Research Article

Journal of Environmental Nanotechnology

Comparative Analysis on Load-deformation Behavior of RC Slabs Incorporating Nano-SiO_2 and Coconut Fibers

A. Kandasamy[1*], P. Priya Rachel[2], Mahmoud Al Khazaleh[3] and K. Athiappan[4]

[1]Department of Civil Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, TN, India

[2]Department of Civil Engineering, S. A. Engineering College, Thiruverkadu, Chennai, TN, India

[3]Department of Civil Engineering, Dean of Munib and Angela Masri Faculty of Engineering, Aqaba University of Technology, Aqaba, Jordan

[4]Department of Civil Engineering, Thiagarajar College of Engineering, Madurai, TN, India

Received: 28.12.2024 Accepted: 28.02.2025 Published: 30.03.2025

*asohankandasamy@gmail.com

ABSTRACT

For modern building materials, improving the structural performance of reinforced concrete (RC) slabs is essential, especially when it comes to maximizing strength, durability, and sustainability. The load-deformation properties of RC slabs with Nano-SiO_2 and coconut fibers are examined in this work. By combining these materials, slabs' mechanical qualities, self-weight, and structural efficiency are intended to be improved. Because of its exceptional strength and self-cleaning qualities, Nano-SiO_2 strengthens the concrete matrix, increasing its resilience to environmental deterioration and durability. As a natural reinforcement, coconut fibers improve flexural performance, toughness, and fracture resistance. Modified RC slabs are cast and tested in this research to assess their overall structural integrity, deflection behavior, and load-bearing capability. Experimental testing, such as load versus deflection analysis, is carried out to compare the slabs' deformation characteristics. The findings show that in comparison to traditional slabs, slabs containing Nano-SiO_2 and coconut fibers have better load resistance, less breaking, and increased ductility. Fiber reinforcement also increases overall structural efficiency by lowering dead weight, which may enable wider spans and lower foundation loads. The results of this study provide essential light on the advantages of incorporating coconut fibers and Nano-SiO_2 into RC slabs. These materials offer a novel approach to lightweight, high-performance slab systems appropriate for contemporary building applications by improving mechanical qualities and sustainability. The research emphasizes how concrete solutions based on cutting-edge and environmentally friendly materials may increase the lifetime and effectiveness of RC constructions.

Keywords: RC slab; Nano-SiO_2; Coconut fiber; Deflection and strain.

1. INTRODUCTION

Modern construction requires improving the structural performance of reinforced concrete (RC) slabs, especially to achieve greater strength, durability, and sustainability. In order to increase structural efficiency, decrease self-weight, and improve mechanical qualities, this study investigates the addition of coconut fibers and Nano-SiO_2 to RC slabs. Nano-SiO_2 provides self-cleaning qualities and improves the concrete matrix by making it more resistant to environmental damage. In the meantime, coconut fibers serve as organic reinforcement, enhancing toughness, fracture resistance, and flexural performance. The structural integrity, deformation behavior, and load-bearing capability of the slabs are evaluated using experimental studies, such as load versus deflection analysis. The findings show that, in comparison to standard slabs, slabs treated with Nano-SiO_2 and coconut fibers have improved ductility, decreased cracking, and more excellent load resistance. Additionally, by cutting material prices, energy consumption, and concrete use by up to 35%, this method promotes sustainability. The study emphasizes how these cutting-edge materials may be used to produce lightweight, high-performance RC slabs that are appropriate for contemporary construction and provide increased structural lifetime and resource economy.

The eco-friendliness, affordability, and potential to improve the mechanical and durability qualities of reinforced concrete (RC) composites have drawn attention to natural fibers like kenaf and coconut fibers (Abedi *et al.* 2023). Their addition to cementitious materials increases the effectiveness of reinforcing and supporting robust and sustainable infrastructure applications. In reinforced concrete (RC) applications, natural fiber-reinforced concrete (NFRC) has shown a great deal of promise for improving impact resistance and structural performance (Wang *et al.* 2023). Studies demonstrate how fiber type, volume, and length affect mechanical characteristics, supporting NFRC as an environmentally friendly substitute for impact-resistant building and structural dynamics. Natural fibers like coconut and kapok may be used to reinforce concrete (RC) to improve pore structure, compressive strength, and thermal insulation, all of which contribute to sustainability (Susurluk *et al.* 2024). According to studies, adding fiber alters the cement matrix, improving its insulating and mechanical qualities for environmentally friendly buildings. In reinforced concrete (RC), natural fiber-based reinforcements provide a sustainable substitute for traditional materials, lowering carbon emissions while improving mechanical performance (Saini *et al.* 2024). Their potential for both new building and retrofitting is highlighted by research, encouraging the use of eco-friendly and practical structural applications. A study on voided biaxial concrete slabs using Bubble Deck technology demonstrated up to 35% dead weight reduction and nearly 100% capacity increase, enabling lighter, stronger, and thinner slabs through recycled plastic spheres (Abg *et al.* 2020). In reinforced concrete (RC), natural fiber-based reinforcements provide a sustainable substitute for traditional materials, lowering carbon emissions while improving mechanical performance (Ahmed *et al.* 2022). Their potential for both new building and retrofitting is highlighted by research, encouraging the use of eco-friendly and practical structural applications. By improving flexural strength, impact resistance, and crack control, treated coconut fibers can be used in reinforced concrete (RC), which promotes sustainable building practices. According to research, the ideal fiber content balances workability and mechanical performance while enhancing toughness and durability (Hwang *et al*. 2016). The mechanical and durability qualities of reinforced concrete (RC) are improved by the addition of natural fibers like coir and industrial byproducts like metakaolin and silica fume (Nawab *et al.* 2023). Their capacity to increase microstructural density and compressive strength is demonstrated by research, supporting high-performance and environmentally friendly cementitious composites. A comparative study on conventional and Bubble Deck slabs found that Bubble Deck slabs reduced weight by 33%, increased load capacity by 23%, and showed higher performance with alternate bubble arrangements, though with slightly greater deflection (Ranjitham and Manjunath, 2018).

In order to improve strength and durability, ultra-high-performance fiber-reinforced concrete (UHPFRC) requires sustainable adjustments, according to recent research (Zaid *et al.* 2023). The addition of eggshell powder (ESP) and Nano-silica (NS) has shown encouraging improvements in flexural strength, fiber-matrix bonding, and resistance to chloride and water penetration (Zhang *et al.* 2023a). Because graphene oxide (GO) may improve mechanical strength, durability, and volume stability, it has drawn a lot of interest as a Nano-reinforcement in cement-based composites (CBCs). Its dispersion, however, improves permeability and corrosion resistance while decreasing fluidity, which impacts CBC's workability. By improving its microstructure and stopping cracks from spreading, the addition of basalt fiber (BF) and Nano-SiO_2 (NS) to recycled aggregate concrete (RAC) improves the material's durability and mechanical qualities (Zheng *et al.* 2023). When NS and BF are used together, interfacial bonding is strengthened, improving resistance to salt erosion, carbonization, and freeze-thaw cycles. By lowering environmental pollution and increasing durability and resistance to chloride penetration, the use of ceramic waste in concrete improves sustainability. Ceramic-based concrete has better freeze-thaw and high-temperature resilience than traditional concrete but has a lower mechanical strength (Zhang *et al.* 2023b). The performance of cementitious materials has been dramatically improved by developments in nanotechnology, especially the use of Nano silica, which increases strength and durability (Aslam *et al.* 2024). Additionally, by using less Portland cement and improving the qualities of concrete in harsh environments, Nano silica lessens its effect on the environment (Jose and Rajkumar, 2024). Under axial compression, ferrogeopolymer confinement has shown encouraging promise for improving the ductility and strength of brick masonry columns. When compared to unconfined columns, the employment of geopolymer mortar with welded steel mesh significantly increases load-bearing capacity, deformation resistance, and energy absorption. In textile-reinforced cementitious composites (TRC), the use of fly ash and lightweight expanded glass aggregates improves sustainability without sacrificing tensile strength (Dinh *et al.* 2024). Cracking resistance is enhanced by higher fabric reinforcement ratios, and the inclusion of nylon fiber and stress-strain behavior is accurately predicted using an analytical model.

The potential of nano alumina and polyacrylamide-based superabsorbent polymers to improve the mechanical and microstructural characteristics of concrete by boosting durability, decreasing shrinkage, and improving hydration under self-curing conditions has been investigated (Sujitha *et al*. 2023). According to earlier research, SAPs facilitate internal curing, while NA improves pore structure to produce concrete that is denser, more resilient to chemical assaults, and more long-lasting. Magnesium phosphate cement (MPC) is a possible substitute for conventional organic coatings for steel protection because of its exceptional corrosion resistance. The resilience and anti-corrosion properties of MPC coatings are further improved by the addition of nanotitania (TiO_2), which successfully prolongs the life of low-carbon steel under challenging conditions. Through microstructure refinement, improved hydration, and strengthened interfacial bonding, nanomaterials including graphene oxide, nano-silica, and nano-titania have been shown to improve the mechanical characteristics of cementitious materials. According to studies, the correct doses are essential for optimising their advantages, with graphene oxide (0.05–0.5%) and nano-silica (1–8%) greatly enhancing concrete strength.

By enhancing hydration and filling microspores, silane-functionalized halloysite Nano clay (SNC) in sodium polyacrylamide (SAP) has been shown to improve cementitious materials' mechanical strength and water absorption. According to studies, SNC/SAP composites are useful for long-lasting concrete applications because they considerably improve compressive, flexural, and tensile strengths while lowering shrinkage and micro crack development. By increasing hydration and decreasing shrinkage, silanized graphene oxide (SGO) in combination with superabsorbent polymers (SAPs) has been shown to improve cementitious materials' mechanical strength, water retention, and durability. According to studies, the SGO/SAP composite is a viable addition for high-performance concrete applications because it increases internal curing, reduces micro cracks, and strengthens the concrete matrix (Sujitha *et al*. 2024). With advantages including decreased density, resistance to cracking, and increased durability, coconut fibres are being investigated more and more as a sustainable reinforcement in cementitious composites. According to research, the combination of coconut fibre with textile mesh improves mechanical performance, which makes it a good substitute for synthetic fibres in concrete applications (Martinelli *et al.* 2023).

There are still a number of research gaps despite significant progress in improving the mechanical and durability qualities of reinforced concrete (RC) using natural fibers, nanomaterials, and sustainable additives. Research on the combined effects of coconut fibers, kapok fibers, and industrial byproducts like silica fume and metakaolin on load-deformation characteristics, crack resistance, and long-term durability is scarce despite studies showing the advantages of adding these materials to RC composites. Furthermore, nothing is known about how Nano-SiO_2 may minimize self-weight and environmental deterioration while maximizing structural effectiveness, especially in large-scale structural applications such as RC slabs. The majority of current research is on improving individual materials rather than examining the synergistic benefits of mixing nano-modifications with natural fibers. Furthermore, there is sometimes a lack of thorough experimental validation with actual building settings in studies on sustainable reinforcing options.

2. MATERIALS AND METHODOLOGY

This study utilizes ordinary Portland cement (OPC), Nano-SiO_2, coconut fibers, fine and coarse aggregates, steel reinforcement bars, superplasticizers, and clean water to enhance the structural performance of reinforced concrete (RC) slabs. Nano-SiO_2 improves the concrete matrix by increasing durability, strength, and self-cleaning properties, while coconut fibers act as natural reinforcement, enhancing flexural performance, crack resistance, and toughness. The slabs are cast and tested using a load testing frame, dial gauges, and strain gauges to analyze their load-deformation behavior through experimental load versus deflection analysis. Results demonstrate that incorporating Nano-SiO_2 and coconut fibers enhances load resistance, reduces cracking, lowers self-weight, and increases ductility, allowing for wider spans and reduced foundation loads. These materials offer a sustainable, high-performance solution for modern concrete applications by improving the mechanical properties, efficiency, and longevity of RC structures.

Table 1. Mix proportion

Slab	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water-Cement Ratio	Nano-SiO_2 (%) (by cement weight)	Coconut Fibre (%) (by cement weight)	Superplasticizer (%)
1	400	700	1200	0.45	1	0.4	1.0
2	400	690	1210	0.45	1. 5	0. 6	1.0
3	400	680	1220	0.45	2	0.8	1.2

The mix proportions for reinforced concrete (RC) slabs using coconut fibers and Nano-SiO_2 are shown in Table 1. It lists the amounts of admixtures, cement, fine and coarse aggregates, and water-to-cement ratio. Three distinct mix designs are shown, with variations in the amount of coconut fiber (0.4–0.8% by cement weight) and Nano-SiO_2 (1–2%). A superplasticizer (1.0–1.2%) is also used to improve workability. The size of the 3 slap is 1m x 0.1m x 0.1m. The following figure 1 shows the specimen images.

Fig. 1: RC Slab image using coconut fibers and Nano-SiO_2

2.1 Concrete Mix Design

By adding a margin (1.65 times the standard deviation) to the characteristic strength of 25 N/mm², the mix design for M25 grade concrete, as per IS 10262:2009, attempts to attain a goal compressive strength of 31.6 N/mm² at 28 days. In accordance with IS 456:2000's maximum limit for moderate exposure circumstances, a water-to-cement ratio of 0.45 is used. According to the design, the mix ratio is 1:1.04:2.21:0.45 (cement: fine aggregate: coarse aggregate: water-cement ratio) with 413.33 kg/m³ of cement, 429.8 kg/m³ of fine aggregate, and 913.9 kg/m³ of coarse aggregate. For conventional construction, this proportioning guarantees a workable mixture with sufficient strength and longevity.

2.2 Experimental Procedure

The slump test and the compaction factor test, both described in IS 1199:1959, are two popular tests used to determine whether new concrete is workable.

2.2.1 The Slump Test

The consistency and workability of concrete are assessed using the slump test. The slump cone, a frustum-shaped mold that is 30 cm tall, 20 cm in base diameter, and 10 cm in top diameter, is used. Three equal layers of new concrete are poured into the cone, which is set on a non-absorbent surface. To guarantee compaction, a conventional tamping rod is used to tamp each layer 25 times. The top surface is leveled after filling, and the cone is cautiously raised vertically. The slump value is calculated by measuring the concrete's subsequent sinking in millimeters.

Table 2. Compaction factor test results

Weight of empty cylinder (W_1)	Weight of cylinder + partially compacted concrete (W_2)	Weight of cylinder + fully compacted concrete (W_3)	Compaction factor $(W_2-W_1) / (W_3-W_1)$
5.787	16.056	17.86	0.85

The compacting factor of the fresh concrete was found to be 0.825.

2.2.3 Compressive Strength Test

The compressive strength test for cubes was conducted using a compression testing machine as per IS 516: 1964. The specimens were cleaned, aligned centrally in the loading frame, and subjected to a continuous load at 140 kg/cm²/min until failure. The ultimate load sustained by each specimen was recorded, as shown in Figure 2.

Table 3. 7th day compressive strength

Specimen	Load (P) (10^3 N)	Area (A) (mm^2)	Compressive Strength = (P/A) (N/mm^2)
1	490	150×150	21.78
2	530	150×150	23.56
3	580	150×150	25.78

Average Compressive Strength of cubes at 7 days = 23.71 N/mm². Shown in Table 3.

Table 4. 28th day compressive strength

Specimen	Load (P) (10^3 N)	Area (A) (mm^2)	Compressive Strength = (P/A) (N/mm^2)
1	725	150×150	32.22
2	690	150×150	30.67
3	730	150×150	32.44

Table 4 shows the average Compressive Strength of cubes at 28 days = 31.78 N/mm²

Fig. 2: Compressive strength test

2.2.4 Split Tensile Strength Test

Concrete cylinders' split tensile strength test was carried out in accordance with IS 516:1964. This test included placing the cylinder specimen horizontally between a universal testing machine's loading surfaces and applying stress until the cylinder failed along its vertical diameter, as shown in Figure 3. The failure resulted from an element on the vertical diameter experiencing horizontal stress when the load was applied along the generatrix. Then, using the proper formula, the split tensile strength was determined. Table 5 displays the findings for the cylinders' 28-day split tensile strength.

Table 5. Split tensile strength of cylinders

Specimen	Load (P) (10^3 N)	Split-Tensile Strength=2P/πLD (N/mm^2)
1	155	2.192
2	160	2.26
3	152	2.15

Average split tensile strength of cylinders = 2.201 N/mm^2.

Fig. 3: Split tensile strength test

2.2.5 Flexural Strength Test

The ability of a beam or slab to tolerate bending failure is known as flexural strength. Unreinforced concrete beams usually sized 100 x 100 x 500 mm, are tested with a span of three times their depth to ascertain it. The Modulus of Rupture (MR), which typically falls between 12 and 20 percent of the compressive strength, is used to represent the strength in N/mm². However, laboratory testing is the most effective way to establish precise correlations for particular materials. After 28 days of external curing, the specimens are examined to determine their flexural strength. The experimental setup is shown in Figure 4.

Table 6. Modulus of rupture of prisms

Specimen	Load P (KN)	Modulus of Rupture=PL/bd^2 (N/mm^2)
1	13	6.5
2	14.5	7.25
3	14	7

Average modulus of rupture of prism = 6.92 N/mm^2. Shown in Table 6.

Fig. 4: Flexural strength test

3. RESULTS AND DISCUSSION

3.1 Testing Procedure

The solid slabs are tested with the support as supported and loaded with a two-point load. The slabs have been tested at an age of 28 days. The specimen is placed in the loading frame of capacity. The centerline and supports are adjusted, and the dial gauge is fixed in their correct locations. At the end of each load increment, observations are made, and measurements are made for mid-span deflection, crack development, and propagation on the slab surface.

The deflection of the specimens is measured at their mid-span beneath the lower face of the tested slabs. When the slab reaches the advanced stage of loading, then the smaller increments are applied until the failure. It was noticed that where the load indicator stopped recording anymore, the deflections increased very fast without any load being applied.

Table 7. Test results of slab 1

S. No.	Load (kN)	Deflection (mm)	Strain			
			I	II	III	IV
1	0	0	0.001	0	0	0
2	2	0	0.001	0.00102	0.00103	0.00101
3	4	0	0.00164	0.00164	0.00166	0.00101
4	6	0	0.00195	0.00195	0.00192	0.00165
5	8	0	0.0038	0.0038	0.0036	0.00194
6	10	1.30	0.00448	0.00448	0.00444	0.0034
7	12	1.52	0.00654	0.006574	0.0658	0.00441
8	14	1.63	0.00774	0.00774	0.00770	0.00656
9	16	2.01	0.00925	0.00925	0.00920	0.00976
10	18	2.150	0.01014	0.01014	0.01010	0.01019
11	20	2.18	0.0123	0.0123	0.0127	0.0130
12	22	2.79	0.01452	0.01452	0.01454	0.01457
13	24	2.93	0.01968	0.01968	0.01964	0.01961
14	26	3.44	0.02214	0.02214	0.02212	0.02217
15	28	3.89	0.02432	0.02432	0.02430	0.02434
16	30	4.12	0.02045	0.02045	0.02648	0.02650
17	32	4.23	0.02948	0.02948	0.02950	0.02949
18	34	4.56	0.03241	0.03241	0.03243	0.03244
19	36	4.88	0.03725	0.03725	0.03726	0.03727
20	38	5.32	0.03950	0.03950	0.03952	0.03952
21	40	5.98	0.04120	0.04120	0.04121	0.04122
22	42	6.12	0.04430	0.04430	0.04432	0.04432
23	44	6.76	0.04820	0.04820	0.04820	0.04821
24	46	7.21	0.05010	0.05010	0.05011	0.05011
25	48	7.94	0.05215	0.05215	0.05215	0.05214
26	50	8.66	0.05728	0.05728	0.05728	0.05730
27	52	9.20	0.06218	0.06218	0.06218	0.06220
28	54	10.45	0.06492	0.06492	0.06493	0.06494
29	56	11.80	0.06810	0.06810	0.06811	0.06810
30	58	12.56	0.0728	0.0728	0.07281	0.07280
31	60	13.20	0.0752	0.0752	0.07521	0.07520
32	62	14.78	0.07918	0.07918	0.07921	0.07918
33	64	15.90	0.08214	0.08214	0.08213	0.08214

The load, deflection, and strain values that were measured during an experimental investigation are shown in Table 7. It contains strain measurements at four sites (I, II, III, and IV) and incremental load values (kN) ranging from 0 to 64, which equate to deflection (mm). Whereas strain measurements exhibit steady fluctuations across the recorded points, deflection rises in direct proportion to load. The information demonstrates how the structure responds to increasing stresses, including deformation and material strain.

In a structural investigation, Figure 5 illustrates the connection between load and deflection. In contrast to the blue line, which first climbs more slowly but becomes more pronounced at higher loads, the red line depicts a linear increase in load. This suggests that as the applied force rises, deflection gradually increases. Increasing deflection at increasing load levels is indicative of a nonlinear deformation behavior, according to the trend.

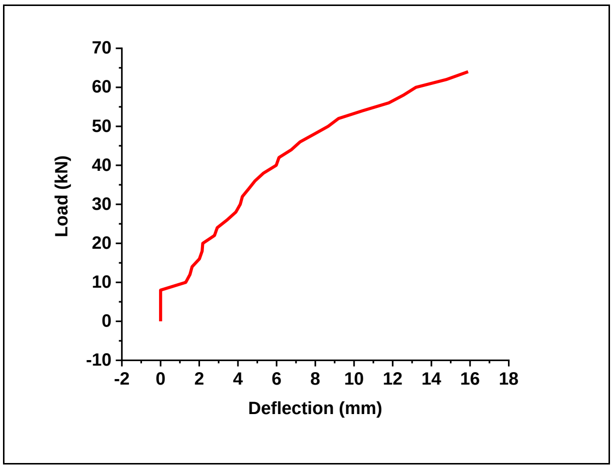

Fig. 5: Load vs deflection curve for slab 1

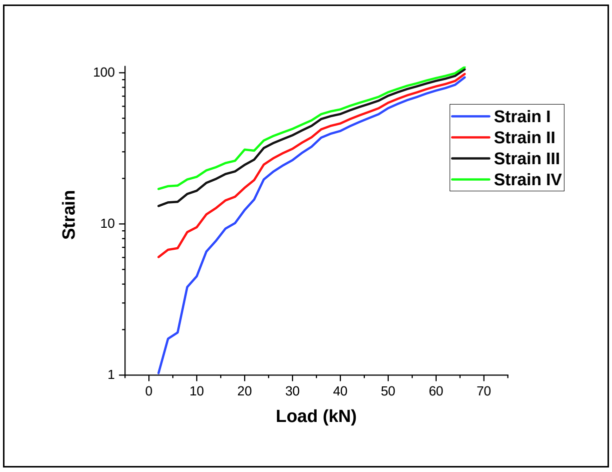

Fig. 6: Load vs strain curve for slab 1

The slabs were supported on two sides. Slabs caused failure by applying a two-point load. The deflections were measured with the help of a dial gauge. Slab 1(Conventional slab) carried a load of 64kN and caused a deflection of about 15.9mm. The connection between load and strain throughout an experiment is shown in Figure 6 at four distinct points (I, II, III, and IV). At first, the load grows significantly, yet the strain values are almost constant and hardly change. The material underwent consistent strain distribution, as shown by the strain curves' clustering toward the top. This implies that variations in strain were comparatively.

Table 8. Test results of slab specimen 2

S. No.	Load (kN)	Deflection (mm)	Strain			
			I	II	III	IV
1	0	0	0	0	0	0
2	2	0	0.00103	0.00103	0.00104	0.00102
3	4	0	0.00174	0.00174	0.00176	0.00175
4	6	0	0.00191	0.00191	0.00190	0.00192
5	8	0	0.00382	0.00382	0.00367	0.00368
6	10	1.30	0.00450	0.00450	0.00447	0.00447
7	12	1.52	0.00656	0.00656	0.00658	0.00660
8	14	1.63	0.00772	0.00772	0.00774	0.00770
9	16	2.01	0.00930	0.00930	0.00927	0.00926
10	18	2.15	0.01012	0.01012	0.01014	0.01016
11	20	2.18	0.01235	0.01235	0.01247	0.0150
12	22	2.79	0.01449	0.01449	0.01451	0.01450
13	24	2.93	0.01968	0.01968	0.01964	0.01962
14	26	3.44	0.02218	0.02218	0.02214	0.02216
15	28	3.85	0.02435	0.02435	0.02428	0.02428
16	30	4.09	0.02640	0.02640	0.02648	0.02648
17	32	4.19	0.02950	0.02950	0.02947	0.02945
18	34	4.54	0.03240	0.03240	0.03242	0.03244
19	36	4.85	0.03721	0.03721	0.03726	0.03724
20	38	5.28	0.03952	0.03952	0.03952	0.03950

21	40	5.96	0.04118	0.04118	0.04121	0.04120
22	42	6.07	0.04431	0.04431	0.04432	0.04434
23	44	6.81	0.04720	0.04720	0.04725	0.04723
24	46	7.25	0.05011	0.05011	0.05005	0.05009
25	48	7.96	0.05316	0.05316	0.05320	0.05320
26	50	8.76	0.05828	0.05828	0.05830	0.05829
27	52	9.22	0.06220	0.06220	0.06218	0.06218
28	54	10.47	0.06594	0.06594	0.06593	0.06595
29	56	11.86	0.06910	0.06910	0.06913	0.06911
30	58	12.58	0.07284	0.07284	0.07281	0.07280
31	60	13.25	0.07620	0.07620	0.07623	0.07622
32	62	14.80	0.07920	0.07920	0.07921	0.07922
33	64	15.95	0.08315	0.08315	0.08316	0.08314
34	66	17.45	0.09315	0.09317	0.09316	0.09314

Test results for Slab Specimen 2 are included in Table 8, along with measurements taken at various load increments. It contains information on strain values collected at different phases, load, and deflection. Progressive deformation is shown by increasing strain and deflection measurements as the load rises from 0 to 66 kN. At a 66 kN load, the maximum strain ever measured is 0.09317.

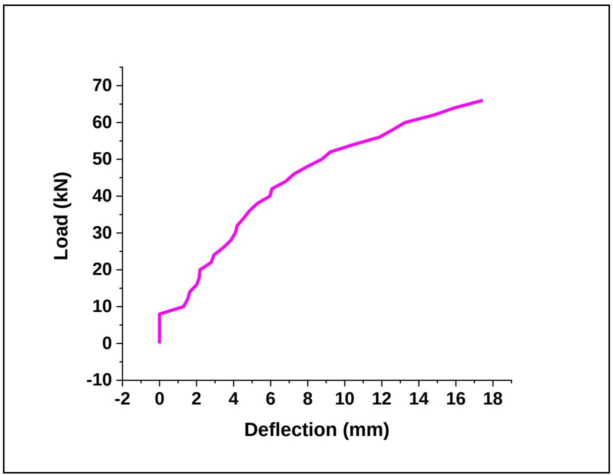

Fig. 7: Load Vs deflection curve for slab 2

The load-deflection connection is shown as a percentage in Figure 7. Nearly instantly, the load approaches 100% and stays there. With some oscillations, the deflection steadily increases over time after beginning low. This shows that under stress, deflection keeps growing even when the load is constant.

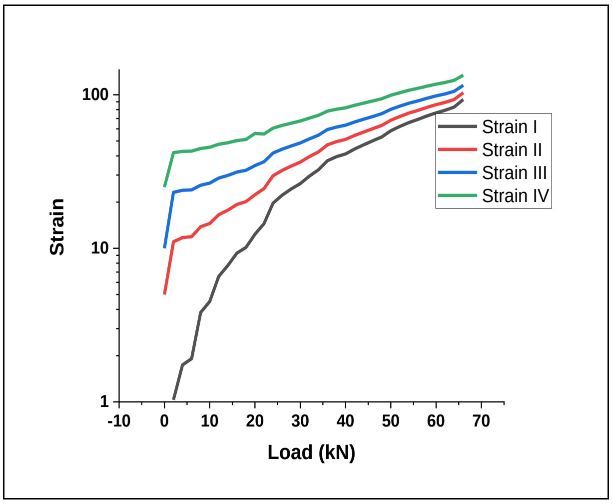

Fig. 8: Load vs strain curve for slab 2

The connection between load and strain at several places (I, II, III, and IV) is shown in Figure 8. Nearly immediately, the load (orange line) approaches 100% and remains steady. Additionally, strain values (gray, yellow, and blue) increase quickly and level out close to 100%. This suggests that strain rises sharply at first before stabilizing.

Table 9. Test results of slab specimen 3

S. No.	Load (kN)	Deflection (mm)	Strain			
			I	II	III	IV
1	0	0	0	0	0	0
2	2	0	0.00109	0.00109	0.00108	0.00107
3	4	0	0.00154	0.00154	0.00152	0.00152
4	6	0	0.00192	0.00192	0.00195	0.00195
5	8	0	0.00278	0.00278	0.00280	0.00280

6	10	0	0.00391	0.00391	0.00389	0.00389
7	12	1.17	0.00634	0.00634	0.00630	0.00631
8	14	1.38	0.00771	0.00771	0.00772	0.00772
9	16	1.45	0.00936	0.00936	0.00931	0.00931
10	18	1.57	0.01018	0.01018	0.01014	0.01012
11	20	1.72	0.0119	0.0119	0.0118	0.0117
12	22	1.89	0.01325	0.01325	0.01322	0.01323
13	24	2.32	0.01968	0.01968	0.01964	0.01961
14	26	2.51	0.02218	0.02218	0.02220	0.02219
15	28	3.29	0.02428	0.02428	0.02426	0.02427
16	30	3.83	0.02634	0.02634	0.02636	0.02636
17	32	4.62	0.02950	0.02950	0.02948	0.02949
18	34	4.80	0.03230	0.03230	0.03231	0.03229
19	36	5.22	0.03628	0.03628	0.03629	0.03627
20	38	5.79	0.03952	0.03952	0.03954	0.03953
21	40	6.13	0.04122	0.04122	0.04120	0.04121
22	42	6.67	0.04432	0.04432	0.04428	0.04428
23	44	6.98	0.04840	0.04840	0.04840	0.04840
24	46	7.32	0.05012	0.05012	0.05013	0.05011
25	48	8.50	0.05340	0.05340	0.05339	0.05341
26	50	9.31	0.05619	0.05619	0.05617	0.05618
27	52	10.11	0.06148	0.06148	0.06152	0.06151
28	54	10.99	0.06492	0.06492	0.06493	0.06494
29	56	11.38	0.06820	0.06820	0.06817	0.06819
30	58	11.92	0.07380	0.07380	0.07382	0.07381
31	60	12.50	0.07620	0.07620	0.07218	0.07218
32	62	12.89	0.07800	0.07801	0.07802	0.07801
33	64	13.34	0.08110	0.08111	0.08109	0.08112
34	66	13.78	0.08433	0.08433	0.08434	0.08437
35	68	13.99	0.08712	0.08710	0.08712	0.08714

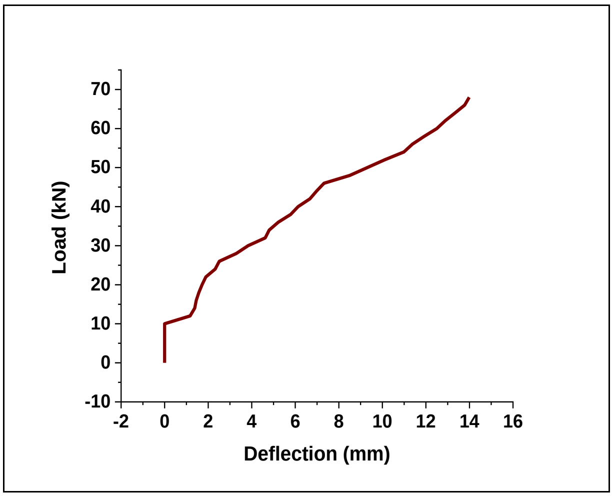

Fig. 9: Load vs deflection curve for slab 3

Table 9 displays the test results for Slab Specimen 3, showing load (kN), deflection (mm), and strain values. As the load increases from 0 to 68 kN, deflection and strain also rise, indicating structural deformation. The strain values are recorded at four different points (I, II, III, IV) to monitor consistency. The highest strain observed is 0.08714 at 68 kN load.

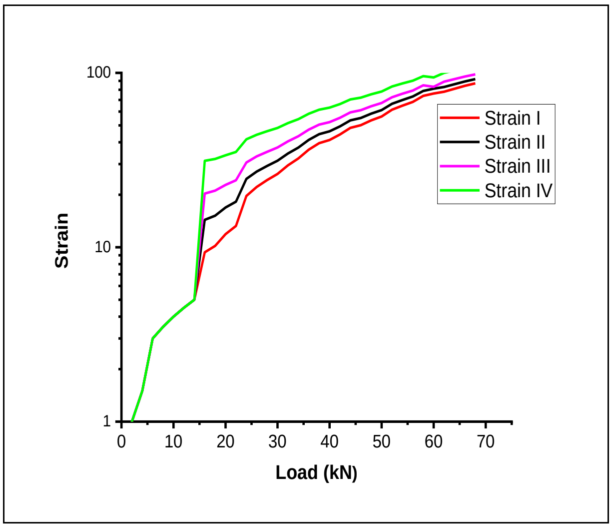

Fig. 10: Load vs strain curve for slab 3

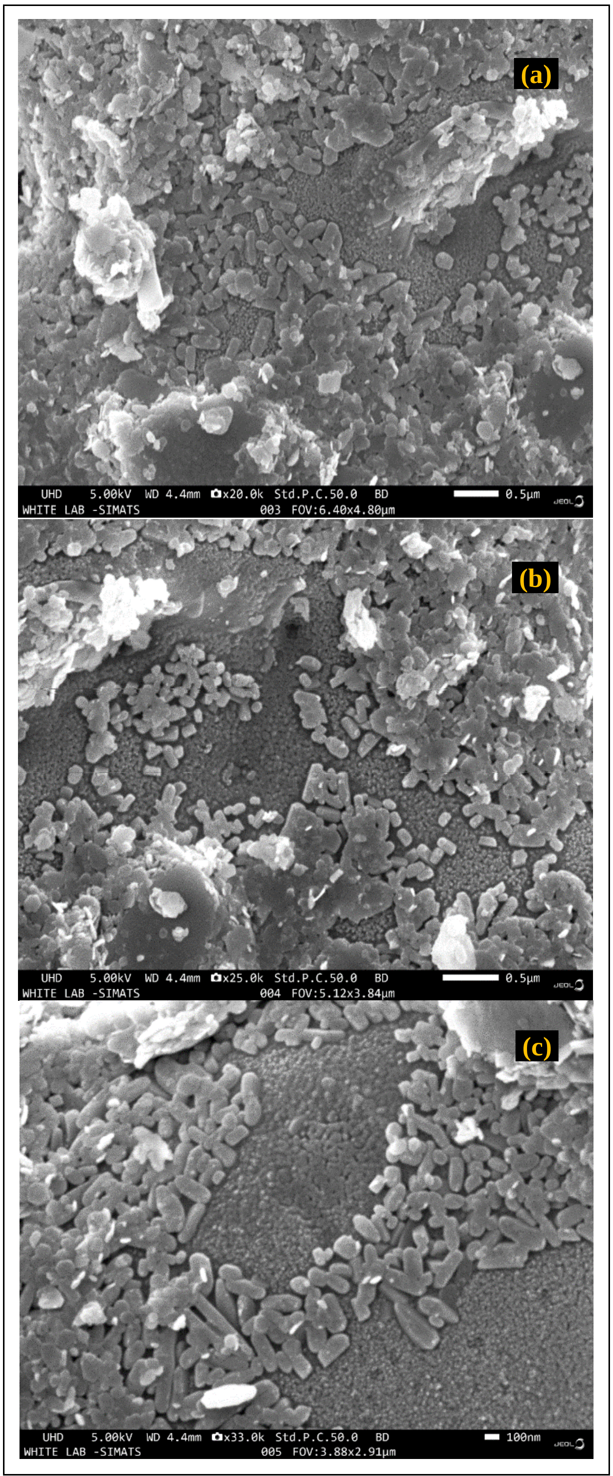

Fig. 10: SEM analysis of RC slab incorporating Nano-SiO_2 and coconut fibers (a) Sample 1, (b) Sample 2 and (c) Sample 3

3.2 SEM Analysis

The connection between load and deflection is seen in Figure 9. The load's linear growth shows a constant force application. Under increasing stress, the deflection (blue line) steadily increases, indicating structural deformation. This implies that deflection starts small and rises with increasing load. A line in Figure 10 illustrating the relationship between load and strain at various levels (Strain-I, Strain-II, Strain-III, and Strain-IV) is shown in the provided image. While the x-axis shows numerical numbers from 1 to 31, the y-axis shows the percentage, which ranges from 0% to 100%. The graph is dominated by the blue load line, which rises sharply to 100%, while the other strain lines are either hardly noticeable or almost flat. This implies that the strain varies little at different levels and that the load quickly achieves its maximum.

The SEM image Figure 10 (a, b, c) reveals the microstructural characteristics of the novel concrete incorporating Nano-SiO_2 and coconut fibers, showing a dense matrix with dispersed Nano-sized particles and hydration products. The rough, irregular formations indicate calcium silicate hydrate (C-S-H) gel, essential for strength development, while the well-distributed Nano-SiO_2 particles contribute to improved packing density and pore refinement. The presence of micro cracks and voids highlights the concrete's porosity, which influences durability and mechanical properties. Additionally, traces of fiber-matrix interactions suggest the reinforcing role of coconut fibers in crack bridging and toughness enhancement. The observed microstructure supports the potential of this composite in achieving superior strength, durability, and sustainability, making it a promising material for modern construction applications.

4. CONCLUSION

- The experimental results show that deflection rises in direct proportion to load, verifying the slabs' structural reaction to increasing stress levels.

- Accurate monitoring of material deformation under load is ensured by the constant changes in strain readings at four distinct sites (I, II, III, and IV).

- The structural performance of the tested specimens varied, with Slab Specimen 2 recording a peak strain of 0.09317 at 66 kN and Slab Specimen 3 displaying a maximum strain of 0.08714 at 68 kN.

- The incorporation of Nano-SiO_2 improves particle packing, lowers porosity, and fortifies the material, as shown by SEM examination, which reveals a thick concrete matrix.

- The function of coconut fibers Effective fiber-matrix interaction is revealed by the microstructural analysis, which promotes toughness, fracture bridging, and increased durability.

- The concrete composite's structural viability was confirmed by its average 28-day compressive strength of 31.78 N/mm^2, split tensile strength of 2.201 N/mm^2, and modulus of rupture of 6.92 N/mm^2.
- By maximizing material use and enhancing performance, the results confirm that adding Nano-SiO_2 and coconut fibers improves strength and durability while also promoting sustainable building.

FUNDING

There is no funding source.

CONFLICT OF INTEREST

The authors declared no conflict of interest regarding publication in this manuscript.

COPYRIGHT

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).

REFERENCES

Abedi, M., Hassanshahi, O., Rashiddel, A., Ashtari, H., Seddik, M. M., Dias, D., Arjomand, M. A. and Keong, C. K. A., sustainable cementitious composite reinforced with natural fibers: An experimental and numerical study, *Constr. Build. Mater.*, 378, 131093(2023). https://doi.org/10.1016/j.conbuildmat.2023.131093

Abg, A., Dyg. S. Q., Kartini, K. and Hamidah, M. S., Comparative Study on Bubble Deck Slab and Conventional Reinforced Concrete Slab – A Review, *J. Adv. Res. Mater. Sci.*, 70(1), 18–26(2020). https://doi.org/10.37934/arms.70.1.1826

Ahmed, M., Khan, S. and Aziz, S., Mechanical Characterization of Precast Self-Compacting Concrete Shell Beam Incorporating Grounded Coal Bottom Ash and Coir Fibre, (2022). https://doi.org/10.21203/rs.3.rs-2296677/v1

Aslam, F. and Shahab, M. Z., Supplementary cementitious materials in blended cement concrete: Advancements in predicting compressive strength through machine learning, *Mater. Today Commun.*, 38, 107725(2024). https://doi.org/10.1016/j.mtcomm.2023.107725

Dinh, N. H., Pham, H. H., Kim, S. H. and Choi, K. K., Tensile performance and cracking characteristics of sustainable textile-reinforced cementitious composites utilizing expanded glass aggregate and fly ash replacement, *Constr. Build. Mater.*, 425, 136084(2024). https://doi.org/10.1016/j.conbuildmat.2024.136084

Hwang, C. L., Tran, V. A., Hong, J. W. and Hsieh, Y. C., Effects of short coconut fiber on the mechanical properties, plastic cracking behavior, and impact resistance of cementitious composites, *Constr. Build. Mater.*, 127, 984–992(2016). https://doi.org/10.1016/j.conbuildmat.2016.09.118

Jose, A. S. R. and Rajkumar, D., Experimental Investigation of Ferrogeopolymer Confinement for Enhancing Brick Masonry Column Resilience under Axial Compression, *Int. J. Civ. Eng.*, 11(4), 80–91(2024). https://doi.org/10.14445/23488352/IJCE-V11I4P108

Nawab, M. S., Ali, T., Qureshi, M. Z., Zaid, O., Ben, K. N., Sun, Y., Anwar, N. and Ajwad, A., A study on improving the performance of cement-based mortar with silica fume, metakaolin, and coconut fibers, *Case Stud. Constr. Mater.*, 19, e02480(2023). https://doi.org/10.1016/j.cscm.2023.e02480

Ranjitham, M. and Manjunath, N. V., Experimental and numerical investigation on the structural behavior of Bubble Deck Slab with conventional slab, *Int. J. Trend Sci. Res. Dev.*, 2(3), 2614–2617(2018). https://doi.org/10.31142/ijtsrd11532

Saini, K., Matsagar, V. A. and Kodur, V. R., Recent advances in the use of natural fibers in civil engineering structures, *Constr. Build. Mater.*, 411, 134364(2024). https://doi.org/10.1016/j.conbuildmat.2023.134364

Susurluk, G., Sarikaya, H. and Bostanci, L., Utilization of natural kapok and coconut fiber in thermally insulated sustainable concrete design, *Environ. Sci. Pollut. Res.*, 31(52), 61469–61490(2024). https://doi.org/10.1007/s11356-024-35324-0

Wang, W., Zhang, Y., Mo, Z., Chouw, N., Jayaraman, K., and Xu, Z., A critical review on the properties of natural fiber reinforced concrete composites subjected to impact loading, *J. Build. Eng.*, 77, 107497(2023). https://doi.org/10.1016/j.jobe.2023.107497

Zaid, O., Zamir, H. S. R., El, O. M. H., Martínez-García, R., De P. G. J. and Yousef, S. E. A. S., Experimental and analytical study of ultra-high-performance fiber-reinforced concrete modified with egg shell powder and nano-silica, *J. Mater. Res. Technol.*, 24, 7162–7188(2023). https://doi.org/10.1016/j.jmrt.2023.04.240

Zhang, P., Sun, Y., Wei, J. and Zhang, T., Research progress on properties of cement-based composites incorporating graphene oxide, *Rev. Adv. Mater. Sci.*, 62(1), 20220329 (2023a). https://doi.org/10.1515/rams-2022-0329

Zhang, P., Zhang, P., Wu, J., Guo, Z., Zhang, Y. and Zheng, Y., Mechanical Properties and Durability of Sustainable Concrete Manufactured Using Ceramic Waste: A Review, *J. Renewable Mater.*, 11(2), 937–974(2023b).
https://doi.org/10.32604/jrm.2022.023290

Zheng, Y., Zhuo, J., and Zhang, P., A review on the durability of nano-SiO2 and basalt fiber modified recycled aggregate concrete, *Constr. Build. Mater.*, 304, 124659(2021b).
https://doi.org/10.1016/j.conbuildmat.2021.124659

Sujitha, V. S., Ramesh, B. and Joseph, R. X., Influence of nano alumina reinforced superabsorbent polymer on mechanical, durability, microstructural and rheological properties of cementitious materials, *J. Build. Eng.*, 79, 107780 (2023),
https://doi.org/10.1016/j.jobe.2023.107780

Sujitha, V. S., Ramesh, B. and Xavier, J. R., Effects of incorporation of nanotitania in magnesium phosphate cement for the protection of carbon steel in harsh environments, *Archiv. Civ. Mech. Eng.*, 24, 79 (2024).
https://doi.org/10.1007/s43452-024-00896-8

Martinelli, F. R. B., Ribeiro, F. R. C., Marvila, M. T., Monteiro, S. N., Filho, F. D. C. G., Azevedo, A. R. G. D., A Review of the Use of Coconut Fiber in Cement Composites, *Polym.*, 15, 1309 (2023).
https://doi.org/10.3390/polym15051309