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Fiber Reinforced Concrete: A Critical Review on Material Properties and Applications

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Abstract

This paper presents a critical review on Fiber Reinforced Concrete (FRC), which is a composite material made up of cement, aggregate, and individual fibers. One of the most well-known building materials is concrete, which is often produced using materials that seem to be commonly accessible nearby. To satisfy the demands of modern building, the current trend in concrete technology is to make concrete more resilient and durable. The investigation's primary goal is to examine the impact of various natural fiber in concrete. This will develop the industry and provide more support for the evolution of the construction industry. Traditional concrete has a hard and brittle character. It is ductile, has a low tensile strength, a high compressive strength, and is not very durable. However, this traditional production of concrete causes a huge amount of Carbon emissions. Using natural fibers in the manufacture of concrete can significantly reduce these emissions**.** Natural fibers like coir, palm, jute, sisal banana, pine, sugarcane, bamboo are used in concrete manufacturing. This paper focuses on the impact of coir, bamboo and sugarcane on concrete production**.** The study simply examines the similarities and differences among these three natural fiber types. This analysis's objective is to present an examination of the variables affecting overall performance and durability. It will be a valuable resource for researchers, engineers, and practitioners in the fields of construction and materials science.

Keywords: *fiber reinforced concrete; high compressive strength; carbon emission; natural fiber; tensile strength.*

1 Introduction

The construction sector utilizes massive amounts of non-renewable materials all around the world. This activity not only wastes millions of tons of minerals, but also emits carbon dioxide, which pollutes the environment. Concrete is the most well-known building material because it is inexpensive, readily accessible, and broadly suitable (Afroughsabet & Ozbakkaloglu, 2015). So nowadays, higher strength and environment friendly concrete is a need of building industry (Breitenbuecher, 1999). Reinforcement of concrete using natural fibers is one of the most promising approaches for increasing strength while minimizing environmental impact (Jamshaid et al., 2022). Natural fiber can be obtained directly from an animal, vegetable, or mineral source. As a result, natural fibers are sustainable, reasonably priced, and biodegradable. It emits less carbon than any other fibers such as steel and synthetic fiber. Due to availability and low environmental impact of natural fiber, in recent decades many researchers have contributed to the use of natural fiber in concrete production. Use of natural fibers can effectively increase the workability, durability and high tensile strengths of concrete. Natural fibers can reduce weight by 10% and energy consumption by 80%, while the component costs 5% less than a comparable fiber glass-reinforced component (Balasubramanian & Selvan, 2015).

There are a variety of natural fiber available that can be used to increase the compressive and tensile strength of concrete including coconut, sisal, sugarcane, bagasse, bamboo, jute, wood and vegetables, canes etc. Studies showed that the use of natural fibers up to 1% of the cement mass not only enhanced the compressive capabilities of concrete, but also limited unexpected brittle failures as the percentage of fibers increases (Jaballi et al., 2017; Prasanthi et al., 2021; Zakaria et al., 2018). This study analyses the effect of three most effective natural fibers (coir, bamboo and sugarcane) on the overall performance and durability of concrete. The aim is to evaluate the similarities and differences among these three natural fibers reinforced concrete.

Based on earlier research on this subject, a review of the literature has been conducted. How adding natural fiber improves the original qualities of standard concrete.

Jawad Ahmad et.al (2022) reported that fibers from coconuts developed flexure strength (47%) more significantly than compressive strength (12%) (J. Ahmad et al., 2022). Habibunnisa Syed et.al (2021) carried out an investigation and concluded that adding coconut fiber to concrete boosts the tensile split strength by a maximum of 5% (Syed et al., 2020). Achudhan et.al (2018) did a test and found that adding fiber at an amount of 1% coir fiber consistently results in a linear improvement in strength (Achudhan et al., 2018). Yalley et.al (2009) reported that for concrete with 0.25%, 0.5%, and 0.75% fiber content, compressive strength decreased on average by 40%, 24%, and 28%, respectively (Yalley & Kwan, 2009).

Faisal Sheikh Khalid et.al (2016) conducted an experiment and concluded the optimum amount of sugarcane is 0.5%, but even though it had no effect on the concrete's compressive strength, the tensile strength of regular concrete was remained unaffected by sugarcane fiber at that percentage (Khalid et al., 2017). K. Lakshmi Priya et.al (2016) concluded that in comparison to concrete with different percentage replacement mixes, the findings showed that concrete with 10% SCBA replacement had the highest strength after 28 days of curing (Priya, 2016). Bharath V B et.al (2020) conducted an experimental study and found that when 10% sugarcane bagasse ash and 10% glass powder were substituted for cement's weight at cure times of 7, 14, and 28, the concrete's compressive strength was greater than that of standard concrete. However, a further rise in replacement rates reduces concrete's compressive strength (Bhadoriya et al.).

Karthikeyan Kumarasamy et.al (2020) did an experiment and found that bamboo fiber reinforced concrete has a strength that increases with fiber addition up to 2% and then slightly drops beyond that (Kumarasamy et al., 2020). Bindu M et.al (2016) stated that the ideal range of aspect ratios, which effectively provided good strength, is found to be between 30 and 80. Furthermore, it has been shown that, although specimens made of conventional concrete fail instantaneously, those built of bamboo fiber reinforced concrete remain intact even after failure (Bindu M et al., 2016). R.E. Marrero et.al (2017) did a study and found an average rise in compressive strength of 22% and tensile strength of 17%. This improvement is due to the fibers bridging, which slows the spread of cracks in the matrix of hardened cement. The bamboo fibers advantageous effects are more pronounced in mixes with weaker mechanical properties (Marrero et al., 2017).

2 Effect of Natural Fiber on Concrete Properties

The mechanical properties of concrete such as strength, toughness, ductility, energy absorption capacity, and damage tolerance can be improved by the addition of natural fiber in concrete (Eswari et al., 2008; Khan & Ali, 2016, 2018; Khan & Cao, 2021). Use of natural fibers can effectively increase the workability, durability and high tensile strengths of concrete as well as reduce the crack propagation inside the concrete. As a result, nowadays many researchers are considering natural fiber as a sustainable approach towards high strength concrete production.

2.1 Coconut Coir

Coconut fibers being the toughest than any other natural fibers are effective enough to take 4 to 6 times more strain than other fibers (Ali et al., 2012; Munawar et al., 2007). According to studies, Up to a specific point, increasing the quantity of coconut fiber in concrete improves its mechanical qualities. It is seen that concrete reinforced with 0.5% coconut fiber has an increase in compressive strength by around 9% (Jamshaid et al., 2022). Many research shows that this increase in strength continues up to 2% of fiber content. Above this a reduction in strength is observed. Aside from the variable percentage of fiber content, the length of the coconut fiber also influences the mechanical properties of concrete significantly The slump value increases as the fiber length grows from 25 to 50 mm, resulting in better workability. However, increasing length to 75mm reduces the slump value thus reduce the workability of concrete (W. Ahmad et al., 2020). Similar result is seen for compressive, tensile and flexural strength of concrete for varying percentage and length of coir fiber. Many studies have been undertaken to determine the optimal fiber content and length to achieve the greatest potential effect. Further research is needed to determine an empirical optimum fiber content and length to ensure maximum improvement in mechanical properties of concrete.

2.2 Bamboo

Bamboo, one of the fastest growing plants, is getting popularity as a natural fiber for FRC as it requires less energy to harvest and transport. In addition to increasing the compressive and tensile strength of concrete, bamboo fibers also play a significant role in preventing the growth and propagation of cracks in concrete (Dewi & Wijaya, 2017). According to studies, increasing the proportion of bamboo fiber in concrete enhances its

compressive, tensile and flexural strength but only up to a certain point. In recent research it has been observed that addition of bamboo fiber increases the compressive, tensile and flexural strength up to 2% of fiber content (Kumarasamy et al., 2020). Above this a decrease in these strengths is observed as the addition of fiber reduced the binding stress between the cement matrix and aggregate. Another research shows that concrete with 2% bamboo fiber provides a 200% increase in flexural strength when compared to standard concrete (Terai & Minami, 2012). According to some researcher at 3% volume fraction, fiber content boosts tensile strength by up to 50% (Terai & Minami, 2012). When the bamboo fiber content is 0.26, the cubic compressive strength and tensile strength are the highest that is 26.25% and 97.21% higher, respectively, than conventional concrete (Zhang et al., 2012). This results of several research on bamboo fiber significantly indicates that although many findings have been obtained on the effect of this fiber on the mechanical properties of concrete, further research is needed to establish an empirical optimum fiber content which will be applicable in all cases.

2.3 Sugarcane

Sugarcane fiber, as an ecologically friendly resource, is particularly valuable in construction because it can improve crack management and ductility in brittle concrete. Many research on sugarcane fiber shows that fiber loading up to 20% improved the mechanical properties of concrete such as tensile strength, elastic modulus, flexural modulus, flexural strength, and impact strength (Devadiga et al., 2020). Some studies shows that although sugarcane fiber increase the tensile strength of concrete with increasing fiber content The compressive strength has dropped significantly compared to the conventional one. It has been observed that addition of 0.5% sugarcane fiber reduces the compressive strength of concrete up to 2.5 Mpa which further decreases to 5.3 Mpa and 8.5 Mpa for 1% and 1.5% respectively (Khalid et al., 2017). On the other hand, tensile strength increases to 0.06 Mpa, 0.12 Mpa and 0.19 Mpa for 0.5%, 1% and 1.5% respectively in comparison to normal concrete (Khalid et al., 2017). So, although sugarcane fiber can be a sustainable fiber alternative for FRC, more research is required in this field to find out an optimum fiber content which is not only environment friendly but also plays an important role in improving the mechanical properties of concrete.

3 Challenges and Limitations

Construction industry has a tendency to stick to its traditional method. As a result, while the use of natural fiber as a replacement for steel and synthetic fiber can be a sustainable solution to concrete manufacturing, the road to its actual application remains fraught with numerous challenges and limitations. From the very beginning of collection of natural fiber, treatment and mass production the path to natural FRC is filled with numerous obstacles.

Coconut fiber one of the toughest natural fiber. But mass production of this fiber for concrete production still has a long way to go. The lack of coconut fiber based concrete production factory is a challenge in adopting this toughest fiber in concrete manufacturing. One of the major limitations of coir is its tendency to segregate which results in a decrease in the workability of concrete. Moreover, other drawbacks of coconut coir include sensitivity to shrinkage during drying or volume variations caused by sequential moist and dry conditions of concrete, reduction in the workability of regular grade concretes, a reduction in density, and a rise in water absorption. (Shcherban' et al., 2022).

Bamboo fiber is one of the most easily available natural fibers. Despite this it has it's own limitations. One of the major drawbacks of bamboo fiber is that although the addition of fibers reduces the breadth of the cracks in concrete and its post-cracking load-carrying capability, increasing the fiber content might result in decreased slump and thus impair the workability and quality of concrete (Dewi & Wijaya, 2017).

Environment friendly sugarcane fiber also have some major demerits. Some research observed that although sugarcane fiber increases the tensile strength, there may be a significant reduction in the compressive strength of concrete. Moreover, increasing fiber content may result in a reduction in the workability of concrete, in terms of slump value (Kotresh et al., 2014).

4 Conclusion and Recommendation

Construction and structures contribute roughly 40% of the carbon footprint due to numerous activities such as electricity, the cooling process, and burning of building materials. Concrete production plays a vital role in this carbon emission of construction industry. As a result, developing sustainable alternatives to concrete manufacture has become a global requirement. Implementing natural fiber in concrete manufacturing works as an effective solution to reduce the carbon emission caused by conventional concrete production. Natural fiber

not only reduce the environmental impact of concrete production but also plays a significant role in increasing the mechanical properties such as compressive, tensile and flexural strength of concrete. A range of natural fibers are already being researched for their use in concrete manufacturing. Among these jute, bamboo, sugarcane, coconut coir, banana etc. natural fibers are showing promising result. More research is being conducted to determine the most effective natural fiber for decreasing the carbon footprint of the building sector while increasing the mechanical qualities of concrete.

Natural fiber reinforced concrete is now widely recognized as the most cost-effective and environmentally beneficial way of manufacturing low-carbon concrete. Although many researches have been conducted to determine the effect of individual natural fibers on the mechanical properties of concrete, only a few studies have been completed to compare the benefits and drawbacks of various natural fibers on the mechanical characteristics of concrete. This review focuses on establishing a comparative analysis of the advantages and disadvantages of coconut coir, bamboo and sugarcane fiber in FRC production and determining the most efficient one. Despite each fiber having their own limitations coconut fiber can be considered as the most effective fiber due to its high toughness and ability to significantly improve the mechanical properties of concrete.

Coconut fiber increases the compressive and tensile strength of concrete up to 2% of fiber content. These properties can be improved further by integrating fiber content with optimal fiber length Bamboo fiber, as one of the most widely available natural fibers, not only increases compressive and tensile strength but also aids in the prevention of fracture formation and propagation in concrete. However, this fiber may hinder the workability of concrete. On the other side, while sugarcane fiber might boost tensile strength, certain studies show that it can reduce compressive strength. Coconut fiber can be considered the most efficient natural fiber to use in concrete manufacturing based on its effect on the mechanical characteristics of concrete and its availability.

Although the advantageous properties of natural fibers have been widely recognized, their use in concrete manufacturing is still inadequate. To enable the practical deployment of natural fiber reinforced concrete, focus should be given on large-scale manufacturing of these fibers, to encourage the construction industry to implement natural FRC.

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