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"Performance Evaluation of M30 Grade Self-Compacting Concrete (SCC) and Normal Conventional Concrete (NCC) Incorporating Steel Fibers and Binary 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 binary Supplementary Cementitious Materials (SCMs), specifically Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Silica Fume (SF). The study 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 are designed with varying percentages of OPC, binary SCMs (10% FA, 15% GGBS, 5% SF), steel fibers (0.5%, 1.0%, and 1.5%), superplasticizer (SP), and VMA. The performance of these mixes is 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 higher strength and improved 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 concrete applications in construction.

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.

I. INTRODUCTION

Concrete is one of the most widely used construction materials in the world, due to its versatility, durability, and relatively low cost. However, traditional concrete is often limited by issues such as low tensile strength and susceptibility to cracking. Over the years, advancements in concrete technology have led to the development of various methods to enhance its performance. Among these innovations, the incorporation of Supplementary Cementitious Materials (SCMs) and steel fibers has shown great promise in improving the mechanical properties and durability of concrete.

Self-Compacting Concrete (SCC), a relatively recent innovation, is a highly flowable and cohesive form of concrete in the design of high-performance concrete for structural and durable applications.

This study aims to evaluate the performance of M30 grade SCC and Normal Conventional Concrete (NCC) incorporating steel fibers and binary blends of SCMs (FA, GGBS, and SF). The objective is to compare the fresh and hardened properties of these concrete mixes, including workability, compressive strength, flexural strength, and durability, with an emphasis on the potential for sustainable, high-performance concrete applications.

By examining the effects of these materials, this research seeks to provide insights into how the use of SCMs and steel fibers can improve the mechanical properties and sustainability of concrete, contributing to the development of more durable, efficient, and environmentally friendly construction materials.

that can spread and fill moulds under its own weight without requiring external vibration. The high workability of SCC makes it ideal for applications where intricate moulds or high reinforcement density are involved, reducing labour costs and construction time. In addition to its workability, SCC has the potential to achieve superior mechanical properties, particularly when combined with SCMs such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Silica Fume (SF), which are known for enhancing durability and sustainability by reducing the carbon footprint of concrete production.

Steel fibers, when incorporated into concrete, contribute to its tensile strength, toughness, and post-crack behaviour, making concrete more resistant to cracking and improving its overall durability. The combined use of SCMs and steel fibers in concrete could offer a synergistic effect, enhancing both fresh and hardened properties, which is of particular interest.

III. 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 binary supplementary cementitious materials (SCMs) such as Fly Ash, GGBS, and Silica Fume. By optimizing the mechanical properties and microstructure of concrete, this study addresses key challenges in modern construction, including strength, durability, and environmental impact. The use of SCMs reduces reliance on Portland cement, thereby lowering CO_2 emissions, while the inclusion of steel fibers enhances tensile and flexural strength. Additionally, the comparative analysis of SCC and NCC provides valuable insights into the advantages of self-compacting technology for practical applications, enabling the development of robust, durable, and eco-friendly materials suitable for diverse construction needs.

IV. SIGNIFICANCE OF MECHANICAL STUDIES

The significance of mechanical studies and workability in M30 grade concrete lies in their critical impact on both structural performance and practical application. Mechanical studies, including compressive, tensile, and flexural strength assessments, provide essential insights into the material's ability to withstand various loads and stresses, ensuring safety and durability in structures. For M30 grade concrete, which is widely used in medium to heavy structural applications, these properties are crucial for meeting the demands of modern construction. Workability, on the other hand, determines the ease of handling, placing, and compacting the concrete, particularly in complex formworks or densely reinforced sections. Achieving optimal workability without compromising mechanical strength is especially significant for M30 grade mixes that incorporate steel fibers and supplementary cementitious materials (SCMs), as these additions can influence the flow and cohesion of the mix. This dual focus on mechanical performance and workability ensures the development of a high-strength, durable, and practical concrete solution that aligns with the needs of sustainable and efficient construction practices.

The main aim of this study is to investigate the mechanical properties for all 20 mixes by conducting various mechanical tests.

V. 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 acid-based, used at 0.8% 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 0.8%.

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 M30 Grade NCC of GROUP-I) QUANTITIES

MIX	OPC Kg/m³	FLY ASH Kg/m³	GGBS Kg/m³	SILICA FUME Kg/m³	C.A Kg/m³	F.A Kg/m³	WATER Kg/m³	STEEL FIBRE Kg/m³	SP Kg/m³
Mix-1	350	-	-	-	1144.66	869.83	140	-	3.5
Mix-2	315	35	-	-	1136.99	864.0	140	39.25	3.5
Mix-3	315	35	-	-	1136.99	864.0	140	78.50	3.5

Mix-4	315	35	-	-	1136.99	864.0	140	117.75	3.5
Mix-5	297.5	-	52.5	-	1142.66	868.32	140	39.25	3.5
Mix-6	297.5	-	52.5	-	1142.66	868.32	140	78.50	3.5
Mix-7	297.5	-	52.5	-	1142.66	868.32	140	117.75	3.5
Mix-8	332.5	-	-	17.5	1140.67	866.80	140	39.25	3.5
Mix-9	332.5	-	-	17.5	1140.67	866.80	140	78.50	3.5
Mix-10	332.5	-	-	17.5	1140.67	866.80	140	117.75	3.5

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

MIX	OPC Kg/m^3	FLY ASH Kg/m^3	GGBS Kg/m^3	SILICA FUME Kg/m^3	C.A Kg/m^3	F.A Kg/m^3	WATER Kg/m^3	STEEL FIBRE Kg/m^3	SP Kg/m^3	VMA Kg/m^3
Mix-1	432	-	-	--	739.27	1100	190	-	7.776	3.456
Mix-2	388.8	43.2	-	-	643.9	1100	190	39.25	7.776	3.456
Mix-3	388.8	43.2	-	-	643.9	1100	190	78.50	7.776	3.456
Mix-4	388.8	43.2	-	-	643.9	1100	190	117.75	7.776	3.456
Mix-5	367.2	-	64.8	-	654.86	1100	190	39.25	7.776	3.456
Mix-6	367.2	-	64.8	-	654.86	1100	190	78.50	7.776	3.456
Mix-7	367.2	-	64.8	-	654.86	1100	190	117.75	7.776	3.456
Mix-8	410.4	--	21.6	-	652.12	1100	190	39.25	7.776	3.456
Mix-9	410.4	-	21.6	-	652.12	1100	190	78.50	7.776	3.456
Mix-10	410.4	-	21.6	-	652.12	1100	190	117.75	7.776	3.456

VI. EXPERIMENTAL PROGRAMME

1.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.

2. Testing Programme

Fresh Properties (Workability)

- 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.

3. 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 90

4. Comparative Analysis

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

RESULTS AND DISCUSSION

TABLE 4: TRIAL MIX RESULTS: FOR NCC (GROUP-I)

MIX	SLUMP CONE VALUES (mm)	COMPACTION FACTOR VALUES
Mix-1	100	0.88
Mix-2	110	0.87
Mix-3	95	0.85
Mix-4	85	0.82
Mix-5	90	0.85
Mix-6	85	0.82
Mix-7	75	0.78
Mix-8	85	0.81
Mix-9	80	0.78
Mix-10	75	0.76

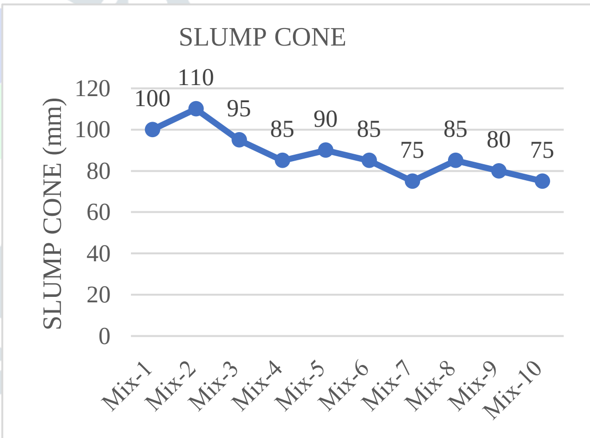

Fig:1 Slump Cone

Observation on test results:

- **Consistent Workability with Slight Variation:** The slump cone values range from 75 mm to 110 mm, indicating that the workability of the mixes varies moderately. Mixes with higher slump values (e.g., Mix-2 at 110 mm) show better flowability, while mixes with lower values (e.g., Mix-7 and Mix-10 at 75 mm) are less workable, likely due to a higher steel fiber content or the combination of SCMs.
- **Influence of Steel Fibers and SCMs**: The slump values are relatively lower for mixes containing higher steel fiber content or certain SCMs (e.g., Mix-7 and Mix-10). This suggests that the incorporation of steel fibers or higher proportions of supplementary cementitious materials may reduce the flowability of the mix, which is expected as these materials tend to increase viscosity.

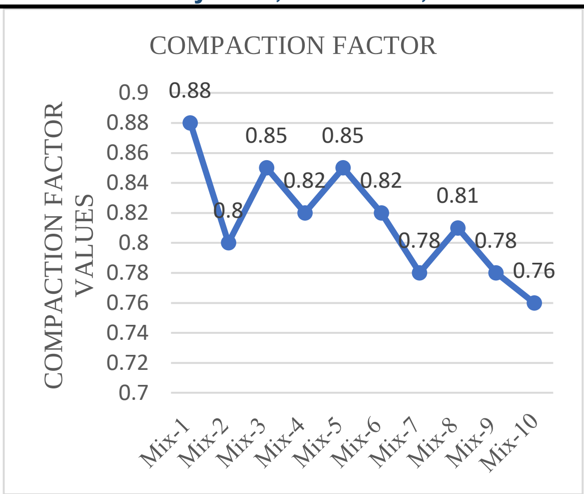

Fig: 2 Compaction Factor

Observation on test results:

- **Slight Variation in Workability:** The compaction factor values range from 0.76 to 0.88, indicating moderate variation in workability. The values are relatively close, suggesting that the mixes maintain a consistent level of workability, but there is a slight decline towards the lower end, potentially due to the impact of steel fibers and SCMs.
- **Good Workability for Most Mixes**: Values around 0.85 (e.g., 0.88, 0.87) indicate that most mixes have adequate workability, suitable for both conventional and self-compacting concrete applications. However, some mixes with lower values (e.g., 0.76) may require optimization to improve handling and compaction.

TABLE 5: TRIAL MIX RESULTS: FOR SCC (GROUP-I)

MIX	SLUMP FLOW (mm)	L-BOX (h2/h1)	V-FUNNEL (SECONDS)
Mix-1	680	0.88	9.5
Mix-2	660	0.83	11.5
Mix-3	630	0.78	14.2
Mix-4	590	0.72	16.8
Mix-5	660	0.84	10.2
Mix-6	640	0.81	12.5
Mix-7	610	0.75	14.8
Mix-8	670	0.85	11.4
Mix-9	640	0.80	13.6
Mix-10	670	0.85	14.0

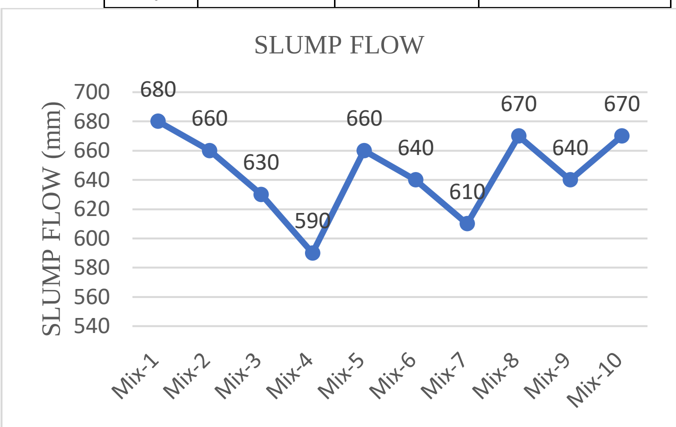

Fig: 3 Slump Flow

Observation on test results:

- **Slump Flow:** The values range from 590 mm (Mix-4) to 680 mm (Mix-1), indicating variations in flowability. Mixes with higher slump flow values (e.g., Mix-1, Mix-8, and Mix-10) exhibit better self-compacting properties, while lower values (e.g., Mix-4 at 590 mm) may indicate reduced workability.

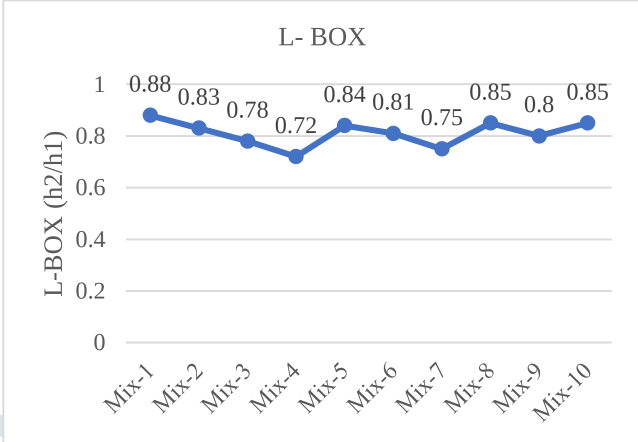

Fig: 4 L-BOX

Observation on test results:

- **L-Box Ratios (h2/h1)**: These range from 0.72 (Mix-4) to 0.88 (Mix-1), reflecting variability in the ability of mixes to pass through confined spaces without segregation. Mix-1, with the highest ratio of 0.88, demonstrates excellent passing ability, while Mix-4 at 0.72 shows a noticeable reduction in this property, which could be due to higher steel fiber content or insufficient optimization of admixtures.

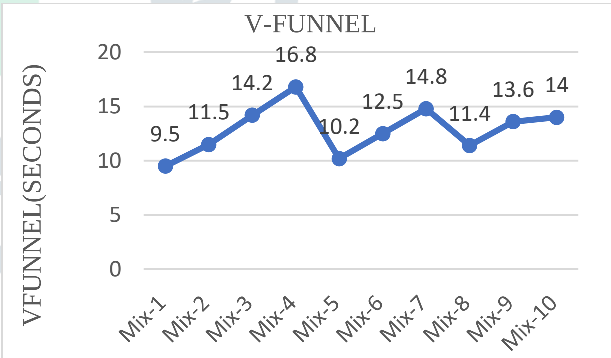

Fig: 5 V-Funnel

Observation on test results:

V-Funnel: The times range from 9.5 seconds (Mix-1) to 16.8 seconds (Mix-4), showing that Mix-4 has the least fluidity, likely due to higher fiber content or specific SCM proportions affecting viscosity.

4. Hardened Properties Testing:

The hardened properties were evaluated through the following tests:

Compressive Strength: Standard 150 mm cubes were cast and tested at 7, 28, 56 and 90 days of curing in accordance with IS: 516.

- **Flexural Strength**: Beam specimens (500 mm × 100 mm × 100 mm) were tested at 7, 28, 56 and 90 days of curing.

- **Split Tensile Strength**: Cylindrical specimens (150 mm × 300 mm) were tested at 7, 28,56 and 90 days of curing.

Table: 6: Mix Proportions M30 Grade NCC(GROUP-I) average compressive strength (MPA)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10
7 Days (MPa)	23.4	23	24.3	26	22.8	25.1	27.5	24.6	26.2	28.1
28 Days (MPa)	34.5	33.8	35.6	37.6	33	35.2	38.5	36.5	37.8	39.8
56 Days (MPa)	38.4	38.8	40	41.5	38	40.5	43.5	41.5	42.5	45
90 Days (MPa)	39.2	40.5	41.8	43.3	40.2	42.7	45.3	43.3	44.2	47.5

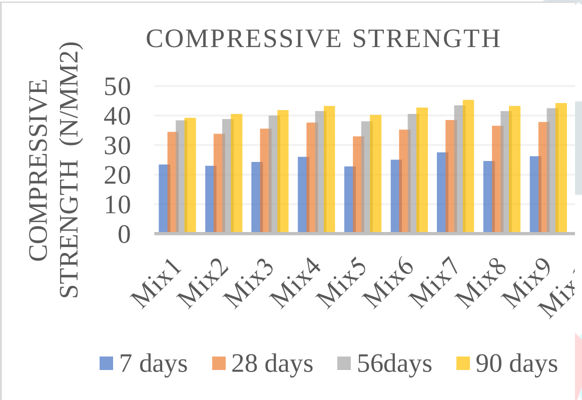

Fig: 6 Compressive Strength

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Observations:

- **Strength Increase with Age:** All mixes exhibit a consistent increase in compressive strength as the curing age progresses from 7 to 90 days, indicating proper hydration and pozzolanic activity of the supplementary cementitious materials.
- **Variation Across Mixes:** Mix-10 achieves the highest strength at all curing ages, reaching at 47.5 MPa at 90 days, suggesting it has the most effective combination of materials and steel fiber dosage. Conversely, Mix-5 shows comparatively lower strength, indicating less effectiveness in its material composition or fiber reinforcement.

Table: 7: Mix Proportions M30 Grade NCC(GROUP-I) average tensile strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10
7 Days (MPa)	3	2.9	3.2	3.5	3	3.4	3.7	3.3	3.6	4
28 Days (MPa)	4.3	4.1	4.5	4.8	4.2	4.7	5	4.6	4.9	5.2
56 Days (MPa)	4.7	4.6	4.9	5.2	4.6	5.1	5.5	5	5.4	5.7
90 Days (MPa)	5	4.9	5.2	5.5	4.9	5.4	5.9	5.4	5.7	6.1

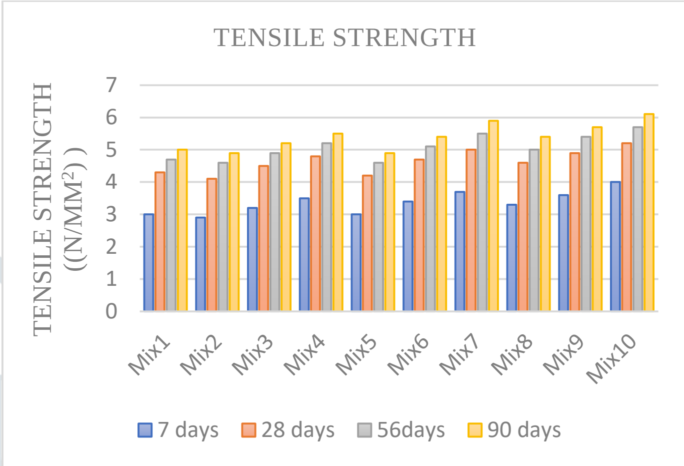

Fig: 7 Tensile Strength

Observation

- **StrengthDevelopmentOverTime:** All mixes show a gradual and consistent increase in compressive strength from 7 to 90 days, indicating continued hydration and pozzolanic activity. For example, Mix-10 increases from 4.0 MPa at 7 days to 6.1 MPa at 90 days, the highest strength among all mixes.
- **Variation Among Mixes:** Mix-10 consistently achieves the highest strength, demonstrating the most effective combination of materials and steel fiber reinforcement. Mix-2 and Mix-5 show comparatively lower strength values, with both reaching at 4.9 MPa at 90 days, indicating less efficient mix designs or material properties.

Table: 8: Mix Proportions M30 Grade NCC (Group-I) average flexural strength (MPA)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10
7 Days (MPa)	5.1	5	5.2	5.5	4.9	5.3	5.7	5.4	5.6	6
28 Days (MPa)	6.3	6.2	6.4	6.7	6	6.5	6.9	6.6	6.8	7.2
56 Days (MPa)	6.8	6.6	6.9	7.2	6.5	7	7.4	7.1	7.3	7.7
90 Days (MPa)	7.1	6.9	7.2	7.5	6.8	7.3	7.7	7.4	7.6	8

Fig: 8 Flexural Strength

Observations:

- **Consistent Increase in Flexural Strength:** All mixes show a steady increase in flexural strength from 7 to 90 days, indicating continued hydration and improvement in concrete quality over time.

- **Mix-10 Exhibits the Highest Strength:** Mix-10 consistently shows the highest flexural strength at all ages, reaching 6.0 MPa at 7 days and 7.4 MPa at 56 days, outperforming the other mixes.

Table: 9Mix Proportions M30GradeSCC (GROUP-I) average compressive strength (MPA)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10
7 Days (MPa)	23.8	24.3	24.8	25.3	26.3	27.3	28.3	30.3	31.8	32.3
28 Days (MPa)	34.2	34.9	35.3	35.8	37.2	38.2	39.2	41.1	42.7	43.2
56 Days (MPa)	41.3	41.6	42.3	42.9	43.6	44.1	45.2	47.3	48.6	49.1
90 Days (MPa)	42.8	43.2	43.7	44.1	44.7	45.2	46.2	48.4	49.7	50.2

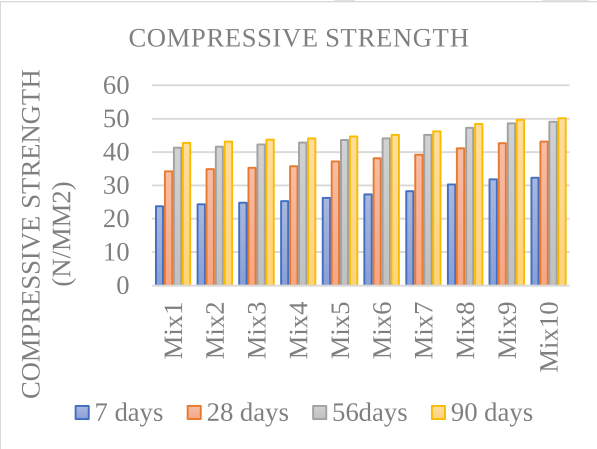

Fig: 9 Compressive strengths

Observations:

- **Strength Development Over Time:** Compressive strength consistently increases with curing age across all mixes, with the most significant gain observed between 7 and 28 days, indicating effective hydration and material performance.
- **Mix Variation Impact:** Strength improves progressively from Mix-1 to Mix-10, with Mix-10 achieving the highest compressive strength at 90 days (50.2 MPa), reflecting the influence of optimized material proportion.

Table: 10: Mix Proportions M30 Grade SCC(GROUP-I) average Tensile Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10
7 Days (MPa)	3.1	3.3	3.4	3.5	3.6	3.7	3.8	4.1	4.3	4.6
28 Days (MPa)	4.4	4.5	4.7	4.9	5.0	5.1	5.2	5.5	5.7	6.1
56 Days (MPa)	5.2	5.3	5.5	5.7	5.9	6.0	6.1	6.5	6.7	7.1
90 Days (MPa)	5.4	5.6	5.8	6.0	6.2	6.3	6.4	6.8	7.1	7.5

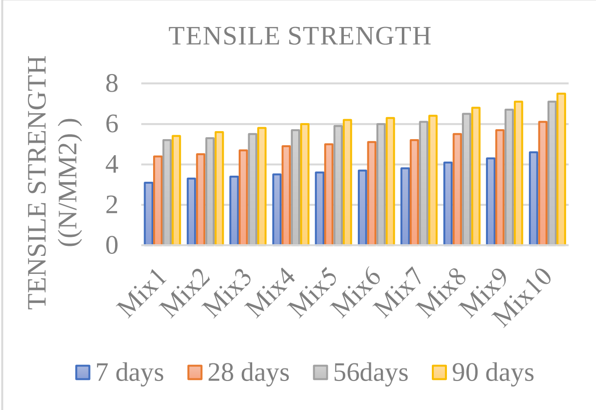

Fig: 10 Tensile Strength

Observations:

- **TensileStrengthGrowth:** Tensile strength steadily increases with curing time for all mixes, with significant gains observed between 7 and 28 days, indicating effective bonding and hydration over time.
- **2.Impact of Mix Design:** Mix-10 exhibits the highest tensile strength across all curing ages, reaching 7.5 MPa at 90 days, highlighting the benefits of optimized material combinations.

Table: 11: Mix Proportions M30 Grade SCC(GROUP-I) average Flexural Strength (MPa)

Age	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7	Mix-8	Mix-9	Mix-10
7 Days (MPa)	5.4	5.7	5.9	6.2	6.5	6.7	7.0	7.2	7.4	7.7
28 Days (MPa)	7.2	7.6	7.8	8.2	8.5	8.7	9.1	9.3	9.5	10.0
56 Days (MPa)	8.6	9.1	9.4	9.8	10.2	10.5	10.9	11.2	11.4	11.9
90 Days (MPa)	9.0	9.4	9.8	10.2	10.5	10.9	11.2	11.5	11.7	12.2

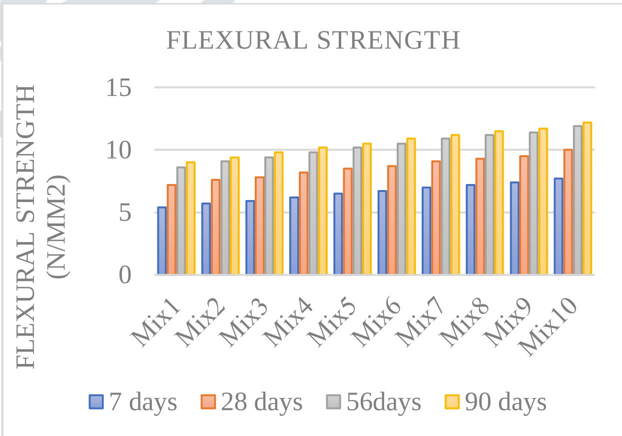

Fig: 11 Flexural Strength

Observations

- FlexuralStrengthProgression:
Flexural strength increases with curing time for all mixes, with substantial improvements between 7 and 28 days. At 90 days, strength continues to improve, reflecting long-term durability and performance.

- 2.Effect of Mix Variations: Mix-10 shows the highest flexural strength across all curing ages, achieving 12.2 MPa at 90 days, indicating the significant impact of optimized material proportions on flexural performance

VIII. CONCLUSIONS

1. **SCC** demonstrated superior workability with high slump flow values (590 mm to 680 mm) and excellent passing ability, making it ideal for complex and densely reinforced structures. In contrast, **NCC** had lower workability, with slump values ranging from 75 mm to 110 mm, requiring more effort for placement and compaction.
2. **Compressive strength:** SCC (Mix-10, 43.2 MPa) outperforms NCC (Mix-10, 39.8 MPa) by approximately 8-10% across all mixes due to better compaction and SCM efficiency's shows greater strength gains over time, achieving 5-8% higher strength than NCC at 90 days.
3. **Tensile Strength**: The tensile strength of SCC Mix-10 (95% OPC, 5% Silica Fume, and 1.5% Steel Fiber) at 90 days is approximately 36.36% higher than NCC Mix-10 (5.5 MPa at 90 days).
4. **Flexural strength:** SCC consistently exhibits higher flexural strength compared to NCC, with SCC Mix-10 showing 52.5% higher flexural strength at 90 days than NCC Mix-10, demonstrating the superior performance of SCC in terms of flexural properties.

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