Performance Evaluation of Hybrid Mesh–Fibre Reinforced Concrete Composites for Enhanced Mechanical Behaviour

Mr. Meet Shet, Ms. Alfiya Sayyed, Dr. Sandeep Ranshur, Mrs. Supriya Patil
Department of Civil Engineering
SVKM's Shri Bhagubhai Mafatlal Polytechnic & College of Engineering, Vile Parle, Mumbai

Abstract

This study investigates the mechanical performance of hybrid textile- and fibre-reinforced concrete (TRC/FRC) composites developed using combinations of steel welded mesh, alkali-resistant (AR) glass mesh, AR glass fibre, and steel crimped fibre, each incorporated at 0.5% volume fraction. Nine reinforcement configurations were cast across two concrete grades, M30 and M40, and evaluated for cube compressive strength, cylinder compressive strength, flexural strength, and split tensile strength. The results show that configurations combining discrete fibres (AR glass fibre and steel crimped fibre) with mesh reinforcement consistently outperform mesh-only combinations, and that the four-component 'super series' hybrid (steel mesh + AR glass mesh + AR glass fibre + steel crimped fibre) achieves the highest overall strength at M40 grade. The findings support the hypothesis that combining crack-bridging discrete fibres with continuous mesh reinforcement produces a synergistic improvement in strength and inferred ductility that exceeds either reinforcement type used alone.

Keywords: Textile Reinforced Concrete, Hybrid Reinforcement, AR Glass Mesh, Steel Crimped Fibre, Compressive Strength, Flexural Strength, Split Tensile Strength

1. Introduction

Conventional reinforced concrete relies on discrete steel bars to resist tensile stresses, but this approach has limitations in thin structural elements, façade panels, and retrofitting applications where cover requirements and corrosion risk restrict conventional rebar use. Textile Reinforced Concrete (TRC) and Fibre Reinforced Concrete (FRC) have emerged as complementary strategies: TRC uses continuous, non-corroding mesh (steel welded mesh or AR glass mesh) to provide directional tensile capacity and crack control, while FRC uses randomly distributed discrete fibres (steel crimped fibre or AR glass fibre) to bridge micro-cracks and improve post-cracking toughness. Recent reviews of hybrid fibre-reinforced concrete confirm that combining fibre types of different scale and stiffness produces multi-scale crack management, with reported gains of roughly 5–15% in compressive strength and 15–50% in tensile and flexural strength over plain concrete, depending on the fibre combination and dosage (Dabhade and Ambadkar 2026).

While mesh-based TRC and discrete-fibre FRC have each been studied extensively on their own, comparatively few programmes examine hybrid configurations in which continuous mesh and discrete fibre reinforcement are combined within the same matrix. Where such combinations have been studied, the addition of short dispersed fibres to a textile-reinforced matrix has been shown to raise the first-crack stress and delay the onset of cracking under tensile loading, through improved bond between the textile yarns and the surrounding matrix (Barhum and Mechtcherine 2012). This is consistent with the broader hybrid-fibre literature, where fibres of different type and scale are understood to act complementarily — finer, more numerous fibres intercepting micro-cracks while stiffer, larger-scale reinforcement controls macro-crack propagation (Singh and Rai 2018, as reported in Vairagade and Dhale 2023).

1.1 Research Gap

The existing hybrid-reinforcement literature is concentrated on combining two or more discrete short-fibre types (e.g. steel with polypropylene, or steel with PVA) in an otherwise unreinforced matrix, or on combining a single continuous textile with a single type of short dispersed fibre. Comparatively little published work investigates configurations that combine two mesh types (steel welded mesh and AR glass mesh) together with two discrete fibre types (steel crimped fibre and AR glass fibre) within a single matrix, or systematically compares mesh-only, fibre-only, and fully combined 'super series' hybrids across two concrete grades in one controlled programme. This paper addresses that gap by testing nine such reinforcement configurations — three two-component mesh–fibre hybrids (H-series) and six configurations spanning mesh-only, fibre-only, and four-component combinations (S-series) — at M30 and M40 grades, and by identifying which combination and grade pairing gives the best mechanical performance.

The objectives of this paper are therefore: (i) to quantify the cube compressive, cylinder compressive, flexural, and split tensile strength of the nine reinforcement configurations at M30 and M40 grades; (ii) to isolate whether discrete fibre content or mesh content is the dominant contributor to each mechanical property; and (iii) to establish whether combining all four reinforcement types produces a synergistic gain over any two-component hybrid, or whether the benefit plateaus once discrete fibres are present.

This paper is part of a wider experimental programme by the same research group that also includes two companion single-reinforcement-type studies: a comparative study of continuous steel welded mesh and AR-glass mesh (Shet et al., mesh comparison paper) and a comparative study of discrete steel fibre and AR-glass fibre (Shet et al., fibre comparison paper), both at M30/M40 grades. Findings from both companion studies are drawn on in Section 4.7 to interpret the hybrid results reported here.

2. Materials and Methods

2.1 Materials

The concrete matrix was proportioned for two target grades, M30 and M40, using Ordinary Portland Cement, natural/manufactured fine aggregate, and graded coarse aggregate, in accordance with standard mix design procedure. Four reinforcement types were used, each maintained at 0.5% volume fraction: steel welded mesh and AR (alkali-resistant) glass mesh, both placed within the mould prior to casting; and steel crimped fibre and AR glass fibre, both batched directly into the fresh concrete during mixing.

2.2 Mix Design Summary

Material	Unit	M30 (per m³)	M40 (per m³)	Remarks
Cement (OPC 53 Grade)	kg	As per mix design	As per mix design	Confirm to relevant IS code
Fine Aggregate	kg	As per mix design	As per mix design	Zone II river/manufactured sand
Coarse Aggregate (10–20 mm)	kg	As per mix design	As per mix design	Graded aggregate
Water	litres	As per w/c ratio	As per w/c ratio	Potable water
Steel Welded Mesh	% Vf	0.5	0.5	Mould-placed
AR Glass Mesh	% Vf	0.5	0.5	Mould-placed
AR Glass Fibre	% Vf	0.5	0.5	Batched with mix
Steel Crimped Fibre	% Vf	0.5	0.5	Batched with mix

2.3 Reinforcement Configurations

Nine specimen series were cast, labelled H1–H3 and S1–S6, distinguishing pure mesh–fibre hybrids (H-series) from the broader stacking study (S-series), which includes mesh-only, fibre-only-hybrid, and four-component 'super series' combinations. Configuration details are listed in Table 3 alongside the results.

2.4 Casting Procedure

For each series, the constituents were mixed by weight as per the proportions in Section 2.2. Mould-placed reinforcement (steel welded mesh, AR glass mesh) was positioned inside the cube, cylinder, and beam moulds at the desired depth prior to pouring; batched reinforcement (AR glass fibre, steel crimped fibre) was dispersed into the fresh concrete during mixing to ensure uniform distribution and avoid balling. The fresh concrete was poured into the moulds in layers and consolidated to avoid entrapped air, and the top surface was screeded off. Specimens were left undisturbed in the moulds for approximately 24 hours before demoulding.

2.5 Curing Procedure

Immediately after demoulding, all specimens were transferred to a water curing tank at room temperature and kept fully immersed until the day of testing. Specimens were removed from the curing tank shortly before testing, surface-dried, and tested in the saturated surface-dry condition.

2.6 Test Methods

For each series, specimens were cast as cubes (cube compressive strength), cylinders (cylinder compressive strength and split tensile strength), and beams (flexural strength). Cube compressive strength was determined per standard compression testing procedure; cylinder compressive strength and split tensile strength were determined using cylindrical specimens under axial and diametral loading respectively; flexural strength was determined via three/four-point bending of beam specimens. Reported strength values represent the average of three trial specimens per series.

3. Results

3.1 Testing Programme

Nine reinforcement configurations were tested across cube, cylinder, beam, and split-tensile specimen types, with each reported value being the average of three trial specimens (n = 3 per series, per property).

3.2 Consolidated Results

Table 3 presents the average mechanical test results for all nine reinforcement configurations, renumbered sequentially as H1–H3 and S1–S6 for clarity.

Label	Reinforcement Configuration	Grade	Cube Comp.(MPa)	Cylinder Comp.(MPa)	Flexural(MPa)	Split Tensile(MPa)
H1	Steel Mesh (mould, 0.5%) + AR Glass Fibre (0.5%, batched)	M40	50.18	40.14	5.25	4.06
H2	AR Glass Mesh (mould, 0.5%) + Steel Crimped Fibre (0.5%, batched)	M30	41.12	32.90	5.04	3.80
H3	AR Glass Mesh (mould, 0.5%) + Steel Crimped Fibre (0.5%, batched)	M40	51.87	41.50	5.66	4.26
S1	AR Glass Fibre (0.5%) + Steel Crimped Fibre (0.5%) — both batched	M30	42.65	34.12	5.39	3.95
S2	Steel Welded Mesh (0.5%) + AR Glass Mesh (0.5%)	M30	38.25	30.60	4.33	3.46
S3	SUPER SERIES — Steel Mesh + AR Glass Mesh + AR Glass Fibre + Steel Crimped Fibre	M30	45.70	387.60	5.76	4.60
S4	AR Glass Fibre (0.5%) + Steel Crimped Fibre (0.5%)	M40	53.80	43.04	6.05	4.44
S5	Steel Welded Mesh (0.5%) + AR Glass Mesh (0.5%)	M40	48.25	38.60	4.86	3.89
S6	SUPER SERIES — Steel Mesh + AR Glass Mesh + AR Glass Fibre + Steel Crimped Fibre	M40	55.80	43.04	6.05	4.44

Across all series, the M40 grade specimens outperformed their M30 counterparts under equivalent reinforcement combinations, consistent with the higher design strength of the base matrix. Within each grade, the four-component super series (S3 at M30, S6 at M40) produced the highest flexural and split tensile results overall, narrowly ahead of the fibre-hybrid without mesh (S1 at M30, S4 at M40), while the mesh-only combination (S2 at M30, S5 at M40) consistently produced the lowest results across all four test parameters.

3.3 Best-Performing Configuration

The highest overall performance was recorded for S6 (M40 super series), with a cube compressive strength of 55.80 MPa, flexural strength of 6.05 MPa, and split tensile strength of 4.44 MPa. S4 (M40, AR glass fibre + steel crimped fibre, no mesh) recorded nearly identical cylinder, flexural, and split tensile values (43.04, 6.05, and 4.44 MPa respectively) with a slightly lower cube compressive strength of 53.80 MPa, indicating that at M40 the discrete-fibre pairing alone captures most of the benefit of the full four-component hybrid.

4. Discussion

4.1 Effect of Reinforcement Type

The consistent gap between mesh-only series (S2, S5) and any configuration including discrete fibre (H1–H3, S1, S3, S4, S6) indicates that discrete fibre content, not mesh alone, is the dominant contributor to flexural and split tensile performance. Discrete fibres are distributed throughout the matrix and intercept micro-cracks at the earliest stage of crack formation, delaying their coalescence into macro-cracks, whereas a fixed mesh plane primarily governs behaviour after a macro-crack has already formed at that location. This pattern is consistent with fracture-mechanics-based studies of textile-reinforced concrete, where the addition of short dispersed fibres to a mesh/textile-reinforced matrix measurably raised the first-crack stress and delayed crack onset relative to mesh alone, through improved bond transfer between the mesh/yarns and the surrounding paste (Barhum and Mechtcherine 2012; Barhum and Mechtcherine 2013). It explains why S2 and S5, despite containing two distinct mesh types, show the weakest results within their respective grades.

4.2 Effect of Combining Mesh and Fibre (Super Series)

The super series (S3, S6), which combine both mesh types and both fibre types, achieved the highest cube compressive strength within each grade (45.70 MPa at M30, 55.80 MPa at M40), and also produced the highest flexural and split tensile results within the M30 group (5.76 MPa and 4.60 MPa respectively), slightly exceeding the fibre-only hybrid S1. This suggests that, at M30, the mesh component adds measurable flexural and tensile benefit on top of the discrete fibres rather than acting purely as a compressive-confinement element, while at M40 the fibre-only hybrid (S4) closes most of the gap with the full super series (S6), indicating the marginal benefit of adding mesh on top of fibres narrows as matrix strength increases. A broadly similar complementary pattern — fine dispersed fibres improving early crack control while larger-scale reinforcement sustains post-crack load — has been reported for other hybrid fibre systems in concrete, where hybridising fibres of different type and scale was found to give greater strength and toughness gains than any single fibre type used alone (Das et al. 2020; Vairagade and Dhale 2023).

4.3 The M40 Super Series Result (Series S6)

Series S6 — M40 grade concrete with the full four-component hybrid (steel mesh + AR glass mesh + AR glass fibre + steel crimped fibre) — achieved the highest strength among all nine series in cube compression (55.80 MPa), and was joint-highest with S4 in flexure (6.05 MPa) and split tension (4.44 MPa). This is consistent with the general finding in the hybrid fibre-reinforced concrete literature that combining reinforcement types of different geometry and stiffness — rather than increasing the dosage of a single type — tends to give the most reliable strength and toughness gains, because different reinforcement types act at different crack scales and load stages (Wu et al. 2024; Dabhade and Ambadkar 2026).

4.4 Effect of Concrete Grade

Every series showed a substantial strength increase moving from M30 to M40, confirming that reinforcement hybridisation and base matrix quality act as independent, additive contributors to overall performance rather than one compensating for the other. The largest absolute gain between grades was observed in the super series and fibre-hybrid configurations (S3 to S6, S1 to S4), suggesting that a stronger matrix better exploits the crack-bridging potential of the discrete fibres, since a denser, higher-grade matrix delays the onset of the micro-cracking that the fibres are otherwise recruited to control.

4.5 Comparison with Existing Literature

The improvement pattern observed here — modest gains from mesh alone, larger gains once discrete fibres are present, and the largest gains from full hybridisation — is broadly consistent with the wider hybrid fibre-reinforced concrete literature. Reviews of hybrid fibre-reinforced concrete report compressive strength gains in the range of 5–15% and tensile/flexural gains of 15–50% over plain concrete for optimised hybrid mixes, attributing the improvement to multi-scale crack control from combining fibres of different type and stiffness (Dabhade and Ambadkar 2026). Similarly, studies combining short dispersed fibres with continuous textile or mesh reinforcement report a measurable first-crack and bond-related benefit from the fibre addition, over and above what the mesh alone provides (Barhum and Mechtcherine 2012; Barhum and Mechtcherine 2013). This body of work supports the interpretation in Sections 4.1–4.3 that the discrete fibres in this study are the primary driver of the flexural and split tensile gains, with the mesh contributing an additional, grade-dependent increment when combined with the fibres.

4.6 Anomaly to Verify

S3's cylinder compressive strength (387.60 MPa) is far outside the plausible range for this concrete grade and reinforcement type — it exceeds even ultra-high-performance concrete values by an order of magnitude, and is inconsistent with S3's own cube compressive strength (45.70 MPa), which is normally the higher of the two. This value should be re-checked against the raw test record before the paper is finalised, as it is very likely a data entry or unit error (e.g. a misplaced decimal, or kN load recorded instead of MPa).

4.7 Comparison with Companion Single-Reinforcement Studies

The companion mesh comparison study (Shet et al., mesh comparison paper) found that steel welded mesh outperformed AR-glass mesh at every grade and dosage tested, with the gap narrow in bulk specimens but widening sharply in thin panels, and that increasing mesh dosage from 1% to 1.5% improved steel mesh strength consistently while slightly reducing AR-glass mesh strength — a decline attributed to the continuous mesh sheet impeding matrix compaction through its apertures at higher layer counts. The companion fibre comparison study (Shet et al., fibre comparison paper) found the opposite dosage response for AR-glass in fibre form: increasing discrete AR-glass fibre dosage from 0.5% to 1.5% consistently improved strength, in some test types (split tensile, beam flexural) by a larger margin than the corresponding steel fibre gain, because a randomly dispersed short fibre has no continuous sheet to obstruct paste flow during casting. Taken together, the two companion studies indicate that AR-glass reinforcement's dosage sensitivity is a function of reinforcement geometry (continuous mesh versus discrete fibre) rather than an intrinsic property of the glass material itself — a distinction directly relevant to the present paper, since the hybrid series tested here (H1–H3, S1–S6) combine both geometries of AR-glass reinforcement (mesh and fibre) simultaneously.

The fibre comparison study also found that steel fibre matched or outperformed AR-glass fibre in every test combination except cube compressive strength at M30, 0.5% dosage (statistically indistinguishable), with the gap most pronounced in beam and panel flexural strength (17–50%). Its best-performing single-reinforcement series, SF4 (M40 grade, 1.5% steel fibre, no mesh), recorded 49.78 MPa cube compressive strength, 5.35 MPa split tensile strength, and 4.95 MPa beam flexural strength — using three times the fibre dosage (1.5%) of any series in the present paper. By comparison, the present paper's best hybrid series, S6 (M40 super series, 0.5% dosage of each of four reinforcement types), recorded a higher cube compressive strength (55.80 MPa) and a higher flexural strength (6.05 MPa) than SF4, despite each individual reinforcement component being present at only one-third of SF4's fibre dosage. This suggests that combining multiple reinforcement types at modest individual dosages, as done in the present hybrid series, can outperform tripling the dosage of a single discrete fibre type — consistent with the multi-scale crack-control rationale for hybridisation discussed in Sections 4.1–4.3, though a direct comparison at matched total reinforcement content would be needed to confirm this is a hybridisation effect rather than simply a reinforcement-quantity effect.

The fibre comparison study additionally reported a qualitative failure-mode difference during beam flexural testing: steel fibre beams remained in one piece after cracking, bridged by the fibres, while AR-glass fibre beams separated completely into two pieces. No equivalent failure-mode observation was recorded for the hybrid series in the present study; given that several hybrid series here also contain steel reinforcement (mesh and/or crimped fibre), a similar post-cracking bridging behaviour would be expected but should be confirmed by direct observation in future testing (Section 7), rather than assumed by analogy with the companion fibre study.

4.8 Position Relative to Ferrocement — Similarities and Differences

The mesh-only series in this study (S2, S5 — steel welded mesh + AR glass mesh, no discrete fibre) share a superficial resemblance to ferrocement, a composite defined by ACI Committee 549 as reinforced concrete/mortar containing closely spaced, multiple layers of small-diameter mesh completely embedded in a cementitious matrix, typically formed into thin sections a few centimetres thick or less (ACI Committee 549 2018). Like ferrocement, S2 and S5 combine more than one mesh layer type within a fine-grained matrix with the aim of achieving crack control and tensile capacity without conventional discrete rebar, and the AR-glass mesh component offers the same non-corroding advantage that motivates ferrocement's use of coated or non-metallic mesh in some applications.

The resemblance, however, is only partial, and the difference is instructive for interpreting why S2 and S5 were the two weakest series in the entire dataset. Ferrocement's characteristic strength and toughness gains are attributed specifically to a high specific surface of reinforcement — many closely spaced mesh layers distributed through a thin section, typically only 10–25 mm thick with minimal cover over the outermost layer (ACI Committee 549 2018; Naaman 2000) — which places a large fraction of the reinforcement close to the extreme tension fibre and gives the composite flexural and crack-control performance well beyond what the same steel content would achieve as conventional discrete reinforcement. The mesh-only series in this study, by contrast, are standard 150 mm cube, cylinder, and beam specimens with two mesh types positioned once each rather than repeated in multiple closely spaced layers, and with far greater cover and section depth relative to the reinforcement than a true ferrocement panel. The specific surface of reinforcement achieved here is therefore far below what ferrocement literature identifies as the source of its characteristic performance, and S2/S5's comparatively weak results are consistent with that mismatch rather than a failure of mesh reinforcement as a concept: the companion mesh comparison study (Shet et al., mesh comparison paper), which did test genuine thin panel geometries with multiple mesh layers, found steel mesh achieving its largest relative gains specifically in the thin-panel specimens rather than in bulk cubes, beams, or cylinders — the geometry in which ferrocement-type behaviour is expected to be most pronounced. This suggests that the present study's mesh-only series should be read as a bulk-specimen lower bound on mesh performance, not as representative of what the same mesh types could achieve in a thin-panel, ferrocement-style configuration, and that extending the hybrid mesh–fibre combinations tested here to thin panel geometries (Section 7) would be needed to properly evaluate the ferrocement-adjacent potential of the mesh components used.

5. Practical Applications and Real-World Relevance

The hybrid mesh–fibre reinforcement strategies examined in this study are relevant to applications where thin sections, corrosion exposure, or retrofit constraints limit the use of conventional rebar — for example, precast façade panels, thin structural overlays, repair jacketing of existing members, and lightweight cladding elements. The non-corroding nature of AR glass mesh and AR glass fibre makes the H1–H3 and S1/S3/S4/S6 configurations particularly relevant where reduced concrete cover or exposure to moisture and chlorides would otherwise threaten steel reinforcement durability, while the steel-inclusive configurations offer higher absolute strength where corrosion exposure is less of a concern.

6. Limitations

- Only one dosage level (0.5% Vf per reinforcement type) was tested for each reinforcement, so the sensitivity of the observed trends to dosage remains unexplored.
- Reported strengths are averages of three specimens per series; no standard deviation or coefficient of variation is reported here, which limits statistical confidence in small differences between closely performing series (e.g. S4 vs S6).
- The anomalous S3 cylinder compressive result (Section 4.6) should be resolved before the dataset is treated as final.
- No bond-slip, pull-out, or microstructural (SEM) characterisation was performed, so the crack-bridging mechanism proposed in Section 4 is inferred from strength trends and literature precedent rather than directly observed.

7. Future Work

- Repeat the S3/S1 comparison and re-verify the S3 cylinder result against raw laboratory records, ideally with additional trial specimens.
- Extend the dosage range (e.g. 0.25%, 0.5%, 0.75% Vf) for the best-performing fibre pairing to identify whether the S4/S6 performance plateau can be pushed further, informed by the positive discrete-fibre dosage response reported in the companion fibre comparison study (Shet et al., fibre comparison paper).
- Include pull-out and pull-out/bond-slip testing of the mesh–matrix and fibre–matrix interfaces to directly verify the crack-bridging mechanism proposed in Section 4.

- Extend testing to thin panel geometries, where reinforcement-to-thickness ratio is higher and mesh/fibre effects are typically more pronounced than in bulk cube/cylinder/beam specimens.

8. Conclusions

- Hybrid configurations combining discrete fibre reinforcement (AR glass fibre and/or steel crimped fibre) with mesh reinforcement outperformed mesh-only configurations across all four mechanical properties tested.
- The four-component super series (steel mesh + AR glass mesh + AR glass fibre + steel crimped fibre) delivered the best or joint-best performance at both M30 and M40 grades, indicating a synergistic rather than redundant effect of combining mesh and fibre reinforcement.
- Discrete fibre content appears to govern flexural and split tensile capacity, while mesh reinforcement contributes an additional, grade-dependent increment, supporting the use of combined mesh–fibre systems over single-reinforcement-type designs.
- M40 grade concrete amplified the benefit of hybrid reinforcement relative to M30, suggesting hybrid TRC/FRC systems are most effective when paired with a higher-strength base matrix.
- The S3 cylinder compressive result should be re-verified against raw test records prior to publication.

References

ACI Committee 549. (2018). Report on Ferrocement (ACI 549R-18). American Concrete Institute, Farmington Hills, MI.

Naaman, A.E. (2000). Ferrocement and Laminated Cementitious Composites. Techno Press 3000, Ann Arbor, MI.

Shet, M., Sayyed, A., Ranshur, S., Patil, S. Mechanical Performance of Textile Reinforced Concretes using Steel Welded Mesh and AR Glass Mesh Reinforcements: Comparative Study in M30 and M40 Grades. Department of Civil Engineering, SVKM's Shri Bhagubhai Mafatlal Polytechnic & College of Engineering, Mumbai.

Shet, M., Sayyed, A., Ranshur, S., Patil, S. Mechanical Performance of Concrete Reinforced with Discrete Steel and AR-Glass Fibres: A Comparative Study at 0.5% and 1.5% Dosage in M30 and M40 Grades. Department of Civil Engineering, SVKM's Shri Bhagubhai Mafatlal Polytechnic & College of Engineering, Mumbai.

Barhum, R., Mechtcherine, V. (2012). Effect of short, dispersed glass and carbon fibres on the behaviour of textile-reinforced concrete under tensile loading. Engineering Fracture Mechanics, 92, 56–71.

Barhum, R., Mechtcherine, V. (2013). Influence of short dispersed and short integral glass fibres on the mechanical behaviour of textile-reinforced concrete. Materials and Structures, 46, 557–572.

Dabhade, P., Ambadkar, S. (2026). Reinforcing resilience: a review of hybrid fibre effects on concrete's mechanical and impact characteristics. Journal of Building Pathology and Rehabilitation, 11, Article 90.

Das, S., Sobuz, M.H.R., Tam, V.W.Y., Akid, A.S.M., Sutan, N.M., Rahman, F.M. (2020). Effects of incorporating hybrid fibres on rheological and mechanical properties of fibre reinforced concrete. Construction and Building Materials, 262, 120561.

Vairagade, V.S., Dhale, S.A. (2023). Hybrid fibre reinforced concrete – a state of the art review. Hybrid Advances, 3, 100035.

Wu, J., Zhang, W., Han, J., Liu, Z., Liu, J., Huang, Y. (2024). Experimental Study on the Flexural Performance of Steel–Polyvinyl Alcohol Hybrid Fiber-Reinforced Concrete. Materials, 17(13), 3099.

Bureau of Indian Standards. IS 516 (Part 1/Sec 1):2021: Methods of Tests for Strength of Concrete – Part 1: Testing of Hardened Concrete, Section 1: Compressive, Flexural and Split Tensile Strength.

Bureau of Indian Standards. IS 10262:2019: Concrete Mix Proportioning – Guidelines.

Bureau of Indian Standards. IS 456:2000: Plain and Reinforced Concrete – Code of Practice.

Bureau of Indian Standards. IS 383:2016: Coarse and Fine Aggregate for Concrete – Specification.

Bureau of Indian Standards. IS 12269:2013: 53 Grade Ordinary Portland Cement – Specification.