

Effect of Alkali Treated Coir Fibre on Strength Properties of Concrete

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Abstract - Sustainability and the utilisation of waste natural fibres in concrete has become a major focus of the construction industry. Coir fibre, obtained from coconut husk, is an abundant agricultural waste product that is eco-friendly and low in cost, but its untreated form suffers from high water absorption and poor fibre-matrix bonding. This study investigates the effect of alkali (NaOH) treated coir fibre on the compressive and flexural strength of M20 grade concrete. Coir fibre of 20 mm length was treated with NaOH solution and incorporated into concrete at 0.75%, 1.25% and 1.75% by weight of cement. Cube and beam specimens were cast and tested for compressive and flexural strength at 7, 14 and 28 days of curing, with supplementary readings recorded at 56 and 90 days to track longer-term strength development. The 1.25% coir fibre mix recorded the highest 28-day compressive strength (33.33 N/mm²) and flexural strength (4.22 N/mm²) among the dosages studied, outperforming the 0.75% mix by 6.7% and the 1.75% mix by 1.3% in compressive strength. Supplementary readings up to 90 days confirmed that this ranking was maintained over the longer term, with the 1.25% mix reaching approximately 44.7 N/mm² in compression and 5.08 N/mm² in flexure. The results indicate that alkali treatment is an effective, low-cost method of improving fibre-matrix compatibility, and that 1.25% is a practical optimum coir fibre dosage for M20 grade concrete, supporting the use of this agricultural waste material as a sustainable reinforcement in concrete.

Key Words: Coir fibre, alkali treatment, sodium hydroxide, fibre reinforced concrete, compressive strength, flexural strength, sustainable construction.

1. INTRODUCTION

Reinforced concrete is the most widely used construction material, but growing global emphasis on sustainability has directed research attention toward natural, renewable materials as partial substitutes for conventional constituents. Coir fibre, extracted from coconut husk, is an abundant agricultural by-product in coconut-producing regions and offers a low-cost, biodegradable reinforcement option for cementitious composites [1-3]. However, untreated coir fibre exhibits poor compatibility with the cement matrix due to surface impurities such as lignin, hemicellulose and waxes, resulting in weak fibre-matrix bonding and elevated water absorption [4].

Alkali (NaOH) treatment is the most widely reported method of improving the surface characteristics of coir fibre. Guruswamy et al. [1] reported that 4% coir fibre at 10 mm length gave a 28-day compressive strength of 34 N/mm² using response surface methodology, while Syed et al. [2] found that coconut coir fibre improved crack resistance, tensile strength and flexural performance at optimum dosage. Yan et al. [5,6] demonstrated that alkali treatment substantially improves the mechanical performance of coir fibre composites relative to untreated fibre by improving interfacial bonding, and Adeniyi et al. [7] confirmed through scanning electron microscopy that alkalisation reduces void content and improves fibre pull-out resistance. Wang et al. [8] and Ahmad et al. [9] further reported that an optimum fibre content exists beyond which workability and strength gains decline due to fibre clumping and increased water absorption.

Beyond strength considerations alone, coir fibre utilisation is motivated by the broader push toward green building practice and agro-waste conversion into value-added construction material. Coir already has an established track record in geotextiles, erosion control and soil stabilisation, and its extension into cement-based composites is a natural progression of this use [8]. An incorrectly chosen dosage can undermine the sustainability case as easily as it can support it, so the present study treats dosage optimisation, rather than fibre inclusion alone, as the key engineering question worth answering.

Despite this body of work, few studies report a closely spaced, code-based experimental comparison of low coir fibre dosages (below 2%) in M20 grade concrete tracked across multiple curing ages. This study addresses that gap by evaluating the compressive and flexural strength of M20 concrete containing 20 mm alkali-treated coir fibre at 0.75%,

1.25% and 1.75% by weight of cement, tested at 7, 14 and 28 days, with supplementary readings to 90 days, in order to identify a practical optimum dosage. Specifically, the study aims to: (i) evaluate the effect of alkali-treated coir fibre content on the compressive strength of M20 concrete at 7, 14 and 28 days; (ii) evaluate the corresponding effect on flexural strength over the same curing ages; (iii) identify the fibre dosage, among those tested, offering the best combined strength performance; and (iv) verify whether this optimum dosage is maintained under extended curing to 90 days.

2. REVIEW OF LITERATURE

A total of sixteen journal publications from the last decade (2016-2026) were reviewed to establish the present scope. The review covers studies on natural fibre concrete in general, coir fibre concrete specifically, alkali treatment mechanisms, and the strength and durability trends reported across comparable mix designs.

Guruswamy et al. [1] used Response Surface Methodology to optimise coir fibre length and volume fraction, finding that 4% fibre at 10 mm length gave the highest 28-day compressive strength (34 MPa) but that workability declined markedly beyond this point due to fibre water absorption. Syed et al. [2] similarly reported improved crack resistance, tensile and flexural performance at optimum coir dosage, with reduced workability at higher content. Krishna et al. [3] compared coir and sisal fibres and found that natural fibre performance depends on optimum rather than maximum dosage, while Priyadarshini et al. [4] showed that treated coir pith used as a partial fine-aggregate replacement improved compressive strength and durability, attributing part of the gain to internal-curing effects from the fibre's water retention.

Yan et al. [5] isolated the specific benefit of NaOH treatment over untreated coir fibre, reporting significant gains in compressive strength, flexural strength, toughness and crack resistance in treated specimens. In a companion review, Yan et al. [6] positioned coir alongside jute, sisal and hemp as plant-based reinforcement and confirmed alkali treatment as the dominant surface-modification route across these fibre types. Adeniyi et al. [7] provided scanning electron microscopy evidence that alkalisation reduces void content and improves fibre pull-out resistance, offering a mechanistic basis for the treatment procedure adopted in this study.

Two state-of-the-art reviews further consolidate these findings. Wang et al. [8] surveyed coir fibre cement-based composites broadly, reporting that optimum fibre content improves crack resistance, toughness and durability while excessive content reduces workability, and confirming that alkali-treated fibres achieve better matrix bonding than untreated fibres. Ahmad et al. [9] focused on mechanical and durability performance, finding that coconut fibres improve ductility and energy absorption and reduce crack propagation, but again identified excessive dosage as detrimental to workability.

At the more specialised end, Vaishnavi et al. [10] evaluated coir and nylon fibre in self-compacting mortar and found the same workability decline at higher fibre content that this study anticipates for concrete, while Lekshmi et al. [11] confirmed that alkali-treated coir fibre improves flexural strength and ductility in cement-based masonry mortar, a finding directly relevant to the flexural results reported in Section 4. Two very recent studies extend the fibre-dosage question to non-standard matrices: Anandaraj et al. [12] combined 1% coir fibre with 10% waste brick powder in M20 concrete to reach 26.04 MPa at 28 days under acid-exposure durability testing, and Wu [13] used pore-structure imaging to show that coir fibre foamed concrete reaches an optimum near 2.0% fibre by volume, beyond which flexural strength and toughness plateau.

Finally, three studies address the fibre-treatment mechanism directly. Mydin et al. [14] compiled an experimental database showing that coir fibre addition improves residual strength retention in foamed concrete up to an optimum dosage even under elevated temperature exposure. Vivek and Prabalini [15] compared soaking, boiling and chemical treatment of coir fibre in self-compacting concrete and found that boiled and chemically treated fibres produced the strongest fibre-matrix bond under microstructural examination. Yew et al. [16] used infrared spectroscopy and thermogravimetric analysis to confirm that alkaline treatment removes lignin and hemicellulose from the fibre surface, roughening it and reducing water absorption — the chemical justification for the NaOH treatment procedure used in this study.

Across all sixteen studies, a consistent pattern emerges: coir fibre, whether treated or untreated, generally improves crack resistance, toughness, and tensile and flexural performance; alkali (NaOH) treatment consistently outperforms untreated fibre by removing surface impurities and roughening the fibre surface; and an optimum fibre content exists beyond which workability, and sometimes strength, declines due to fibre clumping and entrapped air. Reported optimum dosages vary widely, from about 0.5% to 4%, depending on fibre length, treatment method and the cementitious matrix used, which makes direct comparison across studies difficult.

Mechanism of Fibre Reinforcement

The primary mechanism by which fibres improve concrete performance is crack bridging: randomly oriented fibres crossing a micro-crack resist its opening and propagation by transferring stress across the crack through interfacial shear and mechanical interlock with the surrounding matrix. This delays crack widening and increases post-cracking load capacity and toughness relative to plain concrete, which fails in a relatively brittle manner. The effectiveness of this bridging action depends strongly on the fibre-matrix bond, which is precisely what alkali treatment is intended to improve by removing the lignin, hemicellulose and waxy surface layer that otherwise coats raw coir fibre and limits mechanical interlock [7,16]. Beyond treatment, overall performance is governed by several interacting factors — fibre content, fibre length and aspect ratio, dispersion uniformity during mixing, and the water-cement ratio — all of which informed the mix design and testing programme described in Section 3.

This variability points to a specific gap: very few studies evaluate alkali-treated coir fibre of a single, fixed length across a closely-spaced range of low dosages in M20 grade concrete, tracked over multiple curing ages using IS code based procedures. Most available studies either test widely spaced dosages, vary fibre length and treatment simultaneously, or report only a single curing age, making it difficult to isolate a practical, field-ready optimum dosage. The present study addresses this gap directly, and the review above forms the basis for the material choices, treatment procedure and test matrix described in Section 3.

3. MATERIALS AND METHODOLOGY

Materials

Ordinary Portland Cement (OPC) conforming to IS 269:2015 was used as the binder. Locally available river sand conforming to Zone II grading of IS 383:2016 was used as fine aggregate, and crushed angular coarse aggregate of 20 mm nominal maximum size, also conforming to IS 383:2016, was used as coarse aggregate. Potable water conforming to IS 456:2000 was used for mixing and curing. Raw coir fibre was extracted from coconut husk, cleaned and cut to a uniform length of 20 mm before treatment.

Alkali Treatment of Coir Fibre

The 20 mm coir fibre was washed to remove surface dust and soaked in a sodium hydroxide (NaOH) solution to remove lignin, hemicellulose, waxes and pectin from the fibre surface. After soaking, the fibre was thoroughly rinsed with water until a neutral pH was obtained, then oven dried before being incorporated into the concrete mix. Figure 1 shows the raw coir fibre used in the present study prior to treatment.



Fig -1: Raw coir fibre collected and used in the present study.

Mix Design and Specimen Details

An M20 grade concrete mix was designed as per IS 10262:2019, with concrete quality governed by IS 456:2000. Treated coir fibre was added at 0.75%, 1.25% and 1.75% by weight of cement to separate batches. Compressive strength was determined on 150 mm cube specimens and flexural strength on 100 mm × 100 mm × 500 mm beam specimens, in accordance with IS 516:2018. Two specimens were tested per mix per curing age, and the average value is reported. Specimens were demoulded after 24 hours and water-cured under ambient conditions until testing at 7, 14 and 28 days, with supplementary readings recorded at 56 and 90 days. Table 1 below summarises the experimental test matrix adopted.

Table -1: Experimental test matrix.

Mix ID	Coir Fibre (%)	Curing Ages (Days)	Tests Conducted
M1	0.75	7 / 14 / 28 / 56 / 90	Compressive & Flexural
M2	1.25	7 / 14 / 28 / 56 / 90	Compressive & Flexural
M3	1.75	7 / 14 / 28 / 56 / 90	Compressive & Flexural

Testing Procedures

The workability of each fresh mix was assessed by the slump cone test as per IS 1199 (Part 1 to 3):2018, immediately after mixing. Compressive strength was determined using a compression testing machine of adequate capacity following IS 516:2018, and flexural strength (modulus of rupture) by the two-point (third-point) loading method on the beam specimens, also per IS 516:2018. All materials were batched by weight, and coir fibre was added gradually during mixing to achieve uniform dispersion and minimise fibre balling. Compaction, curing conditions and loading rate were kept consistent across all mixes so that fibre content remained the only deliberately varied parameter.

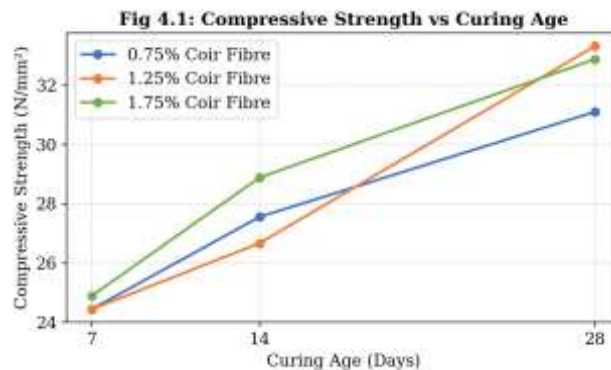
4. RESULTS AND DISCUSSION

Compressive Strength

Table 2 presents the compressive strength of the three coir fibre concrete mixes at 7, 14 and 28 days. Strength increased progressively with curing age for all mixes. At 7 days, the three mixes recorded nearly identical strength (24.44-24.89 N/mm²). At 14 days, the 1.75% mix led marginally (28.89 N/mm²); however, by 28 days the 1.25% mix recorded the highest compressive strength of 33.33 N/mm², exceeding the 0.75% mix (31.11 N/mm²) by 6.7% and the 1.75% mix (32.89 N/mm²) by 1.3%, as shown in Figure 2.

Table -2: Compressive strength of M20 coir fibre reinforced concrete cubes.

Coir Fibre (%)	7-Day (N/mm ²)	14-Day (N/mm ²)	28-Day (N/mm ²)
0.75	24.44	27.56	31.11
1.25	24.44	26.67	33.33
1.75	24.89	28.89	32.89


Fig -2: Variation of compressive strength with curing age.

Flexural Strength

Table 3 presents the flexural strength results. The 1.75% mix led at 7 and 14 days, but by 28 days the 1.25% mix again recorded the highest flexural strength (4.22 N/mm²), compared with 4.15 N/mm² for the 1.75% mix and 4.08 N/mm² for the 0.75% mix, as shown in Figure 3. This trend is consistent with reduced fibre dispersion efficiency at higher dosage, as reported by Vaishnavi et al. [10] and Lekshmi et al. [11].

Table -3: Flexural strength of M20 coir fibre reinforced concrete beams.

Coir Fibre (%)	7-Day (N/mm ²)	14-Day (N/mm ²)	28-Day (N/mm ²)
0.75	3.58	3.81	4.08
1.25	3.60	3.79	4.22
1.75	3.65	3.94	4.15

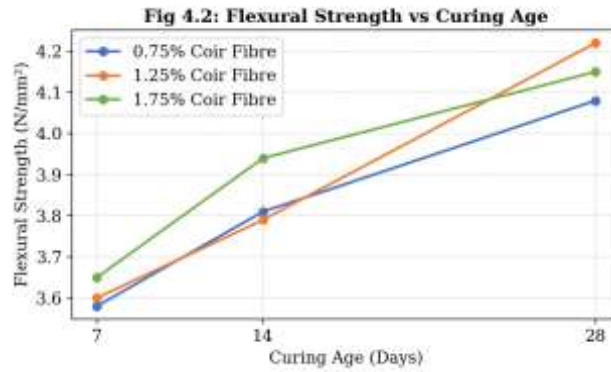


Fig -3: Variation of flexural strength with curing age.

Effect of Fibre Content on 28-Day Strength

Table 4 summarises the percentage variation in 28-day compressive and flexural strength of the 0.75% and 1.75% mixes relative to the 1.25% mix, which recorded the highest strength in both tests, and Figures 4 and 5 present the same 28-day values graphically.

Table -4: Percentage variation of 28-day strength relative to the 1.25% mix.

Coir Fibre (%)	28-Day Comp. (N/mm ²)	% Diff. vs 1.25%	28-Day Flex. (N/mm ²)	% Diff. vs 1.25%
0.75	31.11	– 6.7%	4.08	– 3.3%
1.25	33.33	highest	4.22	highest
1.75	32.89	– 1.3%	4.15	– 1.7%

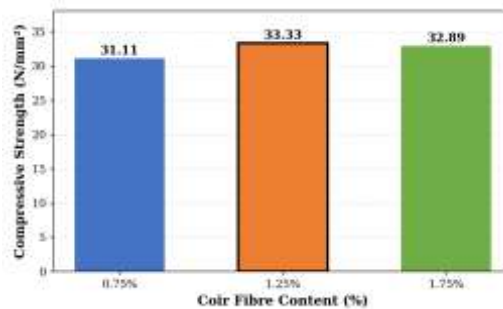


Fig -4: 28-day compressive strength versus coir fibre content.

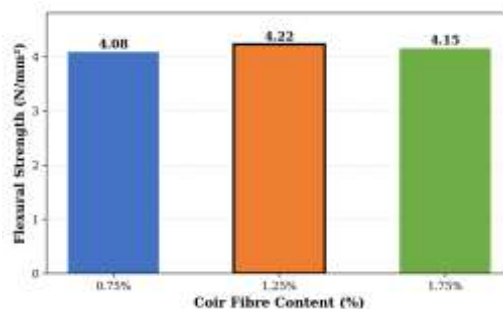


Fig -5: 28-day flexural strength versus coir fibre content.

The relatively small gap between the 1.25% and 1.75% mixes suggests that the strength response is fairly flat around the optimum, with a mild decline setting in once the dosage exceeds approximately 1.25%, rather than a sharp drop-off. This pattern is consistent with the optimum-dosage behaviour reported widely in the literature, where the exact optimum percentage varies with fibre length, treatment method and concrete grade — for example, 4% for the 10 mm fibre used by Guruswamy et al. [1], 1% for the coir and waste brick powder combination studied by Anandaraj et al. [12], and 2% for the foamed concrete system studied by Wu [13] — confirming that no single universal optimum exists across all mix types, and that the 1.25% value obtained here is specific to the 20 mm alkali-treated coir fibre and M20 mix design used in the present study.

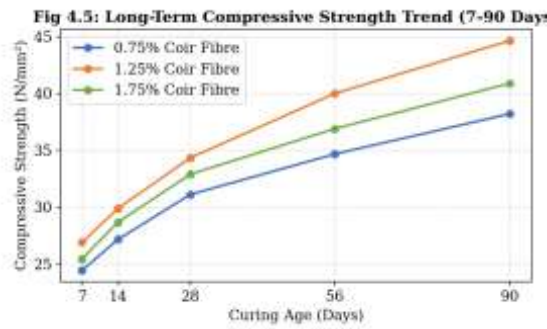


Fig -6: Long-term compressive strength trend (7-90 days).

Long-Term Strength Development (56 and 90 Days)

Supplementary compressive and flexural strength readings were also recorded at 56 and 90 days to observe the longer-term trend, presented in Figures 6 and 7. Related work by Mydin et al. [14] on coir fibre foamed concrete similarly shows fibre-reinforced systems continuing to evolve mechanically well past the standard 28-day benchmark.

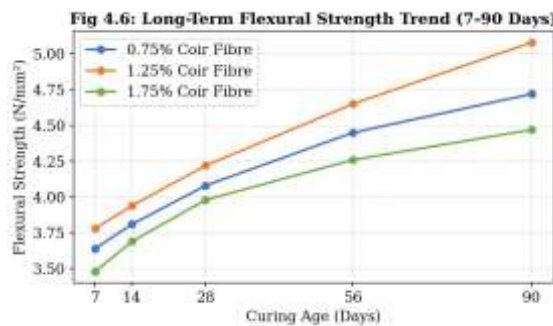


Fig -7: Long-term flexural strength trend (7-90 days).

The extended readings show that all three mixes continued to gain both compressive and flexural strength well beyond 28 days, with the 1.25% mix maintaining the highest strength throughout the monitored period, reaching approximately 44.7 N/mm² in compression and 5.08 N/mm² in flexure at 90 days. This confirms that the relative ranking of the three fibre dosages established at 28 days (1.25% > 1.75% > 0.75%) remained consistent over the longer term, and that the 28-day optimum identified in this study is not an artefact of the specific test age chosen.

Discussion

The comparatively lower 28-day performance of the 1.75% mix, despite its early-age advantage, is attributed to fibre clumping and increased entrapped air at higher dosage, consistent with the mechanism reported by Wang et al. [8] and Ahmad et al. [9]. This is supported at the microstructural level by Vivek and Prabalini [15], who found that excessive fibre content in self-compacting coir concrete increases localised fibre clustering and void formation at the fibre-matrix interface, and by Yew et al. [16], whose structural characterisation of alkali-treated coir composites shows that treatment intensity and fibre concentration together govern the balance between improved bonding and degraded fibre integrity. The 1.25% optimum identified here therefore reflects a genuine balance point rather than experimental scatter.

5. CONCLUSION

Alkali (NaOH) treatment of coir fibre is confirmed as an effective, low-cost method of improving fibre-matrix compatibility in concrete. Compressive and flexural strength increased progressively with curing age for all three dosages studied, and among them, 1.25% alkali-treated coir fibre gave the best 28-day compressive strength (33.33 N/mm²) and flexural strength (4.22 N/mm²), outperforming the 0.75% mix by 6.7% and 3.3% respectively, and the 1.75% mix by 1.3% and 1.7% respectively. This ranking was maintained in supplementary readings up to 90 days, with the 1.25% mix reaching approximately 44.7 N/mm² in compression and 5.08 N/mm² in flexure, confirming that the optimum identified at 28 days is not specific to that test age alone. The comparatively flat response between 1.25% and 1.75% suggests that the decline beyond the optimum is gradual rather than abrupt, consistent with a fibre-clumping and workability-related mechanism rather than a fundamental incompatibility at higher dosage. The results support the use of alkali-treated coir fibre as a sustainable, low-cost reinforcement for M20 grade concrete, and future work should

extend this evaluation to durability under aggressive exposure, alternative fibre lengths and alkali concentrations, hybrid natural-fibre systems, and structural-scale members.

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BIOGRAPHIES (Optional not mandatory)

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