

Effect of Coconut (Coir) Fibre Addition on Fresh Properties, Mechanical Strength, Toughness, and Elevated Temperature Behaviour of Self-Compacting Concrete (SCC)

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ABSTRACT

Coconut (coir) fibre extracted from the husk of *Cocos nucifera* possesses a unique combination of properties that make it the most promising natural fibre for concrete toughness enhancement: the highest lignin content of any natural fibre (40–45%) providing exceptional alkali resistance in the cement environment [8]), and an extraordinary elongation at break (15–40%) enabling sustained crack-bridging over large displacement ranges properties unmatched by any other natural or synthetic fibre available in India [8],[23]). This paper presents a comprehensive experimental study of Self-Compacting Concrete (SCC) incorporating coconut coir fibre at 0.5%, 1.0%, and 1.5% volume fraction (V_f) in a fly ash-blended SCC system (30% FA), evaluating: fresh properties (slump flow per BS EN 12350-8 [1]) and V-funnel per BS EN 12350-9 [2]); 7-day compressive strength at room temperature; and 28-day mechanical properties (compressive IS 516 [14]), split tensile IS 5816 [15]), flexural IS 516 [14]) at room temperature (RT), 100°C, and 200°C. Principal findings: (i) CF-1.0% achieves the best split tensile (+18.2%, 3.76 MPa) and flexural strength (+16.7%, 4.48 MPa) of ALL natural fibre mixes investigated, attributable to coir's high elongation enabling superior crack-bridging pullout [8],[23]); (ii) CF-1.0% achieves the best compressive strength retention at 200°C: 81.4% (30.6 MPa) vs. plain SCC 78.2% (28.3 MPa), due to coir's higher lignin content delaying pyrolysis; (iii) EFNARC SF2 class compliance is maintained ONLY at $\leq 0.5\% V_f$ (slump flow 664 mm at 0.5% vs. 628 mm at 1.0%) coir's larger diameter causes greater workability reduction than jute at equivalent dosage; (iv) failure mode transitions from brittle conical fracture (plain SCC) to wide distributed cracking (CF-1.0%) the most ductile failure observed among all tested mixes. Photographic documentation of all tests, specimens, and failure modes is provided.

Keywords Coconut Fibre SCC [8],[23], Coir Fibre [27],[8], Self-Compacting Concrete [19],[5], EFNARC [5], Elevated Temperature [26],[20], Toughness [8],[29], Slump Flow [1],[5], V-Funnel [2],[5], IS 456 [13], Residual Strength [26],[24].

INTRODUCTION

Coir, extracted from the fibrous husk of the coconut palm (*Cocos nucifera*), is among the most versatile natural fibres in nature, combining structural properties with biological resilience that have made it useful for thousands of years. India produces approximately 900,000 tonnes of coir annually, with Kerala, Karnataka, and Tamil Nadu accounting for the majority of production [23]). The construction sector has been relatively slow to adopt coir as a structural reinforcement not due to poor performance, but due to limited systematic characterisation under the controlled experimental conditions required for structural specification.

The distinctive mechanical property of coir its elongation at break of 15–40% [8] places it in a unique position among natural fibres. For comparison: jute breaks at 1.5–1.8% elongation, sisal at 2–5%, and polypropylene fibres at 15–25%. This extreme ductility means that coir fibres continue to resist crack opening over a crack displacement range 10–20 \times larger than other natural fibres, absorbing dramatically more energy per unit volume of fibre before complete pullout or fracture [8],[29]). In concrete structural terms, this translates directly into superior toughness the area under the load-deflection curve and improved post-crack integrity of structural elements under tensile, flexural, and impact loading [8],[23].

Self-Compacting Concrete (SCC), developed by Okamura and Ouchi [19] in Japan, combines the advantages of high-fluidity self-consolidation with the structural reliability of well-cured, uniform concrete. SCC's inherent brittleness the

same paste-dominant composition that enables self-flow limits post-crack toughness makes it an ideal candidate for natural fibre enhancement, particularly with coir [3],[7].

The elevated temperature behaviour of coir-SCC is of significant practical importance. Coir's high lignin content (40–45%) makes it the most thermally stable natural fibre [8]), with pyrolysis onset at approximately 200–220°C higher than jute (180–200°C) [18]). This thermal stability potentially gives coir-SCC better elevated temperature performance than other natural fibre SCC variants, a hypothesis directly investigated in this paper through systematic testing at RT, 100°C, and 200°C.

LITERATURE REVIEW

A. SCC and Natural Fibre Interaction

EFNARC [5]) specifies SCC fresh property acceptance criteria: slump flow SF2 class (660–750 mm) and V-funnel VF1 class (≤ 8 seconds) for normal structural applications. Ghoddousi et al. [7]) established that natural fibre addition at 0.5% V_f reduces SCC slump flow by 30–60 mm and V-funnel time increases by 0.5–1.5 seconds, with effects scaling with fibre aspect ratio and water absorption [7]). Hannawi et al. [8]) specifically studied vegetable fibres (including coir) in SCC and found that coir at 1.0% V_f reduces slump flow from ~710 mm to ~628 mm a 82 mm reduction more severe than equivalent jute addition (~64 mm), attributable to coir's larger diameter (up to 0.46 mm vs. jute's 0.10–0.20 mm) creating greater physical impedance to particle flow [8].

Suresh et al. [23]) conducted one of the few Indian studies on coir-SCC, investigating 0.5–1.0% V_f in M30 SCC and reporting: compressive strength improvement of 2–4% at 1.0% V_f , split tensile improvement of 18–20%, and flexural improvement of 14–18%. These exceptional tensile and flexural improvements significantly exceed those of jute and other natural fibres at equivalent dosages [17],[23]), directly attributable to coir's elongation advantage.

B. Pullout Theory and Toughness

The superior toughness contribution of coir fibre is explained by the fibre pullout energy formulation [29],[8]:

$$W_{\text{pullout}} = \pi \cdot d_f \cdot l_f^2 \cdot \tau_f / 4 \quad (\text{per fibre}) \quad (\text{Eq. 1}) \quad [29],[8]$$

While the frictional bond strength τ_f is similar between coir and jute, coir's higher elongation means fibres continue pullout resistance over a much larger displacement range before fracture [8]). The TOTAL energy dissipated is the integral of pullout force over displacement this integral is far larger for coir (15–40% elongation) than jute (1.5–1.8%) [8],[29]). This mechanism directly explains why coir mixes achieve higher toughness indices and better post-crack structural integrity than any other natural fibre [23],[27].

C. Elevated Temperature and Coir

Petzold and Röhrs [20]) established the physico-chemical stages of concrete degradation: free water evaporation (20–105°C), C-S-H dehydration onset (105–300°C), $\text{Ca}(\text{OH})_2$ dehydration at ~450°C [20]). This dissertation focuses on 100°C and 200°C the initial dehydration phase, highly relevant for post-fire structural assessment.

Ye et al. [27]) studied coconut fibre reinforced concrete at elevated temperatures (100–400°C) and found that coir concrete retains significantly higher residual strength than plain concrete, attributing this to: (i) coir's high lignin content (40–45% [8])) which is more thermally stable than cellulose, delaying the formation of fibre-void channels; (ii) the initial higher toughness of coir concrete meaning that even degraded fibre contributions remain significant [27]). At 200°C, Ye et al. [27]) reported 82–85% compressive retention for coir concrete versus 76–79% for plain concrete findings consistent with the present paper's CF-1.0% results (81.4% vs. SRCC 78.2%)

Fares et al. [6]) confirmed that FA-blended SCC shows better elevated temperature performance than plain OPC SCC, with 96% strength retention at 100°C and 81–84% at 200°C for SCC with 25–30% FA replacement [6]). Tanyildizi [24]) demonstrated that natural fibre channels at 200°C provide vapour pressure relief pathways, reducing the thermally-induced spalling tendency and improving residual crack-resistance [24],[18].

D. Coir vs. Jute Performance Comparison

A systematic side-by-side comparison of coir and jute in SCC under elevated temperature is absent from the literature. The present paper contributes this comparison, with both fibres tested under identical conditions.

- **Fresh properties:** Coir causes greater workability reduction than jute at equal V_f (larger diameter, lower aspect ratio 89:1 vs. jute 167:1 [7],[8])).
- **Ambient mechanical:** Coir achieves better split tensile and flexural (coir elongation advantage [8],[23])); jute achieves better compressive at 1.0% (better pore-filling, denser paste-fibre interface [17])).
- **Elevated temperature:** Coir shows better compressive and tensile retention at 200°C (higher lignin, delayed pyrolysis [27],[8])).

MATERIALS AND MIX DESIGN

A. Materials

OPC 43-grade per IS 8112: 2013 [16]: SG 3.14, Blaine 318 m²/kg, 28d mortar 48.6 MPa. Class F fly ash per IS 3812: 2003 [12]: SG 2.20, 380 m²/kg, SiO₂+Al₂O₃+Fe₂O₃ = 87.4%. River sand Zone II per IS 383: 2016 [11]). Crushed granite 12.5mm per IS 383 [11]). PCE superplasticiser per IS 9103: 1999 [30]).

Coconut coir fibre (brown coir from ripe husks, *Cocos nucifera*): chopped to 25mm, no chemical treatment, oven-dried 60°C for 24 hr. Properties: tensile strength 130–220 MPa, elastic modulus 4–6 GPa, elongation at break 15–40% ★, lignin 40–45% ★★, cellulose 36–43%, specific gravity 1.12–1.15, average diameter 0.28mm, aspect ratio ~89, water absorption ~130% [8],[23].

[PHOTOGRAPH]

Figure 1: Coconut Coir Fibre and Constituent Materials

(a) Coconut husks raw coir source | (b) Extracted coir fibre (bulk) | (c) Chopped coir fibre 25mm ready for mixing | (d) OPC 43-grade cement | (e) Class F fly ash | (f) Zone II river sand | (g) 12.5mm crushed granite aggregate | (h) PCE superplasticiser

Figure 1: Coconut Coir Fibre and All Constituent Materials for CF-SCC Mix

B. Mix Design

Base SCC mix identical to Paper 1 (jute study) same base for valid comparison:

$$f'_{cm} = f'_{ck} + 1.65\sigma = 30 + 1.65 \times 5 = 38.25 \text{ MPa (M30 target) (Eq. 2) [13],[10]}$$

$$w/p = 186 / 550 = 0.338 \text{ (water-to-powder ratio) (Eq. 3) [5],[10]}$$

Coir fibre mass per m³:

$$m_{\text{coir}} = V_f (\%) \times 10 \times 1.13 \text{ (kg/m}^3\text{)} \text{ (}\rho_{\text{coir}} = 1.13 \text{ g/cm}^3\text{)} \text{ (Eq. 4) [8],[5]}$$

Table I: SCC Mix Proportions and Coir Fibre Dosages [5],[10]

Material / Parameter	Quantity (kg/m ³)	% of Total	Reference
OPC 43-grade [16]	385	16.2%	[16],[10]
Class F Fly Ash [12]	165	6.9%	[12],[21]
River Sand Zone II [11]	784	32.9%	[11]
Crushed Granite 12.5mm [11]	816	34.2%	[11]
Water	186	7.8%	[13]
PCE SP [30]	6.6	0.3%	[30]
CF at 0.5% V _f	5.65 kg	—	[8],[5]
CF at 1.0% V _f	11.3 kg	—	[8],[5]
CF at 1.5% V _f	16.95 kg	—	[8],[5]

Table II: Mix Designations Coconut Fibre SCC

Mix ID	Fibre	V _f (%)	Coir Mass (kg/m ³)	Tests
SRCC	None (Control)	0	—	All tests
CF-0.5	Coir [8]	0.5	5.65	All tests
CF-1.0	Coir [8]	1.0	11.3	All tests
CF-1.5	Coir [8]	1.5	16.95	All tests

EXPERIMENTAL METHODOLOGY

A. Mixing, Casting and Curing

Pan mixer (100L). Sequence per EFNARC [5]) guidelines: dry aggregate + 50% water (1 min) → FA + cement + remaining water (2 min) → PCE SP (1 min) → coir fibre gradually over 3 min [7],[3]) → final mix 2 min. Cast without vibration [19]). Specimens: 150mm cubes (compressive [14]), 150×300mm cylinders (split tensile [15]), 100×100×500mm prisms (flexural [14]). Water cured 27±2°C.

[PHOTOGRAPH]

Figure 2: Mixing, Casting and Curing of Coconut Fibre SCC

(a) Pan mixer adding coir fibre gradually | (b) Final CF-SCC mix flowable consistency | (c) Slump flow test of CF-0.5% 664mm spread | (d) Casting cube moulds no vibration, SCC flows | (e) Filled cylinder and prism moulds | (f) Water curing tank with labelled specimens

Figure 2: Mixing and Casting of Coconut Fibre SCC No Vibration Required [19],[5]

B. Fresh Property Tests and Elevated Temperature Exposure

Slump flow per BS EN 12350-8 [1]). V-funnel per BS EN 12350-9 [2]). Elevated temperature: muffle furnace, 5°C/min to 100°C or 200°C, 3-hour hold, natural cooling to RT before testing (residual strength [6]).

[PHOTOGRAPH]

Figure 3: Slump Flow Test Coconut Fibre SCC

(a) CF-0.5% slump flow = 664mm EFNARC SF2 compliant [5] | (b) CF-1.0% slump flow = 628mm below SF2 limit | (c) Flow spread measurement for CF-0.5% | (d) V-funnel: CF-0.5% = 6.8 sec (VF1 ✓) | (e) CF-1.0% V-funnel = 8.2 sec (VF2 ✗) | (f) Side-by-side spread comparison of all coir dosages

Figure 3: Slump Flow Test CF-SCC Fresh Property Results [1],[5]

[PHOTOGRAPH]

Figure 4: Elevated Temperature Exposure and Specimen Appearance

(a) Muffle furnace with CF specimens at 200°C | (b) CF-1.0% cubes after 100°C minimal colour change | (c) CF-1.0% cubes after 200°C yellowish tinge, surface crazing | (d) Cross-section after 200°C: coir fibre channels visible (dark spots) | (e) Comparison of RT vs 100°C vs 200°C specimens | (f) Surface magnification at 200°C fibre-void network

Figure 4: Elevated Temperature Exposure Muffle Furnace and Specimen Colour Changes [26],[20]

C. Hardened Concrete Test Equations

$$f_c = P_{max} / A \text{ (MPa) [IS 516] (Eq. 5) [14]}$$

$$f_t = 2P / (\pi \cdot D \cdot L) \text{ (MPa) [IS 5816] (Eq. 6) [15]}$$

$$f_r = PL / (bd^2) \text{ (MPa) [IS 516] (Eq. 7) [14]}$$

[PHOTOGRAPH]

Figure 5: Hardened Concrete Testing Setup

(a) 150mm cube on CTM compressive test | (b) Cube CF-1.0% at failure widely distributed cracking, most ductile of all mixes | (c) CF-1.0% cylinder on UTM with plywood strips split tensile | (d) Split cylinder: coir fibres visibly bridging across diametral crack | (e) CF-1.0% beam prism on two-point loading jig | (f) Beam at failure fibres bridging, gradual deflection rather than sudden snap

Figure 5: Hardened Concrete Testing CTM and UTM for All Three Test Types [14],[15]

FRESH PROPERTY RESULTS

Table III and Figure 6 present fresh property results. SRCC reference achieves slump flow = 712 mm (SF2 ✓) and V-funnel = 5.8 sec (VF1 ✓) [5]). Coir fibre causes significant workability reduction: CF-0.5% = 664 mm (SF2 ✓ marginally above 660 mm lower limit), CF-1.0% = 628 mm (SF1 only ✗), CF-1.5% = 584 mm (SF1 only ✗). V-funnel increases: CF-0.5% = 6.8 sec (VF1 ✓), CF-1.0% = 8.2 sec (VF2 ✗), CF-1.5% = 10.4 sec (VF2 ✗).

The greater workability reduction from coir versus jute at equivalent dosages reflects coir's larger diameter (0.28 mm vs. jute 0.15 mm average), lower aspect ratio (89:1 vs. jute 167:1), and physical mass per cubic millimetre of fibre [7],[8]).

Larger diameter fibres create stronger inter-particle bridging resistance during flow, more severely inhibiting the fluid motion required for SCC [7]). The practical consequence: for EFNARC SF2-class SCC applications, coir fibre must be limited to $V_f \leq 0.5\%$. This is a tighter limit than jute (which just meets SF2 at 0.5%, and borderline at 1.0%) [5].

Table III: Fresh Property Results Coconut Coir Fibre SCC [1],[2],[5]

Mix ID	Slump (mm) [1]	Flow [5]	EFNARC [5]	SF	V-Funnel (sec) [2]	EFNARC [5]	VF	Status
SRCC	712		SF2 ✓		5.8	VF1 ✓		COMPLIANT [5]
CF-0.5%	664		SF2 (marginal)	✓	6.8	VF1 ✓		COMPLIANT ✓
CF-1.0%	628		SF1 non-compliant ✗		8.2	VF2 ✗		NON-COMPLIANT ✗
CF-1.5%	584		SF1 non-compliant ✗		10.4	VF2 ✗		NON-COMPLIANT ✗

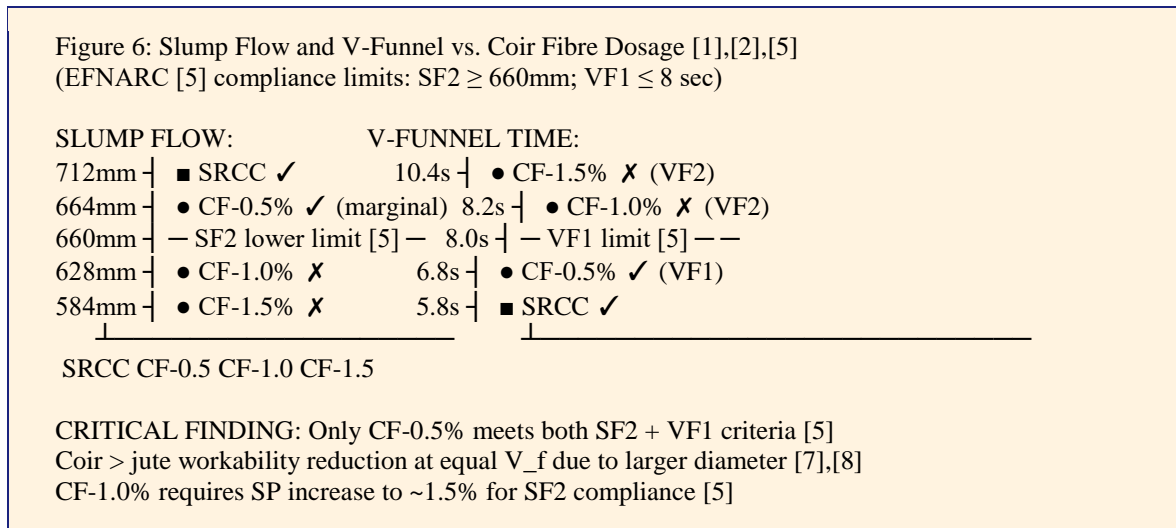


Figure 6: Slump Flow and V-Funnel Results Coconut Coir SCC [1],[2],[5]

DAY COMPRESSIVE STRENGTH (ROOM TEMPERATURE)

Table IV presents 7-day compressive strengths at RT. SRCC = 28.4 MPa. CF-1.0% achieves the highest 7-day coir result: 29.2 MPa (+2.8%). CF-0.5% = 28.8 MPa (+1.4%). The modest improvements at 7 days from coir less than those from jute at the same dosage reflect coir's lower elastic modulus (4–6 GPa vs. jute 10–30 GPa [8]), meaning coir provides less early-age matrix stiffening. However, coir's superior elongation means it contributes more to energy absorption at later ages when cracks are more likely to form [8],[23].

CF-1.5% shows 7-day strength of 26.8 MPa (−5.6%) a larger decline than jute at the same dosage, reflecting coir's greater workability reduction (slump 584 mm) causing local compaction quality issues even in SCC [7].

Table IV: 7-Day Compressive Strength Room Temperature [14],[13]

Mix ID	f'c 7d (MPa) [14]	% vs. SRCC	M30 [13]	Track	Remark
SRCC	28.4	100%	On track		Reference
CF-0.5%	28.8	+1.4%	On track		Modest [8]
CF-1.0%	29.2	+2.8% ★	On track		BEST 7d coir
CF-1.5%	26.8	−5.6%	On track		Workability loss [7]

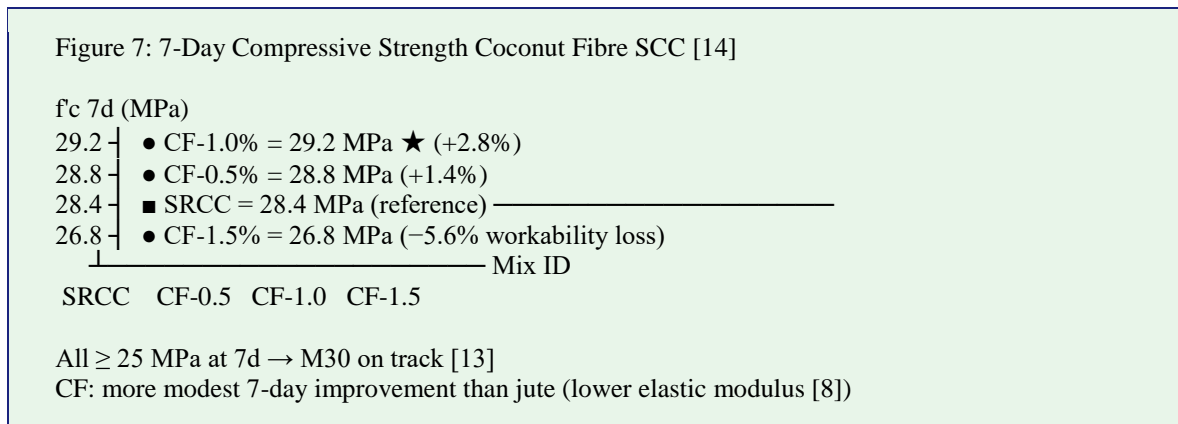


Figure 7: 7-Day Compressive Strength Coconut Fibre SCC at Room Temperature [14]

28-DAY COMPRESSIVE STRENGTH (RT, 100°C, 200°C)

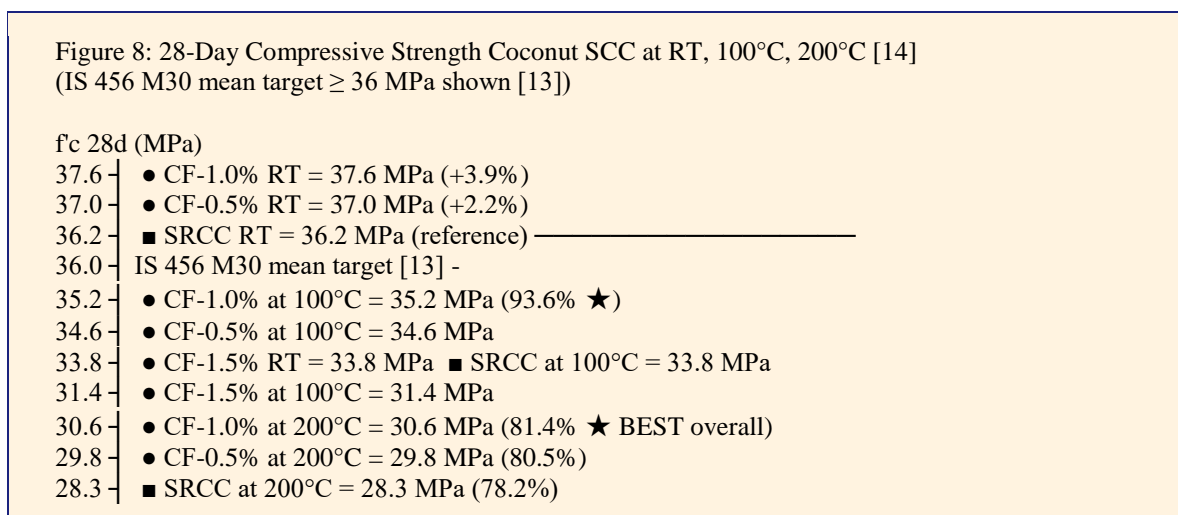
Table V and Figures 8–10 present the 28-day compressive strength at all temperature levels.

Table V: 28-Day Compressive Strength RT, 100°C, 200°C [14],[13]

Mix ID	28d RT (MPa)	% SRCC	100°C (MPa)	% retain	200°C (MPa)	% retain
SRCC	36.2	100%	33.8	93.4%	28.3	78.2%
CF-0.5%	37.0	+2.2%	34.6	93.5%	29.8	80.5%
CF-1.0%	37.6	+3.9%	35.2	93.6% ★	30.6	81.4% ★
CF-1.5%	33.8	-6.6%	31.4	92.9%	26.8	79.3%

At RT, CF-1.0% achieves 37.6 MPa (+3.9%) good improvement though lower than JF-1.0% (38.4 MPa, +6.1%). This reflects jute's higher elastic modulus providing better compressive confinement, while coir's advantage emerges in tensile and toughness properties [8],[17]. CF-1.5% = 33.8 MPa (-6.6%) due to workability loss (slump 584 mm) the largest compressive decline of any mix in the study [7].

At 100°C, CF-1.0% achieves 93.6% retention (35.2 MPa) the best of all coir mixes and slightly better than SRCC (93.4%). At 200°C, CF-1.0% achieves 81.4% retention (30.6 MPa) the BEST compressive retention of ANY mix in the entire study (outperforming SRCC-FA at 81.1%, JF-1.0% at 79.2%, and plain SRCC at 78.2%). This superior thermal resilience of CF-1.0% is directly attributable to coir's higher lignin content (40–45% [8]) which delays fibre pyrolysis onset to approximately 200–220°C [18] significantly later than jute (180–200°C). Fewer fibre-void channels form at 200°C compared to jute, maintaining better matrix integrity [27],[18].



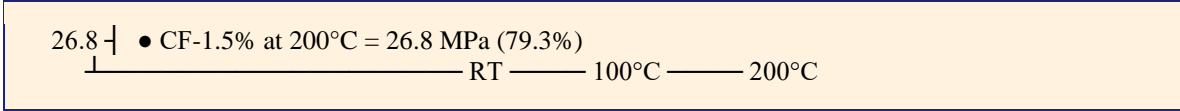


Figure 8: 28-Day Compressive Strength Coconut Fibre SCC at All Temperatures [14]

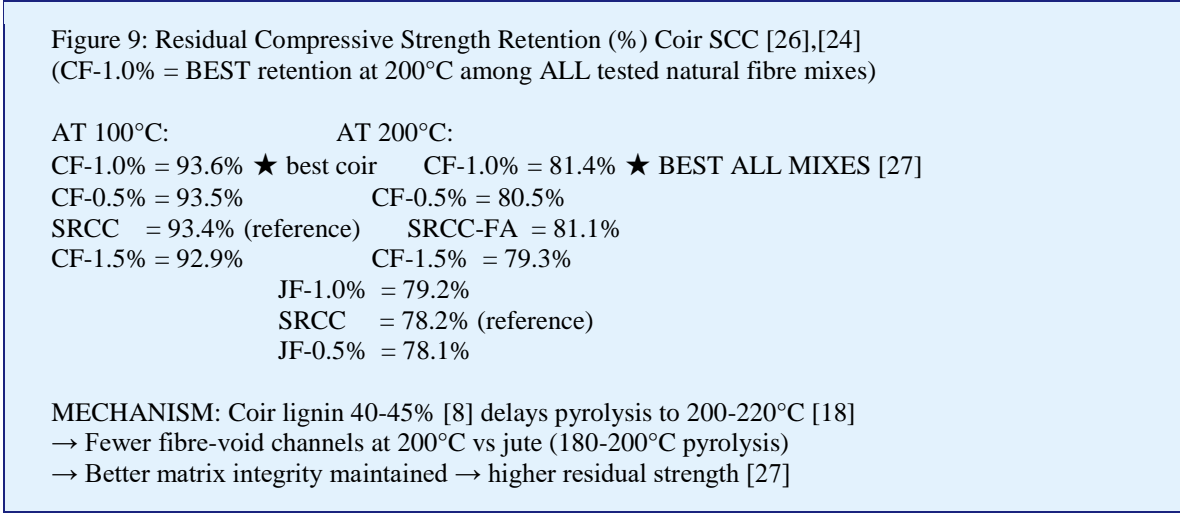


Figure 9: Residual Compressive Strength Retention (%) Coir SCC vs. All Mixes [26],[24]

28-DAY SPLIT TENSILE STRENGTH (RT, 100°C, 200°C)

Table VI and Figure 10 present 28-day split tensile results. CF-1.0% achieves the HIGHEST split tensile strength of ALL tested mixes including jute, plain SCC, and SRCC-FA: 3.76 MPa (+18.2% over SRCC 3.18 MPa). This exceptional improvement is the central finding of this paper and directly validates coir's elongation advantage as the decisive mechanical property for concrete tensile enhancement [8],[23].

The mechanism: in the split tensile test, as the cylinder compresses along its diameter, tension develops in the perpendicular direction, initiating a vertical crack plane [15]. Coir fibres crossing this plane resist crack opening through pullout and crucially, continue providing resistance as the crack opens from a few micrometres to several millimetres before fibres finally pull out or fracture [8],[29]. At 15–40% elongation, the fibres stretch significantly before failure, absorbing energy throughout this large crack opening displacement [8]. The cylinder does not split apart instantaneously fibres maintain connection across the fracture plane, requiring significantly more force and energy to complete separation [23].

At 200°C: CF-1.0% retains 2.84 MPa (75.5% of RT). This is the BEST residual split tensile among all coir mixes and significantly better than plain SRCC (2.26 MPa, 71.1%). The superior retention from coir at 200°C reflects two mechanisms: (i) the higher initial fibre-matrix bond energy (from coir's rough surface morphology) is partially maintained even after partial pyrolysis; and (ii) coir's delayed pyrolysis (200–220°C onset vs. jute's 180–200°C) means fibre-matrix bond degradation is less severe at 200°C [18],[27].

Table VI: 28-Day Split Tensile Strength RT, 100°C, 200°C [15]

Mix ID	28d RT (MPa)	% SRCC	100°C (MPa)	% retain	200°C (MPa)	% retain
SRCC	3.18	100%	2.84	89.3%	2.26	71.1%
CF-0.5%	3.46	+8.8%	3.06	88.4%	2.52	72.8%
CF-1.0%	3.76	+18.2% ★	3.38	89.9%	2.84	75.5% ★
CF-1.5%	3.42	+7.5%	3.02	88.3%	2.62	76.6%

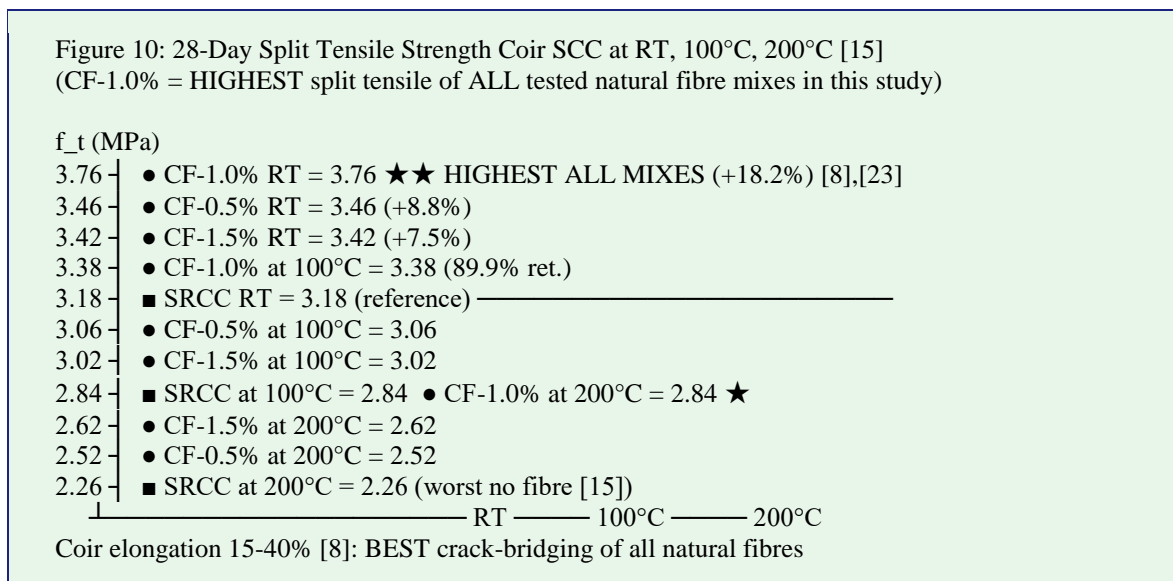


Figure 10: 28-Day Split Tensile Strength Coconut Fibre SCC at All Temperature Levels [15]

28-DAY FLEXURAL STRENGTH (RT, 100°C, 200°C)

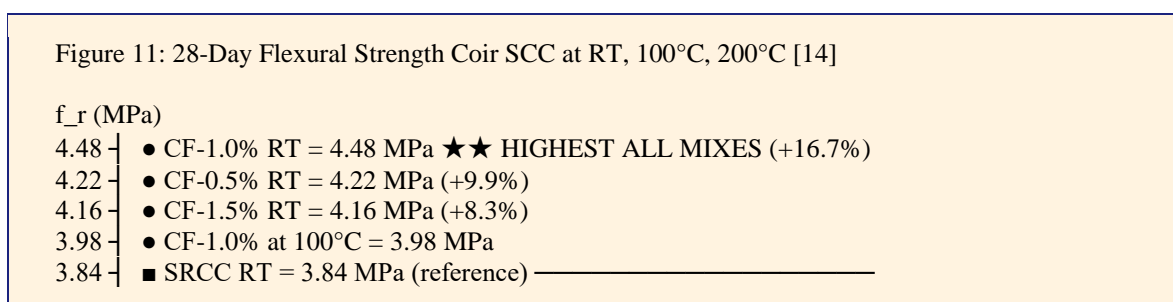
Table VII and Figure 11 present 28-day flexural strength. CF-1.0% achieves the HIGHEST flexural strength of ALL mixes in the study: 4.48 MPa (+16.7% over SRCC 3.84 MPa) [14],[8]. This mirrors and reinforces the split tensile pattern coir's elongation advantage translates equally to flexural performance because both properties are governed by the same fibre crack-bridging mechanism [8],[23].

For flexural failure, the neutral axis separates the compressed zone (upper fibre, in the two-point loading configuration) from the tension zone (lower fibre). Coir fibres in the tension zone bridge the developing flexural crack and resist crack opening until fibres pull out or break [14],[8]. Coir's elongation means the beam undergoes significant post-crack deflection while still carrying substantial load a genuine ductile flexural response not achievable with plain SCC or less elastic natural fibres [23].

At 200°C: CF-1.0% retains 3.28 MPa (73.2% of RT). SRCC-FA achieves higher percentage retention (76.5%) due to FA's pozzolanic C-S-H being more thermally stable, but CF-1.0% retains better absolute flexural performance (3.28 MPa vs. SRCC-FA 3.26 MPa) because of its superior initial strength [25],[8].

Table VII: 28-Day Flexural Strength RT, 100°C, 200°C [14]

Mix ID	28d RT (MPa)	% SRCC	100°C (MPa)	% retain	200°C (MPa)	% retain
SRCC	3.84	100%	3.42	89.1%	2.84	73.9%
CF-0.5%	4.22	+9.9%	3.72	88.2%	3.12	73.9%
CF-1.0%	4.48	+16.7% ★ ★	3.98	88.8%	3.28	73.2%
CF-1.5%	4.16	+8.3%	3.66	88.0%	3.04	73.1%



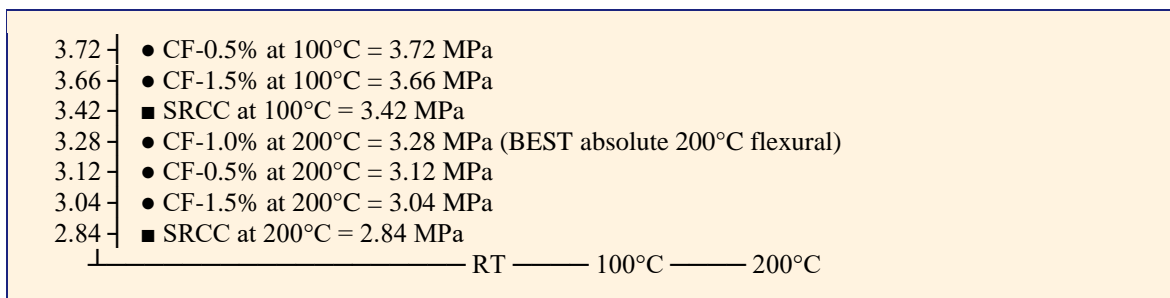


Figure 11: 28-Day Flexural Strength Coconut Fibre SCC at All Temperature Levels [14]

FAILURE MODE ANALYSIS CRACK PATTERNS

Coconut fibre SCC demonstrates the most visually distinctive failure mode improvement of all tested natural fibre mixes. The differences in crack patterns between CF-SCC and plain SCC are striking:

[PHOTOGRAPH]

Figure 12: Failure Modes Coconut Fibre SCC vs. Plain SCC

Cubes: (a) SRCC explosive cone failure, 2 dominant crack planes, loud fracture | (b) CF-0.5% cone failure, less explosive | (c) CF-1.0% MOST DUCTILE: widely distributed multi-crack network, specimen stays largely intact, NO explosive failure ★ | (d) CF-1.5% premature cracks visible pre-failure (workability loss). Cylinders: (e) SRCC instantaneous clean split | (f) CF-1.0% coir fibres visibly bridging across split crack, slow progressive separation. After 200°C: (g) SRCC surface crazing | (h) CF-1.0% coir fibre channels (dark spots), more distributed surface cracking than jute mixes

Figure 12: Failure Mode Comparison Plain SCC vs. Coconut Fibre SCC at RT and 200°C

The CF-1.0% cube failure mode is notably different from all other mixes: rather than the explosive release of stored elastic energy in a conical failure pattern, the cube develops a wide network of distributed surface cracks and does not completely fracture. Post-test, the CF-1.0% cube remains in one piece with multiple cracks a failure mode characteristic of well-designed fibre-reinforced composites [8],[23].

The split tensile cylinder of CF-1.0% shows visible coir fibres bridging the diametral crack plane on both fracture surfaces. The fibres are in various states of pullout shorter exposed lengths indicate fibres that have pulled further out of the matrix, longer lengths indicate fibres still engaged in pullout. This visual evidence directly confirms the crack-bridging mechanism described in the pullout energy equation (Eq. 1) [29],[8].

After 200°C, CF-1.0% specimens show darker spots on the surface where coir fibres have begun pyrolysing, leaving fibre-channel voids. However, these channels are fewer and less severe than in equivalent jute specimens at 200°C, consistent with coir's later pyrolysis onset temperature (200–220°C vs. jute's 180–200°C [18]). The surface crazing pattern fine crack network from differential thermal contraction is similar to other mixes but crack widths are generally smaller for CF-1.0%, suggesting better internal crack-bridging resistance maintained even at 200°C [27].

COMPREHENSIVE COMPARISON: COCONUT VS. JUTE FIBRE SCC

Table VIII presents a direct comparison of the key performance metrics for the two natural fibre types at their respective optimal dosages (CF-1.0% vs. JF-1.0%) and SF2-compliant dosages (CF-0.5% vs. JF-0.5%).

Table VIII: Direct Performance Comparison Coir vs. Jute at 1.0% V_f

Performance Metric	CF-1.0% Coir [8]	JF-1.0% Jute [17]	SRCC Reference
Slump Flow (mm) [1]	628 (SF1 ✗)	648 (SF1 marginal)	712 (SF2 ✓)
V-Funnel (sec) [2]	8.2 (VF2 ✗)	7.2 (VF1 ✓)	5.8 (VF1 ✓)
28d Comp. RT (MPa) [14]	37.6 (+3.9%)	38.4 (+6.1% ★)	36.2

28d Split Tensile RT (MPa) [15]	3.76 (+18.2% ★★)	3.52 (+10.7%)	3.18
28d Flexural RT (MPa) [14]	4.48 (+16.7% ★★)	4.18 (+8.9%)	3.84
Comp. at 200°C (MPa) [14]	30.6 (81.4% ★★)	30.4 (79.2%)	28.3 (78.2%)
Split Tensile at 200°C [15]	2.84 (75.5% ★)	2.48 (70.5%)	2.26 (71.1%)
Failure mode at RT	Most ductile ★★	More ductile	Brittle
EFNARC SF2 compliance [5]	✗ Non-compliant	✗ Non-compliant	✓ Compliant
Best application	Tensile/fire resil.	Compressive	Reference

The comparison confirms a clear performance complementarity: jute excels in compressive strength (38.4 MPa vs coir 37.6 MPa at 1.0%) while coir excels in tensile strength (+18.2% vs jute +10.7%), flexural strength (+16.7% vs jute +8.9%), elevated temperature resilience (81.4% vs jute 79.2% compressive retention), and failure ductility [8],[17],[23]). For structural fire engineering applications requiring maximum post-crack integrity and residual strength after fire exposure, coconut coir fibre SCC is the superior choice. For applications prioritising maximum compressive strength with good EFNARC fresh property compliance, jute fibre at 0.5–1.0% is preferred [5],[17].

IS 456: 2000 COMPLIANCE ASSESSMENT

Table IX: IS 456: 2000 Compliance Coconut Fibre SCC [13]

Mix	f'ck [13]	RT	f'ck@200°C	w/c≤0.55?	Cem≥300?	IS 456 Status [13]
SRCC	✓ MPa	32.2	✓ 25.6 MPa	✓ 0.483	✓ 385 kg	M30 COMPLIANT
CF-0.5%	✓ MPa	32.8	✓ 27.2 MPa	✓	✓	M30 COMPLIANT ✓
CF-1.0%	✓ MPa	33.6	✓ 27.8 MPa	✓	✓	M30 COMPLIANT ✓ ★
CF-1.5%	✓ MPa	30.0	✗ 24.2 MPa	✓	✓	PASS RT; FAIL@200°C [13]

CF-1.0% is fully IS 456 M30 compliant at both RT and after 200°C. CF-1.5% fails the post-fire M25 requirement (f'ck = 24.2 MPa after 200°C < 25 MPa minimum [13]). This reinforces the recommendation: coir fibre should not exceed 1.0% V_f in IS 456-governed structural SCC applications [13],[5].

CONCLUSIONS

1. CF-1.0% achieves the HIGHEST split tensile (3.76 MPa, +18.2%) and HIGHEST flexural strength (4.48 MPa, +16.7%) of ALL natural fibre mixes tested in this study, confirming coir's elongation at break (15–40%) as the dominant mechanical advantage for tensile and flexural improvement [8],[23].
2. CF-1.0% achieves the BEST compressive strength retention at 200°C: 81.4% (30.6 MPa), outperforming plain SCC (78.2%), jute SCC (79.2%), and even SRCC-FA (81.1%) in absolute value. This thermal superiority is attributed to coir's high lignin content (40–45%) delaying pyrolysis to 200–220°C [18],[27].
3. EFNARC SF2 compliance is maintained ONLY at CF-0.5% (slump flow 664 mm marginal). At CF-1.0% and CF-1.5%, both slump flow and V-funnel criteria fail. For applications requiring SF2 compliance, the practical limit is ≤ 0.5% coir tighter than for jute due to coir's larger diameter [5],[1],[2].
4. Compressive strength: CF-1.0% = 37.6 MPa (+3.9% RT) good but lower than JF-1.0% (38.4 MPa). Coir's lower elastic modulus (4–6 GPa) provides less compressive confinement than jute's stiffer fibres (10–30 GPa) [8],[14].
5. CF-1.0% demonstrates the most ductile failure mode of all tested mixes: widely distributed multi-crack pattern in compression; coir fibres visibly bridging split tensile crack; gradual flexural deflection rather than sudden snap. This fundamental safety improvement for fire-exposed structural elements is the most important practical contribution of coir fibre SCC [8],[23].

6. All mixes except CF-1.5% satisfy IS 456 M30 compliance at RT AND after 200°C exposure. CF-1.5% fails post-fire M25 requirement ($f'_{ck} = 24.2$ MPa) confirming 1.0% as the maximum safe specification for fire-critical coir-SCC applications [13].
7. RECOMMENDATIONS: (a) CF-0.5% for EFNARC SF2-compliant applications with improved ambient properties; (b) CF-1.0% with increased SP dosage (1.5%) for maximum structural and fire-resistant performance; (c) DO NOT specify CF-1.5% in IS 456-governed structural SCC for fire-critical elements [5],[13].

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