



From Textile to Structure: Advancing Sustainability in Construction Practices

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Abstract

The construction industry, with its significant environmental footprint, is increasingly turning towards sustainable practices to mitigate its impacts. This article explores the potential of integrating textile materials into construction processes to enhance sustainability. Textiles offer versatility, lightweight properties, and potential for recycling, making them a promising alternative to traditional construction materials. Through a review of current research and innovative case studies, this paper examines the application of textiles in various construction contexts, including structural components, insulation, and façade systems. Additionally, it investigates the environmental benefits associated with utilizing textiles in construction, such as reduced carbon emissions, energy consumption, and waste generation. Furthermore, challenges and opportunities in implementing textile-based construction methods are discussed, including material durability, cost-effectiveness, and regulatory considerations. By highlighting the advancements and possibilities in textile-based construction practices, this article contributes to the discourse on sustainable construction methodologies, providing insights for practitioners, researchers, and policymakers seeking to foster greener approaches within the built environment.

Keywords: Composites; Construction; Properties; Sustainability; Textile Wastes.

1. Introduction

Sustainability has emerged as a paramount concern globally, particularly within the textile industry. The imperative for sustainability spans across all products in response to the rapid pace of modernization. Studies reveal that the textile industry ranks as the second-largest polluter worldwide. India stands out as a major exporter of textile products, contributing to approximately 5% of greenhouse gas emissions. Similarly, in Europe, textile consumption has been identified as the fourth-largest contributor to climate change, underscoring the urgent need for sustainable practices within the industry [5, 6]. In terms of consumption, the apparel industry accounts for a sizable portion of the worldwide fiber market—more than 55%. In 2018, the amount of synthetic fiber consumed worldwide greatly outweighed that of natural fiber, accounting for about two thirds of

the total consumption¹. Although wastes from the textile industry are unwanted, they are unavoidable consequences of many industrial processes, and they frequently go unappreciated and undervalued economically [1, 2]. Although many brands are concentrating on sustainable production for freshly Manufacturing products, the solutions for textile waste that has already been established is less. So, in the realm of construction, the integration of textile waste into composite materials has emerged as a versatile and promising solution, offering a myriad of benefits in terms of sustainability, performance, and cost-effectiveness. With textile waste ranking as the second most-discarded waste globally, its utilization as a building material presents an opportunity to repurpose and add value to this abundant resource. The focus on sustainability in supply chain management has



indeed become a prominent paradigm shift in recent years. It highlights the three key dimensions of sustainability that are crucial for modern supply chains: social, economic, and environmental [17]. This introduction delves into the multifaceted advantages of incorporating textile waste into composite materials for construction applications. Textile fibers, known for their reinforcing properties, have found particular utility in enhancing the mechanical properties of concrete. Even in small dosages, these fibers contribute significantly to the resistance against flexural and compressive stress, thereby improving the overall strength and durability of concrete structures. Various types of textile waste fibers, including polypropylene, cotton, and nylon, have been investigated for their efficacy in reinforcing concrete, showcasing remarkable improvements in tensile strength and toughness. The characteristics of reinforced composite materials play a pivotal role in determining their performance and suitability for construction applications. Hybrid composites, combining textile waste with materials like glass UD preform and jute nonwoven fabric, have demonstrated superior tensile strength compared to conventional composites. Moreover, advancements in water absorption characteristics and durability properties further underscore the potential of textile waste-based composites in construction materials. Research efforts have also focused on evaluating the viability of textile waste fibers as reinforcement in cement-based composites. Findings indicate that an optimum dosage of textile waste fibers can significantly enhance compressive strength, stiffness, and durability properties, positioning them as promising alternatives to conventional reinforcement materials like Kraft Pulp pine Fiber (KPF). Beyond their technical merits, composite materials derived from textile waste offer economic and ecological benefits. These materials are often low-cost, lightweight, and exhibit properties akin to conventional construction materials, making them suitable for various applications ranging from furniture items to infrastructure projects. This paper refers to the point that the integration of textile waste into composite materials represents a

paradigm shift in construction practices, offering a sustainable solution that addresses environmental concerns while meeting performance requirements. However, further research and collaboration among stakeholders are essential to overcome existing challenges and catalyse the widespread adoption of these innovative materials in the construction industry [2- 5].

2. Textile Industry Wastes and its Management

The textile industry indeed generates significant amounts of solid waste, which can have adverse effects on the ecosystem. This waste includes spinning wastes and Clothing wastes which resulted in landfills, resource depletion and pollution. The carpet industry, in particular, contributes substantially to textile waste generation. In the United States, about 1.4 million tons of fibers, such as nylon, polyolefin, polyester, and wool, are utilized annually for carpet production. As carpets typically have a lifespan of 5–10 years before replacement, the disposal of old carpets adds significantly to textile waste. In the US alone, this replacement cycle contributes 2–3 million tons of waste annually, while globally, it amounts to 4–6 million tons [7]. The issue of multi-material end-of-life textile waste presents a significant challenge for the European Union's goal of achieving a circular economy. Unlike discrete fibrous waste, which can be processed using mechanical and chemical methods for recycling, multi-material textiles and blended fabric wastes pose complexities in utilization. Traditional recycling techniques like mechanical shredding or chemical feedstock recovery are ineffective for multi-material waste due to the difficulty in separating different types of fibers and the unsustainable nature of chemical processes. However, there is potential for novel recycling techniques to address this challenge, whether through physical, chemical, or biochemical means [8]. In order to recycle the textile wastes the technologies used are categorized as primary, secondary, tertiary, and quaternary approaches. The primary approach is recycling textile products into their original forms. The secondary recycling involves cutting and shredding textiles to produce new yarns or products at lower quality. The tertiary



recycling utilizes processes like pyrolysis and hydrolysis to break down textile products into their constituent chemicals, monomers, or fuel. The Quaternary Recycling method focuses on waste-to-energy conversion, utilizing the calorific value of textile waste for energy generation [7]. The European Council introduced certain policies like EPR, Closed loop recycling. The Asian countries also took initiatives like Ecomark India, China Water Advisory Services Project [9].

3. Textiles in Construction: A Versatile Solution

The utilization of textile waste as a component in composite materials for construction offers numerous advantages, both in terms of sustainability and performance. Textile waste, being the second most-discarded waste, has gained attention as a prospective building material. It shows potential as a secondary raw material for developing composite materials in the construction sector. Textiles has reinforcing Properties which are used in Concrete. The plain concrete does not have that much tensile strength [10]. Textile fibers act as reinforcements in concrete, contributing to increased resistance against flexural and compressive stress. Even a small dosage of fibers during mixing can substantially enhance the mechanical properties of concrete, including compressive strength, flexural toughness, and tensile strength. Different types of textile waste fibers, such as polypropylene, cotton, nylon, etc., have been studied for their effectiveness in improving concrete properties. For example, recycled nylon fibers from waste fishing nets increased the tensile strength of cement mortars by 35% and its toughness by 13 times. Several factors influence the mechanical properties of composite materials, including the reinforcement-matrix interface, fiber content, and aspect ratio. Proper selection and processing of textile waste fibers are crucial for achieving desired performance in the resulting composites⁴. Textile-based composites have garnered significant attention over the past two decades, finding applications in both the construction of new structural elements [18,3] and the strengthening of existing structures [11,12]. These composites, such as Textile Reinforced

Concrete (TRC), offer enhanced properties including increased flexibility and fire resistance. As a result, TRC is increasingly favoured for strengthening existing structures over the more commonly used fiber-reinforced polymer (FRP) materials.

4. Methodology

The textile waste reinforcement tests have been adopted for different types of materials. In this, we have chosen three methods from different authors. This process gives a review of the suitable adoption of methods for the construction purpose. The details of the methods are as follows:

4.1. Method 1

In this method, we have taken the reference for the Textile Reinforced Concrete and its properties from different authors.

4.1.1. Textile Reinforced Concrete (TRC)

According to Anjana Elsa Alexander et al., 2020, Textile Reinforced Concrete (TRC) is a composite material consisting of fine-grained mortar combined with high-strength textile fabrics as reinforcement. The textile fabrics typically comprise multifilament yarns with high tensile strength, commonly made from materials such as carbon, basalt, alkali-resistant glass, or various polymer materials. It has the characteristics of reinforcement and mechanical properties with the advantage of high tensile strength, corrosion resistance and durability. It finds its applications in the lightweight structural elements in the construction process and also in repairing process. fibers such as carbon, alkali-resistant (AR) glass, basalt, and aramid are commonly used in the manufacturing of textile materials due to their unique properties and suitability for various applications such as Carbon fibre, AR Glass fibre, Basalt fibre, Aramid fibre [9] (Anjana Elsa Alexander et al., 2020).

a) Glass Fibers:

The basic ingredient is silica (SiO_2), with other oxides added to modify the network structure. It has the properties like amorphous and isotropic. The most widely used type is E-glass, which has high electrical resistivity but is sensitive to alkaline environments. To enhance alkali-resistance, zirconia (ZrO_2) is added, making the fibers suitable

for applications like Textile Reinforced Concrete (TRC) due to their good adhesion properties in cement matrices [11] (Thanasis Triantafillou et al., 2006). The Glass Fiber Reinforced Concrete (GFRC) exhibited lower slump values compared to Basalt Fiber Reinforced Concrete (BFRC). Slump is a measure of the consistency and workability of fresh concrete; lower slump values indicate less workable and stiffer concrete mixes Figure 1 [13] (Jawad Ahamed et al.,2022). GF exhibited a superior improvement effect on water absorption compared to PPF. the water/binder ratio plays a crucial role in determining the optimal fiber content and influencing the water absorption properties of fiber-reinforced concrete mixes [14] (Zhu Yuvan et al.,2021).

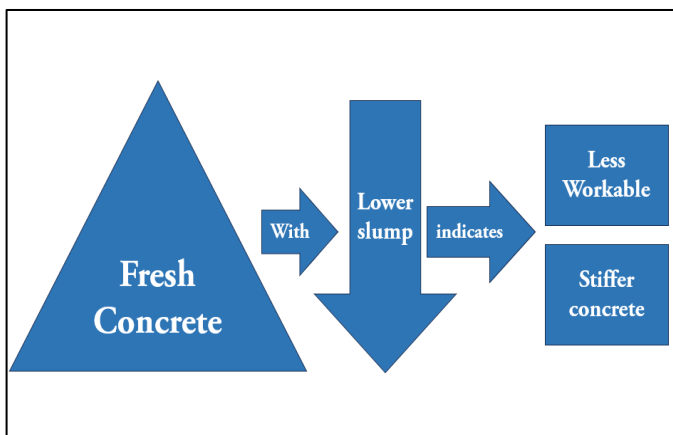


Figure 1 Workability of Fresh Concrete

b) Basalt Fibres:

Basalt textile, consisting of roving's woven in two principal directions, is applied as internal reinforcement in the concrete. It is coated with a styrene-acrylic latex coat. The warp basalt fiber bundles are arranged along the loading direction to act as load-bearing fibers. Tensile tests on textile strips were conducted to determine their mechanical characteristics. The tests were performed on strips with dimensions of 100 mm (length) x 40 mm (width) and consisted of eight warp fiber bundles. Chopped steel fibers, coated with copper, are known for their superior mechanical properties, including high tensile strength and high Young's modulus. Adding these fibers to the concrete matrix can improve the tensile properties of the concrete and

enhance the bond performance between textiles and matrix (John Branston et al., 2016). Both basalt textile and chopped steel fibers are being utilized as internal reinforcements in concrete to enhance its mechanical properties, particularly tensile strength and interfacial bond performance. These reinforcements offer promising opportunities for meeting the increasing demands of the construction industry. Increasing the number of textile layers improves the flexural strength and toughness of BTRC specimens. Multiple cracking behaviour is observed in specimens with two to five layers of textile, mainly in the pure flexural zone. More layer's result in a higher crack number and reduced crack spacing. The increase in textile layers slightly affects pre-cracking flexural stiffness but increases post-cracking flexural stiffness. Prestressing the textile enhances the first-crack flexural stress and pre-cracking flexural stiffness of BTRC Figure 2. However, higher prestress levels lead to decreased flexural strength, ultimate deflection, and toughness. Controlling prestress within an appropriate level is crucial to protect the deforming capacity from deterioration. Adding chopped steel fibers improves the first-crack flexural stress, flexural strength, and toughness of BTRC. The effect of steel fibers on flexural strength becomes more significant with increasing prestress levels. Specimens with steel fibers exhibit multi-crack patterns. Formulas for calculating the flexural strength of non-prestressed BTRC without chopped steel fibers are presented based on the plane section assumption. However, there are limitations such as static loading at room temperature, which may not be applicable to other temperature conditions or dynamic loading scenarios [10] (John Branston et al., 2016).

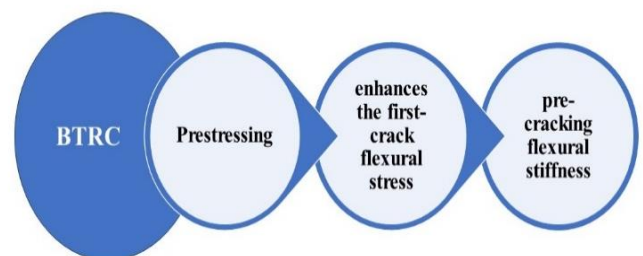


Figure 2 Prestressing

4.2. Method 2

The reference for this method is adopted for Recycled Nylon Fibers and its properties (Saverio Spadea et al., 2015).

4.2.1. Recycled Nylon Fibers

Saverio Spadea et al., 2015 states that R-Nylon fibers can be safely used as reinforcement in cement materials. They exhibit adequate alkali resistance according to recognized standards. They significantly improve the tensile strength (up to +35%) and fracture properties of cement mortars. The inclusion of R-Nylon fibers transforms the failure mode of mortar from brittle to ductile. A higher percentage of fibers (1.5% compared to 1.0%) results in a less noticeable drop in load after the peak value. Higher fiber aspect ratios lead to a hardening-type post-peak behaviour in the reinforced mortar. Increasing the percentage of fibers and fiber length results in remarkable increments in toughness indices and residual strength factors.

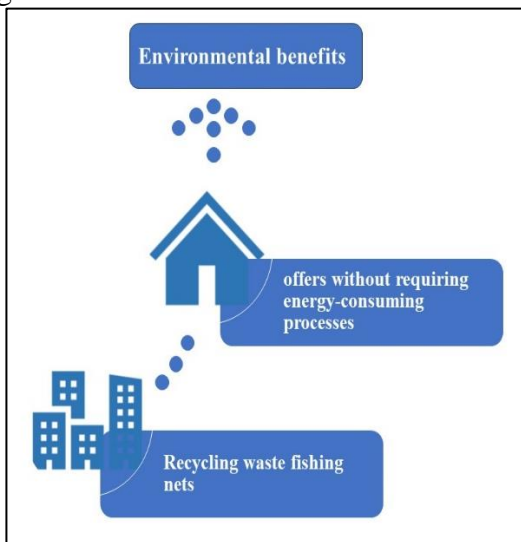


Figure 3 Recycling Waste Fishing Net

The addition of recycled reinforcing fibers significantly benefits the toughness and ductility properties of mortars and concretes. R-Nylon fibers demonstrate superior effectiveness compared to recycled nylon fibers from post-consumer textile carpet waste and recycled PET fibers. R-Nylon fibers show greater improvements in first-crack

strength and compressive strength compared to industrial nylon fibers analysed in previous studies. Recycling waste fishing nets for reinforcement offers environmental benefits without requiring energy-consuming processes like material re-polymerization or extrusion Figure 3. The process involves simple steps such as collection, washing, and cutting of fishing nets, resulting in reduced costs and energy consumption [15] (Saverio Spadea et al., 2015).

4.3. Method 3

This method follows the reference (Belay Taye Windmagegnehu et al., 2021) for the properties of hybrid composites.

4.3.1. Hybrid Composites

Belay Taye Windmagegnehu et al., 2021 says that the combination of two different materials makes these hybrid composites versatile in engineering and technology applications, particularly favoured for weight reduction in industries like automobile and construction. Hybrid composite materials offer a combination of desirable properties such as lightweight, high strength, and cost-effectiveness. These materials find extensive use in various engineering applications due to their versatile properties and ease of construction. Void contents and density in composite materials significantly affect their mechanical properties. Mechanical tests including tensile, flexural, and impact strength evaluations help determine the quality of composites. Glass fiber-only composite exhibits the smallest Young's modulus, indicating lower stiffness compared to hybrid composites. Flexural strength of T/G/T and G/T/G composites are measured at 131.91 MPa and 173.1 MPa, respectively, indicating the influence of fiber arrangement on mechanical properties. Impact strength of textile waste fabric decreases with increasing glass fiber content, while stiffness decreases simultaneously. Water absorption properties vary among composite variants, with the G/T/G hybrid composite showing the highest water absorption. Glass fiber-only composite exhibits the highest percentage of thickness swelling compared to hybrid and textile-only composites. The water absorption characteristics vary depending on the

composition of the hybrid composite Figure 4, with the G/G/G composite showing the smallest water absorption in salt solution [16] (Belay Taye Windmagegnehu et al., 2021).

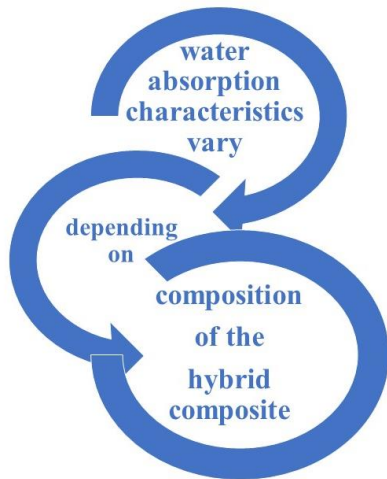


Figure 4 Hybrid Composites

5. Results and Discussions

To determine the best method to adopt, we need to consider several factors such as the specific requirements of the project, the properties of the materials, cost-effectiveness, ease of implementation, and environmental considerations. Let's evaluate each method based on these criteria:

5.1. Results

- **Textile Reinforced Concrete (TRC)** offers high tensile strength, corrosion resistance, and durability. It can be used for lightweight structural elements and repair processes according to Anjana Elsa Alexander et al., 2020. It uses various types of fibers such as carbon, basalt, alkali-resistant glass, and polymers.
- **Recycled Nylon Fibers** offers good tensile strength improvement and fracture properties in cement mortars according to Saverio Spadea et al., 2015. It provides environmental benefits through the recycling of waste materials. It can be used as reinforcement in cement materials with satisfactory results.
- **Hybrid Composites** offers a combination of desirable properties such as lightweight, high strength, and cost-effectiveness according to

Belay Taye Windmagegnehu et al., 2021. It is versatile in engineering and technology applications, favoured for weight reduction. It can utilize various combinations of materials to achieve desired properties.

5.2. Discussions

- In **TRC**, the challenges to be considered are the careful selection of fiber types and fabric geometry. It may have limitations in terms of compatibility with specific environments or applications. TRC is suitable for projects where high tensile strength, corrosion resistance, and durability are crucial, such as lightweight structural elements or repair processes. It may be particularly beneficial in environments where traditional reinforcement materials like steel are prone to corrosion.
- **Recycled Nylon Fibers** may require careful consideration of fiber content and aspect ratios for optimal performance. It has potential variations in material properties based on the source of recycled fibers. Recycled nylon fibers are suitable for projects where environmental sustainability and good tensile strength improvement in cement materials are important considerations. They may be particularly suitable for projects aiming to reduce the environmental impact through the use of recycled materials.
- **Hybrid Composites** needs a careful selection and optimization of fiber types and composite configurations. It may have variations in mechanical properties depending on the composition and manufacturing process. Hybrid composites are suitable for projects where a combination of properties such as lightweight, high strength, and cost-effectiveness is desired. They may be particularly suitable for applications in industries like automobile and construction where weight reduction is a key consideration.

Conclusion

It is concluded from the findings that each and every method has its own benefits. Depending on the need, any of these methods can be adopted. It is seen that



the all the three methods of reinforcements with textile wastes have a high tensile strength. But for the prevention of corrosion, from the findings we may say that the Textile Reinforced Composites are the suitable ones, especially replacing the steel. In the case of reducing environmental impacts, its optimal to utilise the Recycled Nylon fibers. This also gives good tensile strength to the cement materials. For the factors, when considering weight and cost, its optimal to embrace the hybrid composites as they are light in weight with high tensile strength. While the data presented may not confirm our initial hypotheses, it provides valuable insights into textile waste utilization in constructions and underscores the complexity of the composite production. These findings challenge existing assumptions and highlight areas for further investigation. By embracing and thoroughly analysing these reviews, we can refine our understanding and pave the way for more comprehensive and nuanced research in the future. Thus, we conclude that identifying these factors for sustainability may be the best solution for the environmental pollution and landfills.

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