Analysis of Structural Performance of Fibre Reinforced Sustainable Concrete Using Nano-Engineered Laterite Materials

Dr. Swapna Channagoudar[1]
Associate Professor & HOD,
Department of Civil Engineering, SKSVMACET
Lakshmeshwara

Dr Harish B A[2]
Assistant professor Professor
Department of Civil Engineering, GM University
Davanagere

Dr Hanumesh B M [3]
Assistant professor Professor
Department of Civil Engineering, GM University
Davanagere

Varshini Madiwalar [4]
Student, Department of Civil Engineering, SKSVMACET
Lakshmeshwara

Abstract: **The construction industry is increasingly focusing on sustainable materials to reduce environmental impact and improve durability. This study investigates the performance of nano-enabled laterite infused fibre reinforced sustainable concrete. Laterite soil is used as a partial replacement for cement, while nano-silica enhances microstructural properties and steel fibres improve mechanical performance. Various mixes were prepared by replacing cement with laterite at 10%, 20%, and 30% levels and incorporates 1% steel fibres along with 2% nano-silica, and evaluates compressive, split tensile, and flexural strengths at 7 and 28 days. The results demonstrate that the combination of nano-silica and fibres significantly enhances mechanical properties compared with conventional concrete. The optimal mix containing 20% laterite replacement showed improved strength and sustainability. This study confirms that nano-enabled laterite fibre reinforced concrete can serve as an environmentally friendly alternative for structural applications.**

Keywords— Sustainable concrete, Laterite soil, Nano-silica, Fibre reinforced concrete, Mechanical properties.

I. Introduction

Concrete is the most commonly used material in construction in worldwide. However, Cement production contributes significantly to carbon dioxide emissions; hence, researchers are investigating alternative materials to partially substitute cement and enhance sustainability.

Laterite soil is abundant in tropical regions and can be employed as a partial cement replacement. However, laterite can reduce strength if used excessively. To overcome this limitation, nano-materials such as nano-silica are used to improve the microstructure of concrete. Nano-silica enhances the pozzolanic reaction and fills micro-voids within the cement matrix.

Fibre reinforced concrete improves tensile and flexural performance by controlling crack propagation. The integration of fibres and nano-materials with laterite creates a sustainable composite material with enhanced mechanical performance.

This study investigates the mechanical properties of nano-enabled laterite infused fibre reinforced concrete through experimental testing.

Objectives

1. Investigate the effect of laterite incorporation on concrete's mechanical performance.
2. Assess the influence of nano-materials on strength, durability, and microstructure.
3. Assess the impact of fibre reinforcement on improving ductility and resistance to cracking.
4. Perform microstructural characterization and durability analysis.
5. Compare performance with conventional concrete.
6. Develop sustainable and practical mix design guidelines.
7. Promote environmentally friendly and cost-effective construction practices.

II. Litreature Review

Laterite soil has been investigated as a cement replacement due to its availability in tropical regions. According to **B. Singh et al. (2014)**, partial replacement of cement with laterite up to 20% can produce concrete with acceptable compressive strength, provided proper curing is applied. Similarly, **Kumar and Ramesh (2016)** reported that laterite-infused concrete improves workability but requires additional additives for enhanced strength.

A. Nano-silica in concrete:

Nano-silica improves the mechanical and durability properties of concrete by filling micro-voids and accelerating the pozzolanic reaction. **Siddique and Klaus (2011)** observed that 2–3% nano-silica addition increases compressive strength by 10–15% and reduces porosity. **Li et al. (2012)** confirmed that nano-silica enhances the bond between cement matrix and aggregates, contributing to higher tensile and flexural strength.

B. Fibre reinforcement in concrete:

Incorporating steel or synthetic fibres enhances tensile and flexural behavior. **Banthia and Nandakumar (2003)** demonstrated that adding 1–1.5% steel fibres significantly improves crack resistance and toughness. **Mehta and Monteiro (2014)** highlighted that fibre reinforced concrete (FRC) reduces brittle failure and improves energy absorption.

C. Combined approaches:

Recent studies combine fibres with nano-materials and supplementary cementitious materials. **Mahmoud et al. (2017)** reported that concrete containing nano-silica and steel fibres exhibits superior mechanical properties and durability compared to conventional mixes. Likewise, **Chakraborty and Sarkar (2018)** showed that integrating laterite, nano-silica, and fibres can produce sustainable concrete with enhanced performance suitable for structural applications.

III. Materials Utilized

A. Cement

Ordinary Portland Cement (OPC) Grade 53 was used according to IS 12269 standards.

B. Sand(Fine Aggregates)

River sand conforming to Zone - II as per IS 383 was used.

C. Coarse Aggregate

Crushed granite aggregate with a maximum size of 20 mm was used.

D. Laterite Soil

Laterite soil was collected locally and sieved through a 75-micron sieve before use as partial cement replacement.

E. Nano-Silica

Nano-silica particles with an average size of 20–30 nm were used to improve the microstructure of the concrete.

F. Steel Fibres

Steel fibres of hooked-end type, having an aspect ratio of 60, were added at 1% by volume.

G. Water

Clean potable water was used in the mixing and curing processes.

IV. Mix Proportions

Concrete of grade **M30** was designed as per IS 10262.

TABLE I.

Mix ID	Laterite Replacement	Nano Silica	Steel Fibres
M0	0%	0%	0%
M1	10%	2%	1%
M2	20%	2%	1%
M3	30%	2%	1%

Water-cement ratio = **0.45**

V. Experimental Methodology

A. Compressive Strength Test

Concrete cube specimens measuring 150 × 150 × 150 mm were prepared and tested for compressive strength at 7 and 28 days.

B. Split Tensile Strength Test

150 mm diameter and 300 mm height of Cylinder specimens were tested as per IS 5816.

C. Flexural Strength Test

Beam specimens of **100 × 100 × 500 mm** were tested under two-point loading.

VI. Results and Discussion

A. Compressive Strength

TABLE II.

Mix	7-Day Strength (MPa)	28-Day Strength (MPa)
M0	24.8	38.5
M1	26.5	40.2
M2	28.3	42.6
M3	25.1	37.4

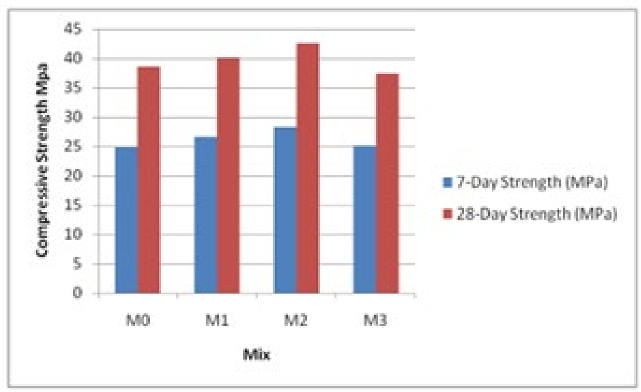

Fig. 1.

The observations show that the compressive strength increased with laterite replacement up to **20%** due to the combined effect of nano-silica and fibres. However, strength decreased at **30% replacement** due to reduced cement content.

B. Split Tensile Strength

TABLE III.

Mix	Tensile Strength (MPa)
M0	3.2
M1	3.6
M2	3.9
M3	3.3

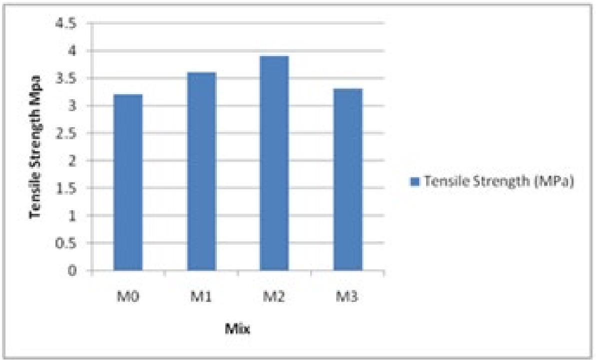

Fig. 2.

Steel fibres significantly improved tensile strength by controlling crack propagation.

C. Flexural Strength

TABLE IV.

Mix	Flexural Strength (MPa)
M0	4.5
M1	5.2
M2	5.8
M3	4.9

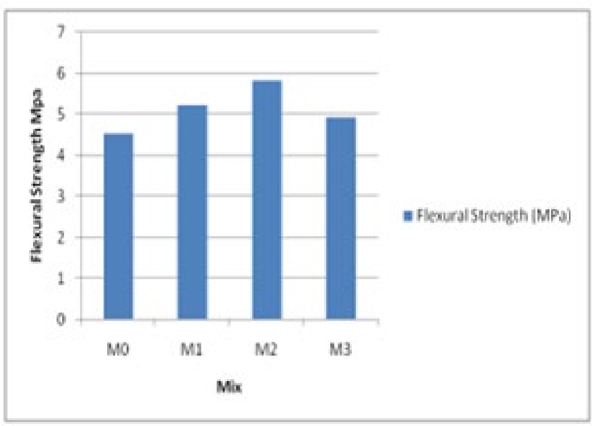

Fig. 3.

The mix with **20% laterite (M2)** showed the highest flexural strength achieved through fibre reinforcement and nano-silica densification.

VII. Microstructural Analysis

Nano-silica particles fill micro-voids in the cement matrix and enhance development of calcium silicate hydrate (C–S–H) gel, which leads to a denser microstructure and improved bond strength between fibres and the matrix.

VIII. Conclusion

The following conclusions were drawn from the experimental investigation:

1. Laterite soil can effectively replace cement up to **20%** without compromising strength.
2. Nano-silica significantly improves the microstructure and mechanical performance of concrete.
3. Steel fibres enhance tensile and flexural strength by controlling crack propagation.
4. The optimal mix **(20% laterite + 2% nano-silica + 1% fibres)** achieved the highest strength.
5. Nano-enabled laterite fibre reinforced concrete is a **sustainable and eco-friendly alternative** for construction.

References

[1] A. M. Neville, Concrete Properties, 5th ed. London: Pearson Education, 2012.

[2] P. K. Mehta and P. J. M. Monteiro, Concrete Microstructure, Properties and Materials. New York: McGraw Hill, 2014.

[3] B. Singh, M. Safiuddin, and M. A. Ismail, “Influence of nano-silica on mechanical properties of concrete,” Construction and Building Materials, vol. 47, pp. 1069-1077, 2013.

[4] IS 10262:2019, Proportioning of Concrete mix Guidelines, Bureau of Indian Standards.