

Review Article

Investigate the Behavior of Mechanical Properties of Concrete with Coconut Fiber

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Abstract

This study explores the mechanical behavior of coconut fiber-reinforced concrete (CFRC) as an environmentally friendly alternative in the construction industry. Coconut fiber, a natural and sustainable material, possesses high tensile strength and ductility, making it a promising additive to enhance the toughness and crack resistance of concrete. The primary objective of this research was to investigate how different proportions of coconut fiber—specifically 0%, 0.25%, 0.50%, 0.75%, and 1.00% by weight of cement—affect the compressive and tensile strengths of concrete. A total of 90 standard cylindrical specimens were prepared and tested following ASTM C39 and ASTM C496 protocols, with 45 cylinders used for compressive strength tests and 45 for split tensile strength tests after 28 days of curing. The experimental findings indicate a general decrease in compressive strength as coconut fiber content increases. At 1.00% fiber content, the compressive strength showed up to a 61.7% reduction compared to plain concrete. This decline is attributed to the irregular distribution of fibers and the increased voids within the concrete matrix. However, tensile strength exhibited a more nonlinear pattern. While low fiber content (0.25% and 0.50%) resulted in moderate strength reductions, some specimens at 0.50% fiber content approached the tensile performance of plain concrete. Higher fiber percentages (0.75% and 1.00%) caused more significant tensile losses, likely due to fiber clumping and disruption of matrix integrity. Despite reductions in strength, the inclusion of coconut fiber improved post-cracking behavior and energy absorption capacity, making CFRC a viable option in applications where ductility and resistance to dynamic or impact loads are prioritized over compressive strength. Moreover, the use of coconut fiber aligns with sustainable construction practices by utilizing agricultural waste and reducing the environmental impact of concrete production. This study concludes that while excessive coconut fiber content can negatively impact strength, optimized dosages can offer performance benefits in specific applications, supporting the potential of CFRC in eco-friendly and cost-effective construction solutions.

Keywords

Mechanical Properties, Coconut Fiber-reinforced Concrete (CFRC), Compressive Strength, Tensile Strength, Coconut Fiber

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1. Introduction

Concrete, while widely used in construction, has inherent brittleness, low strain capacity, and limited durability, necessitating reinforcement to withstand tensile and shear stresses. Traditional reinforcement involves steel bars, but fibers such as steel, glass, synthetic, and natural materials offer additional benefits by effectively controlling cracking through close spacing. Among natural fibers, coconut fibers (coir) stand out for their high ductility and potential as a sustainable reinforcement material. Coconut fiber-reinforced concrete (CFRC) has demonstrated improved mechanical properties, including increased compressive strength, enhanced energy absorption, better ductile behavior, reduced cracking, and greater durability. While not a substitute for traditional steel reinforcement, coconut fibers complement existing methods, particularly for applications requiring toughness and resistance to dynamic loads. This review examines the performance of CFRC, exploring its mechanical properties and applications, while emphasizing its contribution to sustainable construction practices through experimental findings and potential structural uses. Coconut fibers are lignocellulosic in nature and possess high toughness and elongation capacity, making them suitable for enhancing concrete's ductility [1].

It has been explored to improve the bond between the fiber and the cement matrix by using alkali treatment and silane coupling agents [2]. It has been found that chemically treated coconut fibers exhibit improved tensile strength and durability compared to untreated fibers [3]. It was reported a 5-10% decrease in compressive strength with increasing fiber content, attributed to the non-uniform distribution of fibers and increased voids [4]. On the other hand, it has been observed that compressive strength can be maintained at optimal fiber contents of 1% by weight of cement [5]. It was reported a 25% increase in split tensile strength with the addition of 1.5% coconut fibers [6]. Similarly, the flexural strength improved by up to 30% with fiber reinforcement [7]. These findings are supported who emphasized that the fiber length and aspect ratio play critical roles in enhancing these properties [8].

It has been reviewed examines the mechanical behavior of concrete reinforced with coconut fibers, emphasizing its compressive, tensile, and flexural properties, alongside durability considerations and practical applications [9]. The coconut fiber reinforcement resulted in a marginal reduction in compressive strength, likely due to void formation caused by uneven fiber distribution [10]. However, it observed that low fiber content (<2% by volume) had negligible effects on compressive strength, suggesting that proper mix proportions can mitigate adverse impacts [11]. Enhanced post-cracking behavior and energy absorption in coconut fiber-reinforced concrete, attributing this to the fiber's ability to bridge cracks and prevent sudden failure [12]. Emphasized the role of coconut fibers in improving energy absorption during dynamic loading [13]. Similarly, it has been noted that fiber-

reinforced concrete exhibited superior resistance to spalling and fragmentation under impact loads [14]. The fiber pretreatment with chemicals, such as sodium hydroxide, can enhance durability by reducing water absorption and improving the fiber-matrix bond [15].

The studies on the freeze-thaw resistance of CFRC and found that treated fibers improved durability by reducing microcracking [16]. The potential of CFRC to resist sulfate attack, making it suitable for marine applications [17]. The reduction in carbon emissions achieved by partially replacing cement with fibers [18]. Furthermore, the argued that the use of agricultural waste products such as coconut fibers aligns with the principles of sustainable construction [19]. It has been explored the use of CFRC in rural housing projects, demonstrating its potential to provide affordable and sustainable construction solutions [20]. It has been evaluated existing research on the mechanical properties of coconut fiber-reinforced concrete, highlighting advancements in mix design, fiber treatment, and applications [21]. It's noted that the compressive strength decreased with increasing fiber length, emphasizing the importance of optimizing fiber content and aspect ratio [22]. It suggested that treating fibers with cement slurry before mixing improved the bond between fibers and the cement matrix, partially mitigating strength loss [23]. It has been observed a 15% increase in tensile strength with the addition of 0.75% coconut fibers by weight of cement, which also enhanced post-cracking behavior [24]. Similarly, it has been reported that flexural strength improved by up to 20% with a 1% fiber inclusion, highlighting its potential for use in structural applications requiring greater toughness. Fiber length and surface characteristics also influence tensile performance [25]. The shorter fibers (20-30mm) offered better crack resistance, whereas longer fibers risked balling and uneven dispersion [26]. Treating fibers with sodium hydroxide improved their tensile strength by roughening the surface, increasing the bond with the cement paste [27].

It has been observed that fiber-reinforced concrete with coconut fibers exhibited enhanced toughness indices compared to plain concrete, particularly under high-impact loads [28]. Furthermore, the coconut fibers distributed stress effectively across the matrix, delaying failure under dynamic loading [29]. A reduction in fiber strength after prolonged exposure to alkaline conditions [30]. However, chemical treatments, such as sodium silicate coating, have been found to enhance the durability of coconut fibers without significantly altering their mechanical properties [31]. It has been suggested that pre-soaking fibers in a polymer solution reduced their water absorption capacity, improving the overall durability of fiber-reinforced concrete [32]. It has been proposed for earthquake-resistant structures due to coconut fiber-reinforced concrete improved ductility and energy dissipation properties [33]. The coconut fiber-reinforced concrete

provided better fatigue resistance in pavement applications, prolonging service life under repeated loading conditions [34].

This study's primary goal was to ascertain whether it would be feasible to add used coconut fiber in the form of fiber which replaced by fine aggregates to concrete mixtures and how this would affect the mix's mechanical qualities. The effects of coconut fiber on the mechanical characteristics of CFRC were among the parameters that were tracked, ranging from 0% (no rubber) to 1%.

2. Experimental Program

2.1. Test Specimens

To perform this study in total 90 standard cylinder specimens were tested which is given below in Table 1. Among these, 45 cylinders were tested to determine the compressive strength and 45 cylinders were tested to determine the split cylinder strength. The studied variables comprised plain concrete with 0% Coconut fiber and concrete with all types of Coconut fiber present (i.e., 0.25%, 0.50%, 0.75% and 1%).

Table 1. Details of specimens.

Specimen (100 X 200mm cylinder)	Concrete casting					Total
	Coconut fiber				Plain concrete	
Percentage (%) of rubber crumb	0.25	0.50	0.75	1	0	
Compressive strength	9	9	9	9	9	45
Tensile strength	9	9	9	9	9	45
Total =						90

2.2. Material Properties

2.2.1. Cement

Cement was sourced from a local market in Dhaka, with Crown Cement, commonly known as Standard Portland Composite Cement, used to prepare each test mold. The cement exhibited normal consistency, adhering to ASTM

standard C187. Its specific gravity ranges from 3.12 to 3.16 and weight 1208kg/m^3 (94 lb/ft³). Its measured fineness by particles size ranges from 10 microns to 50 microns. The specific gravity of cement used in this study was 3.15. Its approximate unit weight was 3000kg/m^3 . The type of cement utilized was Portland Composite Cement (PCC), consisting of Clinker 80-94%, Fly Ash, Slag, Limestone 6-20%, Gypsum 0-5%.

2.2.2. Aggregate

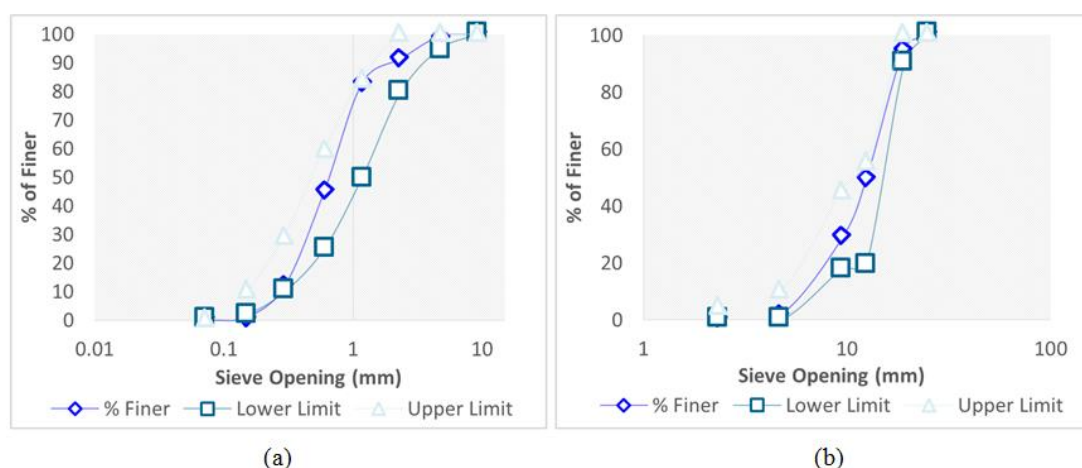


Figure 1. Gradation curve for (a) fine aggregate (b) coarse aggregate.

locally accessible aggregates had employed in compliance with ASTM C33 criteria. It is necessary to decide how much aggregate, in particular coarse aggregate (20mm down and 12mm down), was needed. Aggregate had been blended by sieve analysis while retaining the fineness modulus (F.M.) value and using a standard sieve which show in Figure 1.

2.2.3. Coconut

Here we used locally available coconut fiber. Coconut fi-

ber, is a natural fiber extracted from the outer husk of coconut, and used in products such as floor mats, doormats, brushes, and mattresses. Coir is the fibrous material found between the hard, internal shell and the outer coat of a coconut. Coconut fiber has the highest strength among all-natural fibers. These mechanical characteristics reduce cracking, leading to coconut fiber-reinforced concrete with better flexural behavior and higher impact resistance than traditional concrete.



Figure 2. Cutting of coconut.

2.3. Concrete Mix Design and Specimen Casting

Concrete had mixed using local resources that are easily accessible. All of the material details had been showed in the section previously. Studying the behavior of concrete with various percentages of coconut fiber is the main goal of the mix design process. The water cement ratio is (W/C) 0.55 and the concrete mix ratio is (1:1.5:3) (C: FA: CA). The amount of required material is shown in Table 2 based on this mix ratio. After the components had been fully combined by an automated mixing device, coconut fiber was

uniformly added to the concrete mixture to ensure that the yarns are distributed throughout the concrete. After the cement had been added, water was added to the mixer, and mixing continued until homogeneity had been attained. This approach had been used to mix the concrete for around three minutes. After that, the freshly mixed concrete had passed into the molds with a cylinder shape. Following that, the specimens were left unattended for 24 hours to allow for demolding. They have since spent at least 28 days being treated in water. The specimens were left to dry in the air for 24 hours after the curative period ended before testing. The mix design process has been shown in Figure 3.

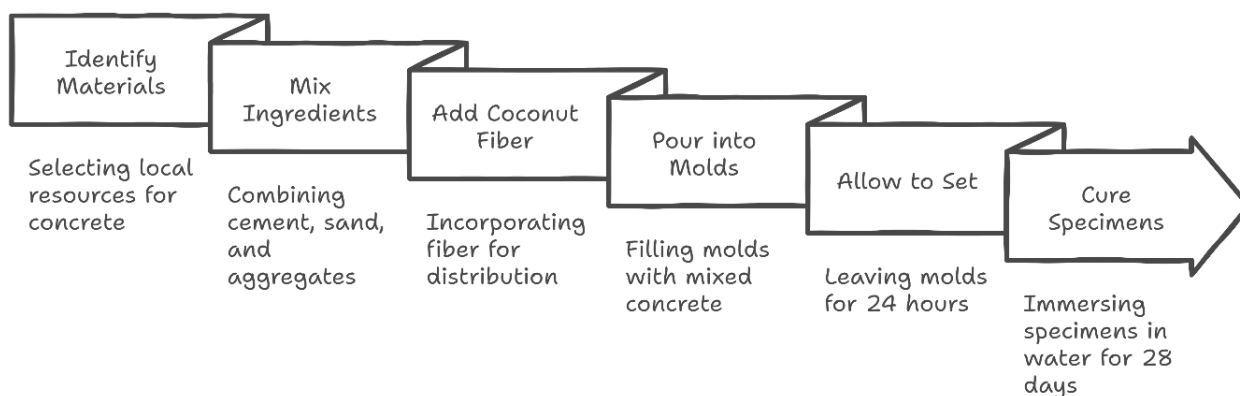


Figure 3. Mix design process.

Table 2. Material properties.

Material (kg)		For a cylinder	Total	Remarks
Cement		0.616	55.44	
Stone chips	CA (12mm)	0.414	37.26	
	CA (20mm)	1.635	147.15	
Sand	FA	1.002	90.18	
	For 0.25%	0.0025	0.226	For 90 specimens
	For 0.50%	0.005	0.452	
Coconut fiber	For 0.75%	0.0075	0.678	
	For 1.00%	0.01	0.904	

2.4. Test of Concrete

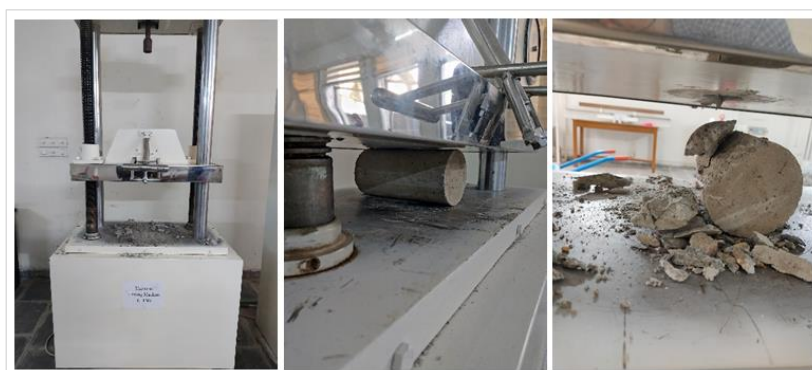
2.4.1. Compressive Strength Test

**Figure 4.** Compressive strength checking by UTM machine.

In accordance with ASTM C39/C39M, the compressive strength test was performed on the of both plain and coconut fiber concrete 28 days after casting. A concrete compression

test device (UTM- Universal Testing Machine) with a 1000kN capacity and loading at a rate of 4 kN/sec over the specimens, as shown in Figure 4.

2.4.2. Tensile Strength Test

**Figure 5.** Split tensile load test.

To assess the tensile strength of both plain and coconut fiber concrete, an indirect tensile strength test had been used in this work. Using the Universal Testing Machine, testing is carried out at 28 days (UTM). The specimens had been loaded at a rate of 4 kN/sec by the UTM. According to ASTM C496/C496M-04, the tensile strength of concrete has been assessed as shown in Figure 5.

3. Experimental Results and Discussion

3.1. Concrete Properties

An experimental results and discussion had been planned to investigate the mechanical properties of concrete (compressive and tensile strength). All test had been performed

for the samples of plain concrete and fiber-reinforced concrete. When a cylindrical specimen was built, the Slump test was conducted using various fiber percentages in accordance with ASTM C39/C39M standard. Also, a laboratory compressive load test was performed following (28 days) of curing. In the process of experimental observation, every aspect of the experiment has been carefully evaluated, and images and data has been meticulously gathered. Following investigation of the specimens, the specimens have been presented for various types of fiber at various percentages in accordance with ASTM C39/C39M standard. Impact on the specimen's workability and strength capacity in all percentages had been demonstrated. Average values have been used to accurately measure the compressive strength has been observed. All details are shown in Table 3.

Table 3. All test results.

Types of cylinders	Specimen no.	% of fiber	Average Comp. Strength (psi)	Average Tensile Strength (psi)
Regular	CR ₃	0.00	1657.12	153.52
	CR ₇		1812.89	311.66
	CR ₂₈		1968.67	326.72
	CC ₁₃	0.25	1241.72	130.92
	CC ₁₇		1605.19	191.17
	CC ₁₂₈		1760.97	213.76
Coconut fiber	CC ₂₃	0.50	982.1	115.86
	CC ₂₇		1241.72	266.48
	CC ₂₂₈		1345.57	292.08
	CC ₃₃	0.75	774.40	100.80
	CC ₃₇		1085.95	236.35
	CC ₃₂₈		1189.80	266.48
	CC ₄₃	1.00	753.63	93.27
	CC ₄₇		899.02	176.11
	CC ₄₂₈		1034.03	191.17

3.2. Effect of Percentage of Fiber on Compressive Strength

The experimental results reveal a significant influence of coconut fiber content on the compressive strength of concrete. The inclusion of coconut fibers results in a general reduction in compressive strength compared to regular concrete, with the extent of the reduction varying depending on

the fiber percentage. Figure 6 illustrates the discernible decrease in the compressive strength of the coconut concrete as the percentage of coconut fiber rose.

The compressive strength of regular concrete cylinders ranged 1657.12 psi (CR₃), 1812.89 psi (CR₇) and 1968.67 psi (CR₂₈) at 3, 7 and 28 days respectively. These values represent the baseline performance, reflecting the high strength and uniformity of the unreinforced concrete matrix. The absence of fibers allows the cement paste and aggregate to form a dense and cohesive structure, maximizing load-

bearing capacity.

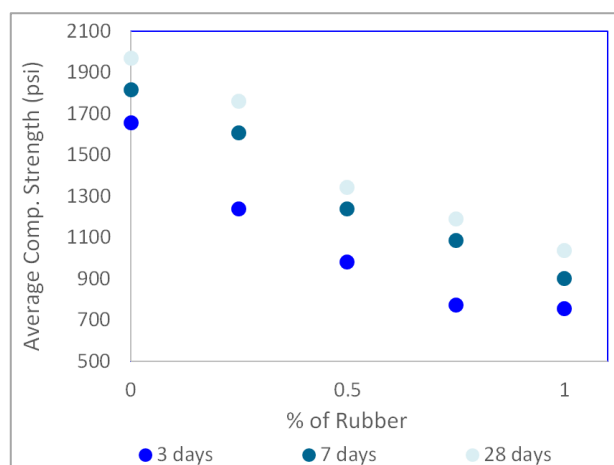


Figure 6. % of coconut fiber (combined) vs compressive strength (psi).

The addition of coconut fibers at varying percentages (0.25%, 0.50%, 0.75%, and 1.00%) resulted in a consistent decrease in compressive strength. 0.25% coconut fiber content, the compressive strength ranged 1241.72 psi (CC13), 1605.19 psi (CC17) and 1760.97 psi (CC128) at 3, 7, and 28 days respectively, representing a reduction of approximately 10.6% to 36.2% compared to the average strength of regular concrete. At 0.50% fiber content, the compressive strength dropped further, ranging 982.1 psi (CC23), 1241.72 psi (CC27) and 1345.57 psi (CC228) at 3, 7, and 28 days respectively. This reflects a 31.6% to 50.1% reduction relative to regular concrete. 0.75% coconut fiber content the compressive strength ranged 774.40 psi (CC33), 1085.95 psi (CC37) and 1189.80 psi (CC328) at 3, 7, and 28 days respectively, showing a 39.5% to 60.7% reduction compared to regular concrete. The highest percentage of coconut fibers tested (1.00%) showed the lowest compressive strength values, ranging from 753.63 psi (CC43), 899.02 psi (CC47) and 1034.03 psi (CC428) at 3, 7, and 28 days respectively. These values represent a 47.5% to 61.7% reduction compared to regular concrete.

3.3. Effect of Percentage of Fiber on Tensile Strength

The experimental results reveal that the tensile strength of the cylinders varies significantly with both the type and percentage of fibers incorporated. Regular concrete (0% fiber) displayed the highest tensile strength across all specimens, while the inclusion of coconut fibers influenced the results in a non-linear manner. Figure 7 illustrates the discernible decrease in the compressive strength of the coconut concrete as the percentage of coconut fiber rose.

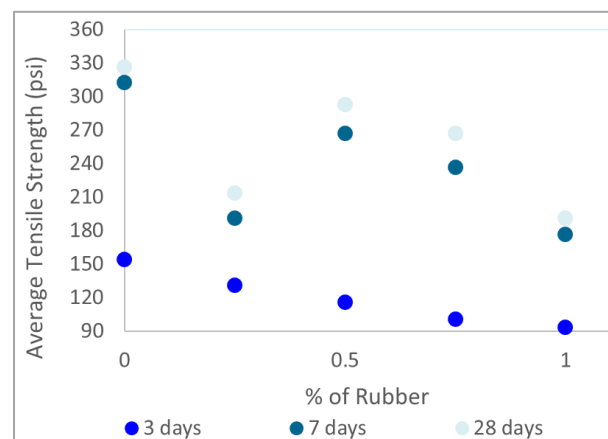


Figure 7. % of coconut fiber (combined) vs tensile strength (psi).

For regular concrete cylinders without fiber (0%) reinforcement, tensile strength values ranged 153.52 psi (CR3), 311.66 psi (CR7) and 326.72 psi (CR28) at 3, 7, and 28 days respectively, with an increasing trend corresponding to higher compressive strength values. These results demonstrate the inherent tensile resistance of unreinforced concrete, attributed to the cohesive bond within the cement matrix and the dense structure of the material.

The introduction of coconut fibers into the concrete matrix showed a complex interaction with tensile strength, depending on the fiber content. The tensile strength for specimens with 0.25% coconut fibers ranged 130.92 psi (CC13), 191.17 psi (CC17) and 213.76 psi (CC128) at 3, 7, and 28 days respectively. This corresponds to a reduction in tensile strength of approximately 30% to 35% compared to regular concrete (CR28). At 0.50% fiber content, tensile strength showed a modest recovery, ranging 115.86 psi (CC23), 266.48 psi (CC27) and 292.08 psi (CC228) at 3, 7, and 28 days respectively. Interestingly, specimens with higher compressive strength (e.g., CC228) achieved tensile strength values nearing those of regular concrete. The specimens with 0.75% fiber content exhibited tensile strength values ranging 100.80 psi (CC33), 236.35 psi (CC37) and 266.48 psi (CC328) at 3, 7, and 28 days respectively. This represents a decline in tensile strength by approximately 15% to 69% compared to regular concrete. At 1.00% fiber content, tensile strength values were the lowest across all fiber-reinforced specimens, ranging 93.27 psi (CC43), 176.11 psi (CC47) and 191.17 psi (CC428) at 3, 7, and 28 days respectively. This indicates that the excessive fiber content likely disrupted the matrix continuity and reduced the effectiveness of stress distribution, leading to significant tensile strength losses.

4. Conclusions

The experimental investigation into the mechanical properties of concrete, incorporating varying percentages of coconut fibers, highlights significant impacts on both compressive and tensile strength.

1. The addition of coconut fibers reduces the compressive strength of concrete, with the extent of reduction increasing with higher fiber content. At 1.00% fiber content, the compressive strength decreased significantly compared to plain concrete, highlighting the negative impact of excessive fiber inclusion.
2. The tensile strength of concrete is affected by coconut fiber content in a non-linear manner. While a slight reduction is seen at 0.25% fiber, higher fiber percentages (0.75% and 1.00%) lead to substantial declines in tensile strength, with excessive fiber disrupting the concrete matrix and weakening stress distribution.

Abbreviations

CFRC	Coconut Fiber-reinforced Concrete
ASTM	American Society for Testing and Materials
PCC	Portland Composite Cement
F.M.	Fineness Modulus
W.C.	Water Cement Ratio
C: FA:	Cement, Fine Aggregate and Course Aggregate
CA	
UTM	Universal Testing Machine

Author Contributions

Pranta Chakraborty: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing

Abhijit Nath Abhi: Data curation, Investigation, Resources, Supervision, Validation, Visualization

Shahin Sheikh: Data curation, Formal Analysis, Methodology, Project administration, Resources, Supervision, Validation, Visualization

Saniul Haque Mahi: Conceptualization, Formal Analysis, Investigation, Project administration, Resources, Software, Supervision, Visualization, Writing – review & editing

Abdul Awol Rabby: Conceptualization, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing

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Conflicts of Interest

The authors declare no conflicts of interest.

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