

Investigation Of Structural M25 Grade Concrete Incorporating Manufactured Sand As Fine Aggregate And Reinforced With Alkali Treated Coconut Coir Fibers

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ABSTRACT

The depletion of natural river sand and the brittle tensile behaviour of conventional concrete motivate the use of engineered fine aggregates and discrete natural-fibre reinforcement. This experimental investigation evaluates M25 grade structural concrete prepared with 100% Manufactured Sand (M-Sand) as fine aggregate and reinforced with alkali-treated coconut coir fibres. Fifty-millimetre coir fibres were treated in a 5% sodium hydroxide solution for 24 hours and incorporated at 0.0%, 0.5%, 1.0%, and 1.5% by weight of cement. The baseline mix used a water-cement ratio of 0.45 and 0.8% polycarboxylate ether superplasticizer. Fresh-state behaviour was assessed through slump-cone and compaction-factor testing, while compressive strength was measured at 7 and 28 days and splitting tensile and flexural strengths at 28 days. Workability decreased progressively with increasing fibre content, with the reported slump falling from 75 mm for the control condition to 0 mm at the highest fibre level. The detailed mechanical results identified CC1.0 as the optimum mix: 28-day compressive strength reached 28.15 N/mm², splitting tensile strength reached 2.47 N/mm², and flexural strength reached 3.80 N/mm². Relative to CC0.0, the corresponding improvements were 4.84%, 16.51%, and 18.75%. Fibre-reinforced specimens also exhibited improved crack bridging and a transition from abrupt brittle fracture toward pseudo-ductile post-cracking behaviour.

Keywords: M25 concrete; Manufactured sand; Coconut coir fibre; Alkali treatment; Compressive strength; Splitting tensile strength; Flexural strength

I. INTRODUCTION

Concrete is widely used for structural construction because of its high compressive capacity, but plain concrete remains brittle and possesses limited tensile strain capacity. M25 grade concrete is used for structural members such as foundations, columns, slabs, retaining structures, pavements, and precast elements. Under tensile stresses, micro-cracks initiate within the cementitious matrix and interfacial transition zones and can propagate rapidly when no internal crack-arrest mechanism is present.

At the same time, natural river sand is becoming increasingly constrained by environmental restrictions and resource depletion. Manufactured Sand (M-Sand), produced through controlled crushing and screening, provides a consistent fine aggregate with angular, rough-textured particles. These characteristics can improve mechanical interlocking in hardened concrete, although the same angularity increases fresh-state friction and water demand. The present investigation therefore uses M-Sand as a complete replacement for river sand.

Coconut coir is a lignocellulosic agricultural by-product with high elongation capacity and useful crack-bridging potential. Untreated coir, however, contains surface waxes, pectins, hemicellulose, and other constituents that can weaken adhesion with cement paste. The study addresses this limitation through a 5% sodium hydroxide alkali mercerization treatment intended to roughen the fibre surface and improve bonding within the cement matrix.

The research problem is therefore to establish whether structural M25 concrete can simultaneously employ 100% M-Sand and alkali-treated coir fibres while retaining acceptable fresh behaviour and improving hardened mechanical response. Four mixes containing 0.0%, 0.5%, 1.0%, and 1.5% fibre by weight of cement were evaluated to determine the dosage that best balances workability, strength, and post-crack performance.

II. OBJECTIVES

- To establish an M25 grade concrete mix using 100% Manufactured Sand as fine aggregate in accordance with the mix-design framework and grading requirements adopted in the study.

- To treat 50 mm coconut coir fibres using a 5% NaOH alkali mercerization process to improve their surface condition and matrix bonding.
- To evaluate the influence of 0.0%, 0.5%, 1.0%, and 1.5% fibre contents on fresh concrete workability using slump-cone and compaction-factor tests.
- To determine 7-day and 28-day compressive strength and 28-day splitting tensile and flexural strengths of the experimental mixes.
- To identify the optimum fibre content and assess crack propagation and failure behaviour in the fibre-reinforced concrete.

III. LITERATURE SURVEY

Previous studies establish M-Sand as a technically viable alternative to natural river sand when grading, water demand, and admixture dosage are controlled. Gurumoorthy et al. reported improved mechanical and durability behaviour for selected M-Sand replacement levels [1], while Batham et al. summarized the influence of angular particle geometry on strength and fresh workability [5]. Zimar et al. showed that manufactured sand could be used up to complete replacement in concrete, although slump decreased as M-Sand content increased [10]. Song et al. similarly emphasized aggregate grading and fresh-workability control in machine-made sand systems [11]. Natural-fibre studies show that coconut coir can improve crack control and post-cracking performance when fibre length and dosage are appropriately selected. Mahi et al. examined fibre length and content in M25 concrete [2], Syed et al. investigated discrete coir and coir-mesh reinforcement [6], and Ng et al. reported improved post-crack integrity in fibre-reinforced thin concrete elements [8]. Pooja et al. highlighted the benefit of chemical treatment for coir-cement bonding [4].

Alkali treatment is particularly relevant because surface modification can remove weak organic constituents and increase fibre roughness. Ramu et al. reported improved interfacial adhesion for alkali-treated coir in composite materials [9]. Collectively, the reviewed literature supports the combined investigation of processed fine aggregate and treated natural fibres, while also indicating a gap in systematic evaluation of M25 concrete containing 100% M-Sand together with alkali-treated coir over controlled fibre dosages.

IV. MATERIALS AND METHODOLOGY



Fig-1 Coconut Coir

Experimental programme

The experimental programme comprised material characterization, M25 mix design, alkali treatment of coconut coir fibres, batching and casting, fresh-concrete testing, water curing, and mechanical testing. OPC 53 grade cement, 100% Zone II M-Sand, crushed granite coarse aggregate, potable water, polycarboxylate ether (PCE) superplasticizer, and alkali-treated coconut coir fibres were used.

Table 1. Key constituent properties

Constituent / property	Reported value
OPC 53 grade cement	Specific gravity 3.15; normal consistency 31%; initial setting time 42 min; final setting time 285 min
M-Sand	Zone II; fineness modulus 2.91; specific gravity 2.68; compacted

	bulk density 1620 kg/m ³ ; silt content 4.2%
Coarse aggregate	Specific gravity 2.72; water absorption 0.45%; crushing value 18.4%; impact value 14.2%
PCE superplasticizer	Specific gravity 1.12; adopted dosage 0.8% by weight of cement
Coconut coir fibre	Average diameter 0.37 mm; length 50 mm; aspect ratio ≈ 135 ; density 1.20 g/cm ³

Table 2. Sieve analysis of Manufactured Sand (Zone II)

Sieve size (mm)	Cumulative retained (%)	Passing (%)	IS 383 Zone II limit (%)
4.75	4.6	95.4	90–100
2.36	17.9	82.1	75–100
1.18	36.2	63.8	55–90
0.60	55.5	44.5	35–59
0.30	81.8	18.2	8–30
0.15	95.2	4.8	0–10
Pan	100.0	0.0	—

Alkali treatment of coconut coir fibres

Raw mature coconut coir fibres were cut to 50 mm and immersed in a 5% NaOH solution prepared at 50 g NaOH per litre of water. The fibres remained in the solution for 24 hours, after which they were washed until the rinse water reached approximately neutral pH. They were then oven-dried at 60°C for 48 hours and stored under dry conditions before batching. The treatment sequence is shown in Fig. 1.

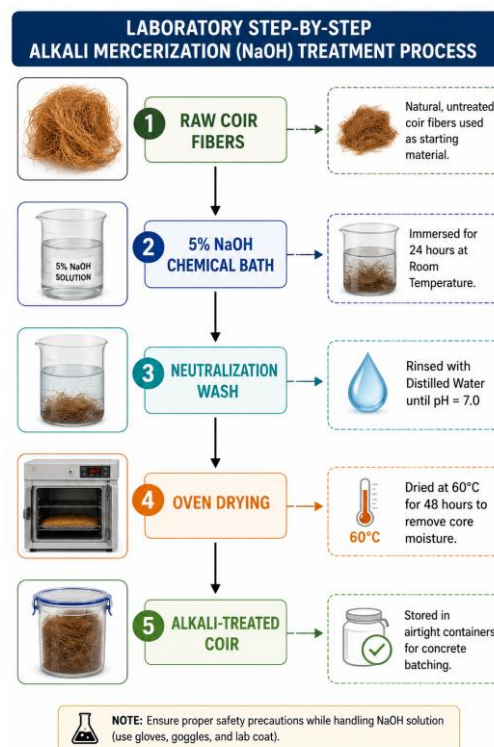


Fig. 2. Laboratory alkali mercerization treatment process for coconut coir fibres.

M25 mix design and experimental matrix

The mix design was developed for M25 concrete with a calculated target mean strength of 31.60 N/mm². A water-cement ratio of 0.45 was selected. The final baseline quantities per cubic metre were 362 kg cement, 163 kg water, 666 kg M-Sand, 1255 kg coarse aggregate, and 2.90 kg PCE. The reported mass ratio was 1 : 1.84 : 3.46 for cement : fine aggregate : coarse aggregate.

Table 3. Baseline M25 mix proportions

Material	Quantity per m ³
OPC 53 grade cement	362 kg
Water	163 kg
Manufactured Sand (Zone II)	666 kg
Coarse aggregate, total	1255 kg
20 mm coarse aggregate fraction	753 kg
12.5 mm coarse aggregate fraction	502 kg
PCE superplasticizer	2.90 kg
Water-cement ratio	0.45

Table 4. Experimental fibre matrix

Mix	Fibre content (% by cement wt.)	Fibre mass (kg/m ³)	Fine aggregate
CC0.0	0.0	0.00	100% M-Sand
CC0.5	0.5	1.81	100% M-Sand
CC1.0	1.0	3.62	100% M-Sand
CC1.5	1.5	5.43	100% M-Sand

Specimen preparation and testing

A pan-type mechanical mixer was used to promote uniform fibre dispersion and reduce fibre nesting. Concrete was cast into cubes, cylinders, and prisms, consolidated on a vibrating table, demoulded after approximately 24 hours, and water-cured until the designated test age. Fresh workability was assessed using slump-cone and compaction-factor procedures. Hardened mechanical testing followed the specimen programme summarized in Table 5.

Table 5. Hardened mechanical testing programme

Property	Specimen	Total samples	Curing age	Standard
Compressive strength	Cube, 150 × 150 × 150 mm	24	7 and 28 days	IS 516
Splitting tensile strength	Cylinder, 150 × 300 mm	12	28 days	IS 516
Flexural strength	Prism, 100 × 100 × 500 mm	12	28 days	IS 516

V. RESULTS AND DISCUSSION

Fresh properties

Fresh-state observations showed a systematic loss of workability with increasing coir-fibre content. The reported slump decreased from 75 mm for the control condition to 0 mm at the highest fibre content. The reduction was attributed to the combined effect of the angular, rough-textured M-Sand particles and the high-aspect-ratio coir network, which increased internal friction, restricted particle mobility, and promoted fibre interlocking. The compaction-factor test was used alongside the slump test to assess mixes that became increasingly stiff at higher fibre dosages.

Compressive strength



Fig-3 compressive strength test

Table 6. Compressive strength results

Mix	Fibre content (%)	7-day strength (N/mm ²)	28-day strength (N/mm ²)
CC0.0	0.0	18.25	26.85
CC0.5	0.5	18.60	27.42
CC1.0	1.0	19.15	28.15
CC1.5	1.5	18.90	27.90

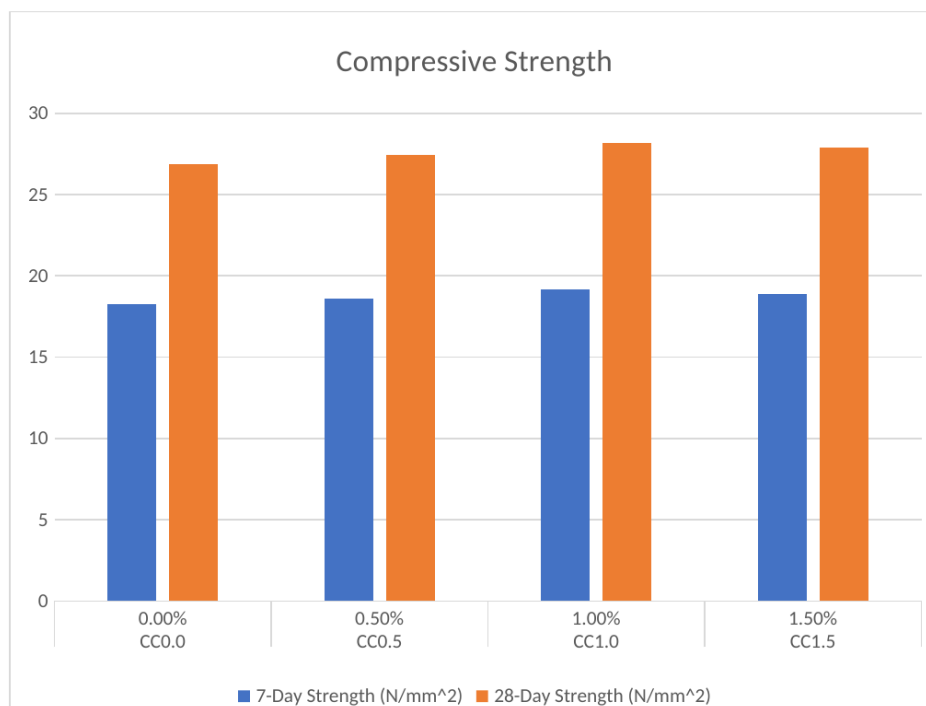


Fig. 4. Compressive strength of the experimental mixes at 7 and 28 days.

Compressive strength increased from CC0.0 to CC1.0 and then declined slightly at CC1.5. At 28 days, CC1.0 reached 28.15 N/mm² compared with 26.85 N/mm² for the control, corresponding to the reported 4.84% improvement. The reduction to 27.90 N/mm² at 1.5% fibre indicates that the benefit of fibre addition reached a

practical saturation threshold. The detailed results remain above the 25 N/mm² characteristic grade value, while the mix-design section reports a higher calculated target mean strength of 31.60 N/mm².

Splitting tensile strength

Table 7. Splitting tensile strength results at 28 days

Mix	Tensile strength (N/mm ²)	Increase vs. control
CC0.0	2.12	—
CC0.5	2.30	8.49%
CC1.0	2.47	16.51%
CC1.5	2.38	12.26%

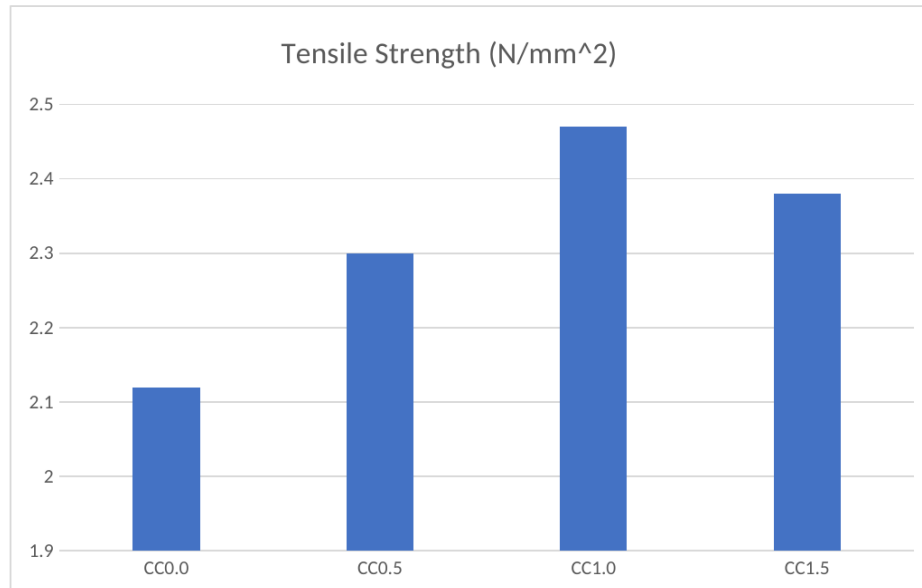


Fig. 5. Splitting tensile strength of the experimental mixes at 28 days.

The splitting tensile strength increased to a maximum of 2.47 N/mm² at 1.0% fibre, representing a 16.51% increase over CC0.0. This improvement is associated with enhanced fibre-matrix interlocking after alkali treatment. Under diametral tensile loading, the treated fibres bridge developing crack planes and transfer stress across the fracture path. The decrease to 2.38 N/mm² at 1.5% fibre is consistent with reduced dispersion efficiency at the highest dosage.

Flexural strength and failure behaviour

Table 8. Flexural strength results at 28 days

Mix	Flexural strength (N/mm ²)	Increase vs. control
CC0.0	3.20	—
CC0.5	3.50	9.38%
CC1.0	3.80	18.75%
CC1.5	3.65	14.06%

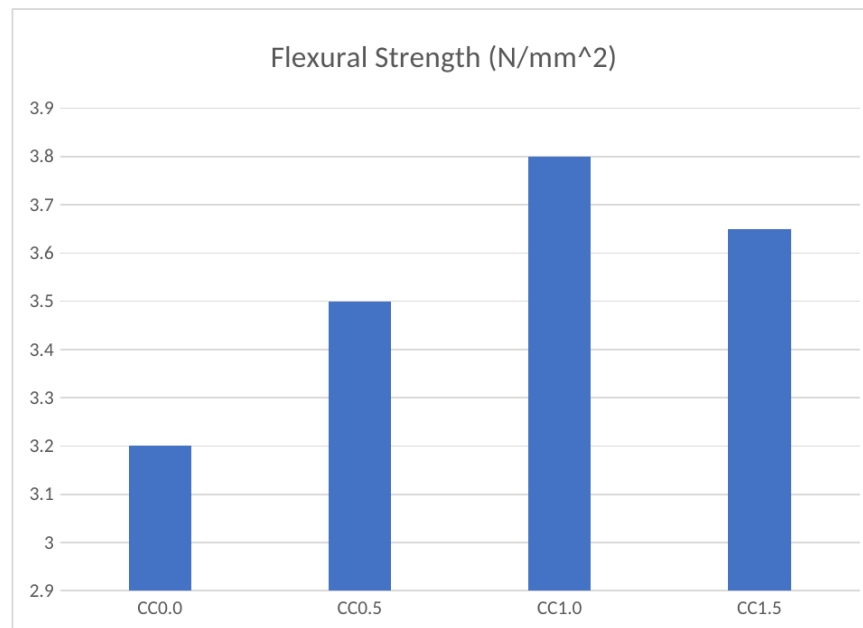


Fig. 6. Flexural strength of the experimental mixes at 28 days.

Flexural strength followed the same optimum trend. CC1.0 reached 3.80 N/mm², an 18.75% increase over the 3.20 N/mm² control value. The control prisms exhibited abrupt brittle fracture, whereas the fibre-reinforced mixes showed a more gradual post-cracking response. The treated coir fibres remained anchored across advancing cracks and dissipated energy through stretching and frictional pull-out.

Considering fresh-state workability and all three mechanical strength measures together, CC1.0 was identified as the optimum formulation. Increasing the fibre level to 1.5% caused a decline in compressive, tensile, and flexural values. This reduction is associated with fibre nesting or balling, which can trap air, increase internal porosity, and interfere with aggregate-paste consolidation.

VI. CONCLUSION

- M25 concrete incorporating 100% M-Sand was successfully evaluated as the baseline matrix for alkali-treated coconut coir fibre reinforcement.
- The 5% NaOH treatment for 24 hours was used to modify the 50 mm coir fibres before incorporation into the concrete.
- Workability decreased as fibre content increased; the reported slump ranged from 75 mm in the control condition to 0 mm at the highest fibre level.
- The optimum mechanical response occurred at 1.0% fibre content (CC1.0), with 28-day compressive strength of 28.15 N/mm², splitting tensile strength of 2.47 N/mm², and flexural strength of 3.80 N/mm².
- Relative to the fibreless control, CC1.0 showed reported improvements of 4.84% in 28-day compressive strength, 16.51% in splitting tensile strength, and 18.75% in flexural strength.
- Fibre-reinforced specimens exhibited improved crack bridging and a transition from sudden brittle fracture toward pseudo-ductile post-cracking behaviour.
- At 1.5% fibre content, the mechanical values declined from the 1.0% optimum, indicating that excessive fibre content can reduce dispersion and consolidation efficiency.

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