Review Article

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Study on the Usage of Synthetic and Natural Fibres in Construction: A Systematic Review

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ABSTRACT

Generally, more and more alternative materials have been explored by the construction industry to improve sustainability, reduce its influence on the environment, and increase the effectiveness of building procedures. In construction materials, fibers are employed for a very long time. Previous research and investigations have revealed promising results regarding the use of Natural Fibres (NFs) and Synthetic Fibres (SFs), highlighting their significant benefits in enhancing the overall physical and Mechanical Properties (MP) of composite materials. Thus, this review aims to study the potential benefits and applications of SFs and NFs in construction. Moreover, the review investigates diverse types of fibers used like glass, carbon, jute, hemp, and sisal, and evaluates their contribution to concrete, plaster, insulation materials, and composites. This review provides valuable perceptions into the ongoing development of fiber-based construction materials by collecting recent studies and findings. This research is important because it has the potential to guide the industry toward more environmentally friendly and performance-oriented fiber materials, which will lead to more sustainable building practices. This study highlights the importance of continuing research into the optimization of fiber usage in construction, promoting innovations that can lead to more sustainable and cost-effective solutions in the construction environment.

Keywords: Synthetic fibers; Natural fibers; Construction materials; Sustainability; Fiber-reinforced concrete.

1. INTRODUCTION

Currently, the construction industry is witnessing the emergence of several advanced materials and innovative solutions. One such advancement is the use of Fiber-Reinforced (FR) materials, which are added to construction materials like concrete, asphalt, and masonry to improve their mechanical properties (MP) (Mohajerani *et al*. 2019). A category of composite plastics, which specifically employ fiber materials to mechanically augment the strength along with the elasticity of plastics, is FR materials like FR plastic polymer (FRP) (Abbood *et al*. 2021). Fibers are broadly classified as either synthetic or natural. Synthetic fibres include materials like carbon, glass, basalt, and aramid, while NFs include plant-based options like jute, hemp, and sisal, as well as animal-derived fibers (Thapliyal *et al*. 2023). Natural fibres are environmentally friendly when weighed against synthetic fibres (Mahir *et al*. 2019). Adding SF and NFs into construction materials stems from the need to develop sustainable solutions, reduce environmental impacts, and enhance material performance (Elfaleh *et al*. 2023).

Here, the study contributes to the growing corpus of research on FR materials by giving a deep review of SF as well as NF. The scope of the study includes an exploration of various types of fibers, their impacts on material strength and durability, and their potential for reducing carbon footprint. The motivation for the study is the growing need for sustainable and cost-effective alternatives in construction. Owing to the high carbon footprint of traditional construction materials and energy-intensive production processes, concrete and steel often have significant environmental impacts. This research is applicable in various sectors of the construction industry, including residential, commercial, and infrastructure projects. Fiber-reinforced materials can be used in concrete, asphalt, geotechnical applications, and road construction, as well as in enhancing the performance of non-structural elements. The behaviour of these fibers under extreme environmental circumstances remains a subject of an ongoing investigation, as the long-term implications of fiber reinforcement in construction materials are not yet fully understood. Despite these limitations, the potential benefits of utilizing fibers make this research a vital contribution to the future of sustainable construction.

2. LITERATURE SURVEY

In construction, the usage of SF and NFs has revolutionized building practices in the construction sector by enhancing material properties, promoting sustainability, and addressing environmental concerns. Synthetic fibres are highly valued because of their

excellent tensile strength (TS), resistance to moisture, and longevity. These fibers are essential for precast constructions, industrial flooring, and pavements because they increase the concrete's resilience to cracking and manage shrinkage. Equally, NFs stand out due to their biodegradability, environmental friendliness, and ability to insulate against both heat and sound. Their uses include composite materials, roofing components, insulation panels, and lightweight construction, making them a sustainable substitute for conventional materials. Yet, challenges persist with the integration of fibers into construction processes. Compatibility between fibers and building matrices can lead to inconsistent performance, while the long-term durability of FR materials remains an area of concern, especially under prolonged stress or environmental exposure.

2.1 Importance of Synthetic Fibers in Construction

In modern construction, SFs play a key role due to their ability to enhance material properties and improve structural performance (Nasir *et al*. 2022). The fibers, such as polypropylene, nylon, and polyester, are widely used for their durability, moisture resistance, and high TS. Synthetic fibres are effective in minimizing shrinkage cracking, increasing impact resistance, and improving the toughness of concrete (Zainal *et al*.2023). In slab-on-grade construction, SFs are often added to concrete to minimize early plastic shrinkage cracking and enhance abrasion resistance (Folorunsho *et al*. 2024). Additionally, SFs are used in precast concrete to improve handling stress resistance and in shotcrete to reduce material waste. The examples of SFs are explored in Fig. 1.

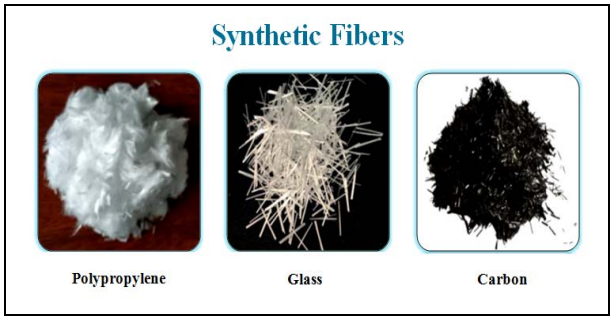


Fig. 1: Examples of synthetic fibers

Mechanical properties and durability assessment of nylon FR self-compacting concrete were explored by Ahmad *et al*. (2021). The durability of modified self-consolidating concrete reinforced with nylon fibers was assessed by employing water absorption, carbonation resistance, permeability, and acid attack resistance tests. Addition of nylon fibers enhanced resistance to all these tests. Similarly, the durability (mechanical property) of other SFs like basalts along with composites in corrosive environments was investigated by Qinyong *et al*. (2017). Accelerated experiments were conducted and the variation in tensile properties was studied using tension testing, scanning electron microscopy, mass loss measurements, and energy spectrum analysis. Basalt fibers exhibited strong resistance to water along with salt corrosion, and moderate resistance to acid corrosion, but experienced severe degradation in alkaline solutions. The hybrid effects of SF, specifically carbon fibres were examined in another study (Xiang *et al*. 2015) in relation to the MPs of Portland cement mortar. As per the laboratory test results, the hybrid fiber mix demonstrated enhanced tensile performance compared to the microfiber mix.

Also, MPs as well as the fracture behavior of similar carbon FR high-strength concrete were investigated by Kizilkanat *et al*. (2016) as experimental research. Compressive strength (CS), fracture energy, load-bearing capacity, together with toughness of concrete is augmented by carbon fiber. Significant SFs like polyvinyl alcohol, glass and polypropylene fibers were analyzed for their effects on structural integrity and cost efficiency (Labaran *et al*. 2024). Polyimide is a type of SF used in construction applications owing to its high (i) thermal stability, (ii) mechanical toughness and (iii) chemical resistance. To develop high-performance, robust, heat-resistant paper, Zhang *et al*. (2025) investigated polyimides and their melting points. This approach streamlines production by bypassing the conventional steps of aramid fiber pre-synthesis, fiber assembly, along with subsequent paper formation, resulting in a more efficient process with lower costs. Resultant cellulose paper exhibited exceptional mechanical, thermal and dielectric properties.

Wang *et al*. (2021) investigated the effect of combining macro polypropylene fibres with basalt fibres on the impact resistance of basalt FRP-reinforced concrete, treating them as a hybrid fibre system. This transformed the brittle failure mode into a well-ductile failure mode. Graphical techniques (that fit the '2' parameter Weibull models) were also employed for characterizing the first crack strength along with failure strength distributions. The combination of aramid and carbon fibres were investigated by Nie *et al*. (2019). This combination enhanced the CS, tensile strain, tensile toughness and TS of specimens. Moreover, the improvement became more pronounced as the fiber volume content increased. Wazerya *et al*. (2017) described that as the glass fiber content increases, there is significant enhancement in the mechanical properties of glass FR polyester composites. The mechanical properties of synthetic fibres discussed in the above research studies are given in Table 1.

The MP, chemical resistance, and challenges associated with different SFs used in composite materials or concrete mixes are discussed in Table 1. Nylon Fibers (NF) were added in varying proportions (0.5%–2%), and

they demonstrated reduced CS (25%–30% less than reference) and improved TS (10%–15%). Durability concerns arose, and advanced equipment was needed for evaluation. Basalt Fibers (BF) were tested under alkaline conditions. Basalt FR polymer (BFRP) exhibited superior TS compared to glass FR polymer (GFRP). It performed exceptionally well in corrosive environments. Carbon Fibers were incorporated in different configurations. Carbon fibers significantly enhanced TS (e.g., 4200–4550 MPa). However, fiber-matrix bonding and the impact of alkali environments posed challenges. PVA showed better CS, while PPF and PVAF offered better tensile properties. Hybrid fiber combinations introduced complexities in performance evaluation. Polyamide was blended into cellulose matrices. Polyamide fibers enhanced TS (125 MPa) but faced challenges in integration and compatibility. Aramid along with Carbon Fibers provided positive effects on TS but were difficult to disperse uniformly in cementitious matrices. Glass Fibers were economical and effective, and they provided CS up to 78.83 MPa even though there was poor bonding that limited their effectiveness. These findings indicated how SFs could enhance properties and highlighted the developments in the kinds of SFs in the construction sector.

Table 1: Values and mechanical properties outcomes attained in the discussed research studies for synthetic fibers

Synthetic Fiber	Mixing Materials Proportions /Mix Name	Compressive Strength	Tensile Strength	Permeability	Chemical Resistance	Specific Gravity	Cost Reduction	Lightweight	Challenges	Ref.
Nylon Fiber (NF)	Concrete mixes in a proportion of 0.5%, 1%, 1.5%, and 2% by weight of cement	25%–30% < the reference mix (7 days)	10%–15% of CS	Decreased as the percentage of NFs increased up to1.5%	Long-term Durability	-	-	Moderate	Access to specialized equipment for advanced analysis might also be limited.	(Ahmad *et al.* 2021)
Basalt fibers (BF)	20 different concrete samples	9.04%	17.42%,	-	-	-	-	Moderate	Corrosive environments vary widely from marine and industrial settings to chemical processing plants.	(Qinyong and Ying, 2017)
Carbon fibers	Control, 2% Micro, 2% Macro, 2% Hybrid and 4% Hybrid	Small and variable	4200–4550 Mpa	-	-	2.235 (Control) and 2.150 (2% Hybrid)	-	-	Fiber-matrix bonding strongly influenced mechanical properties, requiring investigation at both micro and macro levels.	(Xiang *et al.* 2015)
Carbon fibers	R CF0.25 CF0.50 CF0.75 CF1.00 (Mix name)	0.75% carbon fiber was 8.8% higher > plain concrete.	Increased with the increase in carbon fiber content	-	-	3.14	-	Moderate	The alkali environment in HSC could affect the durability of carbon fibers.	(Kizilkanat *et al.* 2016)
polyvinyl alcohol (PVA), glass, and polypropylene fibers	Control, PPF 0.25%, PPF 0.50%, PPF 0.75%, GF 0.5%, GF 1.0% and PVAF 0.75%	PVA: 0.5 mixture high (14-day)	PPF and PVAF: better tensile strength at 7 and 14 days,	Low water permeability	-	-	PVAF (high cost)	High	Hybrid effects or interactions between different fiber types could complicate the assessment.	(Labaran *et al.* 2024)
Polyamide	Cellulose 448 paper 1 (80 g/m²). Cellulose paper 2 (100 449 g/m²) and cellulose paper 3 (80 g/m²)	-	125 Mpa	-	-	-	40%	High	Achieving proper integration of polyimide into the cellulose matrix was challenging due to differences.	(Zhang *et al.* 2025)
Basalt Fibers (BF)	CEM I 42.5 390 kg/m3 , fly ash 155 kg/m3 , quartz sand with a particle size of 0-5 mm 822 kg/m3 ,water 272.5 kg/m3	PC: 37.9 MPF5: 35 MPF7: 38.5 MBF20: 28.5 MBF30: 24.2	About 1000 N/mm2	-	-	-	Efficient	High	Assessing how fibers influence the behavior of the concrete under dynamic loading conditions added another layer of complexity.	(Wang *et al.* 2021)
Aramid and carbon fibers	Mix AF1, AF2 and AF3. Mix CF1, CF2 and CF3	CF1, CF2 and CF3 :3.31%, 8.56% and 12.86%	Positive effect on tensile strength	-	-	-	-	-	Achieving uniform dispersion of aramid and carbon fibers in the cement matrix could be difficult.	(Nie *et al.* 2019)
Glass fiber	fiber percentages (15%, 30%, 45%, and 60% by weight percentage).	-	28.25 MPa to 78.83 Mpa	-	-	-	Very cost-effective	-	Poor bonding between glass and polyester could lead to reduced mechanical performance.	(Wazerya *et al.* 2017)

2.2 Importance of Natural Fibers in Construction

Due to the environmental benefits and practical applications of natural fibres, they are increasingly recognized for their significance in sustainable construction (Abdollahiparsa *et al*. 2023). Natural fibres like jute, coir, hemp, sisal, along with flax are biodegradable, lightweight, and cost-effective (Mahmud *et al*. 2025). In composite materials, these fibers could be used as reinforcements to enhance properties like TS along with thermal insulation while reducing the reliance on synthetic and non-renewable materials. Natural fibres also enhance the fire resistance along with crack prevention of construction materials, thus leading to greater durability and safety in buildings. Also, their production and application leave a lower carbon footprint compared to that of the prevailing construction materials, aligning with the global push towards green building practices (Tazmeen *et al*. 2024). The integration of NFs in construction presents a pathway for innovation while prioritizing environmental conservation and cost savings. A few examples of NFs are shown in Fig. 2.

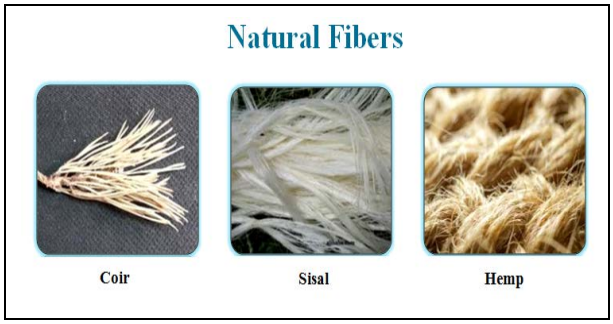


Fig. 2: Examples of natural fibers

The MP of continuous NF (Jute, Hemp, and Flax) was investigated by Awais *et al*. (2020). By employing woven fabrics (jute, hemp, and flax), constant NF Reinforced Polymer (NFRP) laminates were fabricated. For examining the MP of these laminates, tensile, flexural, and impact tests were conducted. The impact strength results for the control specimens revealed that flax woven laminates exhibited greater impact resistance compared to both hemp and jute woven laminates. In a study by Venkatesan and Bhaskar (2020), the abaca-sisal composite was the most significant NF other than flax and hemp. The hybrid composite's (HC) top and bottom layers encompass sisal fibers, while the center layer encompasses abaca fiber. These sisal and abaca HCs were fabricated in various orientations. The stated composite's low density and high TS made it suitable for lightweight structural elements. Another significant fiber was asbestos, which is used in construction for its insulation, fireproofing, and cement composite properties. The asbestos-related experimental analysis was discussed in a study by Chaudhary *et al*. (2017). Efforts were made to evaluate the impact of adding asbestos fiber to ordinary Portland cement concrete at its optimal proportions. Asbestos fibre reinforced concrete's CS marginally enhanced; yet, there was a key augmentation in the FS.

Moreover, Sahoo *et al*. (2022) investigated the performance evaluation of sisal fiber-based FR composites. The specimens were subjected to (i) hardness, (ii) density, and (iii) mechanical tests, including impact, flexural, together with tensile loading. The material fabricated with a specific percentage of reinforced sisal epoxide composites achieved the maximum possible hardness, FS, density, and TS. After exploring the significance of sisal fiber, it was felt essential to discuss another significant flax fiber, which was discussed in another research study (Javanshour *et al*. 2021). The transverse TS and in-plane tensile shear strength of the composites are minimized by the Cellulose Acetate-modification modestly. Other than flax and sisal fiber, the other significant NF was animal fiber, which was briefly illustrated in the research studies by Manivannan *et al*. (2022) and Rajesh *et al*. (2018). The sheep wool fiber was explored with a loading effect on mechanical behaviors (Manivannan *et al*. 2022). When analogized to other counterparts, the optimum sheep wool fibre reinforced polymer (SWFRP) composite sampl e recorded better flexural and impact strength. This was qualified for an enhanced fiber-matrix interfacial adhesion, as established by SEM micrographs. Thus, the SWF were suitable reinforcements meant for polymer composites; also, the SWFRP composites were potentially eco-friendly, sustainable, along with lower-cost materials for engineering applications. The tensile properties of animals along with hybrid FR polyester composites were explored in a study by Rajesh *et al*. (2018). The TS of goat wool reinforced polyester composite improved, while the % elongation at break of the goat hair fibre composite gradually declined.

Table 2. Outcomes of values attained in the mechanical properties of natural fibers

Natural Fibers	Materials/Materials Proportions	Compressive Strength	Tensile Strength	Elastic Modulus	Density	Elongation (%)	Flexural Strength	Challenges	Ref.
Hemp, Jute, Silk, Wool, Sisal, Flax, and Coir	-	-	Flas: 345–1830 Mpa, Hemp: 550–1110 Mpa, Jute: 393–800 Mpa, Silk: 100–1500 Mpa, Coir: 131–220 Mpa, and Sisal: 507–855 Mpa	-	Flas: 1.5, Hemp: 1.5, Jute: 1.5–120, Silk: Continuous, Coir: 20–150, and Sisal: 900	-	-	Large variations in natural fiber properties posed a challenge in accurately predicting the performance of NFRCs.	(Abdollahiparsa *et al.* 2023)
Jute, Hemp, and Flax	-	-	Flax: 40.7 Mpa (high)	Flax: 2732 Mpa (high)	2.45 ± 0.15 Ne	7 % in the warp and 7.2 % in weft direction of flax > hemp	up to 19 % (Flax)	Surface treatments or coupling agents were often required to enhance compatibility.	(Awais *et al.* 2020)
Abaca and Sisal fibers	-	-	0°:1.85 Mpa, 45°: 2.05 Mpa, and 90°: 2.05 Mpa	-	-	0°:5.17, 45°: 5.83, and 90°: 8.67	45 ° oriented fiber and 90 ° oriented fiber : Similar value	Achieving optimal alignment during fabrication could be complex.	Venkatesan and Bhaskar, 2020)
Asbestos	Cement: 1, Water: 0.45, Fine aggregate: 1.6805, Coarse aggregate: 2.9476, and Super plasticizer:0.01	0.33% addition of fiber	-	-	3 kN/m^3 to 8 kN/m^3	-	0.33% and 0.66% increased continuously	Use of asbestos raised environmental issues due to its non-biodegradable nature.	(Chaudhary *et al.* 2017)
Sisal	Sisal fiber, Epoxy resin, and hardener	-	Highest possible for the 20 wt% of the sisal fiber	Extreme for the composite formulated with ten wt % fiber	-	-	Highest for the composite formulated with 20 wt% fiber	Poor bonding between fibers could result in weak spots and reduced overall performance.	(Sahoo *et al.* 2022)
Flax	-	-	67 ± 2 Mpa at ±45◦	Similar in their value (a bit more than 4 GPa)	300 g/m^2	-	-	Addition of thermoplastic toughening agents could complicate the manufacturing process.	(Javanshour *et al.* 2021)
Wool	-	-	Lower tensile strength with 30 wt%	-	-	Higher elongation	Highest flexural strength of 25 MPa.	Determining the optimal fiber loading percentage was challenging.	(Manivannana *et al.* 2022)
Animal fibers like wool, feathers, hair, silk, and so on.	Cellulose, Lignin, Hemicellulose, and Wax	-	Goat hair polyester composite: fiber 7.5% (24.7 MPa)	Both Composites increased in fiber loading	Goat fiber: 0.73 and Madar fiber: 1.45	Goat hair fiber composite decreased. Also, the higher value of elongation was obtained at 2.5%	-	MP of the composite would be weakened and lead to swelling or degradation over time.	(Rajesh *et al.* 2018)
Sisal/Hemp	-	-	Weathered HCs decreased by 7% and 14%	Lower for Weathered HCs	Sisal fiber: 1450 (kg/m^3) and Hemp fiber: 1470 (kg/m^3)	Enhanced elongation	Lower for Weathered HCs	Predicting the long-term behavior of these composites under real-world conditions remained a challenge.	(Senthilkumar *et al.* 2020)
Sisal/flax	Low viscosity LY556 epoxy resin and HY951 hardener	-	165.2 N/mm^2 for the 40 S/0 F	-	-	9.20%	-	Ensuring the unidirectional alignment of fibers was challenging.	(Sundeep *et al.* 2022)

The combinational fiber of sisal and hemp (Senthilkumar *et al*. 2020) and sisal and flax (Sundeep *et al*. 2022) were investigated. In the study by Senthilkumar *et al*. (2020), the HCs subjected to weathering exhibited nearly the same impact strength as the pure sisal together with hemp-centric composites under impact loading. Centered on this finding, sisal/hemp fiber bio-epoxy-centric HCs were recommended for outdoor structural applications demanding impact resistance. Sundeep *et al*. (2022) found that the fabricated composites demonstrated enhanced thermal and MP properties, along with unique characteristics at varying flax fiber concentrations. The superior flexural and impact specimens were applied in civil engineering, storage devices, artificial bricks, mats, ceramic alternatives, defense and aerospace, airframes, helmets, radomes, along with insulation panels. Furthermore, it is crucial to discuss the MP of NFs, which are analyzed in detail in Table 2.

The TS values highlighted the superior performance of fibers like flax (345–1830 MPa) and hemp (550–1110 MPa) compared to others, such as coir (131–220 MPa). Flax composites showed high elastic modulus values (~2732 MPa) and up to 19% elongation, thus signifying their ductility and strength; but, they required surface treatments to enhance compatibility with matrices. For abaca and sisal fibers, alignment significantly affected mechanical performance, with 90° fiber orientation yielding the highest FS (8.67 MPa). Similarly, sisal fiber composites performed best with 20 wt% reinforcement; but, they were prone to weak spots due to poor bonding. Thermoplastic toughening improved the performance of flax composites but complicated manufacturing. Animal fibers, including wool and goat hair, offered unique elongation properties and moderate TS; but, they faced issues like inconsistent quality and moisture sensitivity. Hybrid composites like sisal/hemp encountered durability challenges under weathering, with performance reductions of up to 14%. Thus, these outcomes highlighted the need for advanced engineering techniques to optimize NF composites while explaining their inherent challenges.

2.3 Comparison of Usage of Synthetic Fibers and Natural Fibers

In construction, the usage of SF and NFs has distinctive advantages and challenges, influencing their applications (Silva *et al*. 2020). Synthetic fibres are hugely used in reinforced concrete, geotextiles, and insulation materials, thus offering consistent quality and predictable performance (Haghi *et al*. 2019). However, their production processes are energy-intensive, non-biodegradable, and contribute to environmental pollution, raising sustainability concerns. Natural fibres are renewable, biodegradable, and eco-friendly alternatives that support sustainable construction practices (Girijappa *et al*. 2019). These fibers are lightweight, cost-effective, and possess excellent thermal together with acoustic insulation properties.

In a research study by Calderon *et al*. (2022), sisal along with polypropylene FR concrete properties were compared and evaluated. Compression tests on cylinders along with flexural testing on prismatic samples were part of the former, while tests for ultrasonic pulse velocity as well as rebound number were part of the latter. According to the evaluations, sisal fiber produced more encouraging results, suggesting that NFs might be a more environmentally friendly substitute for plastic fibers because they offer a good mix of workability and strength. Similarly, in a study by Bambach *et al*. (2020), the structural compression characteristics of NF as well as SF-epoxy composites flax, jute, hemp, glass, along with carbon fibers were directly compared. Glass fiber composites exhibited superior tensile properties when weighed against NF composites. Yet, for the same fiber mass, the structural compression properties of NF composite channels were generally comparable to, and in some cases better than, those of glass fiber composite channels. In studies by Kumar and Singh (2015) and Mostafa *et al*. (2019), the MP and cost of glass/jute FR hybrid polyester composites, along with the MP of jute fiber-activated carbon-filled reinforced polyester composites, were analyzed comparatively. In a study (Kumar and Singh, 2015), the experimental results indicated that reinforcing NFs to a certain extent enhanced the MP and lowered the overall fabrication cost of the composites. Mostafa *et al*. (2019) revealed that the tensile moduli along with flexural moduli augmented with the addition of AC filler up to 3 wt%, after which they began to decline upon reaching their peak values.

In another study (Pradeep *et al*. 2015), the MP of jute fiber over glass and carbon FR polymer composites were investigated. It augmented the flexural along with the TS of jute textile FRP when jute fiber textile mats were subjected to heat treatment. From the experimentation on RC beams subjected to bending, the specimens strengthened with fully wrapped jute textile FRP, JF1, and JF2 demonstrated a significant strengthening effect. Pandey *et al*. (2015) compared jute fiber with glass fiber along with carbon FR plastic material composites for civil structures and Reddy *et al*. (2018) did a comparative evaluation of the MP of jute, pineapple leaf fiber, along with glass FR composites with polyester along with epoxy resin matrices. Jute fibre reinforced plastic exhibited the highest deformability index, confirming that jute textile FRP material holds great potential as a structural strengthening material (Pandey *et al*. 2015). As per study by Reddy *et al*. (2018), the jute, pineapple leaf fiber, along with glass FR epoxy composites displayed better MP than their polyester-based counterparts. Furthermore, the comparative evaluation of SF and NFs based on the outcomes is presented in Table 3.

Table 3: Comparative evaluation of synthetic and natural fibers based on the outcomes

Natural Fibers	Synthetic Fibers	Compressive Strength	Failure Strain	Elastic Modulus	Tensile Strength	Flexural Strength	Challenges	Ref.
Sisal	Polypropylene	Sisal: 29.3 ± 1.1 (28 days) and Polypropylene: 27.2 ± 0.8 (28 days)	-	-	Sisal: 3.7 ± 0.1 (28 days) and Polypropylene: 3.6 ± 0.1 (28 days)	Sisal: 4.5 ± 0.4 (Mpa) and Polypropylene: 4.5 ± 0.3 (Mpa)	Adding natural fibers like sisal into concrete required precise control of the mix design.	(Girijappa *et al.* 2019)
Flax, Jute, and Hemp,	Glass and Carbon Fibers	Moderate compression strength (Flax, Jute, and Hemp) and superior compression strength (Glass and Carbon Fibers)	Flax: 3.1, Jute: 1.6, Hemp: 1.8, Carbon:1.1, and Glass: 2.3	Flax: 6.03, Jute: 5.18, Hemp: 3.83, Carbon:72.9, and Glass: 22.9	-	-	Natural fibers offered sustainability benefits even though their compression strength often fell short of synthetic fibers like carbon and glass.	(Bambach, 2020)
Jute	Glass	-	-	-	45 N/mm^2 (Jute) for 40% reinforced and 85 N/mm^2 for 40 % reinforced	80 N/mm^2 (Jute) for 40% reinforced and 85 N/mm^2 for 40 % reinforced	Poor bonding in the fibers led to weak spots and reduced mechanical performance.	(Kumar and Singh, 2015)
Jute	Polyester	-	-	-	Polyester and jute/polyester specimens decreased; activated carbon particle loading increased.	Specimens decreased (polyester and jute/polyester)	Additional treatments and processing were required to enhance fiber-matrix compatibility.	(Mostafa *et al.* 2019)
Jute	Carbon	-	-	Carbon:240 Mpa and Glass: 73 Mpa	Jute:189 Mpa, Carbon:923 Mpa, and Glass: 678 Mpa	Jute: 208 Mpa, Carbon:1587 Mpa, and Glass: 666 Mpa	Poor adhesion led to delamination and reduced mechanical performance.	(Pradeep *et al.* 2015)
Jute	Carbon	-	-		JFRP:189.479 N/mm^2, CFRP : 923.056 N/mm^2, and GFRP: 678.571 N/mm^2	JFRP: 62.5%, CFRP : 150%, and GFRP: 125%	Natural fibers like jute varied in quality due to differences in cultivation and processing, thus leading to inconsistencies.	(Pandey *et al.* 2015)
Jute and Pineapple leaf fiber	Glass fiber	-	-	-	Polyester: 68.24 Mpa and Pineapple: Better tensile strength	Polyester: 232.85 Mpa and Pineapple: Better flexural strength	Fabrication of HCs required precise control to ensure uniform fiber distribution.	(Reddy *et al.* 2018)

The comparative evaluation of SF and NFs highlighted key differences in mechanical performance and sustainability. Moderate MP, including tensile and FSs, were provided by NFs like sisal, jute, flax, and hemp, with sisal showing CS (29.3 ± 1.1 MPa) comparable to polypropylene (27.2 ± 0.8 MPa). Jute demonstrated a TS of 189 MPa, which was significant but lower than carbon fibers (923 MPa) and glass fibers (678 MPa). Also, FS for NFs like jute reached 208 MPa, while carbon fibers showed FS of 1587 MPa. SFs, such as glass and carbon exhibited superior CS, failure strain, and elastic modulus, with carbon offering unmatched stiffness (elastic modulus: 72.9 GPa) compared to NFs like flax (6.03 GPa) and jute (5.18 GPa). Yet, NFs contributed to eco-friendly construction practices and offered sustainability benefits despite their limitations. Challenges include moisture sensitivity in NFs, causing swelling and degradation, and poor fiber-matrix adhesion leading to mechanical inconsistencies. In hybrid compositions, precise control was essential to ensure uniform fiber distribution and optimal performance, particularly with polyester and epoxy resin matrices. Synthetic fibres dominated high-performance applications due to their predictability and durability, while NFs required additional treatments to enhance compatibility and performance. This balance between sustainability and mechanical excellence indicated the importance of cost reduction, environmental impact, and engineering needs when selecting FR composites for construction projects.

3. CONCLUSION

This study explored the usage of SF and NFs in construction focusing on their potential to improve material properties and contribute to sustainable building practices. As per the results from the reviewed studies, SFs like glass and carbon enhanced the strength and durability of construction materials, while NFs, such as jute and hemp, offered sustainable alternatives that reduced environmental footprints. Mechanical properties like TS, flexibility, and crack resistance are augmented by fiber reinforcement, thereby increasing the longevity of building materials. These findings were significant because they present fiber-based solutions that addressed both the sustainability concerns and the performance needs of modern construction. The construction industry could potentially reduce its reliance on energy-intensive materials and enhance the overall environmental sustainability of buildings by incorporating NF and SFs. This analysis noted some limitations despite the encouraging results, such as the lack of long-term performance data on the application of FR materials, particularly in adverse weather conditions. Future studies can concentrate on creating standardized procedures for fiber reinforcing, thus examining the durability of fiber-based materials and evaluating the environmental effects and full lifecycle costs of both NF and SFs.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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REFERENCES

Abbood, I. S., Sief, A. O., Kamalaldin, F. H. and Mohammed, A. J., Properties evaluation of fiber reinforced polymers and their constituent materials used in structures – A review, *Mater. Today*., Proceedings, 43, 1-6(2021). https://doi.org/10.1016/j.matpr.2020.07.636

Abdollahiparsa, H., Ali, S., Patrick, T. and Rijk, B., A review of recent developments in structural applications of natural fiber-Reinforced composites (NFRCs), *Compos. Adv. Mater.*, 32, 1-18(2023). https://doi.org/10.1177/26349833221147540

Ahmad, F., Osama, Z., Fahid, A., Rebeca, M., Yasir, M, A., Mohamed, H. E., Ouni, R. F. and Ibrahim, A. S., Mechanical properties and durability assessment of nylon fiber reinforced self-compacting concrete, *J. Eng. Fibers Fabr.*, 16, 1-13(2021). https://doi.org/10.1177/15589250211062833

Awais, H., Yasir, N., Anjang, A., Hazizan, A. and Shukur, Z. A. M., Mechanical Properties of Continuous Natural Fibres (Jute, Hemp, Flax) Reinforced Polypropylene Composites Modified with Hollow Glass Microspheres, *Fibers Polym*., 21(9), 1-8(2020). https://doi.org/10.1007/s12221-020-2260-z

Bambach, M. R., Direct Comparison of the Structural Compression Characteristics of Natural and Synthetic Fiber-Epoxy Composites: Flax, Jute, Hemp, Glass and Carbon Fibers, *Fibers.,* 8(10), 62(2020). https://doi.org/10.3390/fib8100062

Calderon, A. S., Pablo, G., Natividad, G., Dan, V. B. and Jorge, F., Comparative Evaluation of Sisal and Polypropylene Fiber Reinforced Concrete Properties, *Fibers.*, 10(4), 35(2022). https://doi.org/10.3390/fib10040031

Chaudhary, R., Shahbaz, A., Varshney, K. P. and Nabiullah, K., Experimental Analysis of Asbestos Fibre Reinforced Concrete Composite, *J. Mech. Civ. Eng.,* 14(4), 18-22(2017). https://doi.org/10.9790/1684-1404021822

Elfaleh, I., Fethi, A., Mohamed, H., Furqan, A., Mohamed, G., Mondher, N. and Christian, G., A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials*, Results Eng.,* 19, 1-31(2023). https://doi.org/10.1016/j.rineng.2023.101271

Folorunsho, B. A., Seungwon, K. and Cheolwoo, P., A Review on the Performance of Fibers on Restrained Plastic Shrinkage Cracks, *Build.*, 14, 1-34(2024). https://doi.org/10.3390/buildings14082477

Girijappa, G. T. Y., Sanjay, M. R., Jyotishkumar, P. and Suchart, S., Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A Comprehensive Review, *Front. Mater.,* 6, 1-14(2019). https://doi.org/10.3389/fmats.2019.00226

Haghi, A. K., Experimental Analysis of Geotextiles & Geofibers Composites, *WSEAS Press*, 1-15(2019).

Javanshour, F., Prapavesis, A., Parnanen, T., Orell, O., Lessa, B. M. C., Layek, R. K., Kanerva, M., Kallio, P., Van, V. A.W. and Sarlin, E., Modulating impact resistance of flax epoxy composites with thermoplastic interfacial toughening, *Composites Part A*., 150, 1-11(2021). https://doi.org/10.1016/j.compositesa.2021.106628

Kizilkanat, A., Experimental Evaluation of Mechanical Properties and Fracture Behavior of Carbon Fiber Reinforced High Strength Concrete, *Periodica Polytechnica Civ. Eng*., 60(2), 289-296(2016). https://doi.org/10.3311/PPci.8509

Kumar, A. and Singh, S., Analysis of mechanical properties and cost of glass/jute fiber-reinforced hybrid polyester composites, Proc IMechE Part L: J Materials: *Des. Appl.,* 229(3), 1-7(2015). https://doi.org/10.1177/1464420713507915

Labaran, H. Y., Nihat, A., Mehmet, T. and Kemal, A., High-strength fber-reinforced concrete: assessing the impact of polyvinyl alcohol, glass, and polypropylene fbers on structural integrity and cost efciency, *Discover Civ. Eng.,* 1(37), 1-24(2024). https://doi.org/10.1007/s44290-024-00041-7

Mahir, I. F., Kamrun, N. K., Bijoyee, S., Khandakar., M. N. and Ruhul, A. K., A brief review on natural fiber used as a replacement of synthetic fiber in polymer composites, *Mater. Eng. Res.,* 1(2), 88-99(2019). https://doi.org/10.25082/MER.2019.02.007

Mahmud, A. Z., Fazle, R. M., Didarul, I. and Nayem, H., Synthesis and applications of natural fiber-reinforced epoxy composites: A comprehensive review, *SPE Polym.,* 6(1), 1-19(2025). https://doi.org/10.1002/pls2.10161

Manivannan, J., Rajesh, S., Mayandi, K., Rajini, N. and Sikiru, O. I., Animal fibre characterization and fibre loading effect on mechanical behaviours of sheep wool fibre reinforced polyester composites, *Nat. Fibre*s., 19(11), 4007-4023(2022). https://doi.org/10.1080/15440478.2020.1848743

Mohajerani, A., Siu, Q. H., Mehdi, M., Arul, A., Suksun, H., Aeslina, A. K., Tareq, R. and Farshid, M., Amazing Types, Properties, and Applications of Fibres in Construction Materials, *Mater.,* 12(16), 1-45(2019). https://doi.org/10.3390/ma12162513

Mostafa, H. N., Mustafa, B. H. and Alaa, J., Mechanical Properties of the Jute Fibers-Activated Carbon Filled Reinforced Polyester Composites, *Mater. Res. Express*, 6(12), 1-18(2019). https://doi.org/10.1088/2053-1591/ab5566

Nasir, A. M., Waqas, A., Kaffayatullah, K. and Ayaz, A., A Comprehensive Review of Types, Properties, Treatment Methods and Application of Plant Fibers in Construction and Building Materials, *Mater*., 15(12), 1-31(2022). https://doi.org/10.3390/ma15124362

Pandey, J., Shweta, G., Ramachandran, M. and Kanak, K., Comparison of jute fiber over glass fiber and carbon fiber reinforced plastic material composites used for civil structure, *IOJER*, 11, 1-5, (2015).

Pradeep, P., Edwin, R. D. J., Ramachandran, M. and Stanly, J. R. B., Mechanical Characterization of jute fiber over glass and carbon fiber reinforced polymer composites, *Int. J. Appl. Eng. Res*., 10(11), 1-5(2015).

Qinyong, M. and Ying, Z., Experimental research on the microstructure and compressive and tensile properties of nano-SiO_2 concrete containing basalt fibers, *Underground Space*., 2(3), 175-181(2017). https://doi.org/10.1016/j.undsp.2017.07.001

Rajesh, G., Hemanth, N. B. and Raja, C. C. G., Evaluating Tensile Properties of Animal and Hybrid Fiber Reinforced Polyester Composites, IOP Conf. Series *Mater. Sci. Eng*., 390, 1-8(2018). https://doi.org/10.1088/1757-899X/390/1/012011

Reddy, I. M., Prasad, V. U. R., Ajit Kumar, I., Manikanth, V. and Kumar, R. P. V., Comparative Evaluation on Mechanical Properties of Jute, Pineapple leaf fiber and Glass fiber Reinforced Composites with Polyester and Epoxy Resin Matrices, *Mater. Today Proc.,* 5(2), 5649-5654(2018). https://doi.org/10.1016/j.matpr.2017.12.158

Sahoo, G., Pradeep, G. M., Kamalakannan, R., Manivelmuralidaran, V. and Girimurugan, R., A process of analyzing the performance evaluation of sisal fiber in fiber reinforced composites, *Mater. Today*: *Proce.*, 56, 3201-3206(2022). https://doi.org/10.1016/j.matpr.2021.09.285

Senthilkumar, K., Thitinun, U. C. M., Senthil, M. K. T., Rajini, N., Suchart, S., Harikrishnan, P., Jyotishkumar, P. and Nadir, A., Performance of Sisal/Hemp Bio-based Epoxy Composites Under Accelerated Weathering, *J. Polym. Environ.,* 29, 1-13(2020). https://doi.org/10.1007/s10924-020-01904-7

Silva, G., Suyeon, K., Rafael, A. and Javier, N., Natural fibers as reinforcement additives for geopolymers – A review of potential eco-friendly applications to the construction industry, *Sustainable Mater. Technol.,* 23, 1-11(2020). https://doi.org/10.1016/j.susmat.2019.e00132

Sundeep, D., Eswaramoorthy, K. V., Daniel, E. S., Chandrashekara, S. C. and Gopala, K. A., Mechanical, morphological and thermal analysis of unidirectional fabricated sisal/flax hybrid natural fiber composites, Surface Topography: *Metrol. Prop.,* 10, 1-15(2022). https://doi.org/10.1088/2051-672X/ac5780

Tazmeen, T. and Fasil, Q. M., Sustainability through materials: A review of green options in construction, *Results Surf. Interfaces,* 14, 1-13(2024). https://doi.org/10.1016/j.rsurfi.2024.100206

Thapliyal, D., Sarojini, V., Pramita, S., Rahul, K., Amit, T., Anurag, K., Tiwari., Dhananjay, S., George, D. V. and Raj, K. A., Natural Fibers Composites: Origin, Importance, Consumption Pattern, and Challenges, *J. Compos. Sci.,* 7(12), 1-44(2023). https://doi.org/10.3390/jcs7120506

Venkatesan, K. and Bhaskar, G. B., Evaluation and Comparison of Mechanical Properties of Natural Fiber Abaca-sisal Composite, *Fibers Polym*., 21(7), 1-12(2020). https://doi.org/10.1007/s12221-020-9532-5

Wang, Q., Yining, D., Yulin, Z. and Cecilia, C., Effect of macro polypropylene fiber and basalt fiber on impact resistance of basalt FRP-reinforced concrete, *Struct. Concr.*, 22(1) 1-36(2021). https://doi.org/10.1002/suco.201900482

Wang., Nie, L., Jinyu, X., Xin, L., Haowen, C., Sen, C., Tengjiao and Gaojie, L., Study of aramid and carbon fibers on the tensile properties of early strength cement mortar, *IOP Conf. Series Earth Environ. Sci.,* 267(3), 1-10(2019). https://doi.org/10.1088/1755-1315/267/3/032009

Wazerya, M. S., EL-Elamya, M. I. and Zoalfakar, S. H., Mechanical Properties of Glass Fiber Reinforced ,lPolyester Composites, *Int. J. Appl. Sci Eng.*, 14(3), 121-131(2017). https://doi.org/10.6703/IJASE.2017.14(3).121

Xiang, S., Ryan, K. G., Baoshan, H. and Edwin, G. Burdette., Hybrid effects of carbon fibers on mechanical properties of Portland cement mortar, *Mater. Des.*, 65, 1222-1228(2015). https://doi.org/10.1016/j.matdes.2014.10.015

Zainal, S. M., Iqbal, S., Farzad, H. and Ala, M. A. M., Strengthening of Reinforced Concrete Slabs using Macro and Micro Synthetic Fibers, *Struct*., 51, 1-20(2023). https://doi.org/10.1016/j.istruc.2023.03.120

Zhang, Z., Junxian, Z., Shuang, Z., Haolan, L., Fuyu, Z., Yi, L., Hao, L., Gang, C. and Jinsong, T., A Simple and Cost-effective Method to Produce High-Performance Robust Heatresistant Paper by Directly Synthesizing Polyimide within Cellulose Paper Matrixes, *Chem. Eng. J.,* 508, 160885(2025). https://doi.org/10.1016/j.cej.2025.160885