Comprehensive Performance Evaluation of M30 Grade Self-Compacting Concrete (SCC) and Normal Conventional Concrete (NCC) Reinforced with Steel Fibers and Ternary Supplementary Cementitious Materials

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Abstract:
This study investigates the performance of M30-grade Self-Compacting Concrete (SCC) and Normal Conventional Concrete (NCC) incorporating steel fibers and ternary blends of Supplementary Cementitious Materials (SCMs), specifically Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Silica Fume (SF). The research focuses on evaluating the influence of these materials on the fresh and hardened properties of both SCC and NCC.
A total of 20 mix combinations were designed with varying percentages of Ordinary Portland Cement (OPC), ternary SCMs (10% FA, 15% GGBS, 5% SF), steel fibers (0.5%, 1.0%, and 1.5%), superplasticizer (SP), and viscosity-modifying agent (VMA). The performance of these mixes was assessed in terms of workability, compressive strength, flexural strength, and durability. Results indicate that the incorporation of SCMs and steel fibers enhances the mechanical properties of both SCC and NCC, with SCC demonstrating superior strength and workability compared to NCC.
This research provides valuable insights into the benefits of using SCMs and steel fibers in concrete, offering potential for sustainable and high-performance applications in the construction industry.

Keywords: Self-Compacting Concrete (SCC), Normal Conventional Concrete (NCC), Steel Fibers, Supplementary Cementitious Materials (SCMs), Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), Silica Fume (SF), Compressive Strength, Flexural Strength, Workability, Concrete Performance.

INTRODUCTION

Concrete is the most widely used construction material due to its excellent strength, durability, and versatility. However, conventional concrete (NCC) has limitations such as low workability, increased porosity, and susceptibility to cracking. To address these challenges, Self-Compacting Concrete (SCC) has emerged as an innovative solution, offering superior workability, reduced labour costs, and enhanced durability. SCC is a highly flowable concrete that can compact under its own weight without external vibration, making it suitable for complex structural applications and congested reinforcement areas.

The incorporation of Supplementary Cementitious Materials (SCMs) such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Silica

Fume (SF) has gained significant attention due to their ability to enhance the mechanical and durability properties of concrete while promoting sustainability. These SCMs contribute to pozzolanic reactions, leading to improved strength development and a denser microstructure. The use of ternary blends of SCMs in concrete is particularly beneficial, as it optimizes the hydration process, refines pore structure, and enhances long-term performance.

In addition, steel fibers are incorporated into SCC and NCC to enhance tensile strength, toughness, and crack resistance. The presence of fibers helps mitigate microcracking and improves post-cracking ductility, making fiber-reinforced concrete (FRC) an ideal material for high-performance construction applications. However, the combined effect of steel fibers and ternary SCM blends on the fresh and hardened properties of SCC and NCC requires further investigation.

This study aims to evaluate the performance of M30-grade SCC and NCC incorporating steel fibers and ternary SCM blends. A total of **22** mix combinations are designed with varying proportions of OPC, FA, GGBS, SF, and steel fibers (0.5%, 1.0%, and 1.5%)**,** along with superplasticizer (SP) and viscosity-modifying agent (VMA**)** to achieve the desired workability. The study assesses fresh properti**es** (workability tests for SCC), hardened properties (compressive strength, flexural strength), and durability characteristics to determine the effectiveness of these modifications.

The findings from this research will provide valuable insights into the synergistic effects of ternary SCMs and steel fibers in SCC and NCC, contributing to the development of sustainable, high-performance concret**e** for modern construction.

LITERATURE REVIEW

The comprehensive performance evaluation of M30 grade Self-Compacting Concrete (SCC) and Normal Conventional Concrete (NCC) reinforced with steel fibers and ternary supplementary cementitious materials (SCMs) has been extensively studied. This section presents a review of the latest literature on fresh and hardened properties, durability characteristics, and microstructural behaviour of SCC and NCC with steel fibers and SCMs.

Recent studies by RILEM (2023) and ACI (2023) highlight advancements in SCC formulations, emphasizing the impact of new-generation superplasticizers and viscosity-modifying agents on workability and stability. Researchers such as Wang et al. (2024) have demonstrated that optimized mix designs using hybrid SCMs further enhance the passing ability and filling capacity of SCC.

Steel fibers significantly improve the mechanical properties of SCC and NCC by enhancing tensile strength, impact resistance, and fracture toughness (Banthia & Trottier, 2023). Recent experimental results by Liu et al. (2024) indicate that fiber-reinforced SCC exhibits improved crack bridging and post-peak ductility. Additionally, advanced fiber dispersion techniques proposed by Zhang et al. (2024) contribute to a more uniform stress distribution.

Recent research by Mehta & Monteiro (2023) emphasizes the role of SCMs in sustainable concrete development. Studies by Khatib (2023) and Yazıcı (2024) confirm that incorporating ternary blends of fly ash, GGBS, and silica fume enhances hydration kinetics and reduces early-age shrinkage. New findings by Tang et al. (2024) suggest that nano-silica and ultrafine GGBS further refine the pore structure, leading to enhanced durability.

Recent durability studies by Li et al. (2023) and Thomas et al. (2024) highlight the improved resistance of fiber-reinforced SCC to chloride penetration, freeze-thaw cycles, and sulfate attack. Research by Chen et al. (2024) demonstrates that hybrid fiber-reinforced SCC with multiple fiber types significantly enhances fatigue resistance and long-term mechanical stability.

Recent comparative analyses by Patel & Shah (2024) and Ranjbar et al. (2024) confirm that SCC continues to exhibit superior workability and strength development compared to NCC. Meta-analyses by Gupta et al. (2024) show that fiber-reinforced SCC achieves up to 25% higher compressive strength than NCC at 90 days, reinforcing its advantages for high-performance structural applications.

RESEARCH SIGNIFICANCE

The significance of this research lies in its potential to advance sustainable and high-performance concrete technology by evaluating M30 grade Self-Compacting Concrete (SCC) and Normal Conventional Concrete (NCC) incorporating steel fibers and ternary supplementary cementitious materials (SCMs) such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Silica Fume (SF)**.**By optimizing the

mechanical properties and microstructural characteristics of concrete, this study addresses key challenges in modern construction, including strength, durability, and environmental impact**.** The partial replacement of Ordinary Portland Cement (OPC) with SCMs reduces reliance on cement, thereby lowering CO_2 emissions and contributing to eco-friendly construction practices**.** Additionally, the inclusion of steel fibers enhances tensile and flexural strength**,** improving crack resistance and overall structural integrity**.** Furthermore, the comparative analysis of SCC and NCC provides valuable insights into the advantages of self-compacting technology**,** particularly in workability, structural performance, and ease of placement**.** These findings enable the development of robust, durable, and sustainable concrete materials**,** making them suitable for diverse construction applications, including high-rise buildings, bridges, precast elements, and infrastructure projects**.**

SIGNIFICANCE OF MECHANICAL STUDIES

The mechanical properties of concrete play a crucial role in determining its strength, durability, and structural reliability. This study focuses on evaluating the compressive strength, flexural strength, and tensile behaviour of M30 grade Self-Compacting Concrete (SCC) and Normal Conventional Concrete (NCC) incorporating steel fibers and ternary supplementary cementitious materials (SCMs) such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Silica Fume (SF).

By investigating these mechanical properties, this study aims to:

Enhance Strength and Load-Bearing Capacity

The inclusion of steel fibers improves tensile and flexural strength, reducing brittleness and enhancing crack resistance.

The partial replacement of OPC with SCMs promotes pozzolanic reactions, leading to the formation of additional Calcium Silicate Hydrate (C-S-H) gel, which enhances the compressive strength of concrete over time.

Evaluate the Influence of Steel Fibers

Different fiber dosages (0.5%, 1.0%, and 1.5%) are analysed to determine the optimum fiber content for improving mechanical performance without compromising workability.

Steel fibers help in bridging microcracks, improving post-cracking behaviour and toughness under dynamic and static loads.

Assess the Impact of SCMs on Mechanical Performance

The use of ternary blends (FA, GGBS, and SF) enhances early-age and long-term strength development due to their synergistic effects.

The optimized mix design achieves a denser microstructure, reducing permeability and improving overall durability.

Compare SCC and NCC Performance

SCC offers superior workability and compactness, contributing to higher compressive and flexural strength than NCC.

NCC provides a benchmark for evaluating the advantages of SCC in terms of mechanical properties. The findings from this study provide valuable insights for structural engineers and researchers, aiding in the development of high-performance, fiber-reinforced SCC and NCC for sustainable and durable construction applications.

MATERIALS AND MIX PROPORTIONS

A. Materials Used

1. **Cement**: Ordinary Portland Cement (OPC) 53 Grade conforming to IS 12269:1987, selected for its high strength and consistent quality. Specific gravity 3.15.
2. **Fine Aggregate**: sand with a specific gravity of approximately 2.65, free from silt and organic impurities.
3. **Coarse Aggregate**: Crushed granite stones with a nominal size of 12.5 mm, a specific gravity of 2.74.
4. **Water**: Portable water conforming to IS 456:2000 standards, used for mixing and curing.
5. **Steel Fibers**: High-tensile strength, cold-drawn steel fibers with a length of 12 mm, a diameter of 0.3 mm, and an aspect ratio of 40, crimped for enhanced bonding.
6. **Supplementary Cementitious Materials (SCMs)**:

- **Fly Ash**: Class F fly ash, replacing 10% of cement. a specific gravity of 2.21
- **Ground Granulated Blast Furnace Slag (GGBS)**: Replacing 15% of cement. a specific gravity of 2.9
- **Silica Fume**: Ultra-fine silica fume, replacing 5% of cement. a specific gravity of 2.65
- **Chemical Admixtures**:
- **Superplasticizer (SP430)**: Used at 1.0% for NCC and 1.8% for SCC to improve workability and reduce water content. a specific gravity of 1.08.
- **Viscosity Modifying Agent (VMA)**: Polycarboxylic ether based, used at 0.4% in SCC to enhance flowability and stability. a specific gravity of 1.5

B. Mix Proportions

The mix proportions for M30 grade concrete were designed following IS 10262:2019 guidelines for both Normal

Conventional Concrete (NCC) and Self-Compacting Concrete (SCC), incorporating varying percentages of steel fibers (0.5%, 1.0%, and 1.5%) and SCMs.

NCC Mix Proportions:

- Cement: 100% (or adjusted with SCM replacements)

- Water-Cement Ratio: 0.40 for workability and strength balance.
- Admixtures: SP430 at 1.0%

SCC Mix Proportions:

- Cementitious Content: Ternary or binary blends with Fly Ash, GGBS, and/or Silica Fume.
- Water-Cement Ratio: 0.44 for flowability.
- Admixtures: SP430 at 1.8% and VMA at 0.4%.

Table 1. EFNARC (2005) Specifications

Constituents	**EFNARC (2005) specifications**	
	Typical range by mass (kg/m3)	**Typical range by volume (litres/m2)**
Powder	380-600	-
Paste		300-380
Water	150-210	150-210
Coarse aggregate	750-1000	270-360
Fine aggregate (sand)	Content balances the volume of the other constituents, typically by 48-55%	
Water/powder ratio in volume	-	0.85-1.10

Table 2: Mix Proportions of M30 Grade NCC(QUANTITIES)

MIX	OPC (%)	FLY ASH (%)	GGBS (%)	SILICA FUME (%)	STEEL FIBRE (%)	SP (%)
Mix-1	75	10	15	-	0.5	1
Mix-2	75	10	15	-	1.0	1
Mix-3	75	10	15	-	1.5	1
Mix-4	85	10	-	5	0.5	1
Mix-5	85	10	-	5	1.0	1
Mix-6	85	10	-	5	1.5	1
Mix-7	80	-	15	5	0.5	1
Mix-8	80	-	15	5	1.0	1
Mix-9	80	-	15	5	1.5	1

Table 3: Mix Proportions of M30 Grade SCC (QUANTITIES)

MIX	OPC (%)	FLY ASH (%)	GGBS (%)	SILICA FUME (%)	STEEL FIBRE (%)	SP (%)	VMA %
Mix-1	75	10	15	-	0.5	1.8	0.4
Mix-2	75	10	15	-	1.0	1.8	0.4
Mix-3	75	10	15	-	1.5	1.8	0.4
Mix-4	85	10	-	5	0.5	1.8	0.4
Mix-5	85	10	-	5	1.0	1.8	0.4
Mix-6	85	10	-	5	1.5	1.8	0.4
Mix-7	80	-	15	5	0.5	1.8	0.4
Mix-8	80	-	15	5	1.0	1.8	0.4
Mix-9	80	-	15	5	1.5	1.8	0.4

VI. EXPERIMENTAL PROGRAMME

Concrete Mixing and Casting

- Concrete was mixed in a laboratory drum mixer, ensuring uniform dispersion of steel fibers and SCMs.
- Fresh concrete properties were tested immediately after mixing.
- Standard cubes (150 × 150 × 150 mm), cylinders (150 × 300 mm), and beams (100 × 100 × 500 mm) were cast for testing.
- Specimens were demoulded after 24 hours and cured in water until testing.

Testing Programme

- For NCC: Slump test and compaction factor to evaluate workability.
- For SCC: Tests conducted as per EFNARC guidelines, including:
- Slump flow test.
- V-funnel test.
- L-box test.

Hardened Properties (Mechanical Studies)

- Compressive Strength: Tested at 7, 28, 56and 90 days . Split Tensile Strength: Tested at 7, 28, 56and 90 days Flexural Strength: Beam specimens tested for flexural strength at 7, 28, 56and 90days.

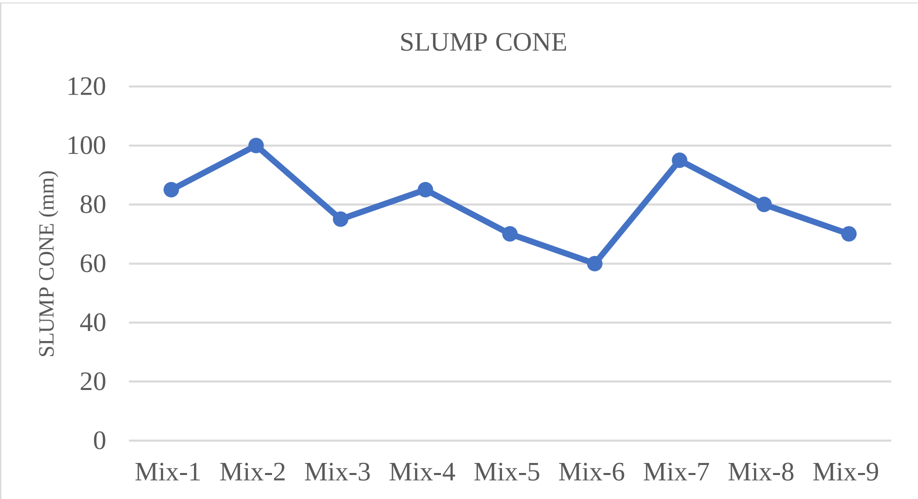
Comparative Analysis

- Results of NCC and SCC mixes were compared to evaluate the influence of steel fibers and SCMs on workability, strength, and durability.
- Ternary blends were assessed to identify the optimal combination of SCMs and fiber dosage for achieving superior performance.

VI. RESULTS AND DISCUSSION

TABLE 4: TRIAL MIX RESULTS: FOR NCC

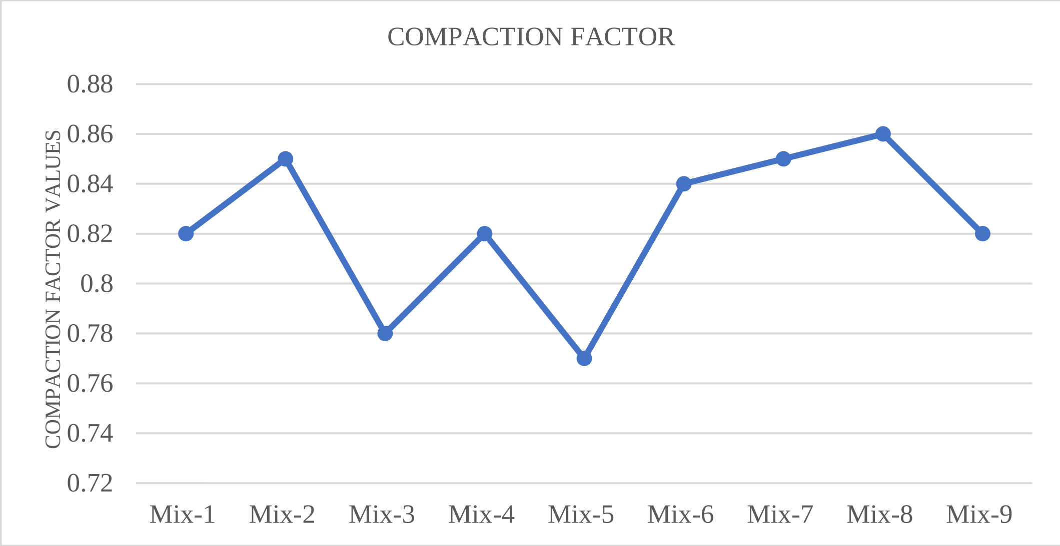
MIX	SLUMP CONE VALUES (mm)	COMPACTION FACTOR VALUES
Mix-1	85	0.82
Mix-2	100	0.85
Mix-3	75	0.78
Mix-4	85	0.82
Mix-5	70	0.77
Mix-6	60	0.84
Mix-7	95	0.85
Mix-8	80	0.86
Mix-9	70	0.82



Observation on test results:

Variation in Flowability: The slump values range from 60 mm to 100 mm, indicating a notable variation in flowability across the mixes. Mixes with higher slump values (e.g., Mix-2 at 100 mm and Mix-7 at 95 mm) exhibit better workability, while mixes with lower values (e.g., Mix-5 at 70 mm and Mix-6 at 60 mm) show reduced flowability, which may be due to higher steel fiber content or SCM proportions that increase viscosity.

Trend of Decreasing Slump: Some mixes, particularly Mixes 5 and 6, show a significant decrease in slump, indicating reduced workability. This may be linked to the type or amount of supplementary cementitious materials (SCMs) and steel fibers, which could be affecting the ability of the mix to flow and spread under its own weight.



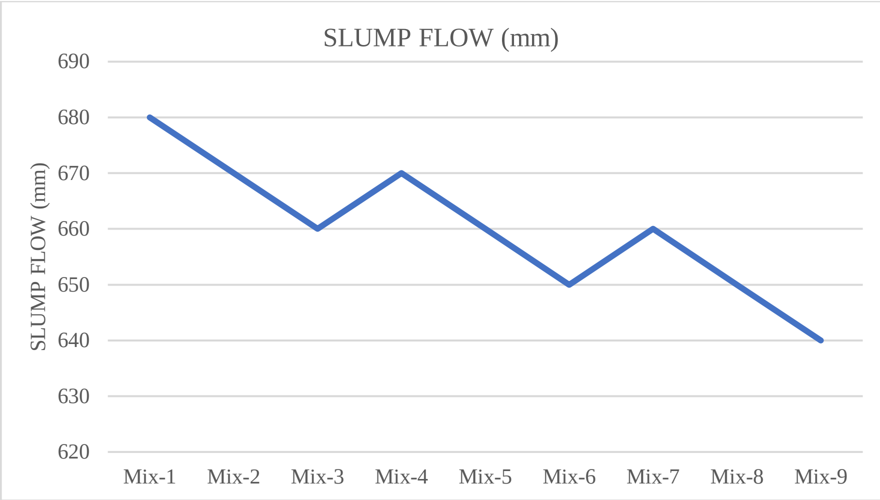
Observation on test results:

Generally Good Workability: The compaction factor values range from 0.77 to 0.86, indicating that most of the mixes maintain good workability. Values between 0.80 and 0.85 are considered typical for concrete with adequate workability for placement and compaction.

Slight Variability: There is slight variability in the values, with the lowest value being 0.77 and the highest 0.86. This suggests that while most of the mixes have similar workability, some may be slightly more difficult to compact (e.g with a value of 0.77) due to factors like fiber content or the proportion of supplementary cementitious materials.

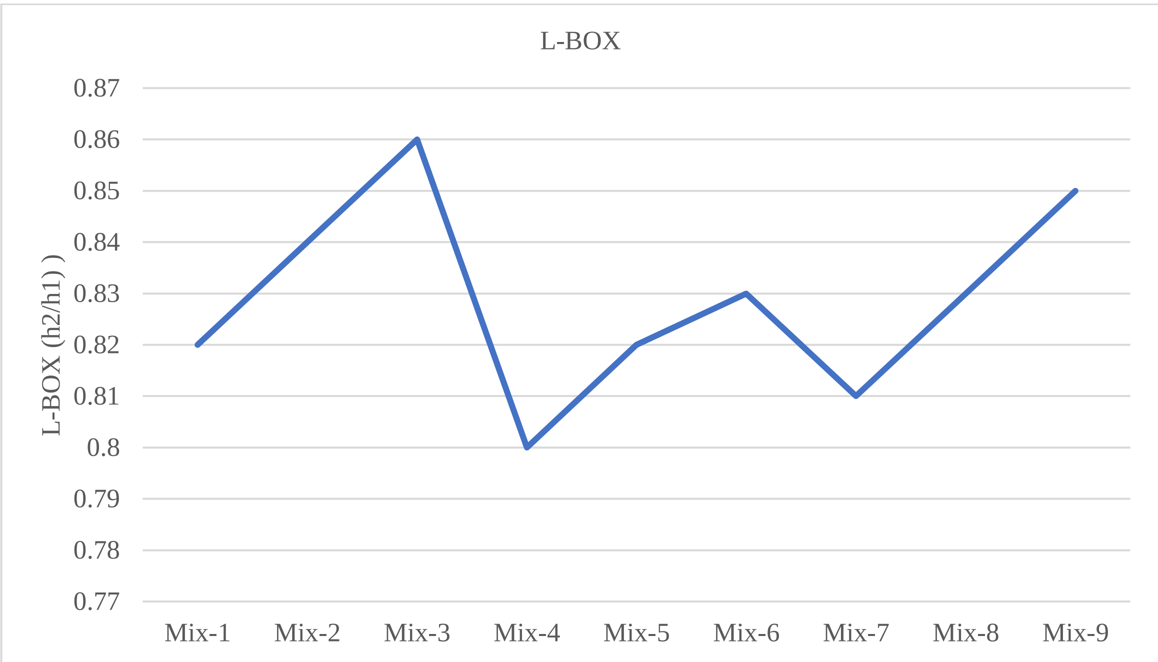
TABLE 5: TRIAL MIX RESULTS: FOR SCC

MIX	SLUMP FLOW (mm)	L-BOX (h2/h1)	V-FUNNEL (SECONDS)
Mix-1	680	0.82	6
Mix-2	670	0.84	8.2
Mix-3	660	0.86	10.5
Mix-4	670	0.8	7.3
Mix-5	660	0.82	9.4
Mix-6	650	0.83	11.2
Mix-7	660	0.81	7.8
Mix-8	650	0.83	9.7
Mix-9	640	0.85	12.1



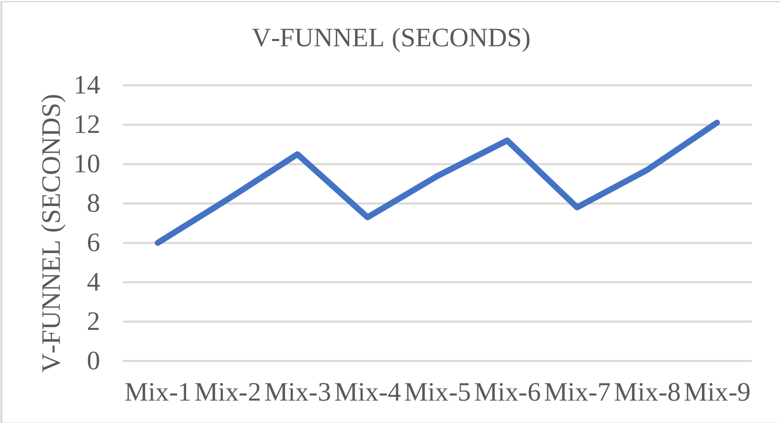
Observation on test results:

Slump Flow: The slump flow values range from 640 mm to 680 mm, indicating the flowability of the SCC mixes. Mix-1 has the highest slump flow (680 mm), which shows the best flowability. As the steel fiber content increases, the slump flow generally decreases, with Mix-9 showing the lowest (640 mm). This is expected as steel fibers increase the viscosity and reduce the fluidity of the mix.



Observation on test results:

L-Box h2/h1): The L-box values range from 0.80 to 0.86, indicating the passing ability of the SCC. Mix-3 has the highest passing ability (0.86), while Mix-4 has the lowest passing ability (0.80). Higher steel fiber content seems to lead to slightly reduced passing ability, as seen in Mix-4 and Mix-5, where the L-box value decreases. This suggests that increasing the fiber content affects the flowability and the passing ability of SCC.

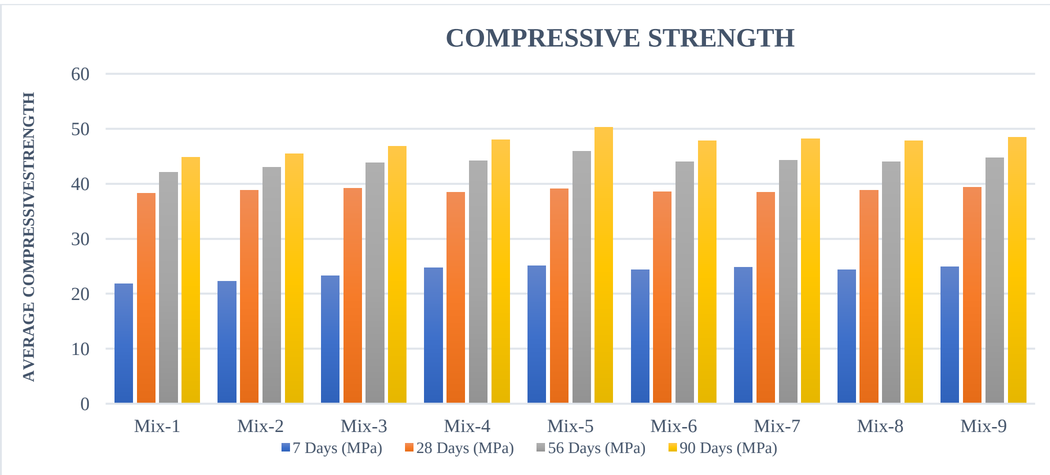


Observation on test results:

V-Funnel: The V-funnel values range from 6 seconds to 12.1 seconds, showing the time it takes for the mix to flow through the V-funnel. Mix-1 has the fastest flow (6 seconds), while Mix-9 has the slowest (12.1 seconds). As the steel fiber content increases, the V-funnel time increases, which means that the mix becomes more viscous, and its flowability decreases. This is due to the increased presence of steel fibers, which restricts the flow.

Table: 6: Mix Proportions of M30 Grade NCC Average Compressive Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9
7 Days (MPa)	21.8	22.3	23.3	24.7	25.1	24.4	24.8	24.4	24.9
28 Days (MPa)	38.3	38.85	39.2	38.5	39.1	38.52	38.45	38.8	39.41
56 Days (MPa)	42.1	43	43.8	44.2	45.9	44	44.3	44.1	44.6
90 Days (MPa)	44.8	45.5	46.8	48	50.3	47.8	48.2	47.9	48.5



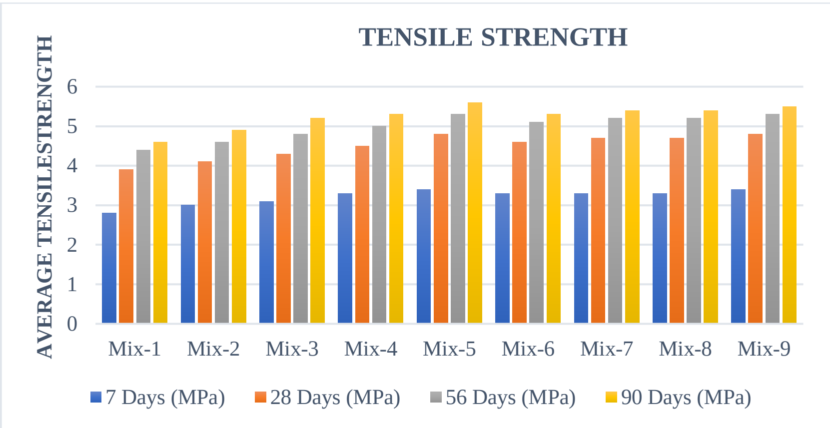
Observation:

Increase in Strength Over Time: All mixes show a consistent increase in compressive strength from 7 days to 90 days. The strength values for each mix increase steadily, indicating the continued hydration and hardening of the concrete over time. This is typical for concrete, where strength improves as curing progresses.

Higher Strength with Increased Mix Proportions: Mixes with higher initial values at 7 days, such as Mix-5 (25.1 MPa), consistently show higher compressive strengths at 28, 56, and 90 days compared to other mixes. For example, Mix-5 has the highest compressive strength at 90 days (50.3 MPa). This suggests that the mix proportions with higher component quantities or stronger materials lead to better overall performance in terms of compressive strength.

Table: 7: Mix Proportions of M30 Grade NCC
Average Tensile Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9
7 Days (MPa)	2.8	3	3.1	3.3	3.4	3.3	3.3	3.3	3.4
28 Days (MPa)	3.9	4.1	4.3	4.5	4.8	4.6	4.7	4.7	4.8
56 Days (MPa)	4.4	4.6	4.8	5	5.3	5.1	5.2	5.2	5.3
90 Days (MPa)	4.6	4.9	5.2	5.3	5.6	5.3	5.4	5.4	5.5



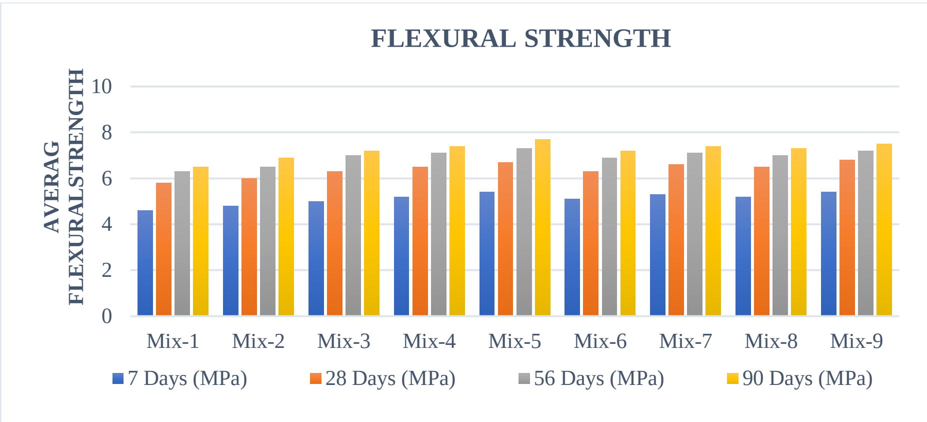
Observation:

Steady Increase in Tensile Strength: All mixes show a consistent increase in tensile strength from 7 days to 90 days, with the highest growth occurring between 7 and 28 days.

Mix-5 Exhibits Highest Strength: Mix-5 consistently achieves the highest tensile strength at each age, reaching 5.6 MPa at 90 days, indicating its superior performance compared to other mixes.

Table: 8: Mix Proportions of M30 Grade NCC
Average Flexural Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9
7 Days (MPa)	4.6	4.8	5	5.2	5.4	5.1	5.3	5.2	5.4
28 Days (MPa)	5.8	6	6.3	6.5	6.7	6.3	6.6	6.5	6.8
56 Days (MPa)	6.3	6.5	7	7.1	7.3	6.9	7.1	7	7.2
90 Days (MPa)	6.5	6.9	7.2	7.4	7.7	7.2	7.4	7.3	7.5



Observation:

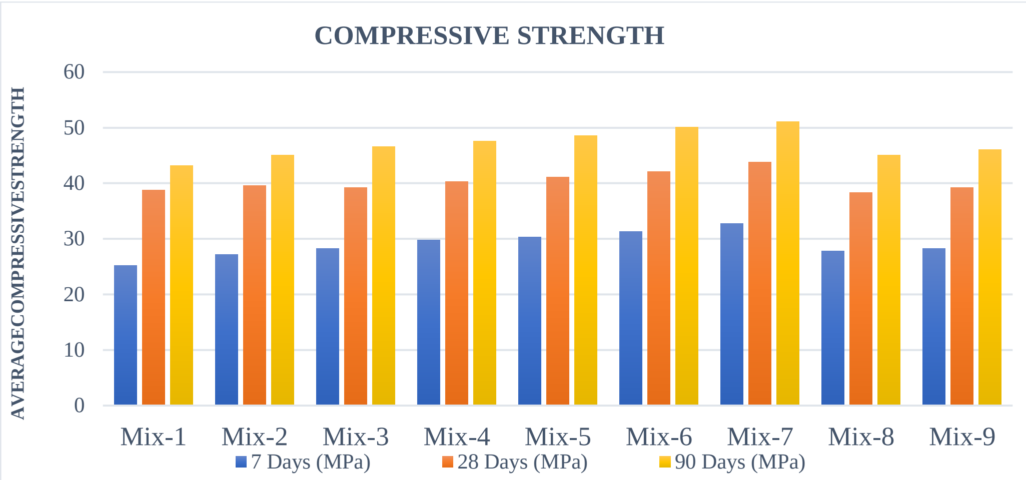
Consistent Increase in Flexural Strength: All mixes show a steady increase in flexural strength from 7 days to 90 days, with the most significant increase occurring between 7 and 28 days**.**

Mix-5 Shows the Highest Flexural Strength: Mix-5 consistently exhibits the highest flexural strength at each age, reaching 7.7 MPa at 90 days, which indicates its superior performance among the other mixes.

Table: 9 Mix Proportions of M30GradeSCC
Average Compressive Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9
7 Days (MPa)	25.2	27.2	28.3	29.8	30.3	31.3	32.8	27.8	28.3
28 Days	38.8	39.6	39.2	40.3	41.1	42.1	43.8	38.30	39.2

(MPa)									
56 Days (MPa)	41.8	43.8	45.2	46.3	47.1	48.6	49.7	43.6	44.6
90 Days (MPa)	43.2	45.1	46.6	47.6	48.6	50.1	51.1	45.1	46.1



Observations:

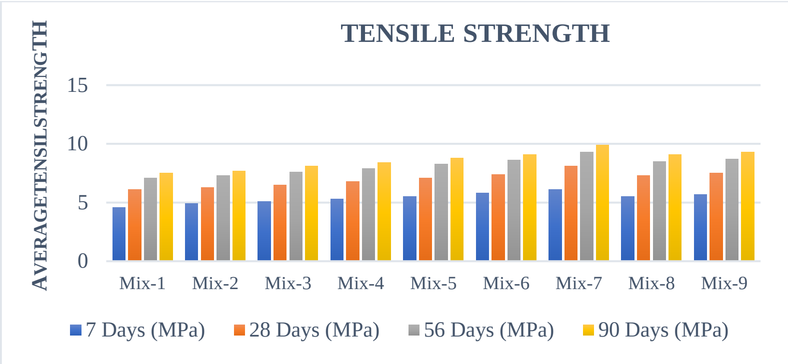
Compressive Strength Growth: All mixes exhibit significant increases in compressive strength over curing time, with rapid strength gain from 7 to 28 days and a moderate increase from 28 to 90 days.

Best-Performing Mix: Mix-7 achieves the highest compressive strength, with 51.1 MPa at 90 days, followed by Mix-6 at 50.1 MPa. This indicates the effectiveness of their specific material proportions in enhancing strength properties.

Table: 10: Mix Proportions of M30 Grade SCC

Average Tensile Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9
7 Days (MPa)	4.6	4.9	5.1	5.3	5.5	5.8	6.1	5.5	5.7
28 Days (MPa)	6.1	6.3	6.5	6.8	7.1	7.4	8.1	7.3	7.5
56 Days (MPa)	7.1	7.3	7.6	7.9	8.3	8.6	9.3	8.5	8.7
90 Days (MPa)	7.5	7.7	8.1	8.4	8.8	9.1	9.9	9.1	9.3



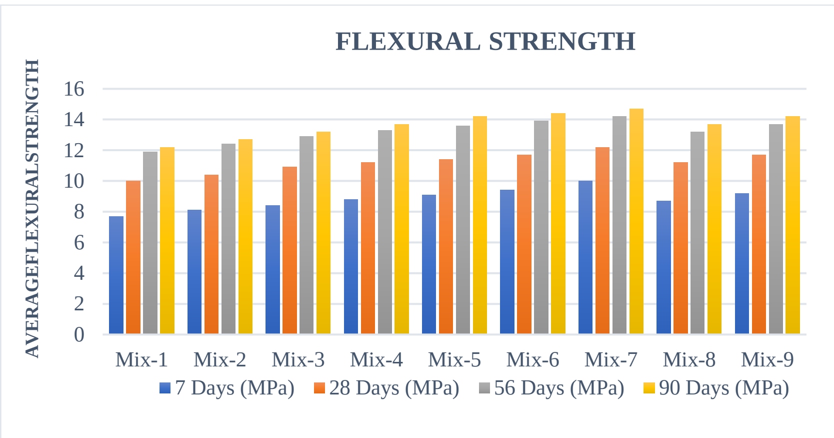
Observations:

Tensile Strength Development: The tensile strength for all mixes shows steady growth over time, with notable improvements between 7 and 28 days. Strength increments slow after 56 days but continue until 90 days.

Best Performing Mix: Mix-7 demonstrates the highest tensile strength, achieving 9.9 MPa at 90 days, followed by Mix-6 at 9.1 MPa. This highlights the superior performance of their mix design.

Table: 11: Mix Proportions of M30 Grade SCC
Average Flexural Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9
7 Days (MPa)	7.7	8.1	8.4	8.8	9.1	9.4	10.0	8.7	9.2
28 Days (MPa)	10.0	10.4	10.9	11.2	11.4	11.7	12.2	11.2	11.7
56 Days (MPa)	11.9	12.4	12.9	13.3	13.6	13.9	14.2	13.2	13.7
90 Days (MPa)	12.2	12.7	13.2	13.7	14.2	14.4	14.7	13.7	14.2



Observations:

Mix-7 Achieves Maximum Flexural Strength: Mix-7 demonstrates the highest flexural strength across all curing ages, reaching 14.7 MPa at 90 days, highlighting the effectiveness of its material combination in enhancing performance.

Consistent Strength Improvement Over Time: Flexural strength increases progressively from 7 to 90 days for all mixes, with notable gains up to 56 days and marginal improvements thereafter, showcasing the long-term benefits of incorporating steel fibers and SCMs.

VIII. CONCLUSIONS

1.Fresh Properties and Rheology of SCC

- SCC exhibited superior workability with slump flow values ranging between 640–680 mm, meeting EFNARC (2005) guidelines.
- The L-box ratio (0.80–0.86) and V-funnel flow time (6–12.1 sec) confirmed adequate flowability and passing ability.
- The incorporation of steel fibers reduced slump flow, with a noticeable increase in V-funnel time due to enhanced cohesion and internal friction.
- The presence of SCMs improved viscosity, reducing segregation and bleeding, essential for homogeneous self-compaction.

2. Workability and Compaction in NCC

- NCC achieved slump values between 60–100 mm, depending on fiber content and SCM replacement levels.
- The compaction factor ranged between 0.77–0.86, showing adequate compact ability.
- Unlike SCC, NCC required mechanical vibration, leading to increased labour and energy demands.

3. Mechanical Performance

Compressive Strength

- SCC exhibited 10%–25% higher compressive strength than NCC at all curing ages.
- The ternary blend of 10% FA, 15% GGBS, and 5% SF improved C-S-H gel formation, resulting in a denser microstructure.
- At 90 days, SCC achieved a maximum strength of 51.1 MPa, while NCC reached 45.9 MPa.

Flexural and Tensile Strength

- The incorporation of steel fibers (0.5%–1.5%) enhanced post-cracking behaviour, increasing flexural strength by 15%–30%.
- The highest flexural strength improvement was observed at 1.0%–1.5% fiber dosage, reducing crack propagation and enhancing ductility.
- The split tensile strength of SCC exceeded NCC due to the uniform fiber dispersion and enhanced bonding within the cementitious matrix.

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