Review Article

Effects of Using Natural Fibers on the Fresh and Mechanical Properties of Concrete: A Comprehensive Review

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Abstract

Most of the materials used in the construction sector are concrete, which has some disadvantages and weaknesses, such as low ductility and tensile strength. Many studies have been conducted to improve these properties, including the use of natural fibers. This article reviews previous experimental work on the use of different types of natural fibers in concrete at varying rates, highlighting their effects on both the fresh and mechanical properties of concrete. Based on the reviewed experimental data, relationships between concrete properties and the rate of fiber usage have been established. The effect of natural fibers on the slump value varies depending on the water absorption ability of the fibers. The slump decreases as the rate of natural fiber usage increases. The effect of natural fibers on compressive strength depends on fiber length and the water absorption ability of the fibers. As fiber length increases, the voids in the concrete increase, leading to a decrease in compressive strength. The effect of natural fibers on the flexural strength of concrete is influenced by fiber length and the elongation ability of the fibers. In terms of tensile strength, it was found that using sisal fiber in concrete at 0.5% increases the tensile strength by up to 30% compared to the control mix. Using jute fiber in concrete at 1.5% increases the tensile strength by up to 110% compared to the control mix. Using coir fiber in concrete at 1.5% increases the tensile strength by up to 60% compared to the control mix.

Keywords: Natural Fibers, Concrete, Slump, Compressive Strength, Flexural Strength, Tensile Strength.

Introduction

Concrete is one of the most widely used materials after water in most countries around the world, due to its high usage in the construction sector [1-4]. Since its discovery, many studies have been conducted on its composition and properties. Given its widespread use, a large amount of raw materials (water, cement, fine aggregate, and coarse aggregate) is required for its production

[5-10], which poses a general threat to the environment. For this reason, many studies have focused on using new materials as partial replacements for fine and coarse aggregates, especially waste materials such as waste plastic and glass [11-20]. To reduce the amount of carbon dioxide emitted by the cement industry, many studies have investigated the use of pozzolanic materials as partial or complete replacements for cement [21,22]. Concrete is cheap to produce and has high compressive strength, but it suffers from low ductility, tensile strength, poor toughness, and tends to crack quickly [23-27]. To address these problems and control crack distribution while increasing tensile strength, fibers have been used [28-31]. Fiber can be used to in improve the properties of different types of concrete [72-73].Various types of fibers from different compositions, such as steel, glass, carbon, and polypropylene, have been developed for use in concrete [32,33,71]. However, the processes of preparing raw materials and producing these fibers require a high amount of energy and are costly, and they also release a large amount of waste gases into the atmosphere [34-38]. For these reasons, natural fibers have been explored as alternatives to synthetic fibers [39,40]. The use of natural fibers in concrete dates back to the nineteenth century [28]. Natural fibers have many properties that make them more desirable compared to synthetic fibers, including low cost, easy availability, low energy consumption, and the ability to protect the environment from the gases emitted in the production of synthetic fibers [41-43]. Many studies have been conducted to investigate the fresh and mechanical properties of concrete with different rates of natural fibers, as shown in Table 1 below [44,45]. The types of natural fibers used include coir, hemp, sisal, jute, henequen, sugarcane, palm, palm fruit bunch fiber (PFBF) and banana fibers [46-50]. Ruben and Baskar [46] investigated the use of coir fiber in two different sets of concrete, each with three different rates (0, 0.5, 0.75, and 1%). The variable in each set was fiber length, to evaluate the effect of fiber rate and length on the compressive strength of concrete. They found that, for both fiber lengths, using 0.75% of coir fiber in concrete resulted in an optimum increase in compressive strength. Navya and Rao [47] investigated the use of coconut fiber in concrete with five different rates (0, 0.1, 0.2, 0.3, 0.4, and 0.5%) to study its effect on water absorption, compressive strength, and flexural strength of concrete. Based on the test results, all rates of coconut fiber increased compressive and flexural strength compared to the control mix, although water absorption also increased due to the fiber’s water-absorbing properties. Awwad et al. [48] also investigated the use of coconut fiber in concrete at four different rates to assess its effect on the density of concrete. The results showed that, as the rate of coconut fiber increased, the density of the concrete also increased. Fareed et al. [70] in their study using Jute (10, 15, 25 mm; 0.1–0.5% vol.) and Kevlar fibers (10, 15, 20 mm; 1–2.5% vol.) improved crack control in concrete, indicating their effectiveness in enhancing mechanical properties and performance. This article investigates the effect of using different types of natural fibers in concrete on its fresh and mechanical properties, including compressive strength, tensile strength, and flexural strength, at different rates and curing times. The natural fibers classifications can be seen in Figure 1 [44].

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Table 1. Reviewed experimental work on using natural fibers in concrete

References Number	Fiber Type	Used Rate (%)	Slump Test	Density Test	Water Absorption Test	Compressive Strength	Flexural Strength	Tensile Strength
[46]	Coir	0, 0.5, 0.75, 1				√		
[47]	Coir	0, 0.1, 0.2, 0.3, 0.4, 0.5			√	√	√	
[48]	Hemp Palm Banana	0, 0.5 0, 0.5, 1 0,1				√ √ √		
[50]	Leaf	0, 1, 1.5, 2				√		
[51]	Sisal Coir	0, 0.5, 1, 1.5 0, 0.5, 1, 1.5				√ √		
[52]	Sisal	0, 0.5, 1, 2				√	√	√
[53]	Jute	0, 0.1, 0.2, 0.3				√		
[54]	Sisal	0, 0.5, 1, 1.5, 2	√	√	√	√		√
[55]	Henequen	0, 0.5, 1, 1.5				√		√
[56]	Jute Sisal Sugarcane Coir	0, 0.5, 1, 1.5, 2, 2.5, 3 0, 0.5, 1, 1.5, 2, 2.5, 3 0, 0.5, 1, 1.5, 2, 2.5, 3 0, 0.5, 1, 1.5, 2, 2.5, 3				√ √ √ √		√ √ √ √
[57]	Coir	0, 0.1, 0.175, 0.25		√			√	
[58]	Sugarcane Palm Banana	0, 0.5, 1, 1.5 0, 1, 2, 3 0, 0.3, 0.5, 0.7, 1				√ √ √		√ √ √
[59]	Hemp	0, 0.5, 0.75, 1				√	√	√
[60]	Jute	0, 1, 2						√
[61]	Coir	0, 0.5, 1, 1.5, 2				√		
[62]	Jute	0, 0.25, 0.5, 0.75, 1	√					
[63]	Jute	0, 0.1, 0.25, 0.5				√		√

RESEARCH SIGNIFICANT

This article deals with the review of previous experimental articles on using different type of natural fiber with different rate in concrete to find the effect of each type on the fresh and mechanical properties of concrete including compressive, flexural, and tensile strength with selecting optimum rate of each fiber which provide higher effect on concrete's properties.

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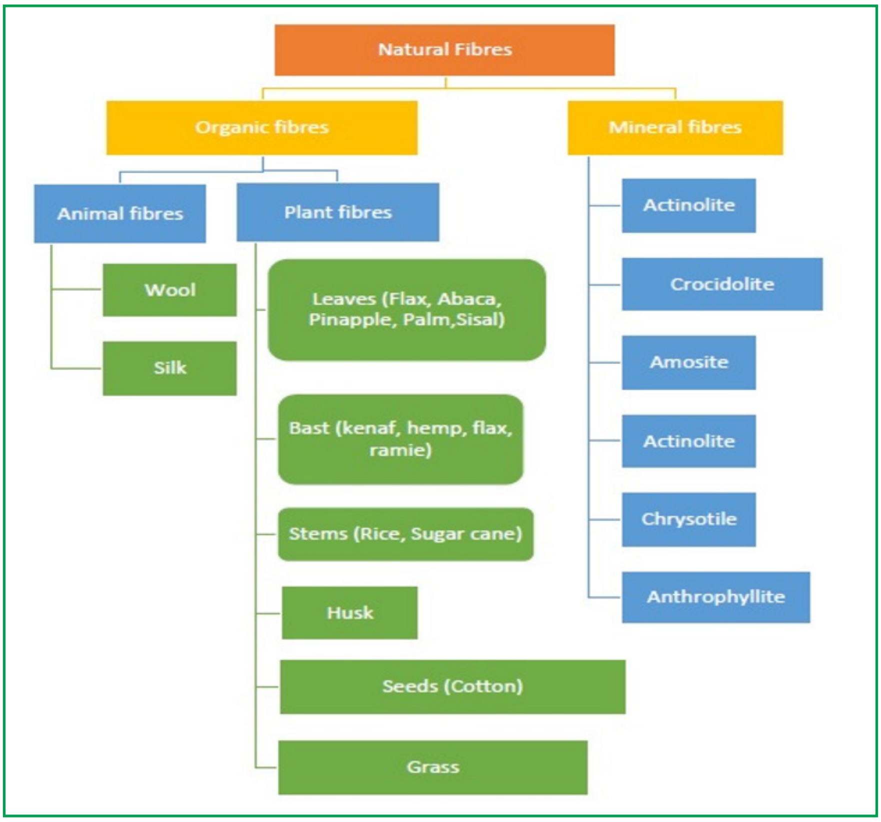

Figure 1. Natural fibers classifications [44]

METHODOLOGY

Based on the target of article, after revising of previous experimental work, experimental data on using different rate of different type of natural fiber have been collected with obtained value of each properties of concrete including slump, compressive strength, tensile strength, flexural strength, density, water absorption as explained in Figure 2, with using normalization the scatter graph has been drawn for different curing time.

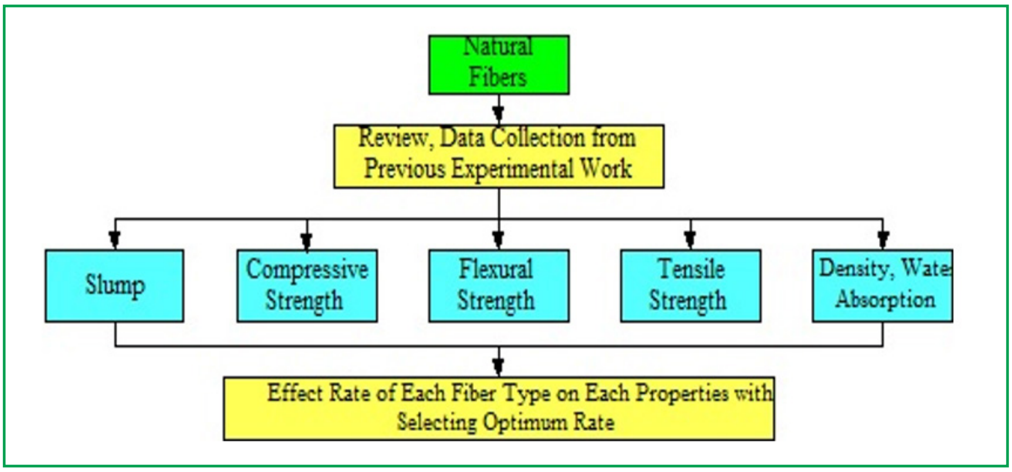

Figure 2. Research methodology flow chart

Review of Prior Experimental Research

Slump Test

Slump is a property used to measure the workability of concrete based on ASTM C143 [64]. As shown in Figure 3, after normalizing the slump value with fiber volume, it was found that when Okeola et al. [54] used sisal fiber in concrete, the workability decreased compared to the control mix. This is due to the water absorption capacity of sisal fiber, which is 43%, meaning it absorbs water equivalent to 43% of the added fiber's dry weight, causing a decrease in the slump value. A similar situation occurred when Kalaivani et al. [62] used jute natural fiber, as jute's water absorption capacity is higher compared to that of sisal fiber. In addition to water absorption, the length-to-diameter (L/D) ratio of the fibers also plays a critical role in influencing the slump value. Fibers with a higher L/D ratio tend to increase internal friction within the concrete mix, as their elongated and slender shape leads to greater surface area and entanglement between fibers. This restricts the flow of the mix, thereby reducing its workability. Furthermore, higher L/D fibers are more likely to create a non-uniform distribution within the mix, further impeding flow. Therefore, in addition to their water absorption behavior, the high L/D ratios of natural fibers such as sisal and jute contribute significantly to the observed reduction in slump.

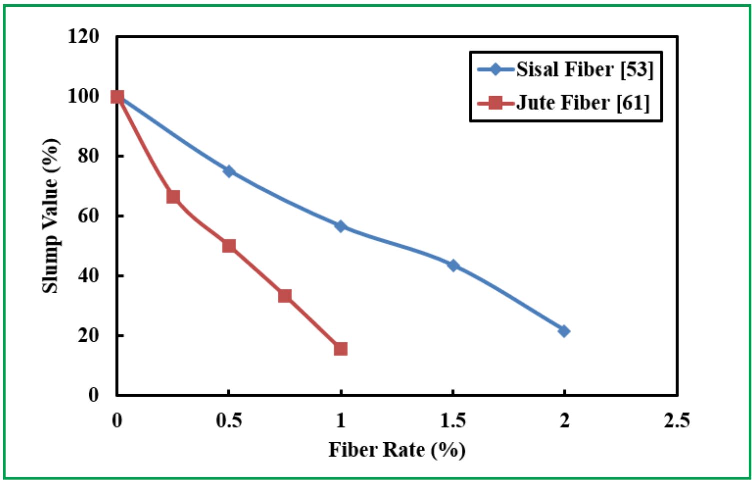

Figure 3. Normalized slump value variation with fiber volume

Compressive Strength

Compressive strength in concrete is one of the most important properties, from which other properties are derived, and is measured based on the procedure outlined in ASTM C39 [65]. As shown in Figures 4, 5, and 6, different natural fibers, including palm, banana, hemp, henequen, sugarcane, sisal, jute, and coir fibers, have been added at different rates to the concrete to investigate their effect on compressive strength. Since the water-to-cement ratio is one of the most influential parameters in the concrete mixture regarding compressive strength, and all types of natural fibers have a high water absorption capacity, the optimum rate for compressive strength increase is achieved when each type of fiber is added in limited amounts, absorbing extra water from the mix. In the reviewed studies, the use of superplasticizers or other chemical admixtures was generally not reported, and in most cases, workability adjustments were made by increasing the water content of the mix to compensate for the water absorbed by the natural fibers. This additional water affects the effective water-to-cement ratio, which in turn influences compressive strength. Therefore, the observed results must be interpreted with consideration of these variations. For instance, Ruben and Baskar [46], when using coir fiber in concrete at 0.75%, obtained an 18% increase in compressive strength compared to the control mix, as shown in Figures 4 and 5. On the other hand, Krishna et al. [60] achieved the optimum increase in compressive strength with a 2% coir fiber addition, yielding an 18% improvement. This difference in behavior is influenced by several factors, such as the water-to-cement ratio and fiber length. Ruben and Baskar [46] used fibers with a length of 200 mm, which created voids in the concrete when the fiber content exceeded a certain level. In contrast, Krishna et al. [61] used fibers with a maximum length of 32 mm, resulting in a lower void ratio. As shown in Figure 6, most types of fibers show activation up to 1.5%, which provides the optimum increase in compressive strength.

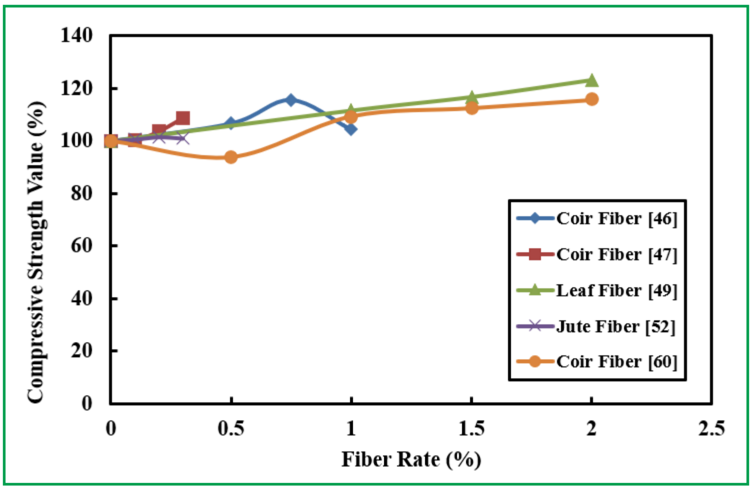

Figure 4. Normalized compressive strength value variation with fiber volume (7 days curing)

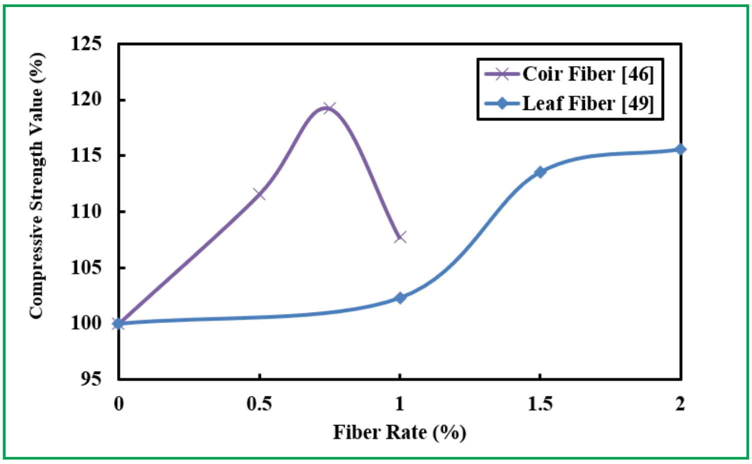

Figure 5. Normalized compressive strength value variation with fiber volume (14 days curing)

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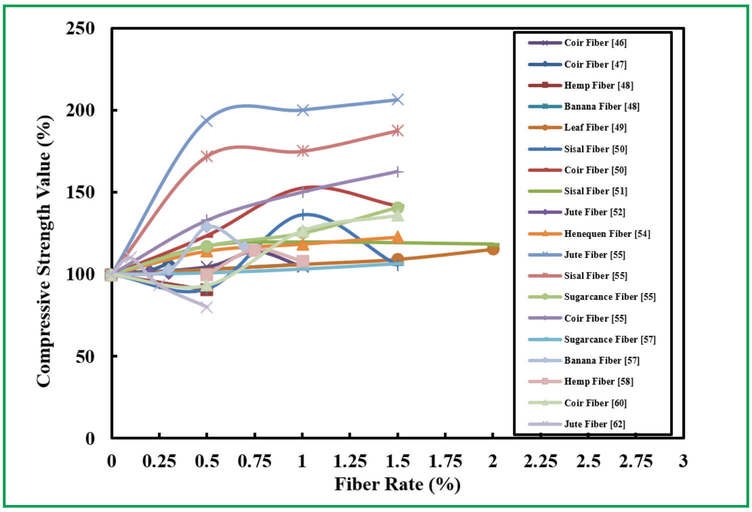

Figure 6. Normalized compressive strength value variation with fiber volume (28 days curing)

Flexural Strength

Flexural strength is one of the important mechanical properties of concrete, measured based on the procedure outlined in ASTM C78 [66]. The samples which were typically 100 mm × 100 mm × 500 mm in the reviewed studies, in accordance with ASTM C78 standards. To improve this property and increase the bending ability of concrete, reinforcement or fibers can be used. Many studies have been conducted on using natural fibers in concrete to enhance its properties. As shown in Figures 7 and 8, the use of natural fibers in concrete can increase flexural strength at varying rates, depending on the elongation ability of the fibers used. Based on the experimental test results for natural fibers, the elongation ability of fibers varies, as expressed in Table 2. Among the fibers used, coir fiber has the greatest effect on flexural strength, while sugarcane fiber has the least effect. A similar result was observed in concrete when Hardjasaputra et al. [57] used coir fiber, resulting in a 65% increase in flexural strength compared to the control sample. In contrast, when Balasubramanian and Selvan [52] used sisal fiber in concrete, only a 40% increase was achieved, as shown in Figure 8.

Table 2. Physical properties of used natural fibers

Fibers Name	Density (kg/m^3)	Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Elongation Break (%)
Sisal Fiber [54]	1100	371	28500	2.45
Henequen [55]	1400	500	13200	-
Jute Fiber [56]	1300	480	37500	2.3
Sugarcane Fiber [56]	820	68	18700	1.5
Coir Fiber [57]	900	175	22000	3.6

Tensile Strength

Tensile strength is one of the most important properties for structural members, especially in buildings located in seismic zones. Tensile strength in concrete is measured based on ASTM C496 [67]. Unfortunately, concrete, which

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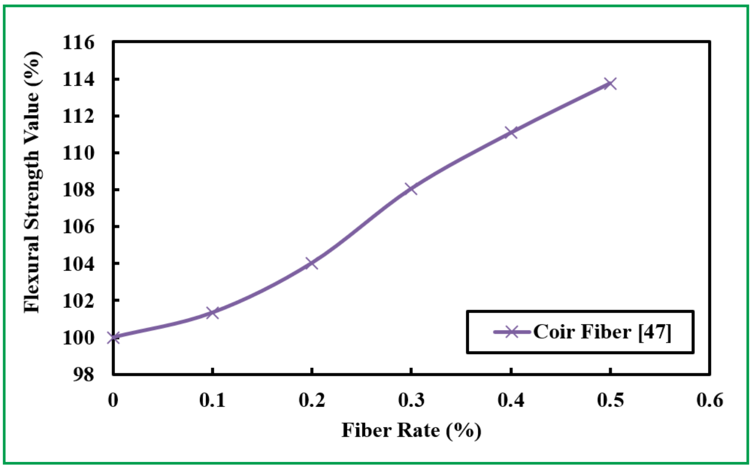

Figure 7. Normalized flexural strength value variation with fiber volume (7 days curing)

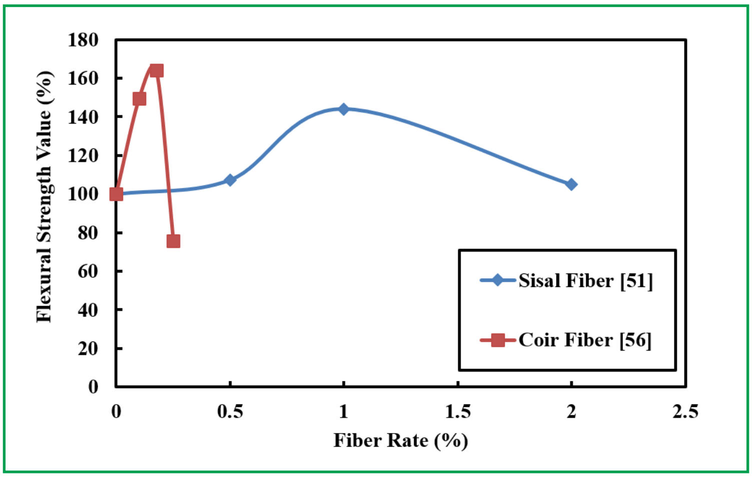

Figure 8. Normalized flexural strength value variation with fiber volume (28 days curing)

is one of the most widely used materials in construction, is weak in this property. As a result, many studies have been conducted to improve and increase tensile strength. One method for achieving this is by using natural fibers. Based on data collected from previous experimental work, the relationships shown in Figures 9 and 10 have been drawn. The use of different types of natural fibers generally affects tensile strength, and this effect varies based on the type of fiber, its length, and the concrete mix design. As shown in Table 2, each type of natural fiber has its own tensile strength. Henequen fibers have the highest tensile strength at 500 MPa, followed by jute fiber at 480 MPa, with sisal, coir, and sugarcane fibers ranking lower. Sugarcane provides the lowest tensile strength at 68 MPa. Sugarcane fiber's low tensile strength is mainly due to its low cellulose and high lignin content—factors that weaken tension resistance, limit combustion performance, and, combined with the fiber's rough and irregular surface, lead to poor bonding and increased stress concentrations in cementitious matrices. [74]. Based on these test results, using Henequen and jute fibers in a constant concrete mixture provides higher tensile strength compared to concrete containing sisal and sugarcane fibers. Another factor that affects the optimum rate of fiber, which provides the maximum effect on tensile strength, is fiber

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length. As fiber length increases, the fiber content also increases, which leads to a higher void content in the mix and reduces tensile strength. For the same type of fiber and constant concrete mixture, different optimum rates will be achieved depending on the fiber length. For example, using sisal fiber, Balasubramanian and Selvan [59] found that the optimum tensile strength was achieved at a 0.5% fiber content, while Okeola et al. [54] found that a 1% fiber content provided the optimum tensile strength. Jute fiber, banana fiber, Henequen fiber, coir fiber, and sugarcane fiber [55,56,58], as shown in Figures 9 and 10, can provide an increase in tensile strength up to a 1.5% fiber content.

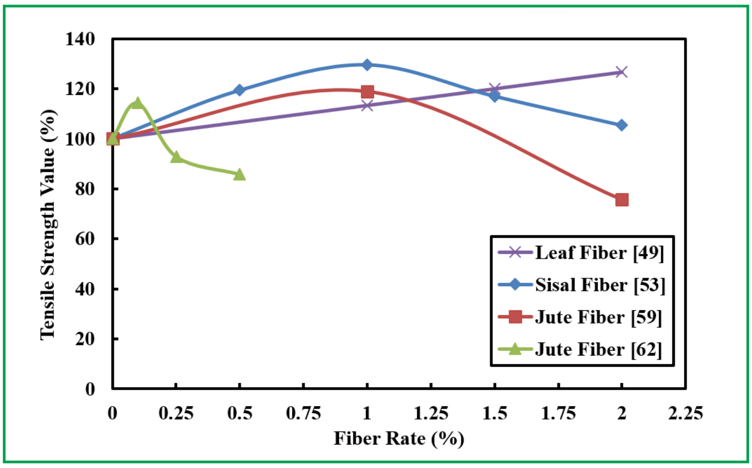

Figure 9. Normalized tensile strength value variation with fiber volume (7 days curing)

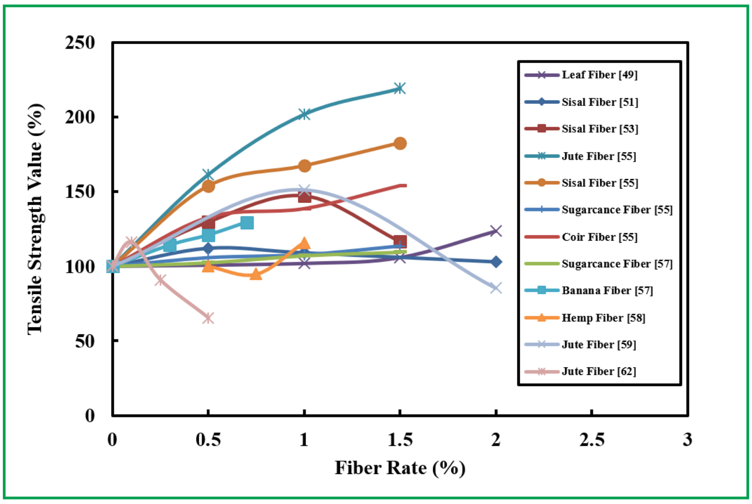

Figure 10. Normalized tensile strength value variation with fiber volume (28 days curing)

Density

The density of concrete is investigated based on the procedure outlined in ASTM C138 [68] which measures the wet (or as-mixed) density of the concrete mixture. Each component of concrete affects the concrete mixture, as all materials together form the concrete. When materials are used as partial replacements for a concrete component, if the added material has a lower density than the removed component, the density of the concrete decreases. Conversely, if the added material has a higher density, the density of the concrete increases [17, 18]. Okeola et al. [54] and Hardjasaputra et al. [57] both used natural fibers in concrete (sisal fiber and coir fiber, respectively). The density of the fibers used was 110 kg/m³ for sisal fiber and 600 kg/m³ for coir fiber, both of which are lower than the density of the aggregates, leading to a decrease in the concrete's density (Figure 11). However, since coir fiber has a high water absorption capacity, it holds a large amount of water inside without allowing it to evaporate. This causes the coir fiber to increase the density of the concrete, but only to a limited extent.

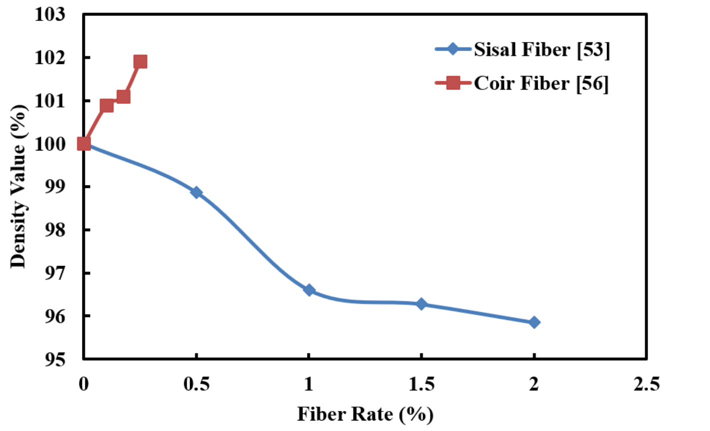

Figure 11. Normalized density value variation with fiber volume

Water Absorption

Water absorption is a property of concrete measured based on ASTM C1585 [69]. It is related to the void content in the concrete or the availability of materials in the concrete that absorb water, as in the case of adding natural fibers. As indicated in Figure 12, sisal fiber alone has a water absorption capacity of 43%, which causes an increase in water absorption in concrete when added. Similarly, other natural fibers also exhibit significant water absorption capacities which directly affects moisture uptake of the concrete [75].

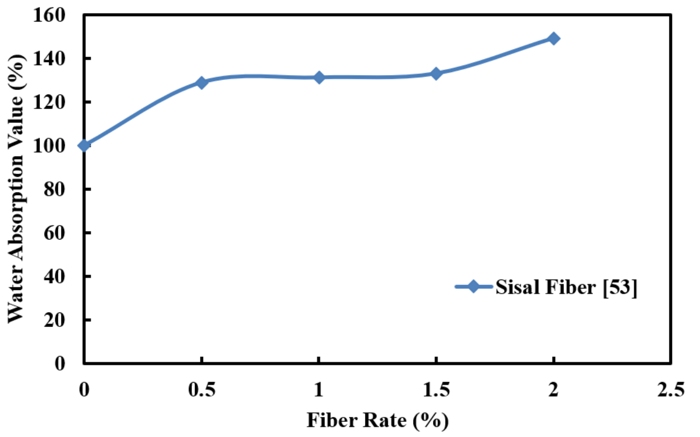

Figure 12. Normalized water absorption value variation with fiber volume

Conclusions

This article reviews previous experimental work on using natural fibers in concrete and examines their effect on the fresh and mechanical properties of concrete. Based on this review, the following points have been observed:

1. The effect of natural fiber on the slump value depends on the water absorption ability of the fiber. Slump decreases with an increase in the amount of natural fiber used.
2. The effect of natural fiber on compressive strength varies based on fiber length and the water absorption ability of the fiber. As fiber length increases, the voids in concrete increase, leading to a decrease in compressive strength.
3. The effect of using natural fibers on the flexural strength of concrete is influenced by fiber length and the elongation ability of the fibers.
4. Coir fiber has a higher elongation resistance compared to other types of natural fibers.
5. The effect of using natural fibers on the tensile strength of concrete depends on fiber length and the tensile strength of the fibers used.
6. Henequen and jute fibers have a higher ability to resist tensile stress compared to other types of fibers used.

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Conflicts of Interest

We confirm that there are no known conflicts of interest associated with this publication, and no significant support has been received for this work that could have influenced its outcome.

Author Contributions

Sardam Salam Shkur: conceptualization, writing- original draft preparation. **Azad Abdwlqadir Mohammed:** conceptualization, writing- original draft preparation. **Soran Abdrahman Ahmad:** methodology, data curation, writing-original draft preparation, writing- reviewing and editing. **Hersh F Mahmood:** methodology, data curation, writing- original draft preparation, writing-reviewing and editing.

Data Availability Statement

All data generated or analyzed in this study have been included in this published article.

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