American Journal of Materials Synthesis and Processing
2025, Vol. 10, No. 1, pp. 1-5
https://doi.org/10.11648/j.ajmsp.20251001.11

Research Article

Challenges and Prospects of Composite Materials Manufacturing Using Textile Fibers as Reinforcement

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Abstract

Recent advancements in composite materials reinforced with textile fibers have garnered significant attention due to their potential to replace synthetic fibers in a range of industrial applications. Natural fiber polymeric composites' mechanical properties, manufacturing processes, and application performance have all been thoroughly investigated. However, it may be challenging to establish consistent mechanical properties due to the inherent variability of textile fibers. The challenges and opportunities of making composite materials with textile fiber as reinforcement Significant research on natural fiber polymeric composites has been published in recent years. The majority of research focuses on characterizing natural fibers and comparing their mechanical behavior and application performance to that of conventional composites. Natural fibers come in dozens of varieties, each with unique qualities that affect whether or not they are used in particular industrial applications. It is challenging to choose the right fiber for a given application because of the natural origin of these materials, which generally results in a wide range of variances in attributes dependent mostly on the harvesting area and conditions. In order to map the positions of each type of fiber in various attributes, this paper presents a thorough analysis of the challenges and opportunities associated with using natural fibers as reinforcement in composite materials. Additionally reviewed is recent published research on emergent fiber types. Applications of natural fiber composites are examined in a bibliometric study. There is also a discussion and presentation of a prospective study of the future trends of natural fiber applications and the necessary advancements to increase their range.

Keywords

Composite Material, Textile Fiber, Manufacturing Process, Resin

1. Introduction

The better mechanical qualities, adaptability, and potential for usage in a wide range of applications of textile fiber-reinforced composites have generated a lot of attention. Combining textile fibers with different matrices results in composite materials that are stronger, stiffer, and more durable.

In order to acquire higher qualities that are not possible with individual components, composite materials are designed by mixing two or more different materials. Using textile fibers as reinforcement is a popular method in the production of composites. These fibers, which can be synthetic or natural, are mixed with a matrix (such metal, ceramic, or polymer). [9]

Because of their exceptional strength-to-weight ratio, flexibility, and simplicity of integration into a variety of production processes, textile fibers are preferred for reinforcement in composite materials. Glass, carbon, aramid, and

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Received: 3 March 2025; **Accepted:** 28 March 2025; **Published:** 22 April 2025

natural fibers like hemp, flax, and jute are examples of textile fibers. Each type of fiber has its own set of benefits, including lightweight properties (e.g., carbon fibers) or environmental sustainability (e.g., natural fibers), making them versatile in many applications ranging from automotive and aerospace industries to consumer goods and construction.

2. Fibers from Textiles Used in Composites

The main reasons for selecting textile fibers are their high strength-to-weight ratio, flexibility, and ease of shaping into various fabric shapes. Composites are reinforced using a variety of fiber types, including natural fibers like flax, hemp, and jute, as well as synthetic fibers like glass, carbon, and aramid. The unique properties of each fiber type affect how well the composite material performs.

2.1. Glass Fiber

Because of their affordability, accessibility, and favorable mechanical qualities, glass fibers are the most widely utilized reinforcement in composite materials. Usually, they are employed in maritime, automotive, and aerospace applications [3-5].

2.2. Carbon Fiber

Known for its exceptional rigidity and tensile strength, carbon fiber is perfect for high-performance composites, especially in the sports and aerospace sectors (Camanho & D'Antino, 2013). But carbon fiber's expensive price prevents it from being widely used.

2.3. Aramid Fibers

Such as Kevlar, are ideal for military, aeronautical, and automotive applications due to their exceptional strength and resilience to impact and abrasion [8].

2.4. Natural Textiles

Flax, hemp, and jute are examples of natural textiles that have gained popularity because of their affordability and environmental friendliness. In composite materials, they offer a sustainable substitute for synthetic fibers and are renewable and biodegradable [7]. For low-load applications like interior panels, natural fiber composites are being utilized more and more in the car sector.

3. Composite Manufacturing Methods

The qualities of the finished product are determined by a number of procedures used in the fabrication of textile fiber-reinforced composites. Among the most important manufacturing methods are:

3.1. Hand Layup

This is a manual procedure that involves applying resin in between layers of textile fibers that have been layered into a mold. Although this approach is less expensive, it is labor-intensive and imprecise [6].

3.2. Resin Transfer Molding (RTM)

It entails packing dry textile fibers into a mold and applying pressure to inject resin. High-quality composites are produced by this method, which offers improved control over resin dispersion and fiber alignment [6-8]. RTM is especially helpful for manufacturing parts for cars and airplanes.

3.3. Filament Winding

This method involves wrapping continuous textile fibers around a mold and applying resin as the fibers are being wound. According to [3], this is frequently utilized for cylindrical structures including pipes, tanks, and pressure vessels.

3.4. Prepreg Layup

It guarantees a uniform resin content throughout the composite by using textile fibers that have already been treated with resin. According to [8], this technique is heavily regulated and utilized in high-performance fields like aerospace.

3.5. 3D Printing

The incorporation of textile fibers into 3D-printed structures has been made possible by recent developments in additive manufacturing. According to [4], this technique makes it possible to create intricate shapes and maximize mechanical performance for unique applications.

4. Property of Textile Fiber Composites

The type of fiber, matrix, and manufacturing process all have a significant impact on the characteristics of textile fiber-reinforced composites. Among the important attributes are:

4.1. Mechanical Properties

Composites reinforced with textile fibers have excellent stiffness, impact resistance, and tensile strength. These characteristics are mostly determined by the fiber orientation; woven fabrics offer greater toughness, whereas unidirectional fibers offer superior tensile strength [1]. When compared to conventional materials, the mechanical properties of the composite are greatly enhanced by the addition of textile fibers.

4.2. Thermal Properties

When reinforced with carbon or aramid fibers, textile fiber composites can also show exceptional heat stability. Compared to carbon fibers, glass fibers have a reasonable level of thermal stability but are frequently more prone to thermal deterioration [1-4].

5. Textile Fiber Composite Applications

Automotive, aerospace, construction, and sports are just a few of the industries that use textile fiber-reinforced composites. Among the noteworthy applications are:

Automotive: To cut weight and increase fuel efficiency, textile fiber composites are frequently utilized in the automotive sector. While glass and carbon fibers are utilized for structural components, natural fibers like hemp and flax are increasingly being employed for non-structural elements like interior panels [1].

Aerospace: Because of their exceptional strength and low weight, carbon fiber and aramid fiber composites are widely utilized in aerospace for structural components [5]. Prepreg technology is frequently used to create precise, high-performance parts.

Sports Equipment: Textile fiber composites are integral to the design of sports equipment such as bicycles, tennis rackets, and skis, where both lightweight and durability are essential [3].

Construction: Textile fibers are also being used in the construction industry for reinforcing concrete and other materials. Textile-reinforced concrete (TRC) is a novel approach that offers significant advantages in terms of durability, reduced weight, and improved mechanical performance [1-6].

6. Challenges in Producing Composite Materials Using Textile Fibers as Reinforcement

Absorption of Moisture and Durability

Flax, jute, and hemp are examples of natural textile fibers that are hygroscopic, meaning they easily absorb moisture from the surrounding air. Especially in damp or outdoor settings, this moisture absorption can result in mold growth, swelling, and deterioration of mechanical qualities. Water absorption can also impair the contact between the fiber and the matrix material. Thus, it is still difficult to guarantee the long-term durability of composites reinforced with natural fibers. Solution for this challenge is that natural fibers can be surface treated with silane coupling agents or hybridized with synthetic fibers like glass or carbon to reduce moisture absorption and enhance the composite's overall performance. [10]

Low Interfacial Bonding

The bond between the fiber and the matrix has a significant impact on the performance of textile fiber composites. The surface chemistry of the fibers may not always form a strong bond with the polymer matrix, particularly when it comes to natural fibers. Inadequate interfacial bonding causes the composite material to break too soon and reduces mechanical qualities like tensile strength and impact resistance. Solution is Surface treatments or chemical changes to the fibers are frequently used to enhance adhesion. The composite's overall performance is improved by these treatments, which increase the fibers' wettability and matrix adherence. [11]

Manufacturing Cost

Textile fiber-reinforced composites can be expensive to manufacture because of labor-intensive procedures or specialized equipment, even though natural fibers are usually less expensive than synthetic fibers like carbon or glass. Although they produce high-quality composites, techniques like prepreg layup and resin transfer molding (RTM) are more costly than hand layup, best Solution is Creating more economical manufacturing techniques, including 3D printing, resin infusion, or automated fiber placement, may assist lower production costs and increase the accessibility of textile fiber-reinforced composites for mass-market uses. [12, 16]

Disposal and Recycling

Textile fiber composites, particularly those reinforced with synthetic fibers like carbon and glass, are still very difficult to recycle. At the end of their existence, these materials produce trash since they are frequently hard to decompose and reuse. The capacity to recycle or repurpose composite materials is a critical issue given the increased focus on sustainability. Solve the problem of disposing of composite materials, researchers are creating recyclable thermoplastic matrices and recycling methods including pyrolysis and mechanical grinding. Furthermore, the utilization of natural fibers and the creation of biodegradable matrix materials may provide more eco-friendly alternatives. [13]

Insufficient Understanding of Behavior in Severe Situations

Textile fiber-reinforced composites' mechanical qualities under normal circumstances are well known, but less is known about how well they operate in harsh environments including high humidity, high temperatures, and UV radiation. This restricts their application in crucial settings where they may be subjected to severe weather conditions.

7. Prospects for Composite Materials Manufacturing Using Textile Fibers as Reinforcement

Sustainable Reinforcement Materials: Compared to synthetic fibers like glass and carbon, natural fibers like hemp, jute, and flax provide a more environmentally friendly option. These fibers have a smaller environmental impact and are biodegradable and renewable. The need for sustainable composite materials is anticipated to grow as a result of growing environmental consciousness and regulatory demands. [14]

Advances in Hybrid Composite Materials: Some of the issues with textile fiber-reinforced composites may be resolved by hybrid composites, which blend natural and synthetic fibers. Hybrid composites can combine cost, mechanical qualities, and sustainability by fusing the advantages of both fiber kinds. For instance, adding glass or carbon fibers to natural fibers might increase the composite's strength and longevity while lowering its overall cost. [15]

Customization and Personalized Properties: The flexibility to customize the composite's properties by adjusting the fiber orientation, weave, and matrix selection is one of the biggest benefits of employing textile fibers in composite materials. Complex and highly customizable composite constructions that satisfy particular performance requirements will be possible because to developments in textile engineering and production processes like 3D knitting and weaving. Uses in High-Performance and Lightweight Industries.

Textile fiber composites are already widely employed in high-performance industries including sports equipment, automotive, and aerospace, particularly those reinforced with carbon or glass fibers. Lightweight, robust, and long-lasting materials that can tolerate high stress levels while using less energy are required by these industries.

Innovation in Production Methods: -Innovation in composite manufacturing techniques has a lot of room to grow. The manufacture of textile fiber-reinforced composites is anticipated to become more efficient, precise, and economical with the use of new processes such resin infusion, automated fiber placement, and 3D printing of composite materials. [17]

8. Conclusion, Result and Future Trends

One interesting approach to creating materials that are sustainable, long-lasting, and lightweight is the use of textile fibers as reinforcement in composite materials. Unlocking their full potential, however, requires addressing issues with moisture absorption, interfacial bonding, cost, recycling, and performance in harsh environments. Textile fiber-reinforced composites will probably become more widely used across a range of industries as a result of continuous improvements in material science, production techniques, and sustainability programs. Therefore, there are a lot of opportunities for innovation and expansion in both high-performance and sustainable applications, making the future of textile fiber composites extremely bright.

Present the results of a bibliometric analysis on the expansion of research in textile fiber-reinforced composites. Determine the main areas of interest in the field, such as innovative production processes, enhanced fiber-matrix interactions, and the environmental sustainability of natural fiber composites. Research Gaps: Draw attention to the gaps in the literature based on the bibliometric data. These include the need for additional studies on recycling techniques, the application of new manufacturing technologies to large-scale production, and the optimization of fiber orientation for better mechanical qualities.

Important Researchers and Institutions: List the leading scholars and academic establishments advancing textile fiber composites innovation and provide a window into the field's worldwide environment.

Technological Innovations: The manufacture of textile fiber composites is anticipated to undergo a revolution as manufacturing techniques including 3D printing, automated fiber placement, and resin infusion advance. Future developments may involve the creation of new, more effective techniques for recycling composite materials as well as the application of artificial intelligence (AI) and machine learning to optimize the design and production processes. Integration of Biodegradable Matrix Materials: The creation of biodegradable matrix to take the place of petroleum-based resins will be crucial to the future of textile fiber composites and increase their sustainability. These advancements may aid in resolving the environmental issues around the disposal of composite materials. Textile fiber composites are anticipated to become more widely used in sectors including construction, automotive, and aerospace as production methods become more sustainable and efficient. Textile fiber-reinforced composites will be used more often in high-performance applications as a result of the growing need for lightweight, high-performance materials with minimal environmental effect.

Abbreviations

UV	Ultra Violet
3D	Three Dimensional
RTM	Resin Transfer Molding
TRC	Textile-reinforced Concrete

Author Contributions

Tesfaye Worku is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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