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Review Article

Plant Fibres in Self-Compacting Concrete: A Literature Review on Mechanical and Thermal Reinforcement

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Abstract - *Self-compacting concrete is a construction material designed to fill complex and congested formwork without requiring vibrations to consolidate the mixture. This makes it particularly useful in situations where traditional compaction methods are impractical. It is commonly used in heavily reinforced structures where mechanical properties are crucial. To enhance these properties, different types of fibres are incorporated, creating a composite material with enhanced strength and durability for construction. This paper aims to evaluate the role of plant fibers in improving the performance of self-compacting concrete. First, it presents a comprehensive overview of this material, including its formulation methods. Then, the focus shifts to plant fibers, discussing their origins, chemical composition, physical characteristics, and mechanical properties. Various fiber extraction methods and treatment techniques are also reviewed, aiming to optimize their performance. Subsequently, the study examines the influence of several types of natural plant fibers on the mechanical and thermal behavior of self-compacting concrete. This led to the main purpose of this paper, which is to demonstrate that reinforcing self-compacting concrete with plant fibers yields positive results in various aspects, potentially providing a substitute for industrial fibers. Incorporating plant fibers, like jute, hemp, banana, and palm fibers, contributes significantly to self-compacting concrete's improved strength and insulation capacity. Banana fibers increased flexural strength by 42,59%, while 5% palm fiber reduced thermal conductivity by 73.4%, demonstrating excellent insulation properties. These results underscore the viability of plant fibers as renewable and environmentally friendly options instead of synthetic fibers, meeting the rising demand for energy-efficient and environmentally conscious construction materials.*

Keywords - *Self compacting concrete, Plant fibers, Fibers treatment, Mechanical properties, Thermal conductivity.*

1. Introduction

Given the increasing environmental awareness and the fact that the cement sector contributes between 5% and 8% of global CO_2 emissions [1], concrete is still the predominant material employed in construction [2]. There is an increasing push to reduce global pollution levels. As a result, consumers are increasingly prioritizing products with reduced environmental impact. In response to this shift, many materials science and engineering researchers have turned their attention to integrating agricultural and industrial waste, particularly natural fibers as partial or complete substitutes for traditional concrete components. Utilizing natural fibers, specifically plant fibers, in civil engineering has become increasingly widespread due to several advantages. These include the abundant availability of plant fibers derived from agricultural waste at a low cost, their biodegradability, which helps reduce environmental impacts, and their lower production energy requirements compared to industrial fibers [3, 4]. Integrating these fibers into concrete composites offers an environmentally friendly, sustainable, and economical replacement for traditional construction materials. When used as dispersed reinforcement in cement composites, natural fibers can significantly enhance the material's performance, offering strength comparable to artificial or metallic fibers.

Building on these inherent benefits, plant fibers have found diverse applications in civil engineering, highlighting their potential to enhance both performance and sustainability:

- Reinforcement in Concrete: Plant fibers like banana, jute, hemp, and sisal are utilized to improve tensile strength, ductility, and crack resistance in concrete. This not only enhances structural performance but also aligns with sustainability initiatives.
- Thermal Insulation: Plant fibers are incorporated into concrete due to their low thermal conductivity, improving energy efficiency by reducing heat transfer and contributing to comfortable indoor environments.
- Lightweight concrete Production: adding plant fibers reduces the overall density of concrete, enabling the

Production of lightweight materials suitable for non-structural and semi-structural applications, which are easier to handle and transport.

- Acoustic insulation: The sound-absorbing properties of plant fibers make them ideal for acoustic panels and soundproof construction materials, enhancing the functionality of spaces such as offices, theatres, and residential buildings.
- Eco-Friendly and Sustainable Construction: By substituting synthetic fibers with renewable plant fibers, the construction materials' carbon and ecological footprint is significantly reduced. This supports green building practices and minimizes carbon emissions.
- Precast components: Plant fibre-reinforced precast concrete elements such as panels, blocks, and tiles benefit from improved strength and reduced weight, enabling their adaptability in diverse uses, from decorative to structural uses.
- Durability improvements: Treated plant fibers enhance the durability of concrete by mitigating shrinkage cracks and increasing resistance to freeze-thaw cycles, ensuring greater resilience in diverse climates.

Using fibers in concrete is not a novel concept. Historically, the structures of traditional buildings were designed not only to withstand loads and external forces, but also to reduce energy consumption and enhance occupant comfort. Furthermore, numerous studies have shown that plant fibers possess excellent thermal insulation properties, making them highly suitable for improving the energy efficiency of construction materials [5-8]. Thanks to their inherent characteristics, like reduced thermal conductivity, lightweight nature, and wide availability, these fibers provide an eco-friendly and high-performance solution, meeting the growing demands for sustainability and thermal comfort in the construction sector. Beyond improving materials' structural and thermal performance, these fibers present a major economic advantage, with a significantly lower overall cost than traditional composites. They thus help reduce production costs while enhancing the performance of the materials [9].

Furthermore, employing fibers derived from agricultural waste provides an effective solution for recycling these residues, which are often disposed of through incineration, a practice that generates smoke and dust, contributing to air pollution. By incorporating these fibers into concrete, not only is the environmental impact of their disposal reduced, but a practical recycling method requiring minimal processing is also promoted, contributing to more environmentally friendly construction practices [9]. This valorization is particularly significant, given that the global Production of natural fibers amounts to approximately 5,000 billion tons per year, primarily derived from agricultural waste. However, a large portion of these fibers remains underutilized, often regarded as mere residues rather than being effectively used [10].

On the other hand, Self-Compacting Concrete (SCC) has garnered considerable interest because of its excellent mechanical performance. It is particularly well suited for structures with high reinforcement density, complex geometries, or tall vertical elements with numerous embedded components, thanks to its capacity to flow and fill formwork without requiring vibration. However, these same characteristics make SCC more susceptible to shrinkage, which can compromise its durability over time.

Meanwhile, numerous studies have confirmed that the introduction of plant fibers to conventional concrete helps reduce the development of cracks resulting from shrinkage [11, 12]. These fibers act as crack-bridging elements, thereby enhancing both the ductility and crack resistance of the material. However, the effect of plant fibers in SCC remains largely underexplored, even though SCC is more prone to shrinkage than ordinary concrete. If proven effective, such fibers could potentially reduce the amount of conventional steel reinforcement required, thereby simplifying construction practices and enhancing the durability of the resulting structures.

Exploring this gap is crucial, as it could address the shrinkage issue and expand the potential applications of plant fibers in construction materials, paving the way for more sustainable and efficient building practices. Building on this premise, the present research emphasizes the innovative application of plant fibers in concrete, presenting new evidence of their role in enhancing both mechanical and thermal properties. Unlike prior studies, this work specifically studies the incorporation of plant fibers into SCC, addressing a notable gap in the literature. The primary objective is to advance the development of sustainable, energy-efficient construction materials while promoting the integration of natural resources into modern concrete technologies.

2. Self-compacting concrete

2.1. General

The initial development of SCC took place in 1988 in Japan to construct durable concrete structures [13]. Over time, it has been regarded as a revolutionary progress in concrete materials. This improved version of traditional concrete is distinguished by its numerous advantages, positioning it as the concrete of the future. Due to its exceptional deformability, SCC can be placed and consolidated without the need for vibration, while retaining sufficient cohesion to prevent segregation during handling [14, 15]. SCC is currently an essential product in structures with large reinforcement bars. Its use makes construction quieter and more environmentally friendly by reducing energy consumption, labor costs, and work time, while also improving compaction [14]. To enhance its characteristics and produce an environmentally friendly SCC, mineral additives are incorporated to optimize the flow behavior of concrete, either as an addition or partial replacement of cement and aggregates [15]. The microstructure of concrete significantly influences its strength and durability. The incorporation of various components can profoundly influence the microstructure of SCC [15]. Advances in microstructural analysis methods have enabled researchers to refine the performance of SCC by optimizing its composition. These methods offer a meaningful understanding of SCC's microstructure, facilitating the investigation of interactions between alternative materials and cement [15].

However, global demographic and economic growth lead to an increasing accumulation of solid waste in landfills, necessitating the study of their use as substitutes for cement. Ruslan and Muthusamy [14] studied the performance of SCC containing solid waste. The findings showed that the specific qualities of the waste material determine the best proportion for substitution and its effect on the mechanical properties of SCC. Therefore, substituting cement with solid waste in SCC is considered acceptable for enhancing fresh concrete characteristics and addressing environmental concerns. At the same time, fibre-reinforced SCC can be considered a significant advancement in construction materials, thanks to the fiber's ability to bridge cracks optimally, given that evenly distributed fibers lead to effective crack bridging [16]. According to Ahmad Wani and Ganesh [16], microstructural studies indicate that factors such as fiber dosage, pre-treatment of fibers, and temperature all impact the behavior and characteristics of fiber-reinforced SCC.

2.2. Mix Design of Self-Compacting Concrete

The main concept in formulating an SCC mix is to consider the mix as a dense and viscous suspension [17]. The dispersed phase concentration in this mixture is low enough to prevent excessive interaction. Commonly known as the "paste," the suspension phase includes fine materials, water, and chemical admixtures. Larger components, termed "aggregates," are included in the dispersed phase. Thus, according to this description, the disparity in density between the cement, paste, and aggregates is directly related to the risk of detachment. The paste content within the mixture must be sufficiently high to minimize particle contact and avoid blockage during flow [17].

Generally, the success of SCC depends on a combination of three important, distinct qualities [18, 19]:

- Filling ability, or unconfined flowability, refers to the ability to flow and occupy all spaces in the mold in the formwork solely under gravity.
- Passability, often referred to as confined flowability, describes the capacity of fresh concrete to flow through small spaces, like the gaps between steel bars, without leading to blockages or material separation.
- Segregation resistance is defined by the capacity to retain a uniform composition while being transported under dynamic conditions and placed (under static conditions).

Self-compactability, the distinguishing characteristic of SCC, can be achieved by verifying the following criteria [13, 10]:

- Limited aggregate content: Blockage risk is reduced by limiting the coarse aggregate amount.
- Combining a reduced water/cement ratio with an increased superplasticizer results in excellent flowability, free from bleeding or segregation.
- Sufficient paste quantity fills all gaps in the aggregate structure, providing each particle with a uniform paste coating, which helps decrease the chances of particle contact and collisions throughout flow.

Hu and Wang [20] considered concrete as a biphasic material, with one phase consisting of aggregates and the other of mortar. The two-phase approach facilitates concrete mix design by treating the proportions of fine aggregates and coarse aggregates as distinct components. They subsequently demonstrated that concrete yield strength and viscosity can be significantly reduced by properly grading aggregates, and these properties generally increase with mortar sand content. The findings of Girish et al. [21] demonstrate that the volume of the paste increases the flow properties of SCC. Sedran and Larrard [22] developed a compressible stacking model to anticipate the fresh-state properties of SCC, based on the characteristics of the granular structure.

Various techniques for designing SCC mixes have been developed, each based on different approaches. Obviously, every method was established within certain environmental contexts and carries its distinctive characteristics and some intrinsic limitations. Furthermore, it is complicated to compare one method to another.

The multitude of SCC formulation methods underscores the challenge of establishing a single approach that covers all mix ranges and is easy to follow. Thus, there is a clear need for further research to develop an approach that is both comprehensive and practical across different contexts [19]. The most common formulation approaches are as follows [23]:

2.2.1. Empirical Mix Design Methods

The initial proportions of the mixture are determined using empirical data such as the sand and gravel, the amount of water and cementitious materials, and the dosage of superplasticizer. Several test mixes and adjustments are done to obtain the optimal mixture proportions that ensure the desired properties [24].

Method Based on Mortar Optimization (Japanese Method)

This approach consists of determining a sand rate in the mortar and a gravel rate in the concrete, then improving the performance of the cement paste in order to guarantee the best performance in the SCC and to respect the workability criteria, by favoring paste content to the detriment of aggregate content. The resulting concretes are low in aggregates, high in binder, and therefore not very profitable economically [13, 25, 26].

Within this method, it has been demonstrated that the risk of blockage is reduced when the volume of gravel is reduced to half of its compactness, which is defined as the fraction of grain volume over the sum of grain and void volumes [23]. This approach is illustrated in Figure 1.

Paste Optimization Method

In this method, concrete is regarded as a biphasic material, with aggregates forming the solid phase and water or cement paste constituting the liquid phase. The liquid phase in SCC serves two purposes: it enhances fluidity by reducing friction between aggregates.

It effectively disperses aggregates to prevent the formation of obstacles around reinforcements, which could potentially lead to flow blockage [23, 27]. This approach involves finding the minimum paste volume needed, $V_{f\,min}$, and allowing it to fulfil each of these two functions [23]:

Fluidity Criterion

This criterion is ensured with a minimum volume of paste $V_{f\,min}$ required to fluidize 1 m³ of concrete, determined from the volume of voids in the gravel and sand mixture V_{vide}, using Equation (1) [23].

$$V_{f\,\min} = 1 - \frac{(1 - V_{vide})}{Ce} \quad (1)$$

Where C_e is the spacing factor, calculated based on the minimum average distance between aggregates to ensure concrete workability (e_{min}) and the average diameter of the aggregates (D_{moy}), determined experimentally with Equation (2) [23].

$$Ce = \left(\frac{e_{\min}}{D_{moy}} + 1 \right) \quad (2)$$

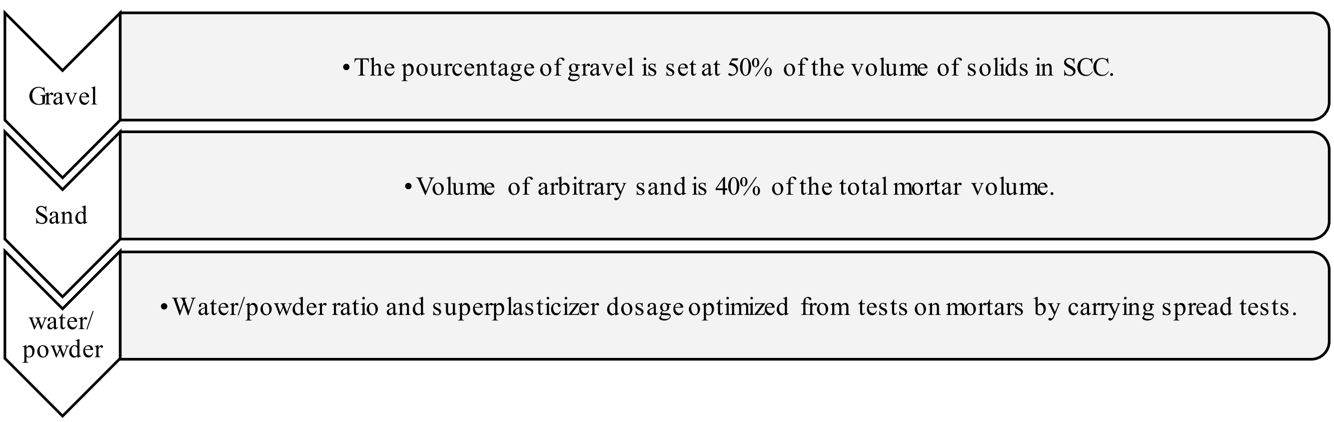

Fig. 1 Principles of the Japanese method

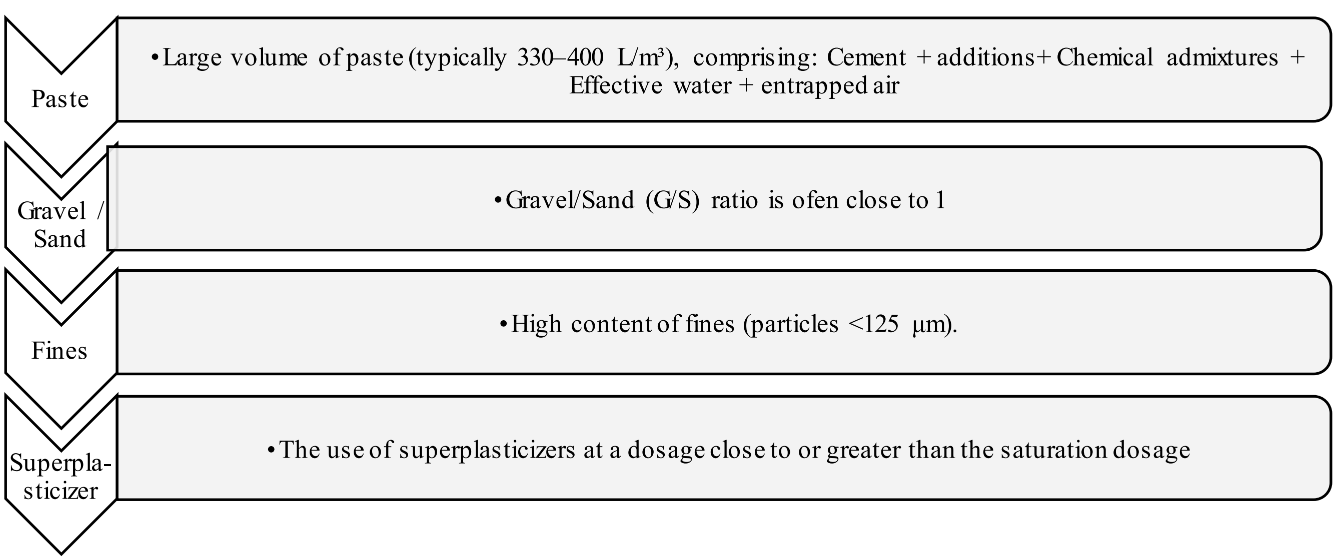

Fig. 2 AFGC method for SCC mix design

Non-Blocking Criterion

To prevent aggregate blockage, the risk R of blockage should be less than 1, calculated based on the volume of aggregate of size di (V_i) and the limit volume of aggregates of size di, required to ensure flow in a confined space, determined experimentally with Equation (3) [23].

$$R = \sum_i \frac{V_i}{V_{bi}} \qquad (3)$$

Approach Relying on the Optimization of the Granular Structure

Given that compressive strength increases according to the aggregates composing the concrete and workability is also influenced by the organization of the granular skeleton, researchers at the LCPC (Central Laboratory of Bridges and Roads) attempted to simulate the behavior of concrete in its fresh state by calculating the granulometry of its granular structure [22, 23].

Sedran and Larrard [22] developed an approach based on a mathematical model known as the compressible packing model. It is based on the classical theory of particle packing to simulate the spatial distribution of aggregates, fines, and possibly fibers within the SCC mixture, thus making it possible to forecast SCC behavior in the fresh phase using characteristics of the granular skeleton. This calculation model (Compressible Stacking Model) involves the following two notions:

- The virtual compactness corresponds to the maximum compactness the granular assembly could achieve if all grains were optimally arranged.
- The tightness index is defined as the sum of the tightness indices of each granular class; it represents the degree of compaction.

AFGC Approach (French Civil Engineering Association)

This approach suggests general guidelines for formulating the SCC, focusing on design principles and required performance, and recommends many tests for formulation validation [28]. It is based on the criteria described in Figure 2.

2.2.2. Compressive Strength Approach

This method calculates the required amounts of cement, aggregates, mineral additions, and water following the target compressive strength. The maximum aggregate size and fine aggregates' fineness modulus have an impact on the amount of coarse aggregates used in this method. The amount of water is determined according to the maximum size of the aggregates and the strength of the concrete. Then, Water/Powder and Water/Cement proportions are determined based on the concrete's compressive strength [24, 29]. This method is described in Figure 3. The original ACI 211.1 method addresses compressive strength values ranging from 15 to 40 MPa [29]. However, this approach has been extended to accommodate SCC with compressive strengths ranging between 15 and 75 MPa, while keeping the water/cement (W/C) ratio below a maximum as mentioned in Table 1 [30].

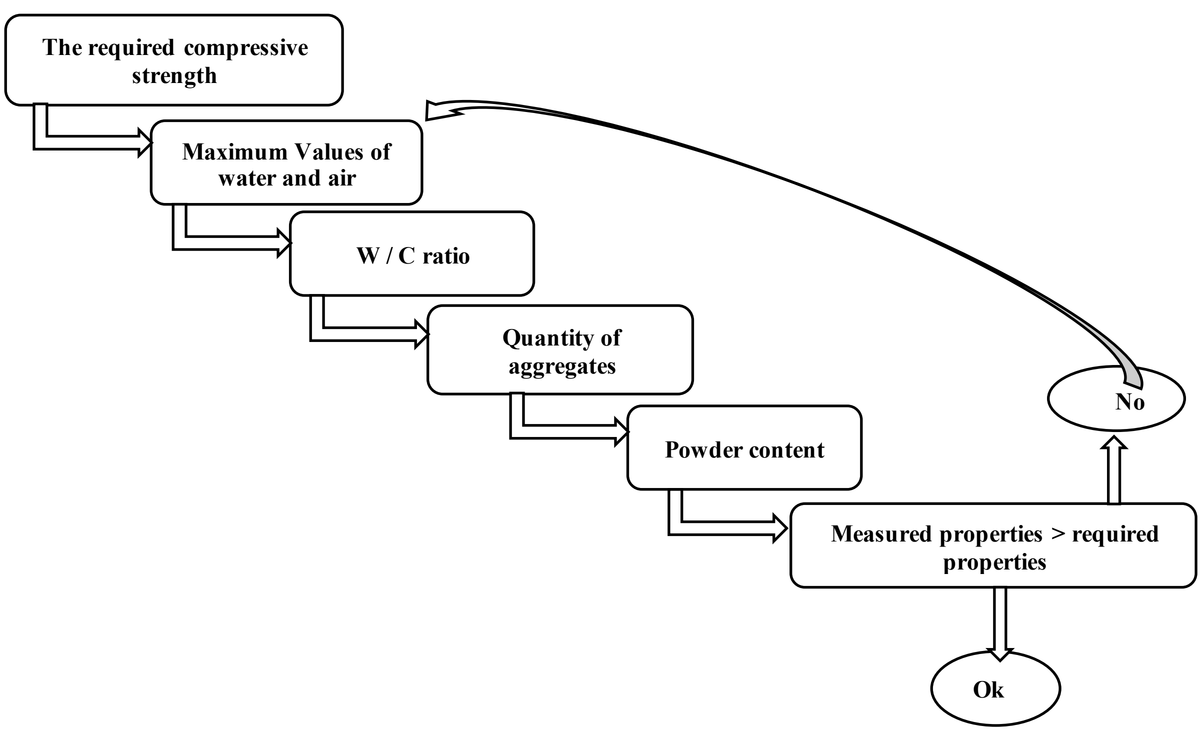

Fig. 3 Compressive strength method

Table 1. Compressive strength of SCC in relation to the water-to-cement ratio

Compressive strength (MPa)	15	20	25	30	35	40	45	50	55	60	65	70	75
Ratio (Water / Cement)	0,80	0,70	0,62	0,55	0,48	0,43	0,38	0,35	0,34	0,33	0,32	0,31	0,29

2.2.3. Concrete Mix Design Method Employing a Factorial Statistical Model

This approach relies on a deep understanding of how mix proportions influence the behavior of SCC from fresh mix to hardened structure. Typically, various parameters are defined within practical ranges, for example, the amounts of cement and supplementary cementitious materials, coarse aggregates, the W/C ratio, and the content of superplasticizer. Based on these inputs, the mix proportions are then determined by adapting conventional concrete mix design methods [24]. Sonebi [31] developed a factorial design to mathematically represent the impact of several key variables (the amounts of cement and fly ash, superplasticizer content and ratio of water/powder) on properties crucial for successful SCC. These properties include filling and flow capacities, segregation and compressive strength.

To achieve this, 21 mixtures were tested to establish statistical models. Workability, flow capacity and rheology of SCC were evaluated using different techniques such as slump flow, V-funnel, L-box, and IBB concrete rheometer. Additionally, novel methods were implemented to assess flow capacity and segregation, such as the slump cone and Orimet combined with JRing. On the other hand, Ozbay et al. [32] utilized the Taguchi method, which is a structured and practical approach for identifying optimal design variables concerning both efficiency and economic factors [33]. The parameters considered in their study include water/binder ratio, water quantity, ratio of fine aggregates to total aggregates, fly ash quantity, air-entraining agent content, and superplasticizer content.

2.3. Comparative Analysis of Self-Compacting Concrete Mix Design Methods

Although empirical design approaches are relatively simple, they rely heavily on thorough laboratory testing of raw materials to accurately define the appropriate mix ratios. While the compressive strength method allows for precise proportions of materials, thereby limiting the necessity of conducting multiple trial mixes, it necessitates modifications and corrections to all constituents to have an optimal mix proportion. The use of a statistical factorial model, although balancing the variables in the mix, also necessitates thorough laboratory tests on available materials. The comparison between the methods cited in this article is presented in Table 2. According to this comparative analysis, it is evident that each method has its own properties and application conditions, and no approach fully meets all the requirements. This makes it necessary to choose the appropriate model based on the specified requirements to achieve an optimum formulation.

3. Plant Fibers

3.1. Characterization of Plant Fibers

Natural fibers include those derived from plants, grasses, fruits, seeds, aquatic plants, leaves, animal feathers, animal skins, etc. Plant fibers used in composite materials are obtained through mechanical and physical transformations of natural materials. It is possible to extract plant fibers from a plant's fruit, leaf, or stem. Their main advantages are their low density, thermal insulation capability, mechanical properties, and, importantly, their biodegradability [2]. Plant fibers are primarily biological structures incorporating lignin, cellulose, and hemicelluloses. Figure 4 shows the various families of plant fibers with examples for each family [34, 35].

Table 2. Comparison between the most well-known SCC mix design methods

Method	Key Characteristics	Advantages	Limitations
Mortar optimization	It involves determining the sand/mortar and gravel/concrete ratios and enhancing cement paste quality to ensure the optimal SCC performance and meet workability criteria.	Empirical adjustment to achieve the desired fluidity.	Dependence on empirical tests.
Paste optimization	Finding the minimum paste volume that ensures both fluidity and prevents SCC blockage.	Precise control over paste rheology.	-Sensitivity to variations in admixture composition. -Typically requires thorough experimental validation - Problems like segregation may arise from poor compatibility between the optimized paste and aggregates.
Granular skeleton optimization	Designing aggregates to maximize compactness and filling.	Enhanced cohesion and segregation resistance.	Requires meticulous selection of granular skeleton and extensive experimental testing.

AFGC approach	General guidelines to optimize workability and stability	Adaptability to specific civil engineering project requirements.	- Lack of specificity for particular project conditions. - Requires rigorous experimental validation.
Compression strength method	Determining proportions based on SCC compression strength.	-Maximizes strength while maintaining manoeuvrability -Reduced number of tests.	-Risk of compromising workability and segregation. -Neglects other important properties by focusing on compression strength.
Statistical factorial model	Using mathematical models to predict SCC properties.	Optimization based on complex component interactions.	-Requires experimental data for model validation. -Interpretation of statistical results requires a deep understanding of variable relationships and model limitations.

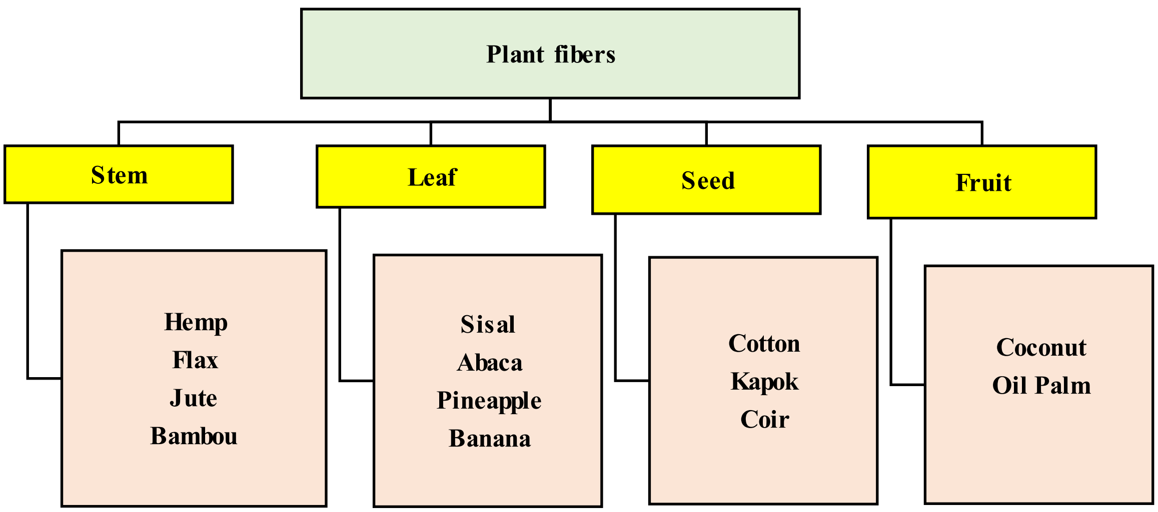

Fig. 4 Classification of some of the most common plant fibers

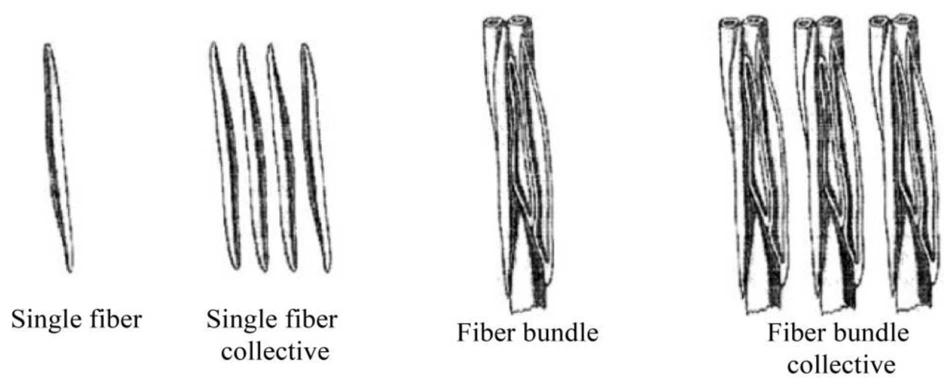

Fig. 5 Different forms of plant fibers [37]

Plant fibers can have several forms, as shown in Figure 5 [3]:

- Single or isolated type of elementary fibrous cell;
- Combined to create a bundle of fibers linked by pectins and hemicelluloses.

Generally, plant fibers can be characterized according to their chemical compositions, physical characteristics, and mechanical behaviors

3.1.1. Chemical Composition

The main macromolecular compounds of plant fibers are cellulose, lignins, hemicelluloses, and pectins. A thorough understanding of the chemical composition of plant fibers is essential to accurately assess their influence on material properties.

- Cellulose: It is the most widespread organic molecule in nature. It is the main component of the structure of plant cells. The properties, production cost, and application choices of fibers are strongly influenced by the proportion of cellulose in the fibers.
- Hemicelluloses are polysaccharides with relatively short and branched chains linked together. They are closely linked to cellulose microfibrils, which coat the cellulose in a matrix. Due to their high hydrophilicity, hemicelluloses contain many sites capable of reacting with water, which contributes to the absorption of water by the fibers.
- Lignins are complex polymers of aromatic hydrocarbons that stiffen plants. Plants would not be able to grow to great heights without lignin. Compared to other chemical components, these polymers have a low molecular weight and an amorphous structure.
- Pectins are complex polysaccharides consisting of a main chain and secondary chains. They are mainly found between microfibrils and in the primary wall. They are known to be good chelators of calcium ions. Indeed, galacturonic acid can bind to another chain while trapping the calcium ion.
- Fatty substances: Natural fibers are composed of wax and oil. These substances comprise various types of water-insoluble alcohols and various acids, including stearic acid, oleaginous acid, and palmitic acid. They are found on the surface of plants, and they are protected.

The influence of these constituents on plant fiber is detailed in Table 3. Each type of fiber exhibits variability in its chemical composition, as some of them (pectin, lignin, waxes) may be present in minimal amounts and considered negligible in several fibers [2]. The quantity of chemical constituents for several fibers is presented in Table 4.

3.1.2. Physical Properties

Among the most commonly used physical characteristics of plant fibers, geometric characteristics like length, diameter, and density are detailed in Table 5.

Table 3. The influence of the main constituents of plant fiber on its properties

Constituent	Chemical Nature	Effect on the Fiber
Cellulose	A polysaccharide composed of multiple glucose units	Principal component of plant cell structure, essential for their architecture and protection
Hemicelluloses	Polysaccharides are branched with short chains.	Contain numerous sites capable of reacting with water, contributing to water absorption by the fibers.
Lignin	Complex polymers of aromatic hydrocarbons	The primary component of wood stiffens plants to achieve significant heights.
Pectins	Complex polysaccharides	Influence the porosity and extensibility of the cell wall.
Fatty substances	Composed of wax and oil	Found on the surface of plants, providing protection

Table 4. Chemical composition of a selection of plant fibers

Fiber	Cellulose	Hemicellulose	Lignin	Pectins	Reference
Sisal	43-78	11.5	8	1,2	[38]
Abaca	61 - 64	21	12	0,8	
Pineapple	80-81	17.5	8.3	4	
Kenaf	50-53	21	17	2	
Bagasse	32-48	21	20-24	10	
Jute	51-84	12-20	9	0,2	
Banana	60-65	6-19	5-10	3-5	
Hemp	70-92	18-22	3-5	0.9	
Coconut	46	0.3	45	4	
Cotton	82-96	2-6	0.5-1	5-7	
leaves of the date palm (Phoenix dactylifera)	33,5	59,5	27	-	[39]
Date palm petiole (Phoenix dactylifera)	35	15,40	20,3	-	[40]

The geometric distribution of plant fibers (length, diameter, density) presented in Table 5 can be explained similarly to their chemical composition (climatic conditions, plant cultivation, and harvest period).

The water absorption coefficient is another crucial factor to consider in the physical identity of plant fibers. Indeed, the affinity of plant fibers towards water has effects that cannot be ignored, especially on the workability of the blend. If the water absorbed by fibers is ignored, the available mixing water may become insufficient, altering the material's rheology and influencing the durability of the composite due to the volume variation of fibers because of Absorbed water can alter the interaction at the fiber/matrix interface. Plant fibers exhibit a high capacity for water absorption, as shown by the values grouped in Table 6. They can absorb an amount of water exceeding their own mass [3].

Table 5. Physical characteristics of plant fibers

Fiber	Length (mm)	Diameter (µm)	Volumic Density (kg/m^3)	Reference
Sisal	1.8-3.1	18.3-23.7	1300-1500	[38]
Abaca	4.6 - 5.2	17 - 21.4	1500	
Bagasse	1.7	20	550-1250	
Banana	2.7	10 - 40	1500	
Hemp	8.3-14.1	17-22.8	1400-1500	
Kenaf	2-2.7	17.7-21.9	1220-1400	
Coconut	0.9-1.2	16.2-19.5	1250	
Cotton	20-64	11.5-17	1550	
Jute	1.9-3.2	15.9-20.7	1300-1500	
Date palm leaves	30	1-2	940	[41]

Table 6. Water absorption coefficient of plant fibers in 24 h

Fiber	Absorption (%)	Reference
Coir	100 ± 20	[42]
Flax	136 ± 25	[43]
	150 ±15	[44]
	152 ± 7	[37]
Hemp	158 ± 36	[43]
	178 ± 15	[44]
Yucca	203 ±16	[43]
Sisal	230 ± 16	[42]
	200	[45]
Jute	281	[45]
Date palm leaves	89	[41]

3.1.3. Mechanical Properties

The mechanical characteristics of plant fibers define their behavior during various transformation processes and the properties of finished products made from these fibers. The tensile strength, Young's modulus, and elongation measurements for several plant fibers are presented in Table 7. Like other properties of plant fibers, there is a large variability in mechanical properties, as mentioned in Table 7. Several factors contribute to this dispersion [22], including the fiber's structure and chemical composition, variability in diameter within the same plant, the number of transverse defects, fiber moisture content, and plant maturity.

3.2. Fiber Extraction and Treatment Methods

The processes of extraction and treatment of plant fibers have a substantial effect on fiber yield and overall quality, as they generally reduce fiber absorption rate and extract natural impurities on the fiber surface known to retard the setting of the cementitious matrix in their applications in construction materials [2].

Generally, there are numerous methods for extracting fibers from plants; the most commonly used are:

3.2.1. Mechanical Extraction

Typically, mechanical extraction of plant fibers involves the use of machines called scrapers, which grate the pulp of the leaf and extract the fibers. These devices are usually composed of a motor that drives the rotation of an axis. The operating principle of this machine is to engage the leaf between the cuirass and the drum and hold it on the other side until it is grated and its fibers are released.

3.2.2. Chemical Extraction

Consists of using chemicals to dissolve non-fibrous components and separate the fibers.

3.2.3. Biological Extraction

Field Retting

Field retting is a natural process that facilitates fiber extraction by spreading the stems (such as flax) in a field after harvest to benefit from the combined action of sun and rain. This promotes the development of microorganisms capable of dissociating non-cellulosic elements of the plant fiber by eliminating the bonds that connect them. Depending on the weather conditions, this operation can last from 6 to 8 weeks.

Table 7. Mechanical properties of some plant fibers

Fibers	Failure Strain (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Reference
Flax	1 -3	798 - 1710	51 - 80	[47]
	1-4	600- 2000	12 - 85	[48]
	2	900	50	[49]
Hemp	2	389	35	[48]

	1,6	690	30 - 60	[50]
	2	389	35	[51]
Sisal	2-4	228 -1002	11 -27	[52]
	5	363	15	[53]
	15	31 -221	-	[54]
Coir	14 -41	108 - 255	3 - 5	[52]
	75	15 - 327	-	[45]
Date Palm	5,10	123,23	2,47	[55]

Water Retting

This method employs the same principle of microorganism development as field retting, but the stems (such as those of hemp) are submerged in water for several days. Anaerobic bacteria act on bundles weighing 5 to 7 kg. Subsequently, once the fibers separate along their entire length, the plant is removed from the water for drying. The type of treatment varies from one type of fiber to another due to the diversity of raw materials. For example, cotton fibers that are more or less spinnable require specific treatment to remove seeds [23]. Treatment methods can be classified into several types; the most applied in construction materials are chemical and thermal treatments, and in some cases, a hybrid treatment that combines two or more different treatments can be applied [24]. Table 8 details the different treatments cited in the literature.

Table 8. Types of fiber treatment in the literature

Fiber Studied	Reference	Treatments Carried	Effect on the Fiber
Sisal	[58]	Thermal treatment: In an oven at 150 °C for over 8 hours, Sisal fibers were heat-treated.	The mechanical behavior of sisal fibers is notably improved by this treatment, mainly due to enhanced cellulose crystallinity, which contributes to higher initial strength and better long-term durability in concrete applications.
		Chemical treatment with Na_2CO_3: The sisal fibers were treated chemically by placing them in a saturated sodium carbonate solution (Na_2CO_3) for varying durations: 7 and 10 days.	The treatment at 7 days improved the durability of the fiber concrete, but, tits tensile strength showed a noticeable decline after 10 days, as a result of alkaline degradation, which negatively impacted their main structural components: lignin, hemicellulose, and cellulose, when exposed to the solution.
	[59]	Chemical treatment: After sterilization and drying to remove any impurities and microorganisms, sisal fibers were immersed in a saturated solution of 2.5% NaOH for 4 hours.	The chemical treatment caused some loss of compressive strength, but it did not compromise the general mechanical performance of fiber-reinforced concrete. However, the tensile strength was increased relative to the reference concrete, regardless of the fiber content added.
		Thermal treatment: The sterilized and dried fibers were subjected to thermal treatment at 150°C for 8 hours in an oven.	Compression strength was increased by the thermal treatment, but started to decrease with higher fiber content, while tensile strength was improved.
		Hybrid treatment: The fibers initially underwent a 2-hour chemical treatment followed by thermal treatment.	Thanks to the hybrid treatment method, Improvements were observed in the concrete's compressive and tensile properties.
Diss	[60]	Thermal treatment: involves boiling the crushed Diss for 4 hours. Once drained, the fibers were washed to eliminate any traces of organic compounds.	The mechanical characteristics of cementitious composites are significantly improved by boiled water treatment without affecting the fiber structure. Samples containing thermally treated fibers and coated with flax oil were more
		Flax oil treatment aims to waterproof the Diss fibres to prevent water absorption. Previously dried, boiled Diss fibers are mixed and washed with flax oil.	

			resistant to tensile stress than untreated Diss fiber composites.
Flax and Hemp	[61]	Chemical treatment: using the following products: - Silane primer - Benzoyl peroxide - Sodium hydroxide - Acetic acid -Acetic anhydride	By chemically treating the fibers, their properties were further enhanced. Allization with 2% (m/m) [NaOH], technical flax, and hemp gave the best results.
Date Palm	[62]	Thermal treatment involves boiling the fibers, discarding the water, and meticulously rinsing them to remove residual organic substances.	The fibers used have a positive effect on reducing the risk of cracking.
	[63]	Thermal treatment: involves boiling the fibers for different durations: 5 minutes, 1 h, 2 h, and 3 h. Following the boiling process, the fibers are drained and then thoroughly cleaned using water, followed by air drying at room temperature for 48 hours.”	This treatment reduces the absorption of date palm fibers compared to raw fibers, especially with boiling durations of 1 hour or more. It’s noted that as the boiling time increases, the absorption decreases.
		Chemical treatment with sodium hydroxide (NaOH): The fibers are soaked for two hours in sodium hydroxide (NaOH) solutions with varying concentrations of 1%, 3%, 6%, and 9% by weight. Following this alkali treatment, they are rinsed using a 1% acetic acid solution and subsequently with distilled water until the solution reaches a neutral PH. In the final step, fibers were oven-dried at 60 °C for a full day.	Chemical treatment lowers the water absorption of fibers when NaOH concentrations are under 9%, with the minimum absorption rate observed at a concentration of 3%. This decrease can be attributed to the partial removal of hemicelluloses, the primary agents behind the fiber’s hydrophilic nature.
		Flax oil treatment: the initial step involves drying the fibers at 50 ± 0,1 °C for 24 hours, then they are coated with linseed oil before being dried again in an oven with constant airflow maintained at 50 ± 0,1 °C.	The water absorption kinetics and the absorption of the fibers are significantly reduced with flax oil treatment, with absorption rates lower than those of untreated fibers. Since this treatment consists of coating and waterproofing the fibers, it also stands out from other treatments by considerably reducing the setting time.
Bamboo	[64]	Thermal treatment: for two hours, the fibers are placed in water at 90°C.	The treatments carried out make it possible to eliminate the substances that prevent the cement from setting.
		Chemical treatment: The fibers are immersed in a 1% NaOH solution for 2 hours at room temperature.	
Oat Straw	[65]	The immersion in hot water treatment at 60°C for 10 seconds before use in concrete.	This hot water treatment makes it possible to easily dissolve the sugar present in the plant elements, which reinforces the compatibility between the two materials.
		Treatment by coating involves fully immersing the straws in Cutback 400-600 bitumen, then slowly mixing the straws until their exterior surface is completely covered by the product.	This treatment prevents water from being absorbed by the straw; however, a decrease in adhesion has been observed.

Chemical treatments, like alkaline (NaOH) treatments, have been shown to improve fiber surface texture through the removal of lignin and hemicellulose, which can minimize the natural hydrophilic behavior of plant fibers and enhance their bonding with the hydrophobic matrix of concrete. This enhanced bonding facilitates a stronger mechanical interlocking of fibers within the concrete, thus contributing to enhanced strength and durability. Meanwhile, thermal treatments, which involve exposing the fibers to high temperatures, can increase their crystallinity and reduce their moisture absorption capacity. These improvements can further boost the fibers’ performance in concrete. However, it is important to note that excessive heating can degrade the fibers if not carefully controlled, highlighting the need for precise thermal treatment processes. Physical treatments, such as coating fibers with polymers or other protective materials, can also enhance their compatibility with the concrete matrix. These coatings not only improve the adhesion between the fibers and concrete but also shield the fibers from environmental degradation, thus preventing embrittlement and extending the longevity of the fibers in concrete.

4. Self-Compacting Concrete Reinforced with Plant Fibers

4.1. Statistical Analysis

Wang et al. [66] observed that the integration of diverse natural fibers in cement-based composites has been studied. Figure 6 shows the number of scientific publications for each type of fiber for the period 1983-2023. It is noted that basalt fibers, coconut fibers, and hemp fibers are the most studied in the context of fiber-reinforced concrete. Despite the growing interest in eco-friendly building materials, the application of these fibers in SCC remains relatively underexplored.

The majority of existing research focuses on ordinary vibrated concrete, and only a limited number of studies have investigated the specific behavior and performance requirements of SCC. This highlights a significant research gap and emphasizes the need for more comprehensive experimental and analytical investigations. Advancing research in this area is crucial to gain a deeper understanding of the interactions between plant fibers and SCC, and to evaluate their potential to enhance mechanical performance, crack resistance, and durability while maintaining the self-compacting characteristics that define this innovative concrete technology. Furthermore, a cement matrix without fibrous reinforcement presents a fragility that manifests itself in a fracture that occurs after the appearance of the first crack. In this context, it has been shown that the initial crack reduces the strength of fiber-cement composites [67]. Adding plant fibers to the cement matrix enhances the composite strength [68]. However, natural fibers can optimize costs compared to artificial fibers, as detailed in Table 9, making them extremely competitive in the market.

4.2. Performance of Concrete Reinforced with Plant Fibers

4.2.1. Workability and Mechanical Properties

Banana Fibers

Poongodi and Murthi evaluated the potential enhancement in impact resistance by adding banana fibers in lightweight structural self-consolidating concrete (LWSCC) at 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, and 1.5% of the concrete volume [69]. The results indicated significant gains in compressive strength, and there was no adverse effect on self-compactability due to the inclusion of banana fibers. For fiber dosages of 1.25%, in hardened LWSCC at 28 days and 90 days, improvements in compressive strength By 14% and impact resistance by 32% and 25% were observed. However, substituting banana fibers above 1.25% in LWSCC negatively impacted compressive strength.

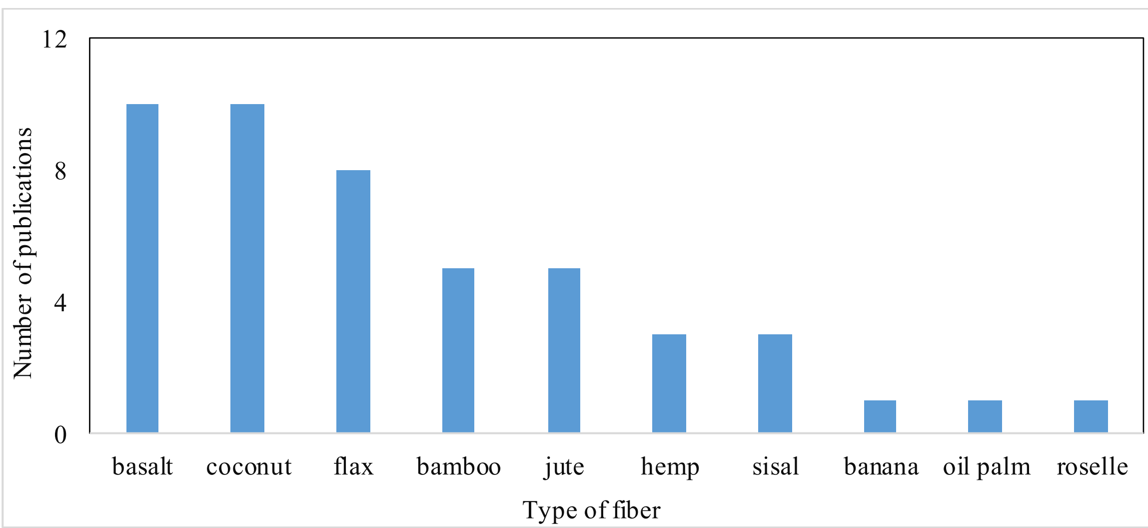

Fig. 6 Distribution of scientific publications on natural fibers used in conventional concrete

In another study, Poongodi et al. [70] demonstrated that at 28 days, the compressive strength with 1.25% banana fibers was estimated at 44.8 MPa, representing an increase of 17% compared to the reference concrete. Additionally, the flexural strength of the control mix showed improvements of 42.59% and 44.18% at 28 and 90 days, respectively.

Sisal Fibers

Patil et al. [71] studied the impact of laterite waste as coarse aggregate LA and sisal fibers SF, and it was observed that substituting 30% LA and incorporating 0.75% SF resulted in improving the mechanical behavior of laterite concrete compared to the control mix or any other variant.

Palm Fibers

Tioua et al. [62] investigated the effects of Date Palm Fiber (DPF) and Shrinkage Reducing Admixture (SRA) on SCC subjected to hot, dry, and regulated laboratory environments. The used DPFs were subjected to a thermal treatment consisting of boiling the cut DPFs, water drainage, and careful washing to clear away organic substances. Because of their ability to limit shrinkage and cracking at early stages in SCC, the results showed that DPF had similar effects on SCC as SRA in hot and dry environments; however, the compressive strength of both DPF and SRA slightly decreased compared to the reference concrete (SCC-Ref) at every stage of their curing process.

Jute Fibers

An experimental investigation conducted by Zhang et al. [72] examined the changes in the mechanical performance of eco-friendly SCC reinforced with jute fibers and mineral additives. The results indicate that coupling jute fiber with mineral powder enhances the mechanical performance of SCC. Mixtures of SCC reinforced with jute fibers and mineral additives fulfil the requirements of common construction uses.

Roselle Fibers

Roselle fibers reduce workability, except that mixtures reinforced with up to 3% fibers meet the minimum requirements established by EFNARC (European federation dedicated to specialist construction chemicals and concrete systems). The increasing presence of Roselle fibers improves the properties of hardened concrete, and the specimen reinforced with 3% fibers obtained the best results in mechanical properties examined [73].

Coconut Fibers

Vaishnavi et al. [74] examined workability tests and compressive strength when incorporating coconut fiber into traditional SCC mixes. They found that as the fiber content and length increased, workability decreased. Nylon fibers showed the opposite pattern, with workability increasing as fiber percentages increased. Both coconut and nylon fibers demonstrated increased compressive strength at a length of 1 cm. However, coconut fibers at a length of 2.5 cm showed reduced compressive strength. Across all cases examined, 1 cm coconut fibers showed the maximum compressive strength. The results of this literature study can be summarized in Table 10. This shows that adding plant fibers to a concrete mix alters its behavior in the fresh phase. In particular, fibers tend to reduce concrete's workability.

Table 9. Comparison between artificial fibers and natural fibers in terms of economic aspects

Economic Aspect	Natural Fibers	Artificial Fibers
Cost of raw material	Generally, less expensive	More expensive
Treatment and transformation	Simple and less energy-intensive	Complex chemical and industrial processes
Equipment needs	Less complex and affordable	Advanced technologies and specialized infrastructure
Local availability	Often available locally, based on local agriculture	International supply chains are often necessary
Price stability	Less exposed to price fluctuations	Subject to volatility in prices of synthetic raw materials

Table 10. Fresh and hardened properties of SCC with plant fibers

Type of Fiber	% of Fibers	Workability	Mechanical Characteristics
Banana fiber [70]	1.25% by volume of concrete	Up to a concrete concentration of 1.25%, the concrete obtained respects the minimum slump flow limit.	Flexural strength and compressive strength at 28 days showed an improvement of 42.59% and 17% compared to the control concrete.
Sisal fiber and Laterite Aggregate [71]	0,75 % by volume of concrete	Adding sisal fibers and laterite aggregates affects the workability of the mixture.	30% of laterite aggregates and 0.75% of sisal fibers showed significantly higher values of compressive, tensile, and flexural strengths
Date Palm fiber DPF [62]	0,1 % by volume of concrete	Adding DPF reduces workability without exceeding the minimum limit.	Incorporation of DPF reduced the compressive strength of SCC.
Jute fiber and Zeolite Powders [72]	0.1% by volume of the mix	Slump flow and J-ring values decreased with increasing fiber dosage.	Inclusion of jute fibers and mineral additives in SCC mixes improved their strength.
Roselle fiber [66]	3% by weight of binder	Reinforced mixtures with up to 3% fiber meet minimum workability requirements.	A 3% reinforcement with Roselle fiber improved compressive strength by 12%, tensile strength by 22%, modulus of rupture by 27%, and elastic modulus by 9%
Coconut fiber [67]	0,3% of solid weight	There is a decrease in workability with increasing fiber content and fiber length.	1 cm of coconut fiber at 0.3% showed higher compressive strength

This loss of workability can be explained as follows [75]:

- Three-dimensional network effect: fibers, especially when long or present in large quantities, intertwine within the cement matrix, creating a three-dimensional network, which restricts the flow of fresh concrete. Furthermore, as illustrated in Figure 7, these fibres may serve as physical obstacles that hinder water penetration into the capillary pores of the matrix, thereby reducing the rate of water permeation. This dual effect, mechanical and hydraulic, increases the rigidity of the mixture and reduces its workability.
- Water absorption for plant fibres: fibres can capture some of the mixing water, thus reducing the amount of free water available to ensure the fluidity of the mix.
- Augmented specific surface area: The incorporation of fibres increases the total surface area needing coverage by the cement paste, necessitating a greater amount of paste to maintain the same workability.

The findings make the inclusion of a superplasticizer indispensable to increase the fluidity of concrete without adding extra water. This is crucial for maintaining good workability even in the presence of fibers, ensuring proper fiber dispersion and homogeneous mixing, and avoiding.

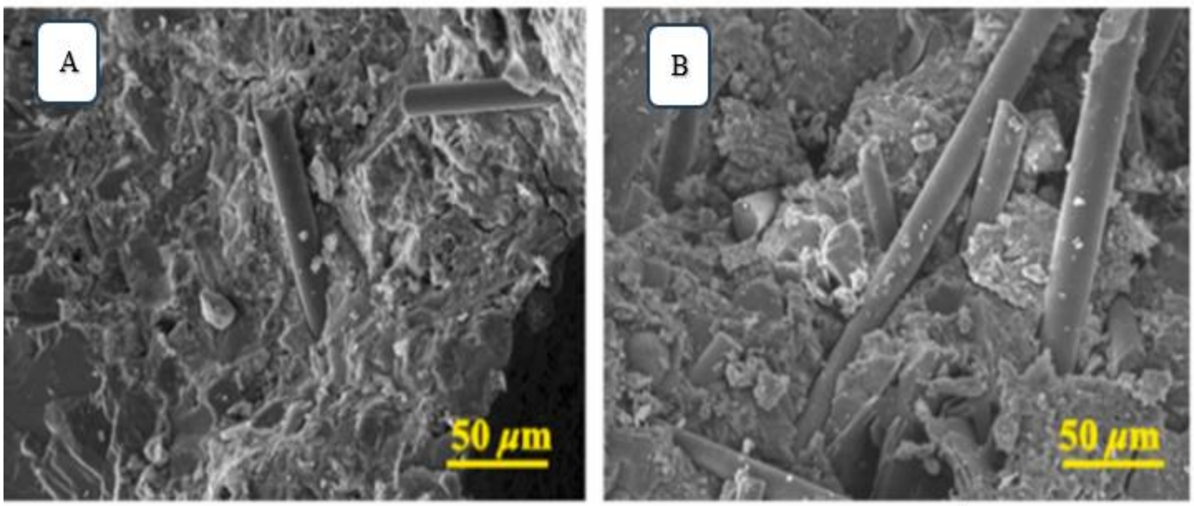

Fig. 7 SEM images of recycled glass fiber reinforced concrete with a fiber dosage of A- 17 Kg/m^3; B- 20 Kg/m^3 [75]

The deterioration of mechanical performance that can result from an excessive water-to-cement ratio On the other hand, adding plant fibers to SCC has shown encouraging performance in enhancing the mechanical properties of the material. This enhancement can be attributed to the natural reinforcement provided by the fibers, which help to distribute stresses more evenly across the concrete matrix, thereby preventing cracks and increasing the material's overall durability.

This effect is primarily due to the capacity of the fibers to link microcracks and distribute stress more uniformly throughout the concrete, as illustrated in Figure 8 [76]. Despite extensive research on mechanical characteristics, there is a lack of comprehensive studies on how various types of vegetal fibers influence other crucial properties of SCC, like its workability, shrinkage, thermal conductivity, and long-term performance under varying environmental conditions. Continued exploration is required to better grasp the range of influences of these fibers, taking into account their differences in properties such as length, thickness, and surface texture, as well as the way these factors influence the interaction with the concrete mix design.

4.2.2. Thermal Performances

Improving the thermal performance of building materials, particularly concrete, has become essential in response to the increasing demand for reduced energy consumption and enhanced building comfort. Materials that offer better thermal insulation play a vital role, as they not only lower heating and cooling costs but also minimize the carbon footprint of structures. A key factor influencing this performance is thermal conductivity, which affects the transfer of heat between the roof and walls of a building [77]. Optimizing thermal conductivity contributes to improving energy efficiency and comfort within the built environment. Natural materials, such as plant fibers, offer superior thermal insulation performance compared to synthetic alternatives. Their incorporation into concrete has increasingly attracted attention due to their potential to reduce thermal conductivity and enhance sustainability, thanks to their low thermal conductivity, as highlighted in Table 11 [8]-natural fibers like date palm, flax, and kenaf. Introduce a lightweight structure that improves insulation and contributes to the overall eco-friendliness of the material. These fibers create voids within the concrete, trapping air and minimizing heat transfer, which leads to better thermal performance.

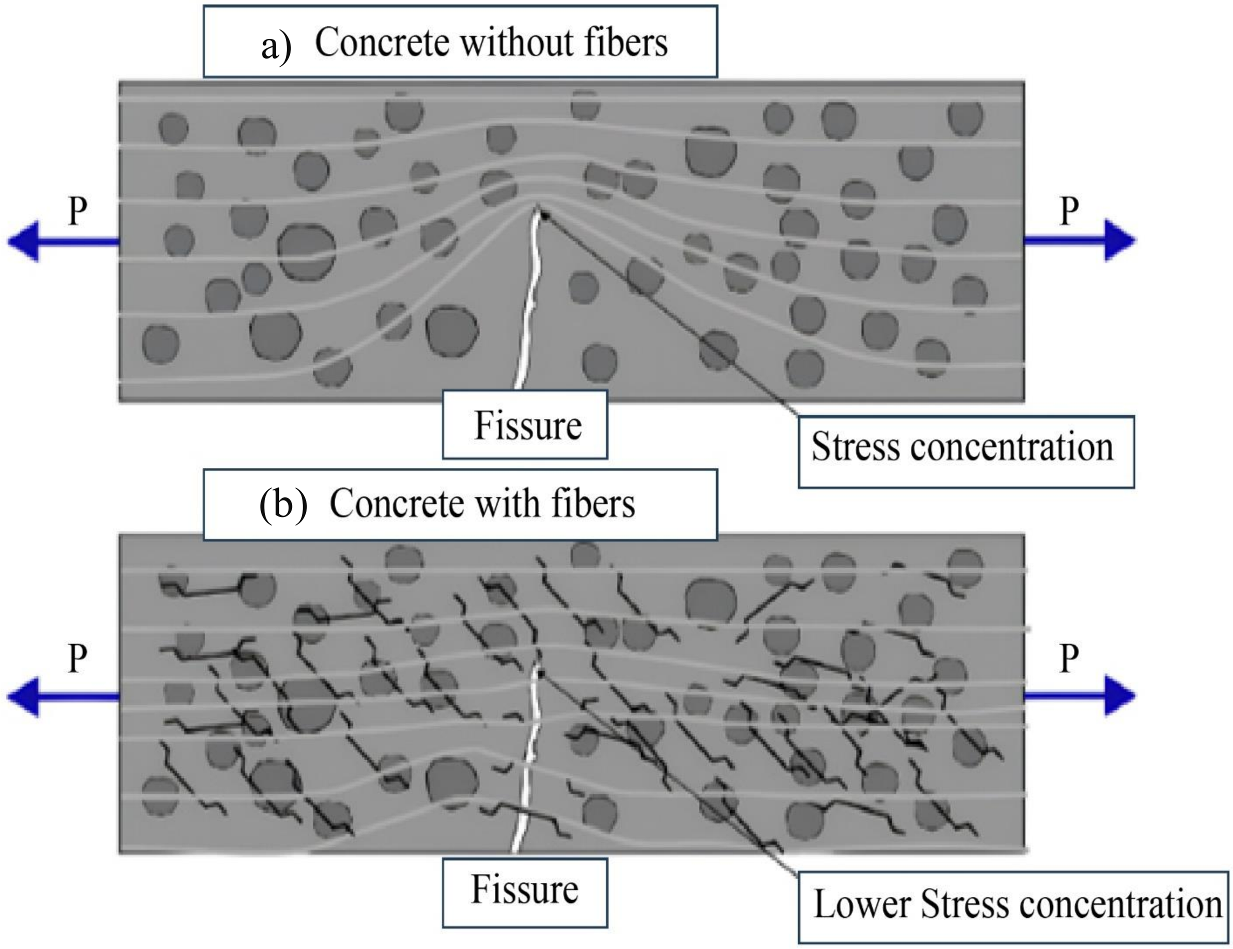

Fig. 8 Bridging effect: (a) Concrete without fibers, and (b) Concrete reinforced with fibers [76]

Table 11. Thermal conductivity of some plant fibers [8]

Fiber	Thermal Conductivity (W/m.K)
Wood	0,038–0,050
Hemp	0,038–0,060
Kenaf	0,034–0,043
Flax	0,038–0,075
Coco	0,040–0,045
Jute	0,038–0,055
Date palm	0,072–0,085

As reported by Kriker et al. [79], date palm fibers are essential for protecting the tree against temperature extremes, making them an excellent choice for enhancing the thermal behavior of various construction materials, especially concrete, which is often vulnerable to severe climate conditions, especially in terms of temperature changes and dryness. By integrating date palm fibers, the thermal performance of concrete can be enhanced, offering improved insulation and decreased heat transfer. This makes date palm fibers a valuable resource for building materials intended for extreme environments. Similarly, Benmansour et al. [6] showed an evident correlation between composite density and thermal conductivity, indicating that adding palm fibers to the mortar matrix decreases the concrete's thermal conductivity. This decline is due to the comparatively lower thermal conductivity of date palm fibers relative to the mortar. Raut and Gomez [79] found comparable results for oil palm fibres, with the thermal conductivity coefficient decreasing by about 40,1% when fibers were added at a content of 1.5%.

Another type of fiber studied by Wijesinghe et al. [80] is Juncus maritimus fibers. The results indicate that increasing the fiber dosage reduces the thermal conductivity of the concrete. In the same way, it was observed that the specific heat and thermal conductivity of the cement matrix were reduced by 12,1% and 81,6%, respectively, following the addition of 15% cellulose fibers [81], as shown in Figure 9.

Furthermore, incorporating 2.0% flax fibers improved the mechanical, thermal, and durability properties compared to concrete without fibers [82]. Table 12 highlights the documented effects of fiber addition on the thermal performance of cementitious composites, as noted in the literature.

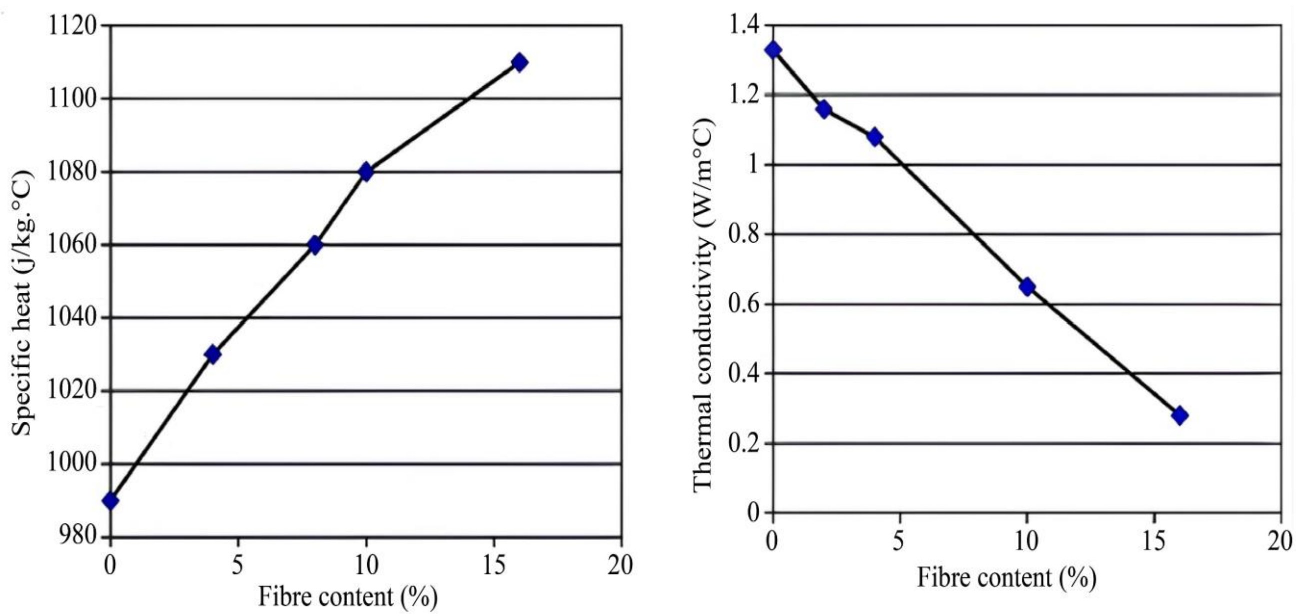

Fig. 9 Specific heat and thermal conductivity versus fiber content

Table 12. The impact of different plant fibers on composite thermal characteristics

Fiber	Thermal Performance of Composite	Reference
Juncus maritimus	Mortar reinforced with Juncus maritimus fibers exhibits improved thermal insulation and reduced density. Both treated and untreated fibers have a similar effect on reducing the thermophysical properties. Tests have demonstrated that the thermal conductivity of untreated composites is twice as high in saturated conditions compared to dry conditions, a trend also seen in treated composites. Water absorption is a significant factor affecting the thermal insulation.	[83]
Alfa	Adding 5% by weight of Alfa fibers makes the composite material approximately 15% lighter, improves its thermal insulation performance by around 57%, and enhances its ability to dampen heat diffusion by nearly 49%. This makes the material particularly promising for construction in the Mediterranean region.	[84]
	This study concludes that Alfa fibers show great potential for developing energy-efficient composites. Incorporating 5-10 % by weight of Alfa fibers in concrete Production can lead to eco-friendly construction materials that enhance building thermal comfort. Notably, adding 10 % by weight of these fibers leads to a substantial 67% reduction in thermal conductivity.	[85]
Wheat straw	The thermal insulation provided by straw mortars was significantly superior to that of the reference material. In particular, the reduction in thermal conductivity for all straw-based composites was between 86% and 91%.	[86]
Jute	The addition of fibers to mortar mixtures results in increased porosity and reduced density, which in turn lowers thermal conductivity. An important reduction in thermal conductivity was observed when the fiber content reached 1.5% and the fibers were 5 mm long.	[87]
Miscanthus	Experimental results showed significant enhancements in the thermal resistance of mortars. The addition of 5.7% by weight of Miscanthus fibers led to an approximate 82% reduction in thermal conductivity.	[88]
Diss	Thermal conductivity can be reduced by as much as 76% when the fiber content is raised to 30% in comparison to the control sample. This reduction in thermal conductivity is attributed to the low thermal conductivity of Diss fibers and the material's elevated porosity. Furthermore, as fiber content rises, thermal diffusivity drops by 68%, and thermal effusivity decreases by 82%.	[89]
Date palm	Experimental findings from thermal conductivity measurements demonstrate a substantial decline in thermal conductivity with the incorporation of date palm fibers. The mixture containing 5% of fibers exhibited enhanced thermal insulation characteristics, with a recorded reduction of 73.4 ± 0.1% in thermal conductivity compared to the reference sample.	[90]

4.2.3. Comparative Analysis of the Mechanical and Thermal Performances of Reinforced Concrete with Plant Fibers

Comparing the impact of plant fibers on concrete's mechanical and thermal characteristics reveals distinct effects in each area. In terms of mechanical properties, plant fibers like flax, banana, jute, and date palm have been shown to enhance concrete by acting as natural reinforcement within the matrix. These fibers improve the material's ability to resist cracking and increase its toughness by bridging microcracks and distributing stress more uniformly throughout the concrete. This reinforcement mechanism helps reduce the concentration of stresses in localized areas, thereby enhancing the composite's resistance to tension, flexure, and overall ductility. Moreover, the inclusion of plant fibers contributes to improving the post-cracking behavior of concrete, allowing it to sustain greater deformation without sudden failure. As a result, concrete reinforced with plant fibers exhibits improved resistance to mechanical loads and durability compared to ordinary concrete. At the same time, the impact of plant fibers on the thermal characteristics of concrete is more pronounced. These fibers can minimize the thermal conductivity of concrete, making it more efficient as an insulating material. This is particularly beneficial for energy-efficient construction, as concrete with plant fibers can help in maintaining stable indoor temperatures by reducing heat transfer. Furthermore, plant fibers contribute to the general.

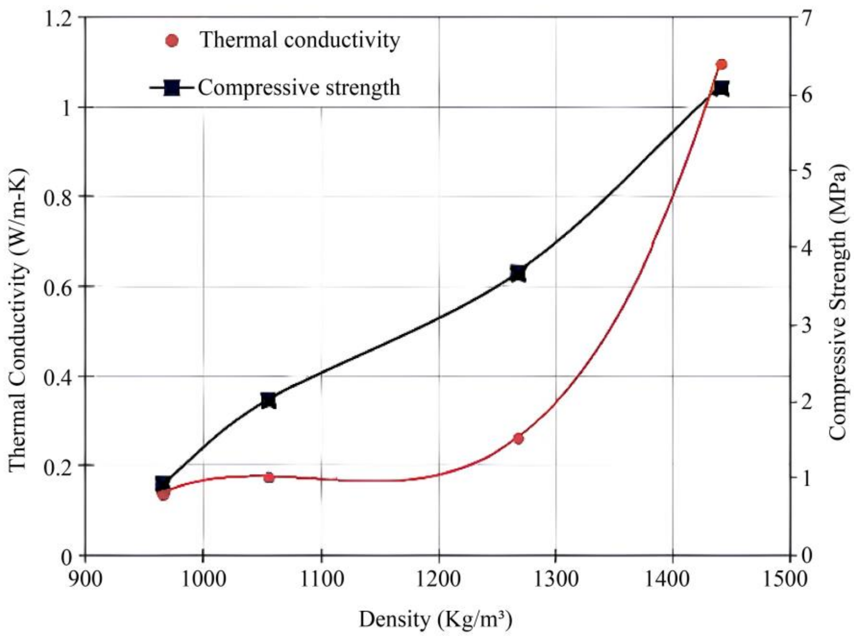

Fig. 10 Impact of density on thermal conductivity and compressive strength [88]

A decrease in concrete density can lead to improved thermal insulation properties, especially in environments with extreme temperature variations. Therefore, while plant fibers primarily enhance the mechanical properties by improving strength and toughness, they also offer significant benefits in terms of thermal performance, providing a balance between structural integrity and energy efficiency.

Sellami et al. [89] demonstrated that compressive strength, thermal conductivity, and density in concrete are interrelated. Figure 10 illustrates that reductions in composite density correspond to decreases in compressive strength and thermal conductivity. This reduction in density is achieved by increasing the plant fiber content within the mix.

The decrease in compressive strength indicates that adding fibers may slightly reduce the material's ability to resist applied forces. This effect likely stems from fibers occupying volume within the concrete matrix that would otherwise be filled by cementitious material, thereby reducing the overall continuity and strength of the matrix. However, this reduction is balanced by a notable improvement in the composite's thermal insulation properties. As more fibers are incorporated, the concrete's thermal conductivity is reduced, thereby enhancing its insulation capacity and resistance to heat transfer.

Beyond these mechanical and thermal benefits, plant fibers offer a promising and eco-friendly substitute to synthetic fibers in construction materials. Their incorporation enhances both the mechanical and thermal characteristics of concrete and significantly reduces environmental impact. By transitioning to plant fibers, industries can adopt more eco-friendly practices, addressing the growing demand for sustainable construction solutions. Their cost-effectiveness and the ability to repurpose agricultural waste further position them as an innovative approach to developing high-performance and environmentally responsible materials.

Despite their potential, research on the thermal conductivity and insulation properties of plant fiber-reinforced self-compacting concrete remains limited. This highlights a critical research gap, as this innovative concrete type could offer significant advantages over ordinary concrete, which is well documented but lacks the sustainability and advanced insulation capabilities of its plant fiber-reinforced counterpart. Exploring how plant fibers can enhance thermal performance, particularly in comparison to traditional materials, is essential to unlock their full potential and drive advancements in sustainable construction.

5. Conclusion

Self-compacting concrete is a novel development in the field of construction materials; however, the choice of an optimal formulation for this latter is a complex operation that requires a thorough experimental analysis of the characteristics of the raw materials used. Various formulation methods have been described in the literature, each with its specifications. Additionally, the use of plant fibers has expanded into multiple fields, especially in construction, owing to their large availability and their capacity to enhance the efficiency of building materials. Their applications have been extended to concrete and, more recently, to self-compacting concrete, although the number of studies carried out in this field remains limited. Nevertheless, literature shows promising results regarding the reinforcement of self-compacting concrete with cellulose fibers. For their large-scale implementation, it is essential to understand the technical challenges better and improve production methods in order to ensure consistent and sustainable performance of materials containing these fibers.

Given the increasing demand for sustainable substitutes for conventional raw materials, this literature review aims to synthesize the results of various studies conducted on the application of plant fibers in cementitious composites, particularly in self-compacting concrete. It presents a comprehensive analysis of self-compacting concrete and its formulation methods and a detailed examination of plant fiber characteristics and the different treatment techniques reported in the literature to improve their performance. Finally, by bridging these two research domains, the review explores the integration of plant fibers into self-compacting concrete formulation. Although studies conducted on this material are limited, they have shown promising results. From the findings in this article, the following conclusions are made, along with potential directions for future research:

- The studies show positive results of mechanical properties, alongside significant economic advantages, since natural fibers can reduce costs compared to industrial fibers while contributing to environmental protection by reducing waste and pollution associated with their Production.
- The incorporation of plant fibers into concrete raises two major problems: on the one hand, often insufficient adhesion between the fibers and the cement matrix, and on the other hand, a significant reduction in the workability of fresh concrete. These limitations can affect both the mechanical performance of the material and its implementation. In this regard, an adapted treatment of the fibers appears to be an effective solution. This treatment aims to modify the morphology or chemical composition of the surface of the fibers in order to improve their compatibility with the cement matrix, thus promoting better interfacial bonding and more efficient stress transfer. In addition, it reduces the water absorption capacity of the fibers, which limits the drying effect of the mixture and helps to maintain satisfactory workability, especially in the case of self-compacting concretes.
- Despite the positive aspects of plant fibers, it is essential to acknowledge limitations, including inconsistencies in uniformity in fiber quality and production conditions, the variability in fiber properties due to factors such as harvest location and timing, as well as sensitivity to humidity or exposure to ultraviolet radiation. An efficient production process is essential to obtain high-quality fibers, which in turn improve the mechanical properties of cement-based materials.
- Incorporating several plant fibers into ordinary concrete has been widely studied; however, reinforcing self-compacting concrete with such fibers is still not affordable and requires further research.
- There is a pressing need to conduct more research on the thermal properties of fiber-reinforced SCC. As sustainable building practices come into greater demand, studying and understanding how plant fibers influence thermal performance could lead to more energy-efficient building materials, as well as reveal innovative applications that not only improve insulation but also improve the overall durability of concrete.

Exploring this area provides a deeper understanding of the potential advantages of incorporating plant fibers, thereby contributing to the advancement of environmentally sustainable construction techniques.

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