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Study of Mechanical Properties of Coconut Fiber Reinforced Concrete

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Abstract

Fiber Reinforced Concrete (FRC) is a composite material that integrates fibers into conventional concrete to improve tensile strength, reducing reliance on steel reinforcement. The fibers can be made from various materials, including natural options like coconut fiber, which is favored for its cost-effectiveness, availability, and environmental benefits, supporting sustainable construction practices.

This study investigates the effect of coconut fiber reinforcement on the mechanical properties of M25 grade concrete, focusing on compressive strength, split tensile strength, and flexural strength. Concrete specimens were prepared with varying coconut fiber content at 0%, 0.5%, 1%, 1.5%, and 2% by weight of cement and tested at timing of 7, 14, and 28 days.

The experimental results indicate that incorporating coconut fibers improves the mechanical performance of concrete to an optimal level. At 28 days, compressive strength increased from 38.87 MPa (control mix) to 43.73 MPa at 1% fiber content. Similarly, flexural strength improved from 3.46 MPa to 4.80 MPa, and split tensile strength increased from 3.10 MPa to 3.39 MPa at the same optimum percentage. Beyond 1% fiber content, strength declined, indicating reduced workability and fiber dispersion issues at higher dosages.

Finally, the findings suggest that Coconut Fiber Reinforced Concrete offers improved mechanical properties and is a sustainable, cost-effective alternative construction material, particularly when optimised at around 1% fiber content.

Keywords: *coconut fiber, compressive strength, flexural strength, split tensile strength*

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Introduction

Plain concrete is a composite mixture of binding materials (cement, lime, polymer), fine aggregate, coarse aggregate, and water. It is known for its high compressive strength, durability and versatility as it can be used in building, road, bridge and dams (Bhavikatti, 2010).

Despite its high compressive strength, concrete is brittle in nature when subjected to load, so it easily forms cracks under loading as it has low tensile strength. Normally reinforced steel rebars have been used. But, alternatives such as Reinforced Cement Concrete (RCC), Reinforced Brick Concrete (RBC), Pre-Stressed Concrete (PSC), Fiber Reinforced Concrete (FRC), cellular concrete and Ferro cement can also be used (Banthia & Sheng, 1996). (Bhavikatti, 2010) Among all these materials, fiber-reinforced concrete has high potential due to its variety available.

Some of the most commonly used types of fibers are steel fiber, plastic fibers, glass fiber, carbon fibers as well as organic fibers such as bamboo and coconut fibers, which improve the performance of concrete by increasing tensile strength, reducing shrinkage, resisting cracks under tension and prevent micro crack spreading, and increasing the deformation capacity before failure, thus increasing the durability of concrete. Steel bar and synthetic fiber increase the cost and environmental impact so there is a need for growing an eco-friendly and sustainable fiber as an alternative of traditional reinforcements methods (Banthia & Sheng, 1996).

Fresh coconut production in Nepal has remained stable over the last 5 years. According to Food and Agricultural Organisation of United Nations, the production was 4,675 metric tons in 2019 and 4,664 metric tons in 2022 with 2023 having about 4738.62 metric tons (Food, 2022). Thus, Coconut fiber is a natural waste product that can be used as one of alternative reinforcement materials in concrete due to its various features such as its workability and tensile strength. Furthermore, the natural fibers use can improve the sustainability aspect by utilising locally available coconut fiber waste, thereby reducing environmental burden while enhancing mechanical performance of concrete. (Ali & Liu, 2012) However, there is limited research on its usage, long-term performance and mechanical properties of concrete.

Coconut fiber (coir), a natural fiber obtained from the outer husk of the coconut fruit, increases the tensile strength along with other properties such as durability, elasticity when added to the concrete. Coconut fiber has variety of uses including traditional purpose such as mats and ropes along with modern applications extending into modern construction and sustainable development, which has a wide application from households as a construction material (reinforcement) as it increases resistance to crack at a lower cost. Its easy availability in localities along with its low cost and eco-friendly nature has led to increase in the use of coconut husk as a reinforced fiber material. Coconut Fiber reinforced concrete (CFRC) is a composite material in which coconut fibers are added as supplementary reinforcement (Salain, Sutarja & Wiryasa, 2014).

This study supplementary reinforcement material to improve the mechanical properties of concrete while promoting sustainable and environmentally friendly construction practices. Factors such as the absence of standardised mix guidelines and lack of a reputable and reliable study on the subject have been the challenges to its practical application

Therefore, this study investigated the potential of coconut fiber as secondary reinforcement in concrete. The objectives are to compare the tensile strength, flexural strength and split tensile strength of plain concrete and CFRC and to assess the improvements with fiber inclusion.

Literature Review

Concrete contains imperfections and tiny cracks both within its structure and at its joints, even prior to the application of any external load. These imperfections and micro-cracks arise from factors such as excessive water content, bleeding, settlement during the plastic phase, thermal contractions, and stress concentrations caused by external constraints. When a load is applied, these micro-cracks begin to grow, merge, and align, leading to the formation of larger cracks. As the load increases, conditions for significant crack growth develop at the ends of those larger cracks, ultimately leading to sudden and severe failure (Tritsch & Weiss, 2022).

Despite different precautions, plastic shrinkage cracking is a significant issue, especially in large surface placements such as slabs at ground level, thin surface repairs, patches, and shotcrete applications. In those expansive areas, fibers interact with the water in the mix to minimise bleeding. Fibers not only help to prevent crack formation but also limit their propagation and growth. Shortly after the concrete is placed, the evaporation of water in the mix along with the internal hydration process generates shrinkage strains. If this contraction is restrained, the resulting stress can exceed the threshold needed to induce cracking. The consequence of this is a reduction in the amount of water available for evaporation and less total shrinkage. When combined with the ability of fibers to bridge cracks post-formation, they help to reduce both the width and area of cracks when the concrete experiences restraint (Banthia & Sheng, 1996).

Table 1 : Properties of Plain Concrete (PC) and Coconut Fiber Reinforced Concrete (CFRC)

Fiber volume fraction%	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural strength (MPa)
–	21.42	2.88	3.25
0.5	21.70	3.02	3.38
1.0	22.74	3.18	3.68
1.5	25.10	3.37	4.07
2.0	24.35	3.35	4.16

Once the concrete has set, properly bonded fibers interact with the matrix at the micro-crack level, effectively bridging these cracks and facilitating stress transfer, which slows down their merging and unstable growth. If the amount of fiber in the mix is sufficiently high, it can enhance the tensile strength of the matrix. Indeed, certain fiber composites with a high volume of fibers have demonstrated a significant increase in tensile and flexural strength compared to traditional matrices. Once the tensile capacity of the composite is reached, micro-cracks merge into macro-cracks. Depending on their length and bonding properties, the fibers continue to inhibit crack opening and growth by effectively bridging across these larger cracks. This bridging mechanism after the peak load is the main reinforcement strategy utilised in many commercial fiber-reinforced concrete composites (Ali & Liu, 2012).

The largest dimension of the coarse aggregate should not exceed 20 mm to prevent a significant decrease in the strength of the composite material. Fibers also can function in fashion similar to aggregates. While their mathematical representation is straightforward, their impact on the characteristics of fresh concrete is intricate. The arrangement and spread of the fibers, as well as the properties of the composite, are influenced by the friction that occurs between the fibers themselves and between the fibers and the aggregates (Singh & Yadav, 2019).

Small quantity of coconut fiber can enhance tensile properties and provide crack resistance, but excessive fiber content reduces concrete strength. The study demonstrates that coconut fiber can be used effectively in construction while also contributing to sustainable material utilisation. Coconut fibers are abundant, inexpensive, and possess high tensile strength, making them suitable for natural fiber-reinforced concrete. In this experimental study, Ordinary Portland Cement (OPC) was partially replaced with 0%, 1%, 2%, 3%, 4%, and 5% coconut fiber by weight. Concrete specimens were cast and tested for workability, compressive strength, and split tensile strength at 7 and 28 days of curing. Compressive strength tests revealed that while curing time increased strength, higher percentages of coconut fiber led to a decrease in strength, with 1–2% fiber providing values close to plain OPC concrete. Similarly, split tensile strength improved slightly at 1% fiber replacement but declined at higher percentages (Reddy et al., 2022).

Coconut are natural, biodegradable fibers having a tensile strength of approximately 21.5 MPa and can withstand strains 4 to 6 times higher than other natural fibers, making them relatively strong and ductile. The fibers, obtained from the husk or bark of coconuts, typically have a diameter ranging from

0.10 to 0.25 mm and a length of 6 mm to 25 mm, depending on the study, with shorter fibers often pre-soaked to reduce high water absorption. Their rough surface texture allows for better bonding with the concrete matrix, enabling them to act as micro-discontinuous reinforcements that reduce the brittleness of plain concrete and improve its load-carrying capacity, especially in flexural applications. The optimal volume of coconut fiber in concrete for enhancing mechanical properties such as compressive strength, flexural strength, split tensile strength, and modulus of elasticity ranges from approximately 1.63% to 1.94% by volume of the concrete (Salain et al., 2014).

Workability and Compaction

The addition of coconut fiber significantly reduces the workability of the concrete mix. This reduction can negatively impact the ability to properly consolidate the fresh mixture. In some cases, even extended external vibration can not achieve adequate compaction of the concrete. The specific amount of fiber at which this issue occurs is influenced by both the length and diameter of the fibers. To enhance the workability and compaction of the mix, increasing the water-to-cement ratio or utilising water-reducing admixtures can be effective. Five different mixtures were created with varying proportions of coconut fiber added: 0%, 0.5%, 1.0%, 1.5%, and 2.0% by weight of the cement (Singh & Yadav, 2019).

Mixing of Concrete

The process of mixing fiber-reinforced concrete requires careful attention to prevent clumping of the fibers, segregation, and challenges in achieving a uniform mix, which is crucial for the fibers to be evenly distributed within the mixture, which can be achieved by adding them before introducing the water. When using a laboratory mixer, incorporating the fibers through a wire mesh basket facilitates better distribution. For practical applications, alternative effective methods should be considered (Singh & Yadav, 2019).

Mix Design

Mix design refers to the method of selecting appropriate ingredients for concrete and determining their proportions to create a mixture that meets specific minimum strength and durability requirements while being cost-effective (Shetty & Jain, 2019).

Experimental Study

Flexural strength test was carried out on standardised beams measuring 10cm x 10cm x 50cm. These specimens included plain concrete as well as coconut fiber reinforced concrete, which was prepared with different fiber percentages (0%, 0.5%, 1%, 1.5%, and 2%). For each variant, the strength values at 28 days were determined using a flexural strength testing apparatus (Singh & Yadav, 2019).

Split tensile strength test were performed on standardised cylindrical specimens with a diameter of 15cm and a height of 30cm. These included both plain concrete and coconut fiber reinforced concrete, using both raw and processed fibers at specified percentages. The strength values at 28 days were measured using a compression testing machine for each case (Singh & Yadav, 2019).

Compressive strength refers to a materials or structure’s ability to withstand loads without experiencing cracking as well as deformation, as compression reduces the material’s size. The compressive strength of concrete provides insight into its characteristics. This single evaluation is crucial for determining the adequacy of concrete production. Tests are conducted on cube specimens after curing periods of 7 days, 14 days, and 28 days, respectively (Singh & Yadav, 2019).

Methodology

Coconut Fiber Reinforced Concrete (CFRC) is a composite concrete in which natural fibers of coconut husks are mixed with plain concrete to form concrete with enhanced mechanical properties, which, otherwise known as coir, are extracted from the outer bark of the coconut shells. They are biodegradable, economical and available in enough quantity in the tropical region (Ali & Liu, 2012).

When added to concrete, natural fibers enhance the properties such as toughness, crack resistance and tensile strength of the material. In contrast to the conventional concrete which could be brittle and susceptible to tensile cracks, the CFRC is ductile and with a high energy absorption property. The fibers act as small reinforcements, spanning developing cracks and retarding them, and slowing the spread, in the process yielding a more durable, and green, building material.

Materials Used

The CFRC composite consists of cement, sand, gravel, water, and coconut fibers obtained from local market of Bharatpur, Chitwan. The gravel used was 20 mm passed and 12.5 mm retained during sieve analysis. The locally available sand was used. The coconut fibers have the length around 50 mm. During the fiber preparation, along with cleaning of fibers, the fibers were cut according to intended length. The details of the preparation of the coconut fibers are shown in Fig.1, as in similar to the description of article of Ali and Liu (2012).

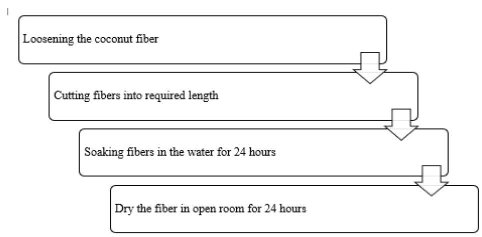

Figure 1. Preparation/Cleaning of the Coconut Fibers

Specimen Preparation

The experimental concretes were plain concrete (PC) and coconut fiber reinforced concrete (CFRC), with designated compressive strength of 25 MPa. Concrete mix design was carried out in accordance with IS 10262:2019 for M25 grade concrete. The target mean compressive strength was taken as 31.6 MPa. The final mix proportions obtained from the design were used for casting the specimens (Bureau of Indian Standards, 2019).

The amount of coconut fibers used is between 0.5% and 2% of the cement weight of designed mix with difference of 0.5%. Fibers approximately 50 mm long are used. Coconut fibers were added to the dry mix during mixing of CFRC. Hand mixing was used to prepare each sample of both plain concrete (PC) and CFRC.

The selected fiber contents (0%, 0.5%, 1%, 1.5%, and 2% by weight of cement) were adopted because fibers in concrete mainly interact with the cement matrix, and this method allows for easier comparison based on previous studies (Singh & Yadav, 2019; Ali & Liu, 2012), which indicate optimal performance within this range.

For plain concrete, cement, sand and aggregate were dry mixed properly first in a tray and then water was added and mixed until homogeneous mix was formed, and for casting CFRC composites, firstly, cement, sand, aggregate, and fiber were dry mixed properly and then water was added for mixing until uniform paste was formed.

Then, the prepared concrete mix was placed in respective mold according to the test to be conducted i.e. compressive strength test, split tensile test and flexural test

Molds of size (150 mm * 150 mm * 150 mm) for cube, size (100 mm * 100 mm * 500 mm) for Beams and size of (150 mm diameter and 300 mm height) for Cylinder were prepared.

After vibrating the sample on a vibrating table, the mix was settled in placed and compacted for 24 hours. The samples were then demolded and cured in water at constant room temperature. All the specimen samples were then cured in water undisturbed for 7, 14 and 28 days before testing. A total of 105 samples were prepared with 45 cube samples along with 30 beam and cylinder samples each.

After curing, the sample was air-dried before testing and testing was conducted using respective machine. (For Compressive strength test was performed in Compressive Testing Machine, split tensile test was conducted using Universal Testing Machine and for Flexural strength test, Universal Testing Machine with two-point loading was used.). The tests being conducted using CTM and UTM for determining compressive, flexural and split tensile strength is shown in figure 2 a., b. and c.

After testing, calculations were performed using obtained data to find the strength of the sample. Formula used for compressive flexural and split tensile strength test are as per equation,1, 2 and 3 respectively.

$f_c = P/A$ ....(1)

Where:

fc= Compressive Strength

P= maximum load applied (N)

A= surface area of cube (mm²)

$f_r = (P*L)/ (b*d^2)$ ....(2)

Where:

fr= Flexural Strength

P= Load at failure (N)

L= Span length (mm)

b= Width of beam (mm)

d= Depth of beam (mm)

$f_t=(2*P) / (\pi*D*L)$.....................(3)

Where:

ft= Split Tensile Strength

P= Load at failure (N)

D= Diameter of cylinder (mm)

L= Length of cylinder (mm)

Figure 2 Strength Testing Machines

Results and Discussion

Compressive Strength

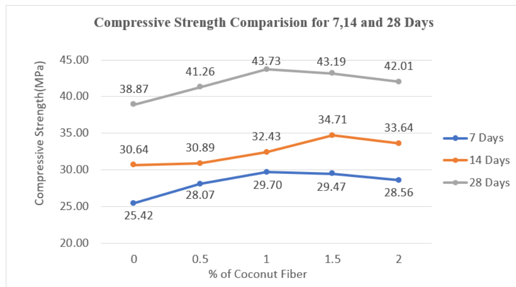

Figure 3 Compressive Strength Test vs Percent of Coconut Fiber

The result shows the relation between the compressive strength vs.% of coconut fiber. The coconut fiber is added at the rate of 0%, 0.5%, 1%, 1.5%,2% as per the weight of cement in the concrete mix of M25 grade (see Figure 3). The compressive strength of concrete was calculated using Equation (1). The concrete cube specimens have been cured for the given duration. The highest 28- day compressive strength was with 43.733 MPa at 1% along with 34.711 MPa at 1.5% for 14 days and 29.704 MPa at 1% for 7 days.

It demonstrates that the compressive strength of fiber increases gradually when fiber content was increased up to 1% and obtains maximum value between 1% and 1.5% and decreases when fiber content is increased further. At higher percentage greater than 1.5%, there is a degradation of compressive strength as the increase in weight of coconut fibers results in loss of cohesiveness between the particles of the concrete.

Tensile Strength

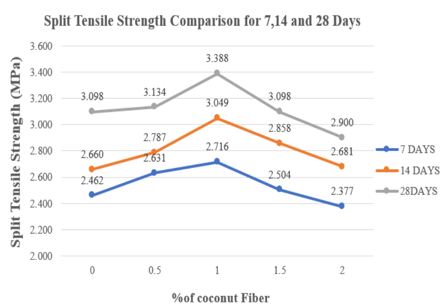

Figure 4 Split Tensile Test vs Percent of Coconut

Fiber

The result represents the graph between the Split Tensile strength vs % of coconut fiber. The coconut fiber is added at the rate of 0%, 0.5%, 1%,1.5% and 2% as per the weight of cement in the concrete mix of M25 grade (see Figure 4). The split tensile strength was determined using Equation (3). The split tensile strength is maximum at 1% having for 7 days is 2.716 MPa ,14 days is 3.049 MPa and for 28 days is 3.388MPa. It indicates the behavior of coconut Fiber Concrete whose strength increases with the addition of fiber up to 1% and if more than 1% fiber is added in concrete mix, the strength decreases. At higher percentage greater than 1%, the increase in weight of coconut fibers results in loss of cohesiveness between the particles of the concrete. This pattern suggests that while a minimal amount of fiber improves the early strength of concrete, excessive fiber content undermines it.

Finally, the data suggests that while a minor addition of coconut fiber can enhance both early and long-term compressive strength, excessive amounts of fiber tend to weaken the concrete

Flexural Strength

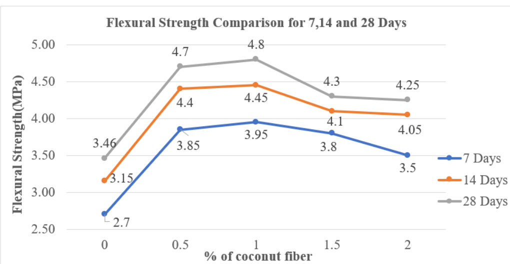

Figure 5 Flexural Strength Test vs Percent of Coconut Fiber

Figure 5 represent the graph between the Flexural strength vs.% of coconut fiber. The coconut fiber is added at the rate of 0%, 0.5%, 1%, 1.5% and 2% as per the weight of cement in the concrete mix of M25 grade. The flexural strength was calculated using Equation (2). The concrete beam specimens have been cured for the given duration.Flexural strength peaks at 1% for 7 days with 3.95MPa, for 14 days with 4.45 MPa and for 28 days with 4.8 MPa. It reveals that the flexural strength of fiber reaches optimum potential at 1% (see Figure 5). This pattern suggests that, while a minor amount of fiber enhances flexural strength in the preliminary stages, higher fiber content leads to a decrease in compressive flexural and split tensile strength.

Discussion

The mechanical strength of Coconut Fiber Reinforced Concrete (CFRC) is best optimised at 1% of fiber content as per mass of cement.

Early-stage strength development also shows similar trend as 7 day and 14 days strengths also peaking at near 1%, which indicates that while moderate fiber inclusion does indeed improve mechanical strength through better crack resistance and higher load bearing capacity, excessive addition of fiber can disrupt the complete bonding of materials in concrete mix and thus reduce overall performance.

Here, the compressive strength improved from 38.87 MPa to 43.73 MPa (~12.5% increase), while, flexural strength increases from 3.46 MPa to 4.8 MPa (~38.7% increase) and split tensile strength also changes from 3.10 MPa to 3.39 MPa (~9.4% increase). The trend of improvement in the value of strength is similar to other studies on the topic such as (Singh & Yadav, 2019) and (Shaikh et al., 2025).

All the studies demonstrate a similar pattern of improvement, where compressive load is slightly improved and split tensile strength is also improved in very minor amounts, comparatively in negligible amount, whereas the flexural strength demonstrates the highest trend of improvement.

Thus, while organic fiber might not appear as a better alternative than steel reinforcements, it certainly can be used as a secondary reinforcement, which can contribute in improving flexural toughness and crack resistance.

Furthermore, the pattern of improvement in the study indicates that, while a minor amount of fiber enhances flexural strength in the preliminary stages, higher fiber content leads to a decrease in compressive flexural as well as split tensile strength.

While the optimum percentage of coconut fiber to be used for maximum improvement can differ from other studies, it can have occurred from difference in materials used such as cement type, aggregate. The hardness, acidity, salts, and other properties of water can have caused some differences in the final results as it is important to note that the test was conducted using local materials such as locally sourced water and coconut fiber, whose quality can vary regionally. Moreover, the preparation methods of coconut fibers are not consistent due to lack of complete and proper standards and specifications are preventing widespread adoption

Hence, developing a standard procedure for mix design, materials preparation and handling can better aid in further studies on the subject. The durability and life span of such Coconut Fiber Reinforced Concrete (CFRC) can also be researched in various conditions in future studies. Additionally, the effect of chemicals, temperature fluctuations as well as weather can be a proper research consideration. Also, the fibers were added in 0.5% interval in the test. Further studies with smaller interval of addition can help in finding more accurate optimum fiber amount

Conclusion

The objective of this study was to examine the effect of coconut fiber addition on the compressive, split tensile, and flexural strength of M25 grade concrete.

The experimental results show the change in mechanical properties such as compressive, flexural and split tensile strength of concrete when coconut fibers are added in proportions as 0.5%, 1%, 1.5%, 2% of the weight of cement in the concrete mix. The tests revealed that addition of around 1% of coconut fiber in the concrete mix can significantly improve the compressive, flexural as well as tensile strength. Whereas, further addition led to decrease in the strength compared to peak improvement at near 1% fiber addition. At 1% fiber inclusion, the 28-day compressive, flexural, and split tensile strengths remained at 43.73 MPa, 4.80 MPa, and 3.39 MPa, respectively, which showed measurable improvements over plain concrete.

While this study highlights the future potential coconut fiber holds as a natural fiber, it is still limited to M25 grade at specific fiber percentages. So, deeper research is necessary to establish consistent standards. The results further testing can be done to check these properties in extreme conditions or testing of other properties and collect data in long term structural application, in order to further encourage eco-friendly practices in construction and better utilise locally available and economical material.

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