highlight their sustainable construction, eco-tourism establishments and eco-friendly hotels may utilize NFC roofing materials. These factories might be found in isolated locations where NFCs—especially hemp or bamboo—are acquired locally.
3) *Pre-formed roofing panels:* NFCs can be molded into easily installed roofing tiles or panels, taking the place of more traditional materials such as corrugated metal sheets, asphalt shingles, or clay tiles. The panels may be made to seem like conventional materials, which makes them a good choice for both practical and decorative purposes [27].
4) *Hybrid Composites:* By combining NFCs with other reinforcing elements, like glass fibers, their mechanical qualities can be enhanced, allowing them to endure wind, heavy loads, and other environmental pressures that are common in residential or commercial roofing [28].

IX. PRACTICAL IMPLICATIONS OF NATURAL FIBER COMPOSITES IN PACKAGING MATERIALS

Natural fibers are just beginning to be used in packaging applications. Numerous advancements have been made in the field of biocomposites recently due to their hard packing properties and flexibility. Biocomposites made of natural fibers have extremely promising for usage in commercial packaging applications. Few businesses have made the effort to lessen the pollution that petroleum use causes in the environment based on packaging materials. Below is a discussion of the recently produced biocomposite in a variety of business areas [29].

A. Pharmaceutical and Personal Care

Biocomposites based on sugarcane waste fiber can be utilized in the pharmaceutical industry's main packaging. The qualities it offers are adequate for pharmaceutical packaging needs. Packaging materials made of jute fiber can also be utilized for outer packaging components for personal care and medicinal products. As seen in Figure 4, Be Green Packaging created unique packaging for the packaging of personal care products [30].

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue I Jan 2025- Available at www.ijraset.com

Figure 4. Packaging for personal care products made from pulp derived from natural fibers.

B. Electronics

Dell has introduced a bamboo-based biocomposite in electrical packaging. Compostability and recyclability are two benefits of using bamboo fiber-based packaging materials in electronic packaging. In a single day, a bamboo plant can grow up to 2 inches. It offers good protective elements for fragile objects that are dependent on electronics. An environmentally friendly and biodegradable laptop case composed of hemp fiber-reinforced PLA composite has been created by a private company. [31]

Chromebook packaging is composed of materials derived from plant fibers. Its substance is lightweight and biodegradable. It has less of an impact on the environment than packaging that has been used before. For Dell Tech, Evocative created packaging made of mushrooms in order to get rid of packaging materials made of petroleum. Mold is used to create it in the precise shape needed for a certain electronic product [32].

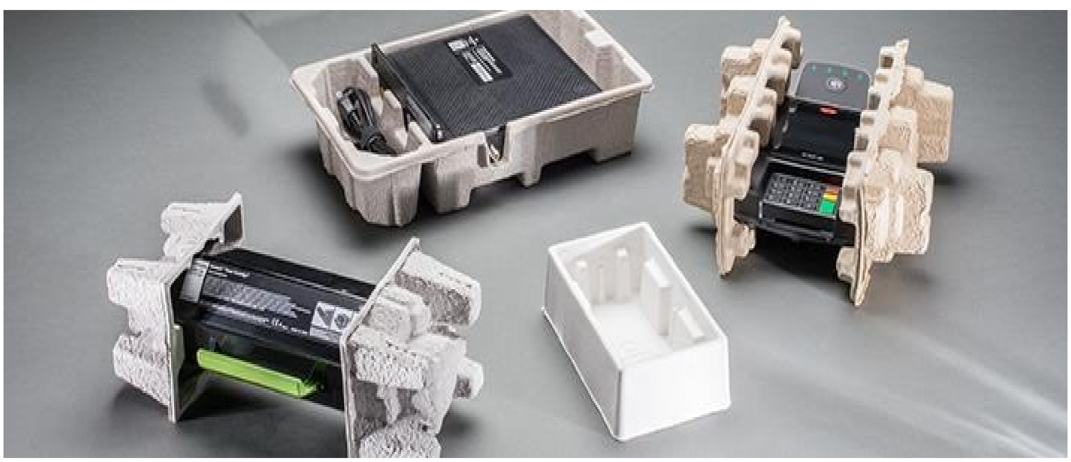

Figure 5. Molded Fiber Packaging used in Electronic Appliances

C. Food

Natural fiber-reinforced biocomposite food packaging offers several benefits, including biodegradability, increased shelf life of the packed food, lightweight design, good shock absorption, and high environmental protection factor. For food packaging, biopolymer composites reinforced with seagrass, rice husks, and almond shells were developed. Additionally, mechanical, thermal, and barrier properties were examined. Recently, Enkev created the food packaging COCOFORM and COCOLOK using compressed coconut husk [33].

Figure 6. Food Packaging materials are made from bamboo fibers and coconut husk fiber.

D. Drinks

Green Kulture and the packaging industry collaborated to create environmentally friendly wheat-fiber bottles and containers. For use in beverage applications including wine, spirits, and beer, SAS Green Gen created a biocomposite reinforced with flex fiber. These environmentally friendly bottles have the potential to replace the petroleum-based bottles seen in the illustration. Eco-friendly fiber bottles for a variety of beverage packaging were introduced by Carlsberg. It is entirely compostable and environmentally beneficial, and it is composed of natural fibers derived from plants [34].

Figure 7. Drink bottles made from wheat fiber

E. Cosmetics

Ecovativ has also created mycelium-based biocomposites for cosmetics goods. Compared to thin, rigid packing material, it offers a higher protection factor and weighs less. The figure illustrates how cosmetics goods are packaged using mycelium-based packaging. One of the businesses that has taken the initiative to reduce the cosmetics industry's reliance on petroleum-based packaging materials is FS Korea. They began utilizing biocomposite materials, which are composed of fibers reinforced with wood. A biocosmetic based on curaua has also been created for perfume bottles. When compared to packaging materials that were previously created, these materials have better qualities. The perfume bottles are biodegradable and composed entirely of natural materials [35].

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue I Jan 2025- Available at www.ijraset.com

Figure 8. Cosmetic packaging made from mycelium-based biocomposites

X. CONCLUSION

Natural fiber composites represent a promising step forward in the pursuit of sustainable and eco-friendly building materials. By leveraging the inherent properties of natural fibers such as jute, hemp, flax, and bamboo, NFCs offer effective thermal insulation, helping reduce energy consumption for heating and cooling in buildings. Their low thermal conductivity, combined with lightweight structure and biodegradability, makes NFCs a suitable alternative to conventional, synthetic composites, especially for roofing applications where insulation and weight are critical factors.

Advancements in chemical treatment and hybrid composite technologies have significantly enhanced the durability of NFCs, addressing challenges such as moisture absorption, UV degradation, and biological decay. These improvements allow natural fiber composites to perform reliably under various environmental conditions, extending their lifespan and making them a competitive choice in the construction industry.

Several natural fiber-reinforced biocomposites that satisfy the functional requirements of product packaging have been successfully developed as a result of recent breakthroughs. Since the biocomposite industry is still in its infancy, it exhibits tremendous growth potential and rapid advancement. Biocomposite-based packaging options have already been launched by some product packaging companies, opening the door for commercial implementation. Biocomposites' incorporation into the packaging industry holds the secret to lessening the environmental issues brought on by traditional packing materials. By adopting these sustainable alternatives more widely, we may significantly advance the cause of a more environmentally conscious and greener future. Increased investment and encouragement of the use of biocomposites are essential in packaging to promote a circular economy and bring about positive environmental changes.

Despite their promising attributes, the large-scale adoption of NFCs in construction still requires further research and development, especially in optimizing performance under diverse climate conditions and ensuring consistency in quality. Continued innovation in composite treatments, as well as studies on long-term environmental impacts, will be essential in making NFCs a mainstream solution for sustainable roofing and other building applications.

In conclusion, natural fiber composites have the potential to transform sustainable building practices, providing an environmentally friendly alternative with both functional and economic benefits. As the demand for green materials grows, NFCs are well-positioned to contribute to energy-efficient, durable, and sustainable building solutions and packaging materials.

XI. RECOMMENDATIONS

In the context of Bangladesh and the Bangladesh Army, proposals for breakthroughs in sustainable composite materials, particularly biodegradable fibers, recycling innovations, and their uses in packaging and roofing, should focus on practical and scalable solutions. A primary recommendation is to leverage Bangladesh's abundant natural fibers such as jute, bamboo, bananas, and coir as key components in composite creation. These locally available materials are not only affordable and climate-appropriate but also renewable, making them ideal for developing sustainable composites.

Academic institutions like BUET and MIST can play a crucial role by promoting research and development in natural fiber composites (NFCs). By introducing advanced NFC fabrication and testing equipment, these institutions can accelerate the development of environmentally friendly composites suitable for both military and civilian applications. This approach would enable the creation of customized products that meet Bangladesh's specific environmental and durability requirements.

The Bangladesh Army could significantly benefit from piloting sustainable composite roofing solutions, especially given the country's vulnerability to natural disasters. Implementing lightweight, resilient, and quick-to-deploy roofing for military operations and disaster relief shelters would not only enhance operational effectiveness but also contribute to waste reduction. Such an initiative would provide a practical demonstration of sustainable technology in critical infrastructure.

Developing a closed-loop recycling system for composite materials represents another strategic recommendation. By establishing a comprehensive recycling mechanism for composites derived from packaging, shelter construction, and other sources, Bangladesh can dramatically improve resource efficiency, minimize waste, and conserve valuable resources. This systematic approach to material lifecycle management would set a precedent for sustainable resource utilization.

Lastly, incorporating biodegradable composite materials into military packaging offers a transformative solution. By replacing single-use plastics and non-biodegradable packaging materials with sustainable alternatives for packaging military supplies like food rations, medical kits, and equipment, the Bangladesh Army can significantly reduce its environmental footprint. This approach not only addresses ecological concerns but also demonstrates leadership in sustainable innovation within military logistics and supply chain management.

REFERENCES

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

[2] Shishir, S., Chowdhury, M. S., & Islam, S. (2018). "Thermal properties of jute fiber-reinforced composites: A review." Materials Research Express, 5(4), 1-14.

[3] Saba, N., Jawaid, M., & Sultan, M. T. H. (2019). "An overview of mechanical and physical testing of composites for renewable and sustainable energy applications." Journal of Industrial Textiles, 48(3), 578-600.

[4] Puglia, D., Biagiotti, J., & Kenny, J. M. (2005). "A review on natural fiber- based composites—Part II: Thermal properties." Journal of Natural Fibers, 2(4), 23- 65.

[5] Jawaid, M., & Khalil, H. P. S. A. (2011). "Cellulosic/synthetic fiber reinforced polymer hybrid composites: A review." Carbohydrate Polymers, 86(1), 1-18.

[6] Rahman, M. R., & Bakri, M. K. B. (2013). "Thermal conductivity and thermal expansion of natural fiber composites: A review." Journal of Reinforced Plastics and Composites, 32(15), 1003-1017.

[7] N.M. Stark, L.M. Matuana, Mater. Today Sustain 15, 100084 (2021).

[8] Primary, Secondary & Tertiary Packaging, Saxon Packaging.

[9] Bamboo-Nature's Eco-friendly Packaging Solution | Dell Dominican Republic.

[10] Flax bottle seeks to offer eco-friendly alternative for wine, beer and spirits.

[11] Enhancing Packaging Sustainability with Natural Fiber Reinforced Biocomposites: An outlook into the future by Vishal Srivastava, Sumer Singh and Dipayan Das.

[12] S. Vandelook, E. Elsacker, A. van Wylick, L. de Laet, E. Peeters, Fungal Biol. Biotechnol (2021).

[13] Satyanarayana, K. G., Arizaga, G. G. C., & Wypych, F. (2009). "Biodegradable composites based on lignocellulosic fibers—An overview." Progress in Polymer Science, 34(9), 982-1021.

[14] Joshi, S. V., Drzal, L. T., Mohanty, A. K., & Arora, S. (2004). "Are natural fiber composites environmentally superior to glass fiber reinforced composites?" Composites Part A: Applied Science and Manufacturing, 35(3), 371-376.

[15] Gañán, P., & Mondragón, I. (2004). "Surface modification of natural fibers for reinforcement in composite materials: A review." Polymer Composites, 25(1), 65- 78.

[16] Scelsi, L., Bonner, M., Hodzic, A., Hayes, S. A., & Njuguna, J. (2011). "A review on composite materials and environmental impact assessment." Composites Part B: Engineering, 43(1), 71-73.

[17] Sullins, T., Pillay, S., Komus, A., & Ning, H. (2017). "Hemp fiber reinforced polypropylene composites: The effects of material treatments." Composites Part B: Engineering, 114, 15-22.

[18] Khan, R. A., Kumar, R., & Khan, S. U. (2014). "Biodegradable natural fiber- reinforced polymer composites: A review." Polymer-Plastics Technology and Engineering, 53(5), 489-505.

[19] Asim, M., Jawaid, M., & Ishak, M. R. (2016). "The effect of alkali treatment on the mechanical properties of kenaf fiber and its reinforced composites: A review." Journal of Natural Fibers, 13(5), 529-541.

[20] Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011). "A review on the tensile properties of natural fiber reinforced polymer composites." Composites Part B: Engineering, 42(4), 856-873.

[21] La Mantia, F. P., & Morreale, M. (2011). "Green composites: A brief review." Composites Part A: Applied Science and Manufacturing, 42(6), 579-588.

[22] Song, Y. S., Youn, J. R., & Gutowski, T. G. (2009). "Life cycle energy analysis of fiber-reinforced composites." Composites Part A: Applied Science and Manufacturing, 40(8), 1257-1265.

[23] Kumar, R., & Prakash, O. (2018). "Environmental impacts of military building materials and the potential of natural fiber composites." Sustainable Materials and Technologies, 17, e00065.

[24] Khanna, R. K., & Maheshwari, S. (2016). "Natural fiber composites for green technology in military applications." Procedia Technology, 24, 380-389.

[25] Rahman, M., & Huque, M. M. (2014). "Use of jute fiber reinforced polymer composites as construction materials for low-cost housing and military shelters." Journal of Reinforced Plastics and Composites, 33(13), 1200-1208.

[26] Khan, R., & Roy, T. K. (2016). "Evaluation of jute as a sustainable roofing material for rural housing in Bangladesh." Environmental Engineering Research, 21(4), 329-335.

[27] Fiore, V., Scalici, T., Di Bella, G., & Valenza, A. (2015). "A review on basalt fiber and its composites. Part 1: Processing, properties and applications." Composites Part B: Engineering, 74, 74-94.
[28] Dhakal, H. N., Zhang, Z. Y., Richardson, M. O. W., & Errajhi, O. A. (2007). "The low velocity impact response of non-woven hemp fibre reinforced unsaturated polyester composites." Composites Part B: Engineering, 38(5-6), 675-680.
[29] . Shalwan, A., & Yousif, B. F. (2013). "In state of art: Mechanical and tribological behaviour of polymeric composites based on natural fibres." Materials & Design, 48, 14-24.
[30] Ramesh, M. (2016). "Hemp, jute, banana, and kenaf fiber-reinforced hybrid composites: A review." BioResources, 11(4), 11067-11104.
[31] Thakur, V. K., & Thakur, M. K. (2014). "Processing and characterization of natural cellulose fibers/thermoset polymer composites." Carbohydrate Polymers, 109, 102-117.
[32] Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). "Biocomposites reinforced with natural fibers: 2000–2010." Progress in Polymer Science, 37(11), 1552-1596.
[33] Baiardo, M., Frisoni, G., Scandola, M., & Rimelen, M. (2004). "Thermal and mechanical properties of plasticized poly(lactic acid)–hemp composites: A preliminary study." Polymer International, 53(6), 728-734.
[34] Venkateshwaran, N., Elayaperumal, A., & Sathiya, G. K. (2012). "Prediction of tensile properties of hybrid-natural fiber composites." Composites Part B: Engineering, 43(2), 793-796.
[35] M. J. John and S. Thomas, "Biofibres and biocomposites," *Carbohydrate Polymers*, vol. 71, no. 3, pp. 343-364, 2008.