

Experimental study on effect of Nano Silica and polypropylene fibers-based concrete in RCC beam

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Abstract— Concrete, though the most widely used construction material, is limited by low tensile strength and brittle failure. To address these shortcomings, this study investigates the combined incorporation of Nano Silica (NS) and Polypropylene Fibers (PPF) in M40 grade RCC beams. Nano Silica, owing to its ultrafine pozzolanic properties, enhances the microstructure and strength, while Polypropylene Fibers improve ductility, toughness, and crack resistance. The research analyzes the flexural behavior of RCC beams and compares conventional and modified beams in terms of first crack load, ultimate load, and deflection. To determine the optimum mix, concrete specimens including cubes, cylinders, and prisms were cast with a constant 2% NS and varying PPF dosages (0.25%, 0.5%, 0.75%, and 1%). Mechanical properties such as compressive, tensile, and flexural strengths were evaluated at 7, 14, and 28 days. The findings reveal that the optimum performance was achieved with 2% NS and 0.25% PPF, resulting in notable improvements in compressive, tensile, and flexural strength compared to conventional concrete.

Index Terms—NS-Nano silica, PPF- Polypropylene Fibers, RCC- reinforced cement concrete

I. INTRODUCTION

Concrete is the backbone of modern construction because of its strength, durability, and adaptability in structures like buildings, bridges, and pavements. Yet, despite its advantages, it has some inherent drawbacks such as low tensile strength, brittleness, and a tendency to crack, which limit its performance in reinforced cement concrete (RCC). To address these challenges, researchers have turned to innovative materials such as fibers and nanomaterials to enhance concrete's overall properties.

One such material is Polypropylene Fiber (PPF), a synthetic, lightweight, and chemically stable fiber. When mixed into concrete, PPF forms a fine network of reinforcement that helps control shrinkage cracks,

delays crack spreading, and adds toughness and ductility. This not only improves durability but also increases resistance to impact and temperature variations.

Similarly, Nano Silica (NS), an ultrafine pozzolanic material, refines the microstructure of concrete. By reacting with calcium hydroxide during cement hydration, it forms extra calcium silicate hydrate (C-S-H), making the concrete denser, stronger, and more durable.

When used together, NS and PPF create a synergistic effect NS strengthens the concrete matrix while PPF enhances ductility and crack resistance. This combination results in concrete with superior compressive, tensile, and flexural performance, making RCC beams more reliable, durable, and sustainable.

II. LITERATURE REVIEW

[1] Piroti et al. (2020) Investigated M30-grade concrete with 0.5–1% PPF and 2% NS. Results showed compressive strength improved by 18–25%, split tensile strength by 15%, and flexural strength by 20% compared to control mixes. The study emphasized that optimum fiber dosage was crucial, as excessive PPF reduced workability and uniformity.

[2] Gong et al. (2023) Studied recycled brick aggregate concrete with 2% NS and 1% PPF. Frost resistance improved by 35%, while compressive strength increased by 22% compared to control concrete. The combination enhanced durability in freeze–thaw conditions, proving effective for sustainable construction with recycled aggregates.

[3] Prashanth et al. (2019) Evaluated M40 concrete modified with 2% NS. Chloride ion penetration was reduced by 40%, and water absorption decreased by

25%, enhancing durability. Compressive strength improved by 15% at 28 days. The study confirmed NS effectively improves long-term performance in aggressive environments.

[4] Chithra et al. (2016) Assessed colloidal NS in high-performance concrete at 2–3% replacement. Workability improved slightly, compressive strength increased by 18–20%, and porosity decreased by 30%. The refined microstructure enhanced both mechanical and durability properties, validating NS as a performance-enhancing admixture.

[5] Zhang et al. (2021) Investigated cementitious composites with fly ash and 1–2% NS. Impact resistance improved by 25%, compressive strength by 20%, and flexural strength by 18%. SEM analysis revealed a denser microstructure and stronger interfacial bonding, showing NS as a key enhancer in blended cement composites.

III. MATERIALS USED AND THEIR PROPERTIES

In the present investigation, the materials used include cement, fine aggregates, coarse aggregates, nano silica (NS), and Polypropylene Fibers (PPF).

A. Cement:

Cement is used as a binding agent that is used to bind various construction materials. Given its adhesive and cohesive properties, it is an essential ingredient of concrete and mortar. OPC 53 Grade Cement is a high-strength Ordinary Portland Cement (OPC) that conforms to IS 12269:2013 standards in India.

Sl.no	Tests	Results	IS standards
1	Fineness of Cement	5%	Less than 10%
2	Standard Consistency of Cement	27%	26%-33%
3	Initial Setting time	70 mins	-

B. Fine aggregate:

Fine aggregates are defined as inert granular materials. It has many properties that affect the performance of the concrete. Fine aggregate refers to sand or crushed stone particles that are smaller than 4.75 mm in size and play a vital role in concrete, mortar, and plastering applications

Sl.no	Tests	Results	IS standards
1	Specific Gravity	2.63	2.3-2.7
2	Gradation	Zone II	-

C. Coarse aggregate:

Coarse aggregates are granular materials. It is often used in construction for concrete making. Its major composition includes crushed stone, gravel, or recycled concrete. Coarse aggregates typically account for more than 60-80% of the volume of the concrete. Their durability depends on the quality of the coarse aggregate, significantly impacting the strength and workability of the concrete. Coarse aggregates are classified as those larger than 4.75 mm according to sieve analysis.

Sl.no	Tests	Results	IS standards
1	Specific Gravity	2.63	2.3-2.7
2	Gradation	Zone II	-

D. Properties of nano silica:

The nano silica was purchased from Silica Nano Solutions, located in Fatehpur, UP. Their product is renowned for its high purity and fine particle size, ideal for various industrial applications.

Description	Property
Particle size	20-80nm
Appearance	White powder
Nature	Hydrophilic
BET Surface area	170-200 m ² /g
PH Value	5-7
Bulk Density	0.18-0.23g/cm ³
Source	Silica Nano Solutions, UP

E. Properties of polypropylene:

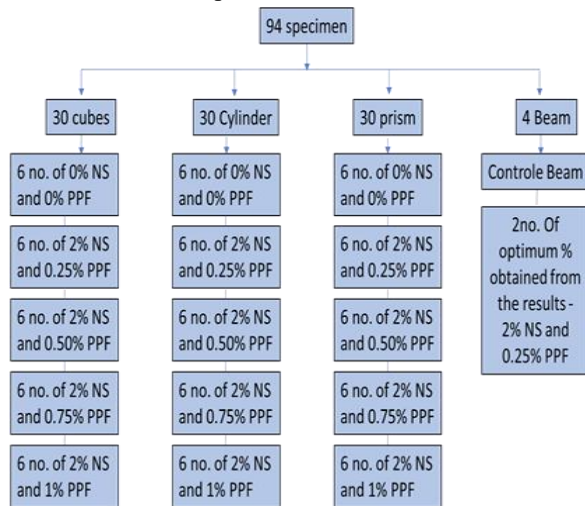
Reliance Polypropylene fiber, branded as Recron 3S, is used in this project for its superior durability, strength, and resistance to environmental-factors.

Description	Property
Particle size	6mm
Dia	18-35 microns
Appearance	White, silky fibre
Tensile strength	400Mpa
Elastic modulus	3.5Gpa
Water absorption	nill
Source	Reliance, Recron 3S, Jaynagar

F. Mix proportion:

Mix Design M40	
Material	Quantity (kg/m ³)
Cement	379
Water	175
Fine-aggregate	647
Coarse-aggregate	1214
Admixture (Superplasticizer)	1.5
mix proportion (by weight)	1: 1.71: 3.21: 0.38

G. Specimen flow chart:



H. Test on fresh concrete - SLUMP TEST:

In a slump test, fresh concrete is placed into a cone-shaped mould in layers, with each layer compacted using a tamping rod. Once the mould is carefully lifted upward, the concrete subsides. The reduction in height, measured between the mould and the settled concrete, represents the slump value.

Sl. No	Mix Type	Slump Value (mm)
1	Control	108
2	2% NS + 0.25% PPF	102
3	2% NS + 0.50% PPF	89
4	2% NS + 0.75% PPF	82
5	2% NS + 1.00% PPF	75

I. Cube specimens – compressive-strength test:

To determine the compressive-strength of concrete, standard cube specimens measuring 150 mm × 150 mm × 150 mm were used. For this study, concrete was mixed with 2% Nano Silica and Polypropylene Fibers at varying dosages of 0.25%, 0.5%, 0.75%, and 1%,

along with a control mix containing no NS or PPF. For each mix, 2 cube specimens were cast, resulting in a total no. of 10 cube specimens. The concrete materials were proportioned, mixed, and placed into cube molds in three layers, each compacted with 25 strokes using a tamping rod. After 24 hours of initial setting, the cubes were demolded and cured in water at $27 \pm 2^\circ\text{C}$. Compressive-strength tests were conducted at 07th-14th-and 28th days using a Compression-Testing-Machine (CTM). The maximum applied load was recorded, and compressive-strength was calculated



Fig: Testing of cube

J. Cylinder specimens – split tensile-strength test:

To assess the split tensile-strength of concrete, cylinder specimens with dimensions 150 mm in diameter and 300 mm in height were used. Two cylinders were cast for each of the five mixes (four with NS + PPF and one control), giving a total no. of 10-cylinder specimens. The concrete-mix was prepared according to the designated proportions and poured into molds in three layers with proper compaction. After 24 hours, the cylinders were demolded and immersed in water for curing. Testing was carried out at 07th-14th-and 28th days by placing the cylinder horizontally and applying compressive load along its diameter. This test indirectly evaluates tensile strength



Fig: Testing of cylinder

K. Prism specimens – flexural-strength test:

To evaluate the flexural-strength of concrete, prism specimens of size 100 mm × 100 mm × 500 mm were cast. A total no. of 10 prisms was prepared, with 2 specimens for each mix proportion covering four different combinations of Nano Silica (NS) with Polypropylene Fibers (PPF) at dosages of 0.25%, 0.5%, 0.75%, and 1%, along with a control mix without any additions. During casting, the fresh concrete was placed into the molds in successive layers, each layer being properly compacted either manually with tamping rods or mechanically using a vibrator to eliminate air voids and ensure density. After 24 hours of casting, the specimens were demoulded carefully and transferred to a curing-tank, where they were subjected to continuous water curing for specified durations of 07th-14th-and 28th days. Flexural-strength testing was carried out using a two-point loading system, in which the prism was simply supported at both ends and load was applied at one-third points of the span, creating a constant bending moment region at the center. The ultimate load at failure was recorded.



Fig: Testing of prism

L. Beam specimen preparation and test:

The RCC beam specimens were designed with dimensions of 150 mm × 200 mm × 1500 mm using M40 grade concrete and Fe500 steel. The longitudinal reinforcement comprised two 12 mm bars at the bottom to resist flexural tension and two 8 mm bars at the top as hanger bars for holding stirrups and providing nominal compression reinforcement. For shear resistance, two-legged 8 mm stirrups were provided at 125 mm spacing. This detailing ensured the beam behaved like a conventional RCC member, effectively resisting bending and shear forces.

Four RCC beams were cast two control beams and two beams with an optimized mix containing 2% Nano Silica (NS) and 0.25% Polypropylene Fibers (PPF), determined from preliminary strength tests on cubes, cylinders, and prisms. The concrete mix was prepared by first blending cement, Nano Silica, fine and coarse aggregates in a mixer. Water was added gradually for proper hydration, and Polypropylene fibres were introduced slowly to ensure uniform dispersion. The concrete was poured into oiled moulds in three layers, each compacted using a mechanical vibrator. Reinforcement cages with adequate cover were properly positioned before casting.

After 24 hours of setting, the beams were demoulded and cured in water for 28 days as per IS specifications. Before testing, beams were whitewashed to enhance crack visibility. Flexural testing was conducted using a four-point bending setup on a 50-ton loading frame. The beams were simply supported on rollers, and loading was applied gradually through two-point loads using a hydraulic jack in 2 kN increments. Deflections were recorded using dial gauges at one-third, mid-span, and two-thirds span positions. Cracks initiated at the tension zone and propagated upward with increasing load. The first-crack load and ultimate load at failure were recorded, providing valuable data on flexural behaviour, crack development, and strength performance of both control and modified RCC beams.





Fig: Testing of Beam CB-01, CB-02, PF-NS-01, PF-NS-02

IV. RESULTS

A. Compressive-strength test results:

Sl.no	Control	2% NS and 0.25% PPF	2% NS and 0.50% PPF	2% NS and 0.75% PPF	2%NS and 1% PPF
7 th -day	36.67	37.51	33.95	27.52	23.11
14 th -day	39.17	43.26	37.31	28.65	26.33
28 th -day	50.21	56.14	44.62	38.31	36.25



Fig: Compressive-strength graph

B. split tensile-strength test results:

Sl.no	Control	2% NS and 0.25%PPF	2% NS and 0.50% PPF	2% NS and 0.75% PPF	2% NS and 1% PPF
7 th -day	2.35	2.68	2.21	1.96	1.89
14 th -day	2.45	2.84	2.44	2.27	2.12
28 th -day	2.78	3.17	2.77	2.59	2.33

Fig: split tensile-strength graph

C. Flexural-strength test results:

Sl.no	Control	2% NS and 0.25% PPF	2% NS and 0.50% PPF	2% NS and 0.75% PPF	2% NS and 1% PPF
7 th -day	2.35	2.68	2.21	1.96	1.89
14 th -day	2.45	2.84	2.44	2.27	2.12
28 th -day	2.78	3.17	2.77	2.59	2.33

Fig: Flexural strength graph

D. Beam testing results:

Reinforced cement concrete (RCC) beams of 150 mm × 200 mm × 1500 mm were cast using M40 grade concrete. The specimens included two control beams without any additions and two beams prepared with the optimized mix of 2% Nano Silica (NS) and 0.25% Polypropylene Fibers (PPF). This optimum proportion was identified from preliminary mechanical property tests—compressive-strength on cubes, split tensile-strength on cylinders, and flexural-strength on prisms. Since the optimized mix performed better than other dosages, it was selected for beam casting, and the corresponding test results are presented below

1. Control beam 1:

The control beam specimen was cast with dimensions of 150 mm × 200 mm × 1500 mm using M40 grade concrete and Fe500 grade steel. It was designed as a conventional RCC beam without any addition of Nano Silica or Polypropylene fibers. The longitudinal reinforcement consisted of two 12 mm diameter bars at the bottom (tension zone) and two 8 mm diameter bars at the top (compression zone), while shear reinforcement was provided in the form of two-legged 8 mm diameter stirrups placed at 125 mm c/c spacing throughout the length. A clear cover of 25 mm was maintained using cover blocks to be sure durability and protection of steel. The beam was cast by mixing cement, Fine-aggregate, and coarse-aggregate in the required proportion, with water added gradually to achieve proper workability. The fresh concrete was placed in mounds in three layers, each compacted using a mechanical vibrator to remove air voids and achieve density. After 24 hours, the control beam was carefully demolded and placed in water for 28 days of continuous curing.

Beam designation	CB-01
Date of casting (DOC)	24/07/2025
Date of testing (DOT)	22/08/2025
First-crack load (Pcr)	26Kn
Ultimate load (Pu)	98Kn
Ultimate deflection (Δu)	15.9
Total number of cracks	9
Maximum crack-width	1.9mm

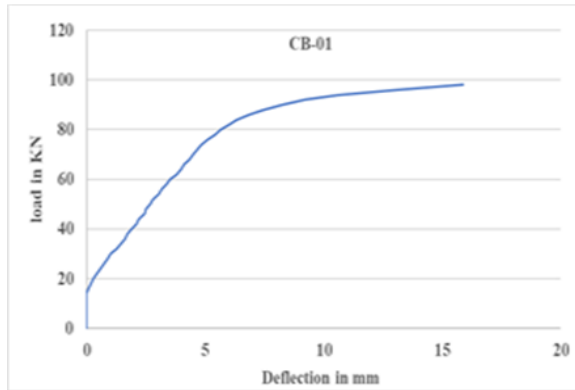


Fig: Beam CB-01

2. Control beam 2:

Beam designation	CB-02
Date of casting (DOC)	24/07/2025
Date of testing (DOT)	22/08/2025
First-crack load (Pcr)	22Kn
Ultimate load (Pu)	96Kn
Ultimate deflection (Δu)	12.2
Total number of cracks	12
Maximum crack-width	1.7mm

Fig: Beam CB-02

3. NS and PPF beam 1:

The modified beam specimen was cast with dimensions of 150 mm $\times$ 200 mm $\times$ 1500 mm using M40 grade concrete and Fe500 grade steel, similar in geometry and reinforcement to the control beam. In this case, however, the concrete mix was altered by incorporating 2% Nano Silica (by weight of cement) and 0.25% Polypropylene Fibers (by volume of concrete). This particular combination was selected based on the results of the mechanical property tests conducted earlier on cubes, cylinders, and prisms, where it was found to be the optimum mix for achieving the best balance of compressive, tensile, and flexural-strength. The reinforcement consisted of two 12 mm diameter bars at the bottom (tension zone) and

two 8 mm diameter bars at the top (compression zone), while shear reinforcement was provided using two-legged 8 mm diameter stirrups at 125 mm c/c. A clear cover of 25 mm was maintained using cover blocks to protect steel against corrosion and ensure durability. The concrete ingredients, including cement, Fine-aggregate, coarse-aggregate, Nano Silica, and Polypropylene Fibers, were mixed in proper proportions, with water added gradually for workable consistency. The fresh concrete was placed in molds in three layers and each layer was compacted with a mechanical vibrator to remove entrapped air. After 24 hours, the beam was demolded and kept in water for 28 days of curing before testing.

Beam designation	NS-PPF-01
Date of casting (DOC)	24/07/2025
Date of testing (DOT)	22/08/2025
First-crack load (Pcr)	28Kn
Ultimate load (Pu)	116Kn
Ultimate deflection (Δu)	19.54
Total number of cracks	10
Maximum crack-width	1.4mm

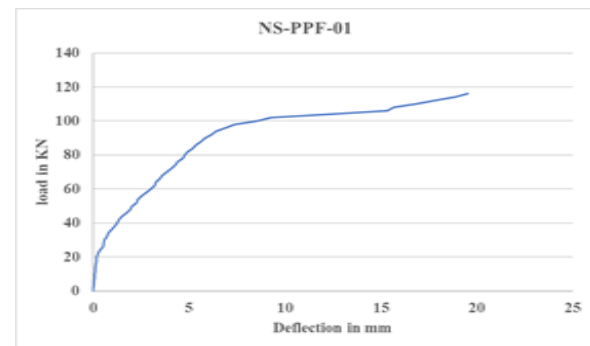


Fig: NS and PPF beam 1

4. NS and PPF beam 2:

Beam designation	NS-PPF-01
Date of casting (DOC)	24/07/2025
Date of testing (DOT)	22/08/2025
First-crack load (Pcr)	28Kn
Ultimate load (Pu)	116Kn
Ultimate deflection (Δu)	19.54
Total number of cracks	10
Maximum crack-width	1.4mm

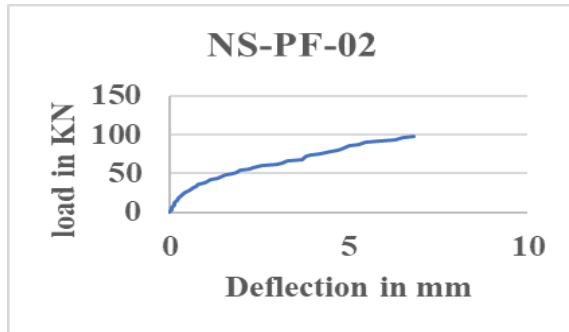


Fig: NS and PPF beam 2

V. DISCUSSION

A. Load vs deflection curve:

The Load vs Deflection Graph compares the behavior of Control Beams (CB 01 and CB 02) and 2% Nano Silica and 0.25% Polypropylene Fibers Beams (NS-PPF 1 and NS-PPF 2). The graph plots load in kilonewtons (kN) against deflection in millimeters (mm). It shows that NS-PPF Beams can withstand higher loads compared to Control Beams for similar deflections. This indicates that the addition of NS-PPF likely enhances the load-carrying capacity of the beams. Both types of beams exhibit a non-linear relationship between load and deflection, typical in beam bending tests. Overall, the NS-PPF Beams demonstrate better performance in terms of load capacity.

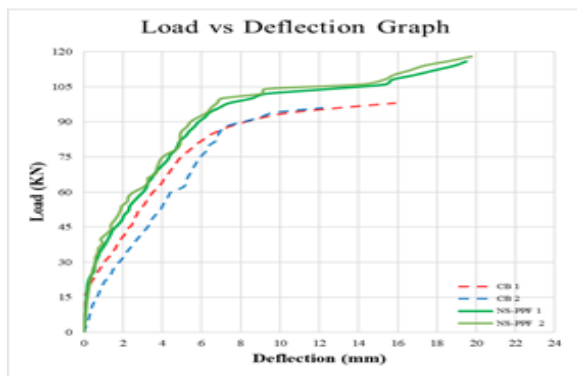


Fig: Load vs deflection graph

B. First load crack:

The results for the first-crack load clearly show a difference between the control beams and those modified with Nano Silica (NS) and Polypropylene Fibers (PPF). In the control category, beam CB-01 developed its first-crack at 26 kN, while CB-02 cracked earlier at 22 kN. On the other hand, the beams

incorporating NS and PPF displayed improved performance. Beam NS-PPF-01 resisted cracking up to 28 kN, and NS-PPF-02 reached 30 kN before the first-crack appeared. This improvement highlights the positive role of adding 2% Nano Silica with 0.25% Polypropylene Fibers, as they enhance the concrete matrix, delay crack initiation, and increase toughness. While the fibers help in controlling micro-cracks by bridging them, nano silica contributes to better particle packing and bond strength. These observations indicate that the modified beams possess greater resistance to crack initiation compared to conventional beams.

Beam designation	First-crack(kN)
CB-01	26
CB-02	22
NS-PPF-01	28
NS-PPF-02	30

C. Ultimate load:

The graph shows a comparison of the ultimate load-carrying capacity of different beam designations. A table lists four beam designations: CB-01, CB-02, NS-PPF-01, and NS-PPF-02, along with their respective ultimate loads in kilonewtons (kN). The ultimate loads are 98 kN for CB-01, 96 kN for CB-02, 116 kN for NS-PPF-01, and 118 kN for NS-PPF-02. Below the table, a bar graph showing that NS-PPF beams have a higher ultimate load capacity compared to CB beams. This suggests that the NS-PPF beams perform better in terms of load-carrying capacity. NS-PPF beams exhibited nearly 20% higher ultimate load than control beams, confirming enhanced strength and improved flexural behavior.

Beam designation	Ultimate load (kN)
CB-01	98
CB-02	96
NS-PPF-01	116
NS-PPF-02	118

D. Deflection:

The graph illustrates the deflection values for four different beam designations: CB-01, CB-02, NS-PPF-01, and NS-PPF-02. Were CB-01 shows 15.9mm of deflection, CB-02 shows 12.9 mm of deflection, NS-PPF-01 shows 19.54 mm of deflection and NS-PPF-02 shows 19.84 mm of deflection.

Beam designation	Deflection (Δu) in mm
CB-01	15.9
CB-02	12.2
NS-PPF-01	19.54
NS-PPF-02	19.84

VI. CONCLUSION

- The experimental study revealed that the optimum mix combination of 2% Nano Silica with 0.25% Polypropylene Fiber provided the best mechanical performance compared to other tested proportions. It was found that increasing Polypropylene Fiber dosage beyond 0.25% while keeping Nano Silica constant at 2% led to reduced strength and workability, negatively affecting overall structural performance.
- When comparing the tested beams, it was observed that the beam with 2% NS and 0.25% PPF performed more effectively than the control beams. The ultimate load-carrying capacity of the NS-PPF beam increased by 20.6% compared to the control beam.
- The beams with Nano Silica and Polypropylene fibers started cracking later, at around 29 kN, compared to 24 kN in the regular ones. That's a 21% improvement, meaning they held up better under initial stress. The added materials clearly helped delay cracking and improved the beam's early performance.
- The NS-PPF beams showed about a 20% increase in load-carrying capacity. At failure, they recorded a deflection of 19.69 mm under a load of 118 kN, while the conventional beams deflected 14.05 mm under 96 kN. This clearly highlights that adding Nano Silica and Polypropylene fibers not only improved the strength of the beams but also enhanced their flexibility under maximum loading.

REFERENCES

- [1] Piroti, A., et al. (2020). Effect of polypropylene fibres and nano silica on the mechanical performance of M30-grade concrete. *Journal of Construction Materials Research*, 8(2), 45–56.
- [2] Gong, Y., et al. (2023). Influence of nano silica and polypropylene fibres on frost resistance and strength of recycled brick aggregate concrete. *Construction and Building Materials*, 368, 130423. <https://doi.org/10.1016/j.conbuildmat.2023.130423>
- [3] Prashanth, K., et al. (2019). Durability studies on nano silica-modified M40-grade concrete. *International Journal of Engineering and Advanced Technology*, 8(6S3), 260–264.
- [4] Chithra, S., Kumar, S. R. R. S., & Chinnaraju, K. (2016). The effect of colloidal nano-silica on workability, mechanical and durability properties of high-performance concrete. *Construction and Building Materials*, 113, 469–480. <https://doi.org/10.1016/j.conbuildmat.2016.03.066>
- [5] Zhang, P., Wan, J., Wang, K., & Li, Q. (2021). Effect of nano silica particles on impact resistance and mechanical properties of cementitious composites with fly ash. *Nanomaterials*, 11(9), 2362. <https://doi.org/10.3390/nano11092362>
- [6] Manoj, G. (2024). Experimental investigations on nano silica concrete. *E3S Web of Conferences*, 538, 02002. <https://doi.org/10.1051/e3sconf/202453802002>
- [7] Raveendran, N., et al. (2024). Synergistic effect of nano silica and metakaolin on the mechanical and durability properties of concrete. *Materials Today: Proceedings*, 94, 123–132. <https://doi.org/10.1016/j.matpr.2024.01.089>
- [8] Jassim, A., & Anwar, K. (2016). Mechanical characteristics and impact resistance of polypropylene fibre-reinforced concrete. *Journal of Civil Engineering Research*, 6(3), 85–92.
- [9] Dharan, T., & Lal, A. (2016). Performance evaluation of polypropylene fibre reinforced concrete with varying fibre content. *International Journal of Civil Engineering and Technology*, 7(4), 356–364.
- [10] IOSR. (2018). Optimal polypropylene fiber content for improved compressive and flexural-strength of concrete. In *Proceedings of IOSR Conference on Advances in Civil Engineering* (pp. 55–62). IOSR Journals. Retrieved from <http://www.iosrjournals.org>