International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 11 | Nov - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Experimental Investigation of the Influence of Nano-Silica and Natural Fibres on the Mechanical and Durability Properties of Concrete

*** DOKKARA RAGHAVA PRASANTHI[1], K. DILEEP CHOWDARY[2]**

[1]M. Tech Scholar (Structural Engineering), Department of Civil Engineering,

Sanketika Vidya Parishad Engineering College, P.M. Palem, Visakhapatnam – 530041, Andhra Pradesh, India

[2]Assistant Professor, Department of Civil Engineering, Sanketika Vidya Parishad Engineering College,

P.M. Palem, Visakhapatnam – 530041, Andhra Pradesh, India

Abstract

This study experimentally evaluates the influence of nano-silica (NS) and three natural fibres—pineapple fibre (PAF), sisal fibre (SF) and bamboo fibre (BF)—on the fresh, mechanical and selected durability properties of M25 concrete. Cement was partially replaced with NS at 1–4% by mass, while each fibre was investigated separately over dosage ranges of 0.25–1.0% for PAF, 0.25–1.25% for SF and 0.25–1.50% for BF. Compressive, split tensile and flexural strengths were determined at 7 and 28 days. The reported 28-day compressive strength increased from 35.33 MPa for the control mixture to 45.70 MPa at 3% NS, corresponding to an increase of approximately 29.35%; split tensile and flexural strengths increased from 4.16 to 4.73 MPa and from 4.22 to 4.78 MPa, respectively. Among the fibre mixtures, the maximum reported 28-day compressive strengths were 39.92 MPa at 0.75% PAF, 40.02 MPa at 1.0% SF and 40.43 MPa at 1.25% BF. The maximum 28-day split tensile strength was 5.02 MPa at 1.25% BF. Selected mixtures containing 3% NS and 1.25% BF exhibited lower reported mass and compressive-strength losses after 30-day chemical immersion than the control. No water was collected during the three-day permeability test; the calculated coefficient was consequently reported as zero. Although reinforced-concrete beam testing and ANSYS analysis are mentioned in the study description, corresponding numerical results are unavailable; structural performance is therefore not quantified. The findings are subject to limitations arising from incomplete data tables and inconsistent mix descriptions.

Index Terms—Nano-silica, natural fibre, pineapple fibre, sisal fibre, bamboo fibre, M25 concrete, compressive strength, durability.

I. INTRODUCTION

Concrete is widely used in buildings and infrastructure, but its relatively low tensile capacity and susceptibility to cracking motivate the use of supplementary cementitious materials and discrete reinforcement. Nano-silica (NS), owing to its high specific surface area, may contribute to pore filling and pozzolanic reactions, while plant-derived fibres can bridge cracks and influence post-cracking behaviour.

Recent reviews and experimental investigations have examined nano-silica-modified cementitious materials and natural-fibre reinforcement, including the effects of fibre treatment, dosage and interfacial behaviour [3]–[8], [11], [12]. The present study compares three natural fibres within a common M25 concrete mix design. The experimental programme considers workability, compressive strength, split tensile strength, flexural strength, elastic modulus and selected durability exposures.

A. Objectives and Scope

The objectives of this investigation are to: (i) evaluate the effects of NS replacement on concrete properties; (ii) compare PAF, SF and BF as natural-fibre additions; (iii) assess selected durability indicators for control, NS, BF and combined NS–BF mixtures; and (iv) examine the potential application of the optimum NS–BF combination in prototype reinforced-concrete beams. Numerical results are available for the first three objectives. The beam-testing objective cannot be evaluated quantitatively because the corresponding results are not included in the available material.

II. MATERIALS AND EXPERIMENTAL PROGRAMME

M25 concrete was proportioned with reference to IS 10262:2009. The control mixture contained 390.98 kg/m³ cement, 574.35 kg/m³ fine aggregate, 1246 kg/m³ coarse aggregate, 191.58 kg/m³ water and 1.95 kg/m³ superplasticizer. The stated mix ratio was 1:1.47:3.19, with a water–cement ratio of 0.40. The quantities and ratio are reproduced in Table I.

TABLE I. CONTROL MIX PROPORTIONS

Ingredient	Quantity (kg/m³)	Mix ratio
Cement	390.98	1.00
Fine aggregate	574.35	1.47
Coarse aggregate	1246.00	3.19
Water	191.58	0.40
Superplasticizer	1.95	0.50 (reported)

Cement was replaced with NS at 0, 1, 2, 3 and 4% by mass. PAF was investigated at 0.25, 0.50, 0.75 and 1.0%; SF at 0.25, 0.50, 0.75, 1.0 and 1.25%; and BF at 0.25, 0.50, 0.75, 1.0, 1.25 and 1.50%. The fibres were cut to a nominal length of 50 mm and treated in 5% sodium hydroxide solution for 48 h, followed by washing and drying. Three specimens were reportedly tested for each condition, and average values were used.

TABLE II. PROPERTIES OF THE NATURAL FIBRES

Fibre	Diameter (µm)	Density (g/cm³)	Moisture (%)	Tensile strength (MPa)	Modulus (GPa)
Bamboo	110	1.35	12	620	15.5
Sisal	150	1.45	11	580	12.0
Pineapple	70	1.44	8	520	34.5

Compressive strength was measured using 150 mm cubes, split tensile strength using cylinders measuring 150 mm in diameter and 300 mm in length, and flexural strength using prisms measuring 100 × 100 × 500 mm. Specimens were water-cured and tested at 7 and 28 days. For durability assessment, 150 mm cubes were immersed for 30 days in 2% HCl (reported pH 1.54), sodium bicarbonate solution (reported pH 12.30), 5% sodium sulphate and 3% sodium chloride. Water permeability was assessed using a three-cell apparatus at a stated pressure of 10 kg/cm² for three days.

III. RESULTS AND DISCUSSION

A. Influence of Nano-Silica

The slump decreased from 120 mm for the control mixture to 95 mm at 3% NS, indicating a reduction in workability. A slump value for the 4% NS mixture is not available. The 28-day compressive strength increased from 35.33 MPa to 45.70 MPa at 3% NS, a gain of 29.35%, and then decreased to 42.08 MPa at 4% NS. Among the investigated replacement levels, 3% NS produced the highest reported strength.

TABLE III. EFFECT OF NANO-SILICA ON 7- AND 28-DAY STRENGTH

NS (%)	Comp. 7 d (MPa)	Comp. 28 d (MPa)	Split 7 d (MPa)	Split 28 d (MPa)	Flex. 7 d (MPa)	Flex. 28 d (MPa)
0	24.02	35.33	3.44	4.16	3.46	4.22
1	26.14	38.44	3.58	4.34	3.6	4.38
2	28.36	41.58	3.73	4.51	3.76	4.55
3	31.08	45.7	3.9	4.73	3.98	4.78
4	29.22	42.08	3.8	4.54	3.81	4.59

.

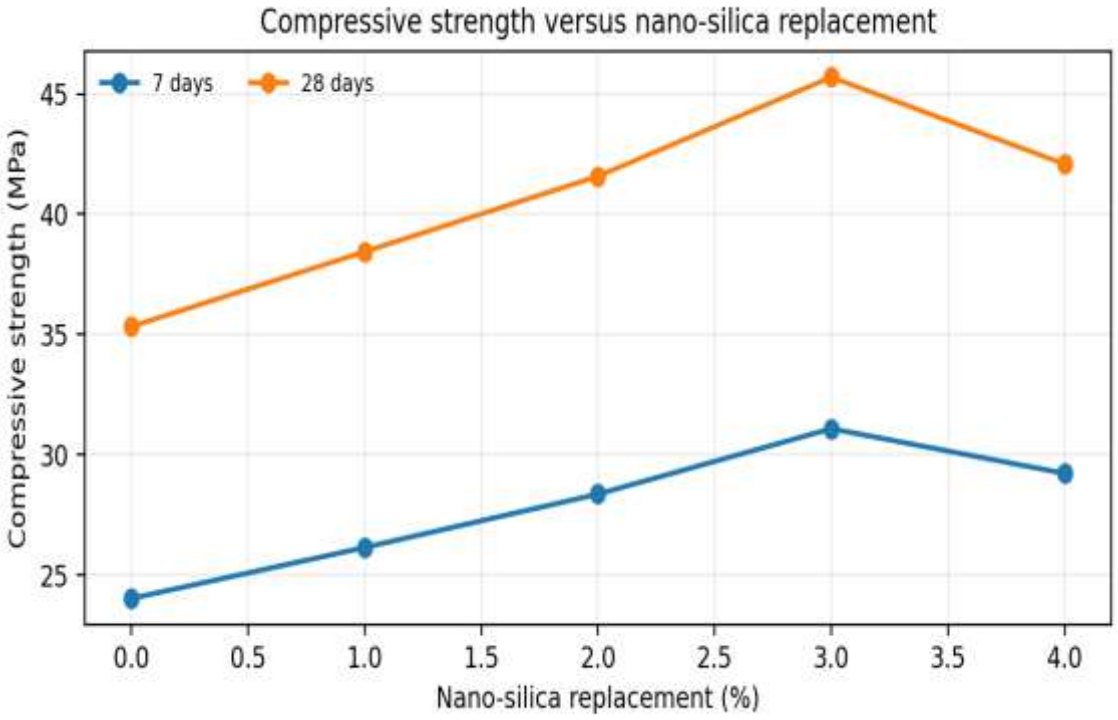


Fig. 1. Compressive strength at 7 and 28 days for different NS replacement levels.

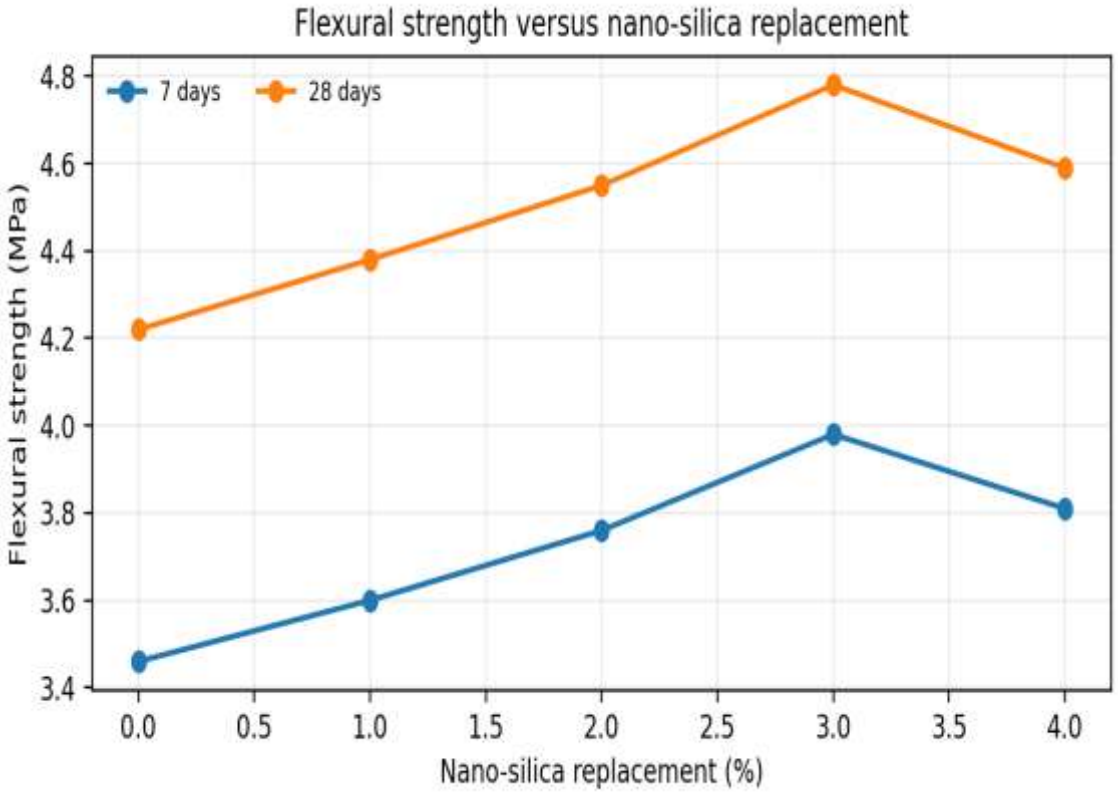


Fig. 2. Flexural strength at 7 and 28 days for different NS replacement levels.

At 3% NS, the 28-day split tensile strength increased from 4.16 to 4.73 MPa (13.37%), while the 28-day flexural strength increased from 4.22 to 4.78 MPa (13.27%). At 4% NS, the reported flexural strength decreased to 4.59 MPa but remained above the control value. The observed trends are consistent with explanations involving pore refinement and matrix densification reported in the literature [5], [6].

B. Influence of Pineapple, Sisal and Bamboo Fibres

All three fibre types reduced slump as fibre dosage increased. At 1% fibre, the reported slump values were 95 mm for PAF, 80 mm for SF and 75 mm for BF, compared with 120 mm for the control. At 1.5% BF, slump decreased to 60 mm. These results indicate a greater workability reduction for the BF and SF mixtures than for PAF at the stated dosage comparison.

TABLE IV. 28-DAY COMPRESSIVE STRENGTH OF FIBRE-REINFORCED CONCRETE

Fibre (%)	PAF (MPa)	SF (MPa)	BF (MPa)
0	35.33	35.33	35.33
0.25	36.72	36.94	36.91
0.5	38.12	38.26	38.63
0.75	39.92	39.84	40.08
1.0	38.46	40.02	40.21
1.25	—	39.53	40.43
1.5	—	—	39.46

TABLE V. 28-DAY SPLIT TENSILE STRENGTH OF FIBRE-REINFORCED CONCRETE

Fibre (%)	PAF (MPa)	SF (MPa)	BF (MPa)
0	4.16	4.16	4.16
0.25	4.46	4.54	4.64
0.5	4.62	4.76	4.83
0.75	4.85	4.88	4.91
1.0	4.66	4.92	4.98
1.25	—	4.84	5.02
1.5	—	—	4.74

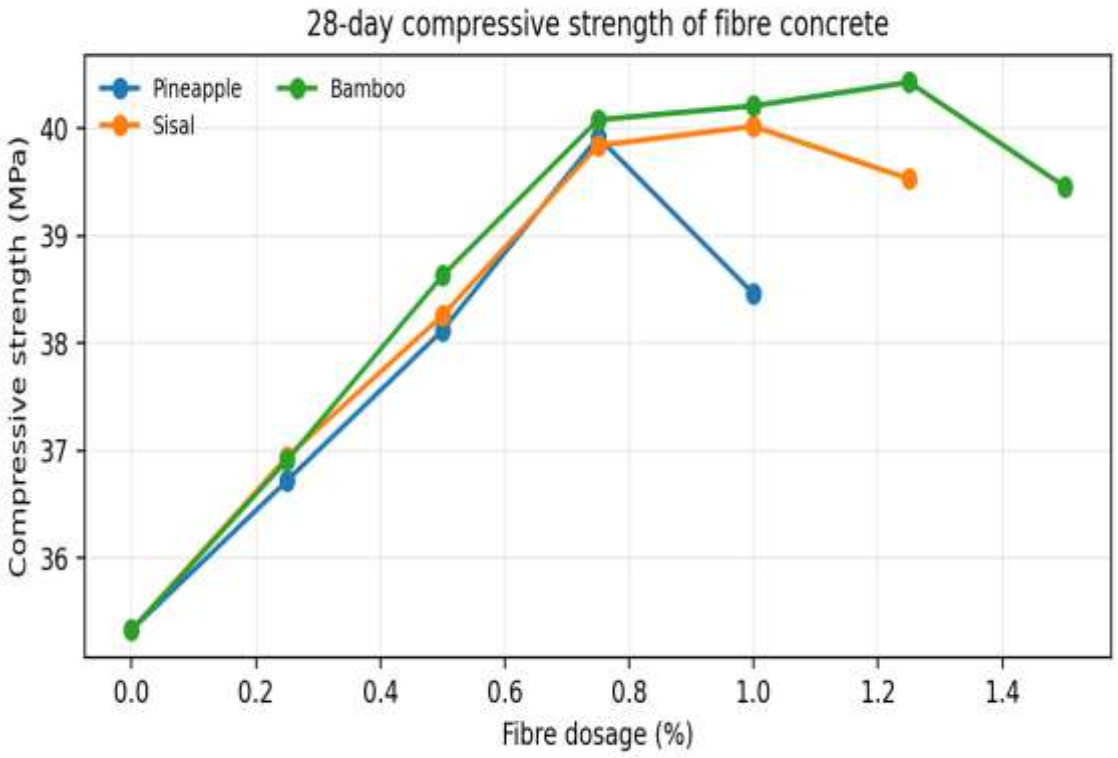


Fig. 3. Effect of fibre dosage on 28-day compressive strength.

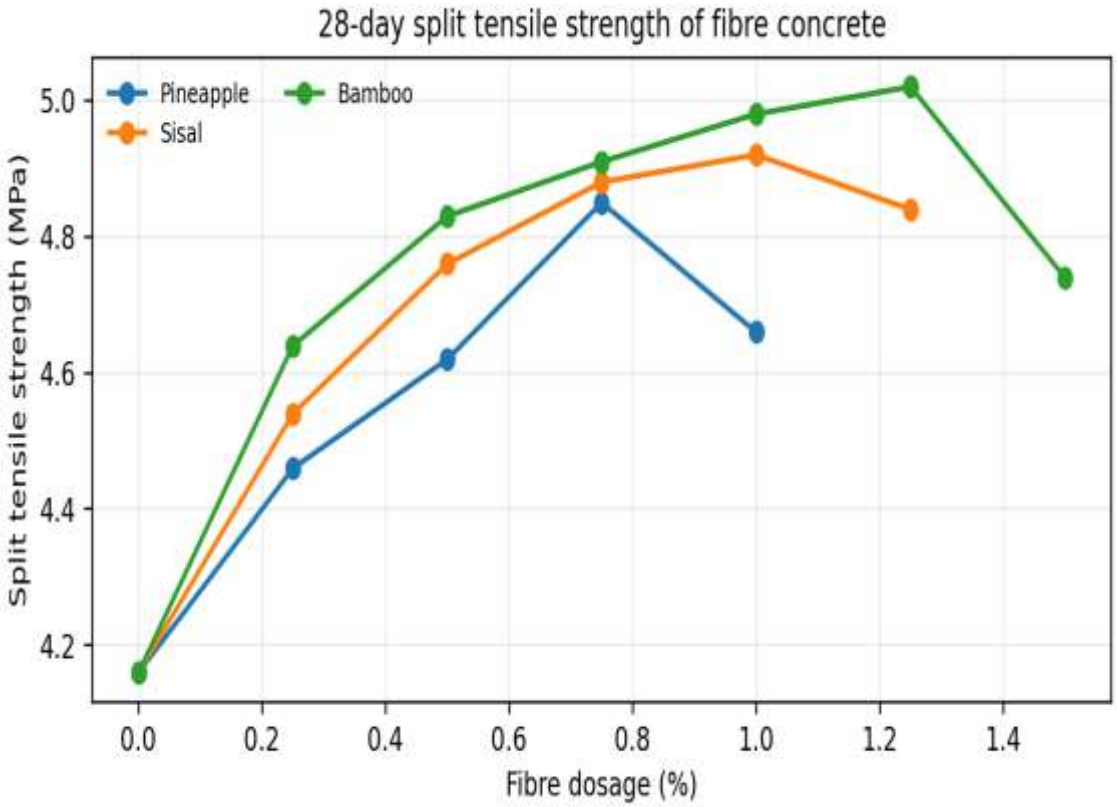


Fig. 4. Effect of fibre dosage on 28-day split tensile strength.

The maximum reported 28-day compressive strengths were 39.92 MPa at 0.75% PAF, 40.02 MPa at 1.0% SF and 40.43 MPa at 1.25% BF. Relative to the 35.33 MPa control, these values represent increases of approximately 13.0%, 13.3% and 14.4%, respectively. The maximum split tensile strength was 5.02 MPa at 1.25% BF, approximately 20.7% above the control value of 4.16 MPa. Strength decreased beyond the reported optimum dosages. Fibre clustering and non-uniform dispersion are possible explanations, although these mechanisms require direct microstructural or dispersion evidence [3], [9], [11].

The available flexural-strength table provides numerical values only up to 1.0% fibre content. The accompanying discussion reports a maximum 28-day flexural-strength improvement of 22.27% at 1.25% BF, but the corresponding absolute strength is not provided in the table. Accordingly, no missing flexural-strength value is inferred.

C. Young's Modulus

TABLE VI. YOUNG'S MODULUS OF SELECTED CONCRETE MIXTURES

Mix	NS (%)	BF (%)	7 days (MPa)	28 days (MPa)
C1 – Control	0	0	24500	29725
C2 – NS	3	0	27800	33800
C3 – BF	0	1.25	26820	31780
C4 – NS + BF	3	1.25	29410	34850

The combined C4 mixture exhibited the highest reported modulus, with values of 29,410 MPa at 7 days and 34,850 MPa at 28 days. Compared with the control, these values represent increases of approximately 20.0% and 17.2%, respectively. The NS-only and BF-only mixtures also exhibited higher reported moduli than the control; the NS-only mixture produced the greater value of the two individual additions at both test ages.

D. Durability Performance

The durability programme compared four mixtures: C1 (control), C2 (3% NS), C3 (1.25% BF) and C4 (3% NS + 1.25% BF). The reported mass losses and changes in compressive strength after 30-day chemical immersion are presented in Tables VII and VIII. In general, C4 recorded the lowest reported mass loss and strength reduction among the four mixtures.

TABLE VII. MASS LOSS AFTER 30-DAY CHEMICAL IMMERSION

Exposure	C1 Control	C2 NS	C3 BF	C4 NS + BF
2% HCl	0.38%	0.26%	0.28%	0.23%
Alkaline solution	0.57%	0.51%	0.52%	0.49%
5% Na_2SO_4	0.40%	0.39%	0.39%	0.37%
3% NaCl	0.35%	0.26%	0.24%	0.23%

TABLE VIII. COMPRESSIVE-STRENGTH LOSS AFTER CHEMICAL IMMERSION

Exposure	C1 Control	C2 NS	C3 BF	C4 NS + BF
HCl	3.40%	3.20%	2.70%	2.50%
Alkaline	4.30%	3.90%	4.00%	3.10%
Na_2SO_4	6.90%	5.40%	5.70%	5.10%
NaCl	3.10%	2.60%	2.70%	2.30%

For HCl exposure, the reported strength loss decreased from 3.40% for the control to 2.50% for C4. For alkaline exposure, the corresponding values were 4.30% and 3.10%; for sulphate exposure, 6.90% and 5.10%; and for chloride exposure, 3.10% and 2.30%. The mass-loss results show a similar overall trend. These results indicate that C4 performed best among the four mixtures under the stated immersion conditions. They do not establish long-term field durability or resistance to reinforcement corrosion.

No water was collected during the three-day permeability test, and the reported calculation consequently gave $Q = 0$ and a coefficient of permeability equal to zero. Because the measurement limit, specimen count for each mixture, apparatus calibration and detection threshold are not documented, this result should be interpreted as no measurable flow under the stated test conditions rather than proof of absolute impermeability.

IV. CONCLUSIONS

1. Among the investigated NS replacement levels, 3% NS produced the highest reported 28-day strengths: 45.70 MPa in compression, 4.73 MPa in split tension and 4.78 MPa in flexure.
2. The natural fibres improved the reported mechanical properties up to fibre-specific optimum contents. The maximum 28-day compressive strengths were 39.92 MPa at 0.75% PAF, 40.02 MPa at 1.0% SF and 40.43 MPa at 1.25% BF.
3. The highest reported 28-day split tensile strength was 5.02 MPa for the mixture containing 1.25% BF, approximately 20.7% higher than the control value.

4. Fibre addition reduced slump, with the largest reduction reported for BF at higher dosage. Workability control is therefore important when incorporating natural fibres.
5. The combined mixture containing 3% NS and 1.25% BF exhibited the highest reported Young's modulus and the lowest mass and compressive-strength losses among the four mixtures included in the durability programme.
6. No measurable water discharge was recorded during the three-day permeability test. This is a test-specific observation and does not establish zero permeability under all conditions.

REFERENCES

[1] F. Zhu, H. Qiao, and J. Li, "Sulfate attack resistance and reliability analysis of fibre-reinforced concrete materials," Emerging Materials Research, vol. 9, no. 4, pp. 1121–1130, 2020, doi: 10.1680/jemmr.20.00110.

[2] M. D. de Klerk, M. Kayondo, G. M. Moelich, W. I. de Villiers, R. Combrinck, and W. P. Boshoff, "Durability of chemically modified sisal fibre in cement-based composites," Construction and Building Materials, vol. 241, Art. no. 117835, 2020, doi: 10.1016/j.conbuildmat.2019.117835.

[3] J. Ahmad and Z. Zhou, "Mechanical properties of natural as well as synthetic fiber reinforced concrete: A review," Construction and Building Materials, vol. 333, Art. no. 127353, 2022, doi: 10.1016/j.conbuildmat.2022.127353.

[4] J. Liu, X. Xie, and L. Li, "Experimental study on mechanical properties and durability of grafted nano-SiO_2 modified rice straw fiber reinforced concrete," Construction and Building Materials, vol. 347, Art. no. 128575, 2022, doi: 10.1016/j.conbuildmat.2022.128575.

[5] M. Tabish, M. M. Zaheer, and A. Baqi, "Effect of nano-silica on mechanical, microstructural and durability properties of cement-based materials: A review," Journal of Building Engineering, vol. 65, Art. no. 105676, 2023, doi: 10.1016/j.jobe.2022.105676.

[6] F. Althoey, O. Zaid, R. Martínez-García, F. Alsharari, M. Ahmed, and M. M. Arbili, "Impact of nano-silica on the hydration, strength, durability, and microstructural properties of concrete: A state-of-the-art review," Case Studies in Construction Materials, vol. 18, Art. no. e01997, 2023, doi: 10.1016/j.cscm.2023.e01997.

[7] J. Liu, W. Zhao, and L. Li, "Effects of nano-SiO_2 grafting on improving the interfacial and mechanical properties of concrete with rice straw fibers," Construction and Building Materials, vol. 398, Art. no. 132516, 2023, doi: 10.1016/j.conbuildmat.2023.132516.

[8] V. S. Kashyap, G. Sancheti, J. S. Yadav, and U. Agrawal, "Smart sustainable concrete: Enhancing the strength and durability with nano silica," Smart Construction and Sustainable Cities, vol. 1, Art. no. 20, 2023, doi: 10.1007/s44268-023-00023-1.

[9] K. Karthik et al., "State of the art: Natural fibre-reinforced composites in advanced development and their physical/chemical/mechanical properties," Chinese Journal of Analytical Chemistry, vol. 52, no. 7, Art. no. 100415, 2024, doi: 10.1016/j.cjac.2024.100415.

[10] T. A. Fode, Y. A. C. Jande, T. Kivevele, and N. Rahbar, "Effect of waste water bottle and treated sisal fibers on the durability and mechanical properties of concrete," Scientific Reports, vol. 15, Art. no. 7945, 2025, doi: 10.1038/s41598-025-92306-z.

[11] Y. Lin, M. Ding, L. Wang, and Y. Wei, "Experimental study on mechanical properties of raw bamboo fibre-reinforced concrete," Case Studies in Construction Materials, vol. 21, Art. no. e04003, 2024, doi: 10.1016/j.cscm.2024.e04003.

[12] K. Shanmugam, V. Deivasigamani, G. K. Arunvivek, and B. C. Olaiya, "Effect of nano-silica and sisal fibre on the mechanical and durability properties of concrete," Scientific Reports, vol. 16, Art. no. 8212, 2026, doi: 10.1038/s41598-026-37901-4.