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Nano-Modified Self-Compacting Concrete: Performance Evaluation Of Zinc Oxide And Magnetite Nanoparticles On Mechanical Strength Parameters

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Abstract: *In India's ready-mix concrete sector, Self-Compacting Concrete (SCC) has become increasingly popular and is now extensively used in major construction projects. This study aims to conduct a comparative analysis of the hardened properties of M30 grade SCC by evaluating the influence of nanomaterials.[1],[3] This research is centred on the use of Nano Zinc Oxide (ZnO) and Nano Ferric Oxide (Fe_3O_4) as performance-enhancing additives. The experimental program involves assessing the mechanical properties of SCC mixtures with and without nanomaterials, as well as mixtures incorporating varying proportions of these nanomaterials (0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% by weight of the total powder content). The findings reveal a noticeable improvement in compressive strength at both 14 and 28 days with increasing dosages of nanomaterials. This study undertakes a comprehensive assessment of the mechanical performance of SCC, highlighting the potential benefits of Nano ZnO and Nano Fe_3O_4 in enhancing strength characteristics and contributing to the development of high-performance concrete.*
Key words: Self Compacting Concrete, Nano ZnO, Nano Fe3o4, Mechanical Strength

INTRODUCTION

As the world's most widely applied synthetic material, concrete is experiencing continuous growth in demand across the field of construction.[2] In recent years, construction has become a cornerstone of infrastructure development in almost every region, with concrete playing a central role due to its versatility and reliable properties.
Concrete is composed of fine and coarse aggregates bound together by cement, which acts as a key binding agent. When it hardens, concrete becomes a strong, rock-like material. The material is widely applied in numerous structures—ranging from buildings, bridges, highways, and dams to smaller elements like structural parts, kerbs, pipelines, and sewage networks.[4] Its durability, abundance, and relatively low maintenance requirements, along with its resistance to compression and non-combustible nature, make it one of the most preferred materials in construction.[5] One of concrete's most important features is its ability to be shaped and moulded before it sets, which makes it suitable for a variety of architectural and structural applications. However, designing the right concrete mix involves balancing cost with performance parameters such as strength, durability, density, and aesthetic appeal.
Concrete grades are classified based on strength and performance into regular, standard, and high-strength categories. Regular grades include M10, M15, and M20; standard grades comprise M25 to M45; and high-strength grades such as M50, M55, and M60 are used in structures that demand greater load-bearing capacity.[6] Self-Compacting Concrete (SCC) was introduced to address the limitations of traditional concrete, which requires mechanical vibration for proper compaction. Due to its self-flowing nature, SCC completely fills moulds and eliminates gaps without vibration.[7] This contributes to faster construction processes while maintaining high uniformity and durability, even in structures with complex shapes or heavy reinforcement. SCC mixes are generally designed according to guidelines provided in IS 10262:2019, which also applies to conventional concrete. Once the mix is finalized, the hardened properties of SCC are tested to confirm compliance with the design requirements.
In this research, attention is directed toward Self-Compacting Concrete (SCC), a concrete type that has witnessed widespread acceptance in the Indian ready-mix industry, especially in high-volume construction applications. Nano materials, which exist at a scale of nano meters to sub-microns, can significantly improve the mechanical and durability properties of cementitious materials. Their inclusion also makes it possible to reduce the quantity of Ordinary Portland Cement (OPC) without compromising on

strength, contributing to more sustainable construction practices. While Graphene Oxide and Nano-SiO_2 have been studied in the past for their impact on concrete performance, this study focuses on the lesser-explored Nano Zinc Oxide (ZnO) and Nano Ferric Oxide (Fe_3O_4). In recent years, nanomaterials have drawn significant interest within the construction industry because of their potential to improve the physical performance of concrete. Studies have demonstrated that their inclusion can greatly enhance both the structural integrity and overall efficiency of OPC-based mixes. Nevertheless, research specifically examining the influence of Nano ZnO and Nano Fe_3O_4 on the mechanical characteristics of Self-Compacting Concrete is still quite limited.
The present research seeks to address this gap by carrying out an in-depth experimental study on the influence of Nano ZnO and Nano Fe_3O_4 on the strength and performance characteristics of M30 grade Self-Compacting Concrete (SCC). The objective is to highlight the potential advantages these nanomaterials bring, particularly in enhancing different mechanical properties, thereby supporting the development of durable, high-performance concrete for future construction applications.

UTILIZATION OF MATERIALS

The materials were used for SCC are mentioned in following Table 1.

Table 1. Material required

1	Nano material
2	Fine Aggregate
3	Coarse aggregate
4	Cement
5	Fly ash
6	Super Plasticizer
7	water

PROPORTIONING AND MIX DESIGN DEVELOPMENT

A. *Mix proportion*

The mix proportions SCC1-SCC13 indicate the incorporation of Nano ZnO and Nano Fe3O4 at concentrations of 0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0% by weight of the powder content [7][8]. The specific mix designations are detailed in Table 2.

Table 2. Mix proportion

MIX	CEMENT Kg/m^3	WATER Kg/m^3	F.A. Kg/m^3	C.A. Kg/m^3	SP	W/P RATIO	NANO ZnO	NANO Fe3O4
SCC1	420	180	810	770	3.28	0.38	0	0
SCC2	420	180	810	770	3.28	0.38	0.02	-
SCC3	420	180	810	770	3.28	0.38	0.04	-
SCC4	420	180	810	770	3.28	0.38	0.06	-
SCC5	420	180	810	770	3.28	0.38	0.08	-
SCC6	420	180	810	770	3.28	0.38	0.1	-
SCC7	420	180	810	770	3.28	0.38	0.12	-
SCC8	420	180	810	770	3.28	0.38	-	0.02
SCC9	420	180	810	770	3.28	0.38	-	0.04
SCC10	420	180	810	770	3.28	0.38	-	0.06
SCC11	420	180	810	770	3.28	0.38	-	0.08
SCC12	420	180	810	770	3.28	0.38	-	0.1
SCC13	420	180	810	770	3.28	0.38	-	0.12

HARDENED PROPERTIES:

A. *Compressive strength*

Compressive strength serves as a key parameter for evaluating the performance of hardened concrete. For this assessment, cube specimens of 150 mm × 150 mm × 150 mm are cast and tested using a compression testing machine. A gradual vertical load is applied until the specimen fails, and the resulting strength is recorded. The specimens are cured in water for 7, 14, and 28 days, enabling the observation of strength gain over time. The results of the compressive strength tests for Self-Compacting Concrete (SCC) incorporating Nano ZnO and Nano Fe_3O_4 are presented in Tables 3 and 4, respectively, highlighting the influence of these nanomaterials on strength development at different curing periods.

Table 3. Results for Nano ZnO

SAMPLE	% of Nano ZnO	Compressive strength (MPa)		
		7 Days	14 Days	28 Days
SCC1	0	21.45	31.2	37.8
SCC2	0.5	22.1	32.15	38.2
SCC3	1.0	22.45	32.45	38.53
SCC4	1.5	22.65	32.66	38.82
SCC5	2.0	22.76	32.99	39.13
SCC6	2.5	22.89	33.4	39.27
SCC7	3.0	22.81	33.23	39.21

Table 4. Results for Nano Fe3O4

SAMPLE	% of Nano Fe3o4	Compressive strength (MPa)		
		7 Days	14 Days	28 Days
SCC1	0	21.45	31.2	37.8
SCC8	0.5	21.7	31.8	37.9
SCC9	1.0	21.82	32.2	38.23
SCC10	1.5	22.04	32.56	38.67
SCC11	2.0	22.24	32.8	38.96
SCC12	2.5	22.5	33.3	39.25
SCC13	3.0	22.59	33.35	39.3

B. Tensile strength

The shear resistance of concrete is assessed through this test, which employs a cylindrical specimen with a diameter of 15 cm and a height of 30 cm. The specimen is loaded progressively until failure occurs, at which point its shear strength is determined. To examine the strength gain with curing duration, the test is performed after 7, 14, and 28 days of water curing.

Table 5. Results for Nano ZnO

SAMPLE	% of Nano ZnO	Tensile strength (MPa)		
		7 Days	14 Days	28 Days
SCC1	0	5.05	6.55	7.09
SCC2	0.5	5.1	6.59	7.12
SCC3	1.0	5.13	6.67	7.18
SCC4	1.5	5.18	6.72	7.26
SCC5	2.0	5.22	6.8	7.33
SCC6	2.5	5.26	6.82	7.4
SCC7	3.0	5.3	6.83	7.42

Table 6. Results for Nano Fe3O4

SAMPLE	% of Nano Fe3o4	Tensile strength (MPa)		
		7 Days	14 Days	28 Days
SCC1	0	5.05	6.55	7.09
SCC8	0.5	5.25	6.8	7.32
SCC9	1.0	5.32	6.89	7.45
SCC10	1.5	5.38	6.98	7.56
SCC11	2.0	5.46	7.12	7.62
SCC12	2.5	5.51	7.21	7.75
SCC13	3.0	5.56	7.28	7.79

C. *Flexural strength*

The flexural strength of concrete is assessed using beam specimens with dimensions of 100 mm × 100 mm × 500 mm. This property can be measured through either the three-point or the two-point loading technique. In the present investigation, the two-point loading method is adopted. The applied load is gradually introduced at two designated points on the specimen until failure occurs, thereby indicating the concrete's capacity to resist bending stresses and flexural deformation.

Table 7. Results for Nano ZnO

SAMPLE	% of Nano ZnO	Flexural strength (MPa)		
		7 Days	14 Days	28 Days
SCC1	0	6.33	7.74	8.65
SCC2	0.5	6.4	7.76	8.69
SCC3	1.0	6.45	7.8	8.75
SCC4	1.5	6.51	7.85	8.81
SCC5	2.0	6.6	7.92	8.86
SCC6	2.5	6.63	7.94	8.91
SCC7	3.0	6.66	7.93	8.92

Table 8. Results for Nano Fe3O4

SAMPLE	% of Nano Fe3o4	Flexural strength (MPa)		
		7 Days	14 Days	28 Days
SCC1	0	6.33	7.74	8.65
SCC8	0.5	6.6	7.85	8.82
SCC9	1.0	6.69	7.92	8.91
SCC10	1.5	6.76	7.99	9.01
SCC11	2.0	6.86	8.12	9.12
SCC12	2.5	6.94	8.23	9.26
SCC13	3.0	6.98	8.29	9.32

ANALYSIS OF FINDINGS:

A. *Compressive strength*

The incorporation of Nano ZnO into Self-Compacting Concrete has been observed to enhance its compressive strength. Among the investigated proportions, the most notable improvement is achieved with a 2.5% Nano ZnO addition. The variations in compressive strength at curing ages of 7, 14, and 28 days for different Nano ZnO dosages are illustrated in Figures 1, 2, and 3. Furthermore, Figure 4 presents a comparative chart highlighting the compressive performance of SCC at these three curing intervals with respect to Nano ZnO content.

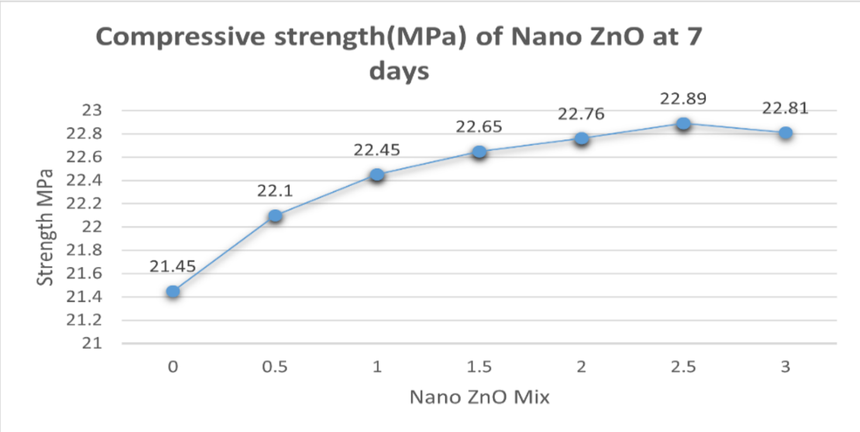

Fig.1. Compressive strength - Nano ZnO - 7 days

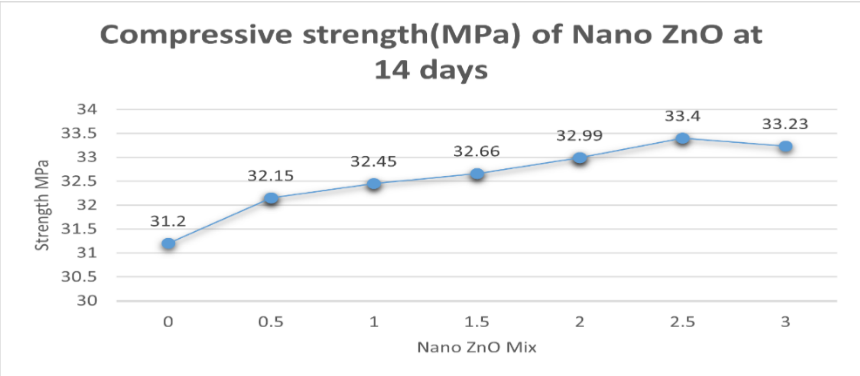

Fig.2. Compressive strength - Nano ZnO - 14 days

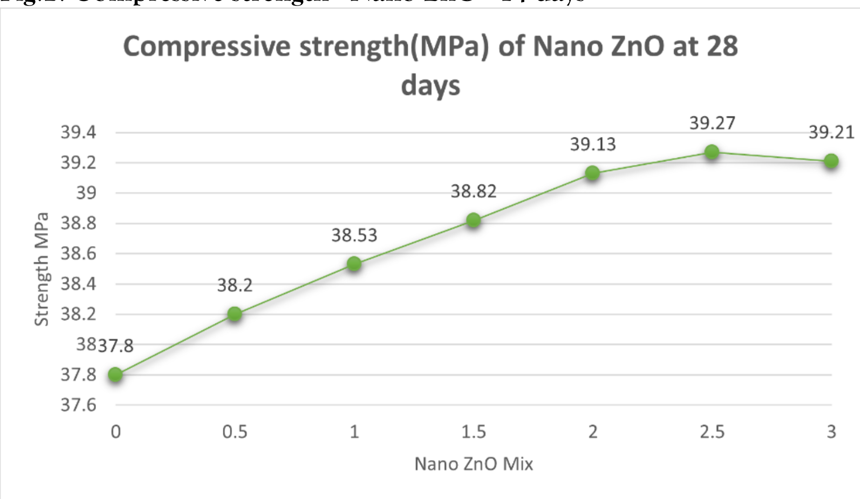

Fig.3. Compressive strength - Nano ZnO - 28 days

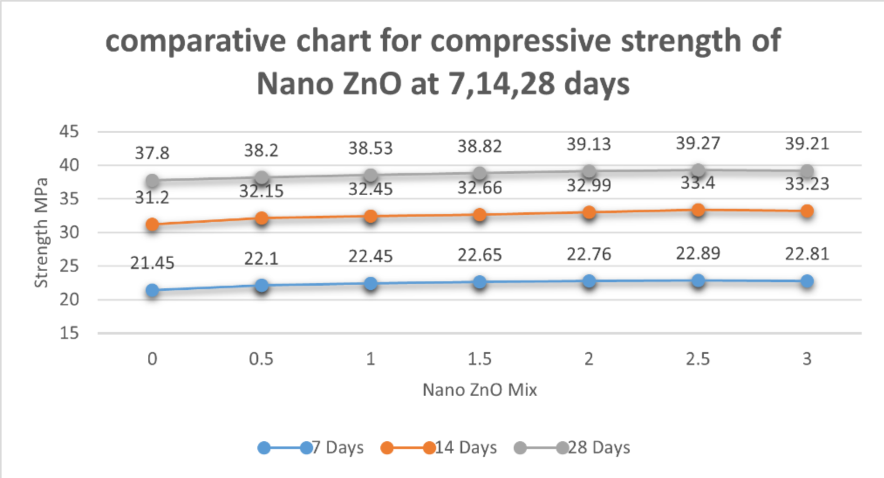

Fig.4. Comparative chart for compressive strength - Nano ZnO - 7, 14, 28 days

The variation in compressive strength corresponding to different proportions of Nano Fe_3O_4 at curing ages of 7, 14, and 28 days is illustrated in Figures 5, 6, and 7. Additionally, Figure 8 presents a comparative chart highlighting the effect of Nano Fe_3O_4 incorporation on the compressive performance of SCC over the same curing periods. The experimental outcomes indicate that higher dosages of Nano Fe_3O_4 contribute to a notable enhancement in compressive strength.

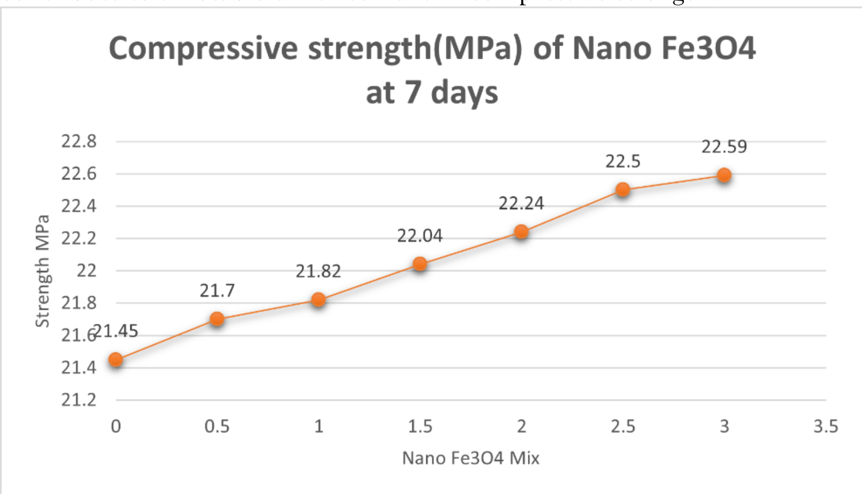

Fig.5. Compressive strength - Nano Fe3o4 - 7 days

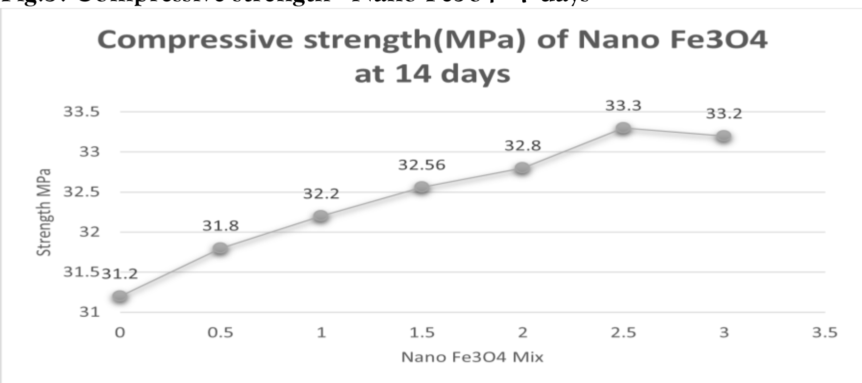

Fig.6. Compressive strength - Nano Fe3o4 - 14 days

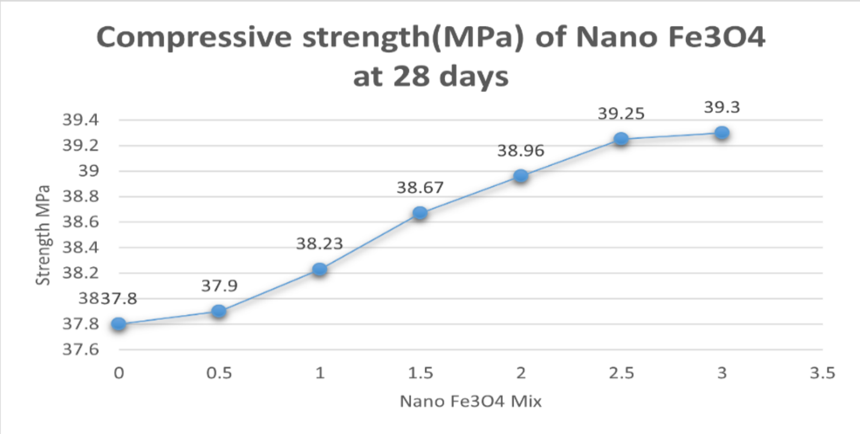

Fig.7. Compressive strength - Nano Fe3o4 - 28 days

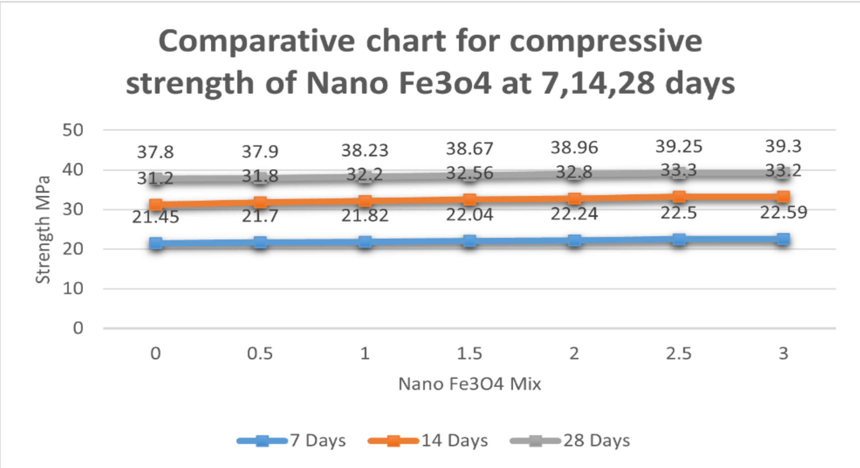

Fig.8. Comparative chart for compressive strength - Nano Fe3O4 - 7, 14, 28 days

B. Tensile strength

Due to the enhanced bonding between concrete particles at the nano scale, the tensile strength of the material shows a clear improvement with higher concentrations of nano materials. Figures 9, 10, and 11 present graphical representations of tensile strength measured at 7, 14, and 28 days for varying proportions of nano ZnO. Figure 12 provides a comparative chart illustrating the compressive strength of self-compacting concrete at the same intervals—7, 14, and 28 days—specifically highlighting the influence of nano ZnO addition.

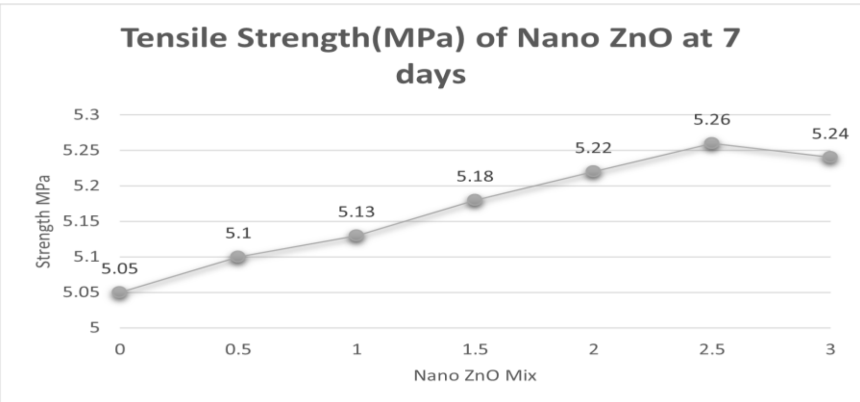

Fig.9. Tensile strength - Nano ZnO - 7 days

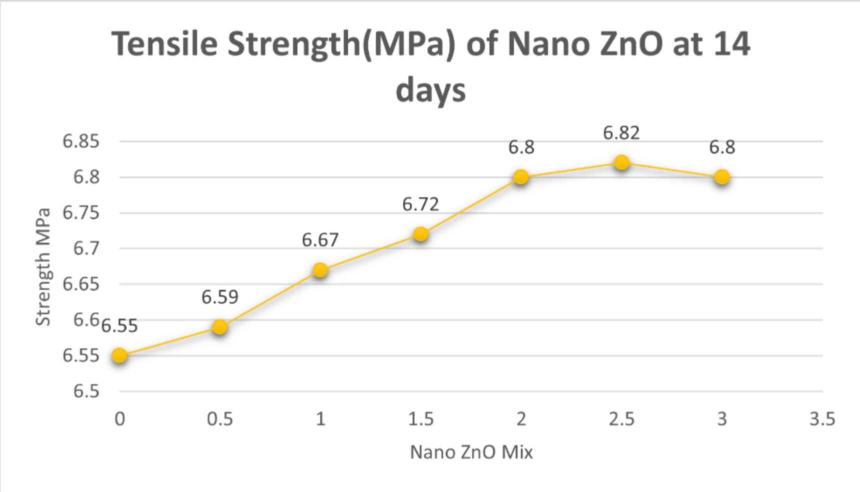

Fig.10. Tensile strength - Nano ZnO - 14 days

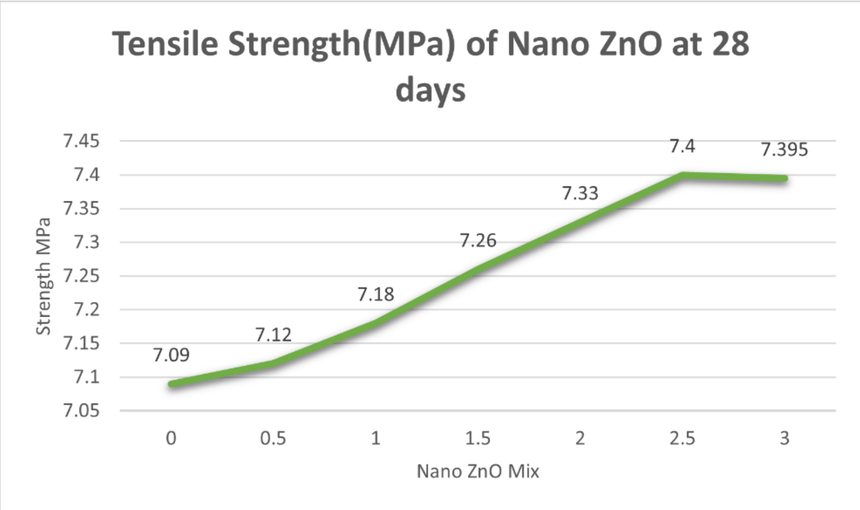

Fig.11. Tensile strength - Nano ZnO - 28 days

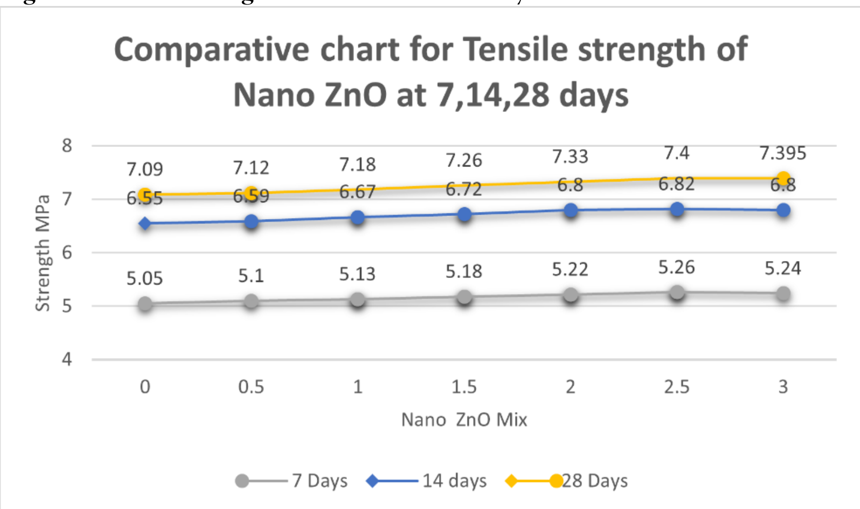

Fig.12. Comparative chart for Tensile strength - Nano ZnO - 7, 14, 28 days

In a similar way, Figures 13, 14, and 15 show graphs of tensile strength recorded at 7, 14, and 28 days for various proportions of Nano Fe_3O_4. Figure 16 presents a side-by-side comparison, highlighting how the addition of Nano Fe_3O_4 influences the tensile strength of self-compacting concrete over the same time intervals.

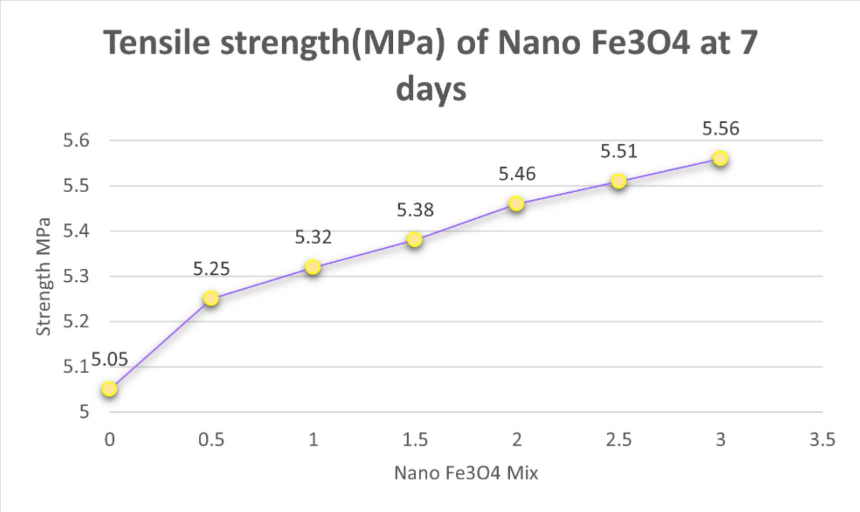

Fig.13. Tensile strength - Nano Fe3o4 - 7 days

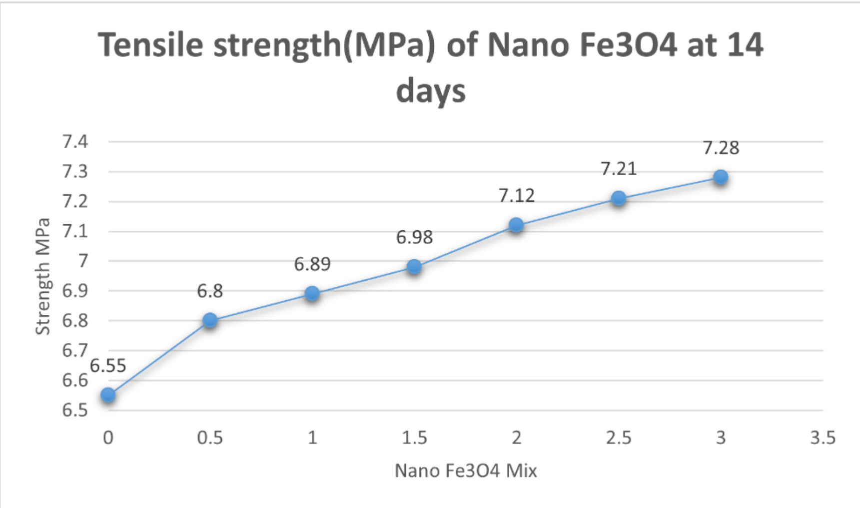

Fig.14. Tensile strength - Nano Fe3o4 - 14 days

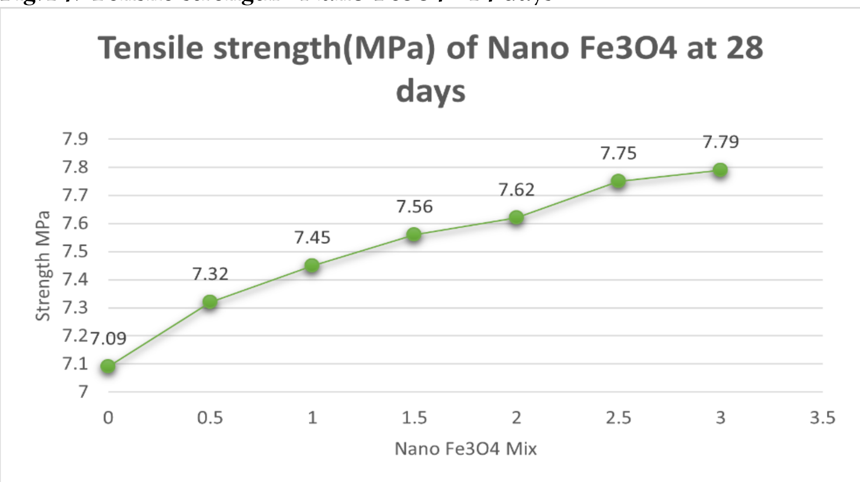

Fig.15. Tensile strength - Nano Fe3o4 - 28 days

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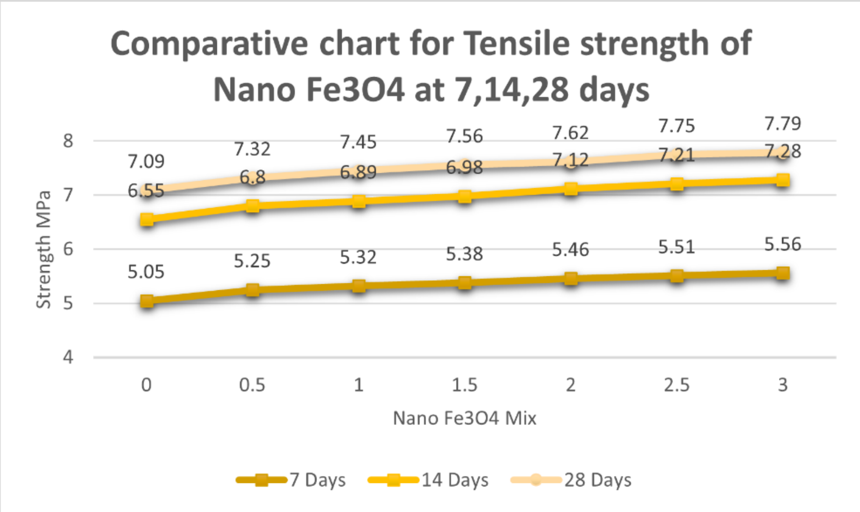

Fig.16. Comparative chart for Tensile strength - Nano Fe3O4 - 7, 14, 28 days

C. *Flexural strength*

Table 7,8 presents the flexural strength results at 7, 14, and 28 days for mixes SCC1 to SCC13, each containing varying amounts of Nano ZnO and Nano Fe_3O_4. The trends are further illustrated in Figures 17, 18, and 19 for mixes with Nano ZnO, and in Figures 21, 22, and 23 for mixes with Nano Fe_3O_4, across the same time intervals. It is evident that the mix with 3.0% Nano ZnO and Nano Fe_3O_4 achieved the highest flexural strength values. The comparative charts in Figures 20 and 24 clearly show that as the percentage of these nano materials increases, the flexural strength consistently rises, reflected by the positive slope of the plotted curves.

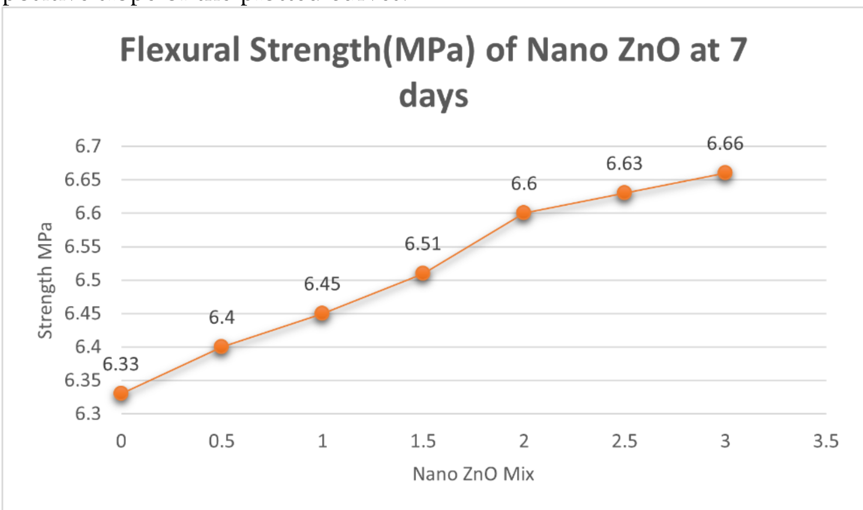

Fig.17. Flexural strength - Nano ZnO - 7 days

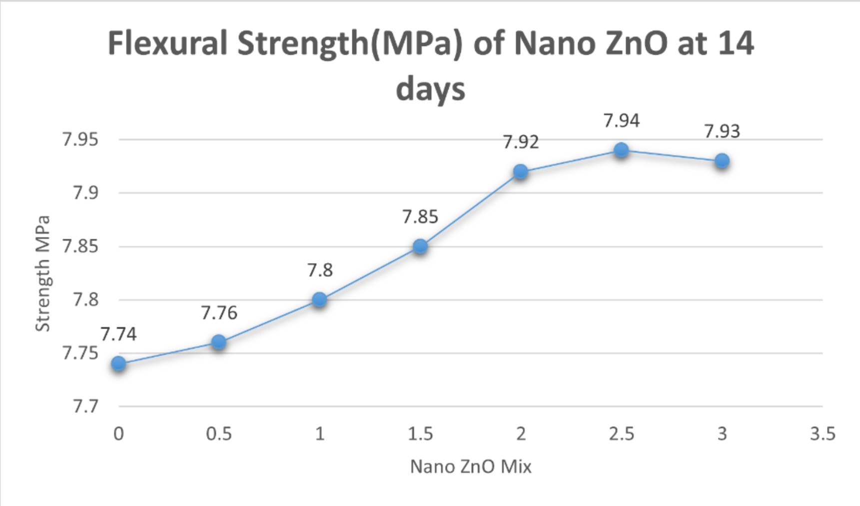

Fig.18. Flexural strength - Nano ZnO - 14 days

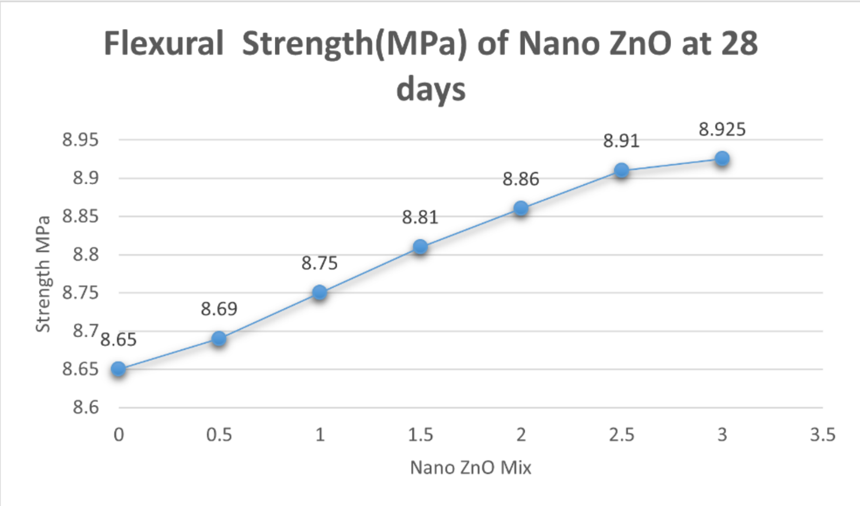

Fig.19. Flexural strength - Nano ZnO - 28 days

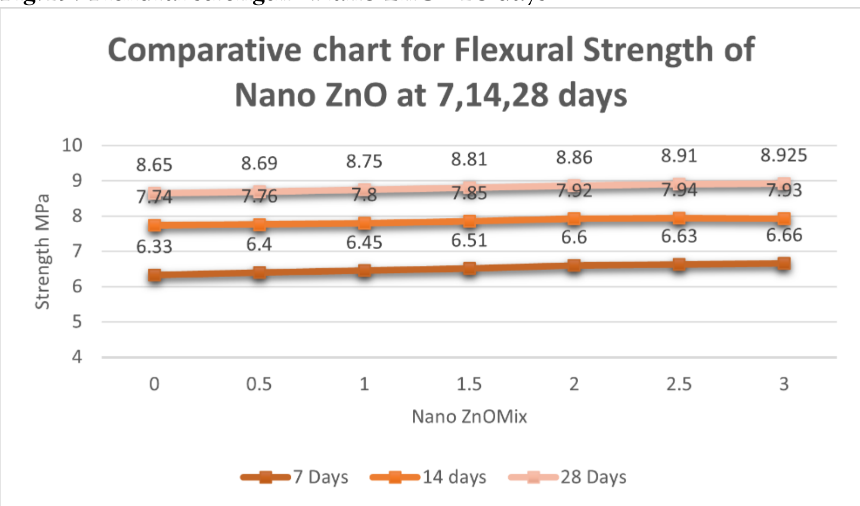

Fig.20. Comparative chart for Flexural strength - Nano ZnO - 7, 14, 28 days

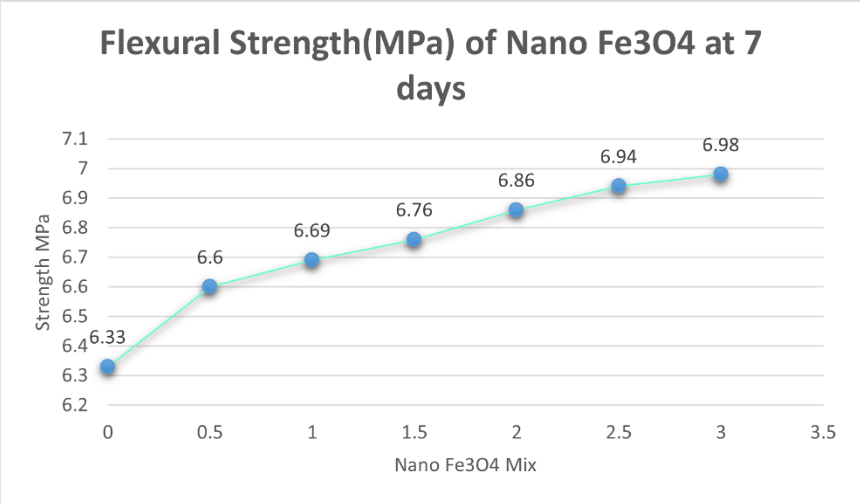

Fig.21. Flexural strength - Nano Fe3o4 - 7 days

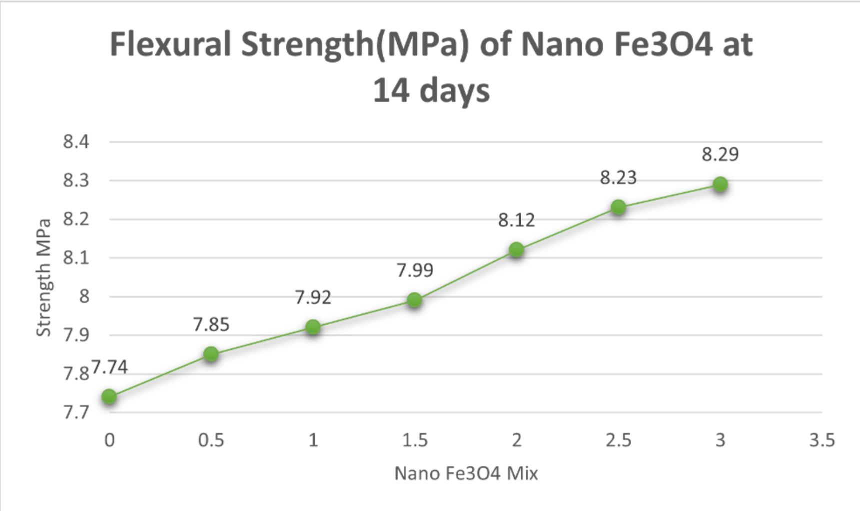

Fig.22. Flexural strength - Nano Fe3o4 - 14 days

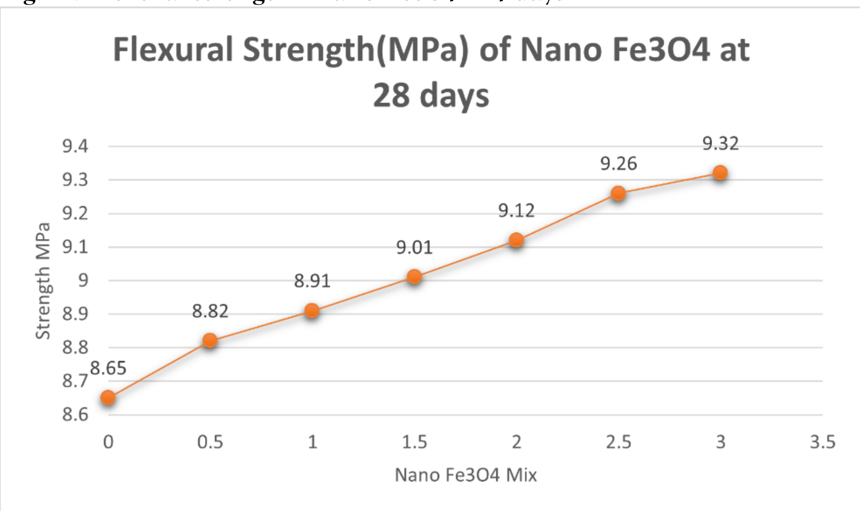

Fig.23. Flexural strength - Nano Fe3o4 - 28 days

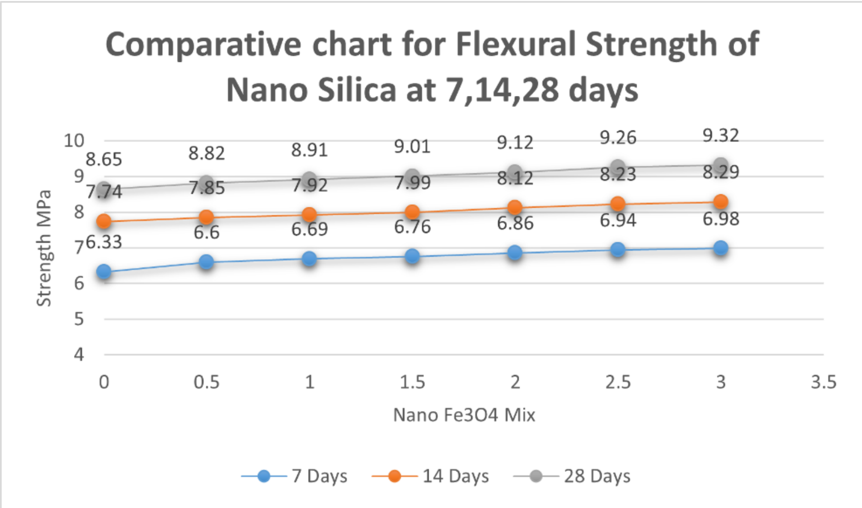

Fig.24. Comparative chart for Flexural strength - Nano Fe3O4 - 7, 14, 28 days

CONCLUSION

When casting self-compacting concrete, carefully controlling its workability is crucial. The workability largely depends on the contact area of the powdered materials—more powder means more contact area, which improves the flow and filling ability of the mix. Adding Nano ZnO and Nano Fe_3O_4 to cement is a key step in achieving optimum performance in self-compacting concrete.

In this comparative study, mixes containing Nano ZnO showed better compressive strength than those without nano materials. Among all proportions tested, adding 2.5% Nano ZnO to the cement produced the best results for M30 grade self-compacting concrete. However, increasing the Nano ZnO content beyond this point caused a slight drop in compressive strength. On the other hand, incorporating Nano Fe_3O_4 also improved compressive strength compared to mixes without nano materials.

When it came to tensile and flexural strength, Nano Fe_3O_4 performed better than Nano ZnO. Across different proportions, Nano Fe_3O_4 significantly enhanced both tensile and flexural capacity, with the 3.0% addition delivering the highest values.

Overall, the study shows that combining Nano ZnO and Nano Fe_3O_4 in M30 grade self-compacting concrete leads to noticeable improvements in the hardened-state properties of the material, making it stronger and more durable.

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