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An Experimental Investigation on M-30 Grade Concrete Prepared by Partial Replacement of Cement with Polypropylene Fiber, Coconut Shell Ash and Colloidal Nano Silica

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ABSTRACT

Alternative materials that may partly replace cement while preserving or improving concrete performance are being investigated in response to the growing need for sustainable building. In order to produce M-30 grade concrete, part of the cement was replaced with polypropylene fiber (PPF), coconut shell ash (CSA), and colloidal nano silica (CNS). To increase energy absorption capacity, ductility, and fracture resistance, polypropylene fibers were added. Cement use and environmental effect were decreased by using coconut shell ash, an agricultural waste with pozzolanic qualities. Colloidal nano silica was used to improve early-age strength, optimize pore structure, and speed up hydration because of its ultra-fine particle size and strong reactivity. Experimental research was conducted to examine the combined effects of these materials on workability, compressive strength, split tensile strength, flexural strength, and durability (acid and alkali resistance). According to the results, a mixture of 1% to 1.5% of each ingredient produces the best mechanical performance, showing respectable resistance to harsh chemical conditions and notable gains in compressive, tensile, and flexural strengths when compared to traditional M-30 concrete. This study shows that PPF, CSA, and CNS may be used as sustainable partial cement substitutes in structural applications.

Keywords – M-30 Concrete, Polypropylene Fiber, Coconut Shell Ash, Colloidal Nano Silica, Compressive Strength, Durability

1. INTRODUCTION

Concrete is essentially a heterogeneous composite material that is carefully constructed by combining water, hydraulic cement, and inert particles of different grades. When this combination undergoes the chemical process of hydration, it creates a sturdy, stone-like mass that is now the foundation of the world's infrastructure. However, there are serious environmental repercussions associated with the manufacture of regular Portland cement, which serves as the main binding agent in this matrix. Fossil fuels are used in high-temperature kilns to aid in the clinkerization process, which makes the production process very energy-intensive. Furthermore, significant amounts of carbon dioxide are chemically released into the environment during the calcination of limestone, a crucial raw material. The cement industry contributes significantly to the greenhouse effect and associated environmental contamination, accounting for around 8% of the world's anthropogenic CO2 emissions. This calls for prompt corrective action.

The building materials industry has been aggressively looking for workable ways to lower the net cement content of concrete without sacrificing its structural integrity in response to these urgent environmental concerns. Using additional cementitious materials, especially those with pozzolanic qualities, is one of the most popular and successful tactics. Pozzolanas are siliceous or aluminosiliceous materials that have little to no cementitious value on their own. However, when they are finely divided and exposed to moisture, they react chemically with the calcium hydroxide released during cement hydration to form compounds that have binding properties similar to those of cement.

Polypropylene fibers are synthetic, thermoplastic fibers widely used in civil engineering and construction materials due to their favorable mechanical, physical, and chemical characteristics. These fibers are produced from propylene monomers through polymerization, resulting in a lightweight material with a relatively low density compared to other synthetic and natural fibers. The low specific gravity of polypropylene fibers, typically in the range of 0.90–0.91 g/cm³, makes them particularly attractive for use in cementitious composites, as they do not significantly increase the self-weight of concrete while contributing to improved performance characteristics.

In concrete and mortar applications, polypropylene fibers are primarily employed as secondary reinforcement to control plastic shrinkage cracking and microcrack propagation. Due to their short length, commonly ranging from 8 to 12 mm, and uniform dispersion within the matrix, these fibers effectively bridge microcracks that develop during the early stages of hydration. This crack-arresting mechanism enhances the integrity of the cementitious matrix, reducing the likelihood of crack coalescence and subsequent durability-related issues.

Coconut shell ash (CSA) is an agricultural waste material obtained by controlled burning of coconut shells. When incinerated at temperatures between 600°C and 800°C, the organic matter decomposes, leaving behind an amorphous silica-rich ash that exhibits pozzolanic properties. The ash is then ground to a fine powder to enhance its reactivity. In this study, CSA was used as a partial replacement for cement at varying percentages (0%, 0.5%, 1%, 1.5%, and 2% by weight).

The pozzolanic activity of CSA helps in forming additional calcium silicate hydrate (C-S-H) gel, which contributes to long-term strength and reduces the permeability of concrete. Its use also addresses the environmental problem of agricultural waste disposal.

Nano-silica is a new pozzolanic material commercially available in the form of water emulsion of colloidal silica. It is potentially better than the other pozzolanic materials because of high content of amorphous silica (>99%) and the reduced size of its spherical particles of order 5-10nm.

2. REVIEW OF LITERATURE SURVEY

Sharma, A. et al. (2025) examined how the mechanical characteristics of M 30 grade concrete were affected by the combined effects of polypropylene (PP) fiber, coconut shell ash (CSA), and colloidal nano silica (CNS). The experimental matrix included PP fiber at a constant volume fraction of 0.5%, CNS at 1%, 2%, and 3% by weight of binder, and CSA at 5%, 10%, and 15% replacement of cement. Additional calcium silicate hydrate gel was formed within the capillary pores as a result of the pozzolanic reaction between CSA and CNS, and the fibers filled in microcracks. With compressive strength improvements of 8.4% at 7 days and 11.7% at 28 days in comparison to the control mix, the findings showed that the ternary blend of 10% CSA, 2% CNS, and 0.5% PP fiber provided the best performance. Flexural strength increased by 14.1% and split tensile strength by 16.3%. A significant increase in durability was shown by the two pozzolanic materials' combined action, which decreased water absorption by 32% and the fast chloride penetration test charge passed from 2540 to 1380 Coulombs. [31]

Rao, P. N. and Menon, G. (2025) investigated the durability properties of M 30 grade concrete made using polypropylene fibers, colloidal nano silica, and coconut shell ash. In addition to a set 2% CNS and 0.4% PP fiber by volume, the program included substituting CSA for cement at 0%, 5%, 10%, 15%, and 20%. The pore structure was greatly improved due to the nucleation impact of CNS and the pozzolanic reactivity of CSA, and the PP fibers offered micro-level fracture arresting capability. The results showed that the optimum durability indices were obtained using 10% CSA, 2% CNS, and 0.4% PP fiber. In comparison to the control, sorpitivity declined by 38% and the coefficient of water permeability by 44%. After 28 days, there was a 13.2% rise in compressive strength and a 15.8% increase in split tensile strength. The optimized mix lost just 1.3% of its weight after 90 days in a 3.5% sodium chloride solution, whereas the control group lost 3.1%, indicating improved resistance to chloride-induced degradation. [26]

Saranya, K. et al. (2019) investigated M-30 grade concrete in which cement was partially replaced with coconut shell ash (CSA) and colloidal nano-silica (CNS). Owing to the high amorphous silica in both CSA and CNS, a pozzolanic reaction consumed calcium hydroxide and precipitated additional calcium-silicate-hydrate gel, densifying the matrix. The experimental programme considered CSA replacements of 0%, 5%, 10% and 15% by weight of cement, with CNS kept constant at 2% for the blended mixes. The results showed that 10% CSA with 2% CNS was the optimum combination, delivering a 28-day compressive strength of 42.3 MPa compared to 37.8 MPa for the control mix—a gain of 11.9%. Split tensile strength and flexural strength increased by 14.2% and 10.8% respectively at the same replacement level, while water absorption dropped from 3.9% to 2.6%, confirming a substantial refinement of the pore network. [30]

3. OBJECTIVES OF THE RESEARCH

In this research work we will go for the following objectives:

- To study the effect of Polypropylene Fiber, Coconut Shell Ash and Colloidal Nano Silica in concrete.
- To economise the Civil Engineering Construction activity.
- Improvement of mechanical properties of concrete.
- To achieve the designed/ desired workability in the plastic stage.
- Increases compressive, tensile and flexural strength of concrete.
- Reduce emission of CO2 in to the atmosphere.

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4. MATERIAL AND PROPERTIES

4.1 Cement

In the present investigation Ordinary Portland cement (OPC) of 43 Grade confirming to IS specifications was used.

Table 1. Properties of Cement

Property	Value
Specific Gravity	3.15
Normal Consistency	33%
Initial Setting Time	40 min
Final Setting Time	6 hours

4.2 Aggregate

Locally available river sand confirming to IS specifications was used as the fine aggregate in the concrete preparation.

Table 2. Properties of Fine Aggregate

Property	Result
Specific Gravity	2.6
Fineness Modulus	2.8
Bulk Density (Loose)	1575 kN/m^3
Grading of Sand	Zone II

Coarse aggregate of nominal size 20 mm and 10 mm, obtained from the local quarry confirming to IS specifications was used. The coarse aggregate used for the preparation of concrete is a mixture of 20 mm and 10 mm size aggregates in ratio 1.5: 1.0.

Table 3. Properties of Coarse Aggregate

Property	Result
Specific Gravity	2.6
Bulk Density (Loose)	14.15 kN/m^3
Water Absorption	0.50%
Fineness Modulus	7.2

4.3 Coconut Shell Ash

Table 4. Properties of Coconut Shell Ash

Property	Value
Colour	Dark grey

Specific Gravity	2.05 – 2.15
Bulk Density (Loose)	780 – 850 kg/m³
Fineness (passing 90 µm sieve)	> 85%
pH	9.5 – 10.5
Chemical Composition (major oxides)	SiO_2: 45–55%; Al_2O_3: 8–15%; Fe_2O_3: 3–6%; CaO: 4–8%

4.4 Nano Silica

Table 5. Properties of Nano Silica

Property	Actual Analysis
Active Nano Silica Content	35–40%
pH	9.3–9.6
Specific Gravity	1.08–1.1
Texture	Milky White Liquid
Dispersion	Water

4.5 Water

Water used for casting and curing concrete test specimens is free from impurities which when present can adversely influence the strength of concrete.

5. EXPERIMENTAL INVESTIGATION

5.1 Slump Test

This test is use for determining the consistency of concrete where the nominal maximum size of the aggregate does not exceed 38 mm.

The slump test is used to determine the consistency of a new batch of concrete before it sets. Slump is used to test the workability of freshly mixed concrete, and workability is defined as the ease with which concrete flows. It can also be used to detect a batch that has been poorly mixed. The workability of a concrete mix increases as the slump value rises.

(Copy Fig 4.3 Slump Test from thesis here.)

5.2 Compressive Strength of Concrete: (As per IS: 516-1959)

Because the Compressive Testing Machine was manual, the specimen's measured compressive strength was computed by dividing the greatest force applied to the specimen during the test by the cross-sectional area, and the number we needed was in N/mm2.

$$f = P/A$$

Here,
f = compressive strength
P = Maximum load applied
A = Cross sectional area of specimen

Fig. 1: Compressive Strength Testing Machine

Fig. 2: Compressive Strength Testing

5.3 Split Tensile Strength of Concrete Specimen: (As per IS: 5816-1999)

The specimen's recorded splitting tensile strength, f, was estimated to the nearest 0.05 N/mm2 using the formula below:

$$f = 2P/\pi DL$$

Here,

f = Split tensile strength of specimen

P = Maximum load applied to the specimen

D = Cross sectional dimension of the specimen

L = Length of the specimen

Fig. 3: Split Tensile Strength Test machine

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Fig. 4: Split Tensile Strength Testing of Cylinder

5.4 Flexural Strength Test of Concrete Specimen: (As per IS: 516-1959)

The Flexural Strength or modulus of rupture (fb) is given by (for 2 point loading)

$$fb = pl/bd2$$

Here,
b = width of specimen (cm)
d = failure point depth (cm)
l = supported length (cm)
p = max. Load (N)

Fig. 5: Flexure Strength Testing Machine

Fig. 6: Flexure Testing of beam

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5.5 Resistance against Acid Attack

A 150 x 150 x 150 mm concrete cube with different percentages of different combinations was made for the acid attack test.

The specimens were thereafter fully submerged in a prepared 5% sulfuric acid (H_2SO_4) solution that was kept within high-density polyethylene (HDPE) tanks.

The specimens were carefully removed from the corrosive bath after the 28-day immersion time in the very aggressive acid solution.

$$\boldsymbol{Weight\ Loss}\ (\%) = [(\boldsymbol{Initial\ Weight} - \boldsymbol{Final\ Weight}) \,/\, \boldsymbol{Initial\ Weight}] \times \mathbf{100}.$$

A lower percentage of weight loss indicates better durability and a denser, less porous microstructure that successfully withstood the aggressive chemical intrusion.

6. RESULTS AND DISCUSSION

The experimental results obtained from various tests conducted on M-30 grade concrete prepared by partial replacement of cement with polypropylene fiber (PPF), coconut shell ash (CSA), and colloidal nano silica (CNS) are presented and discussed in this chapter. The tests include workability (slump cone), compressive strength, split tensile strength, flexural strength, and durability under acid and alkali attack.

6.1 Slump Cone Test

Table 6. Slump Cone Test (in mm)

% of Material	Polypropylene Fiber	Coconut Shell Ash	Nano Silica
0	80	70	78
0.5	78	68	75
1	75	64	72
1.5	72	61	69
2	70	59	67

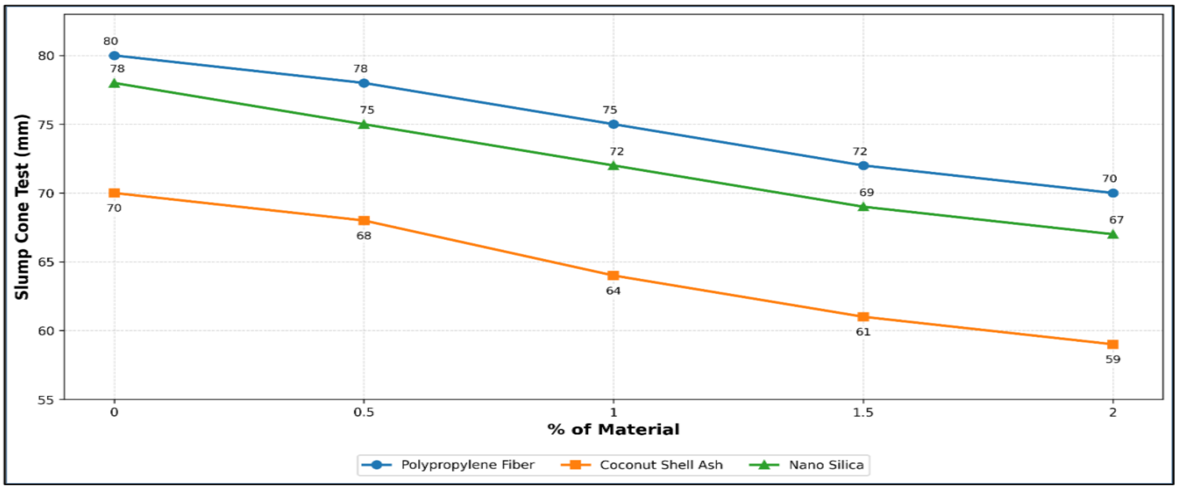

Fig. 7: Slump Cone Test (in mm)

Inference: For polypropylene fiber, slump values decrease progressively from 80 mm at 0% to 70 mm at 2%, indicating a consistent reduction in workability with increasing fiber content. Similarly, coconut shell ash incorporation yields slumps from 70 mm (0%) to 59 mm (2%), while nano silica shows a decline from 78 mm (0%) to 67 mm (2%), reflecting the densifying effect of these pozzolanic and fibrous materials on fresh concrete consistency.

6.2 Compressive Strength Test

Table 7. Compressive Strength of M30 Grade Concrete (in kN/m³)

% of Material	PPF 7 Days	PPF 14 Days	PPF 28 Days	CSA 7 Days	CSA 14 Days	CSA 28 Days	Nano Silica 7 Days	Nano Silica 14 Days	Nano Silica 28 Days
0	19.6	26.5	32.67	17.52	24.42	30.59	18.32	25.22	31.39
0.5	20.41	26.12	33.47	18.33	24.04	31.39	19.13	24.84	32.19
1	21.5	28.46	35.84	19.42	26.38	33.76	20.22	27.18	34.56
1.5	22.8	29.47	36.79	20.72	27.39	34.71	21.52	28.19	35.51
2	21.71	28.76	35.6	19.63	26.68	33.52	20.43	27.48	34.32

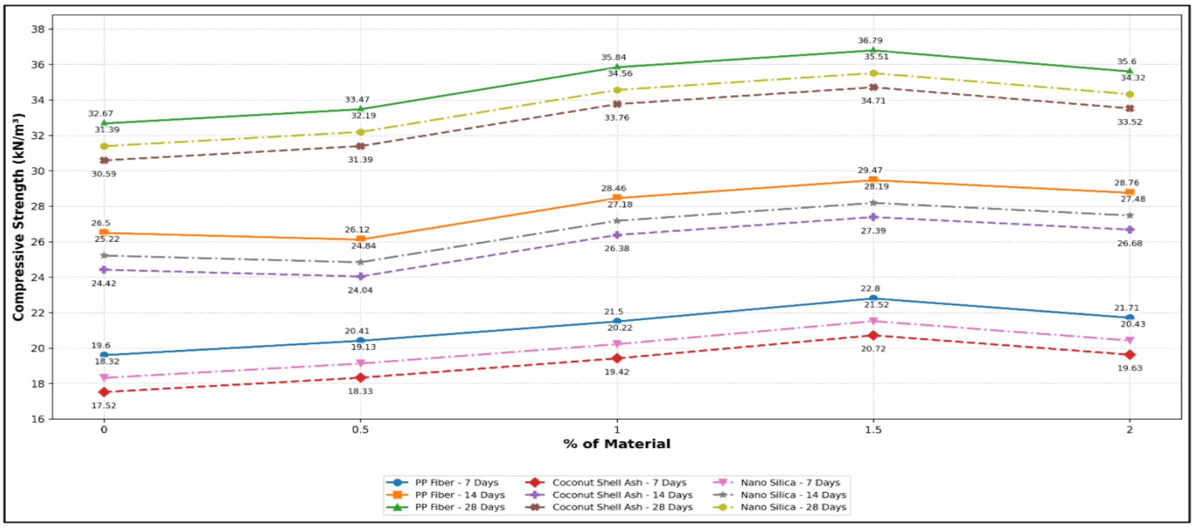

Fig. 8: Compressive Strength of M30 Grade (in kN/m³)

Inference: Polypropylene fiber exhibits peak strengths at 1.5% dosage across curing periods, attaining 22.8 kN/m³ (7 days), 29.47 kN/m³ (14 days), and 36.79 kN/m³ (28 days), with a marginal decline at 2%, indicative of optimal fiber reinforcement before agglomeration effects. Coconut shell ash and nano silica display analogous trends, with maximum values of 20.72 kN/m³, 27.39 kN/m³, and 34.71 kN/m³ for CSA, and 21.52 kN/m³, 28.19 kN/m³, and 35.51 kN/m³ for CNS at 1.5%, underscoring their efficacy in enhancing early- and long-term mechanical performance up to an optimal threshold.

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6.3 Split Tensile Strength

Table 8. Split Tensile Strength of M30 Grade Concrete (in kN/m³)

% of Material	PPF 7 Days	PPF 14 Days	PPF 28 Days	CSA 7 Days	CSA 14 Days	CSA 28 Days	Nano Silica 7 Days	Nano Silica 14 Days	Nano Silica 28 Days
0	1.99	2.97	3.33	1.01	1.99	2.35	1.72	2.7	3.06
0.5	2.42	3.33	3.97	1.44	2.35	2.99	2.15	3.06	3.7
1	2.51	3.48	4.12	1.53	2.5	3.14	2.24	3.21	3.85
1.5	2.22	3.29	3.64	1.24	2.31	2.66	1.95	3.02	3.37
2	2.04	3.06	3.41	1.06	2.08	2.43	1.77	2.79	3.14

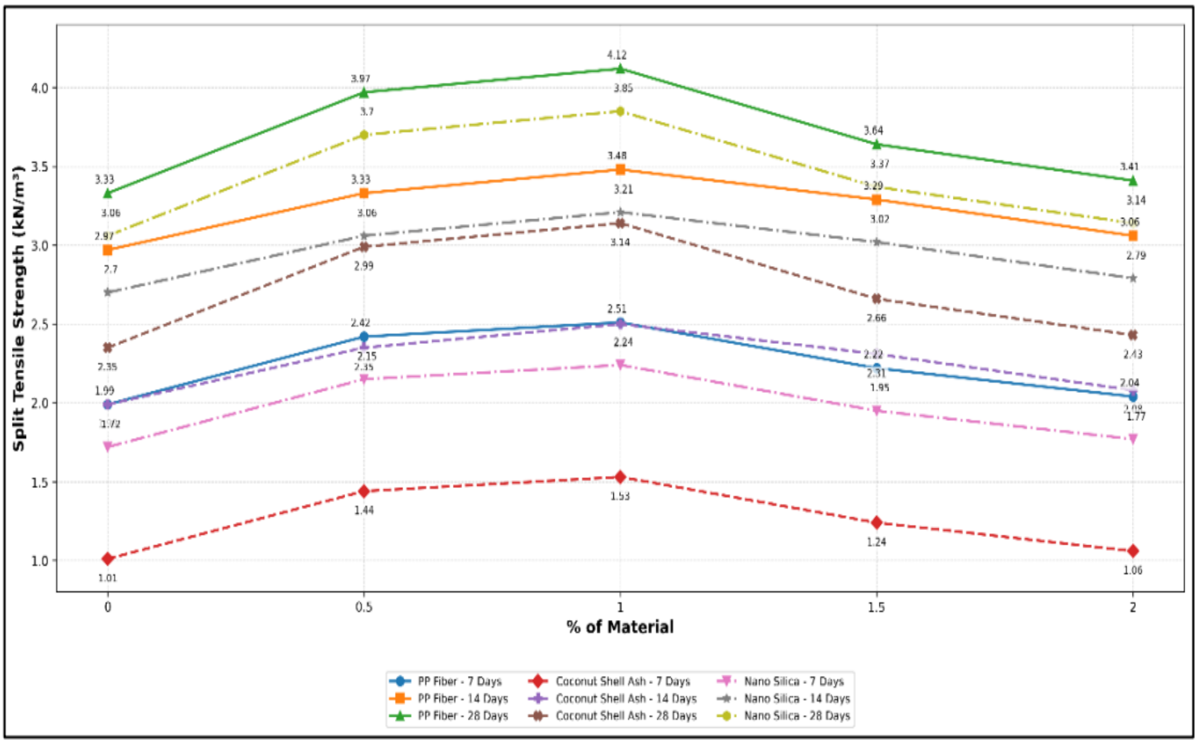

Fig. 9: Split Tensile Strength of M30 Grade (in kN/m³)

Inference: Polypropylene fiber demonstrates superior tensile enhancement, peaking at 1% addition with values of 2.51 kN/m³ (7 days), 3.48 kN/m³ (14 days), and 4.12 kN/m³ (28 days), followed by a reduction at higher dosages attributable to fiber clustering. Coconut shell ash and nano silica likewise exhibit optimal performance around 1–1.5%, achieving maxima of 1.53 kN/m³, 2.5 kN/m³, 3.14 kN/m³ for CSA and 2.24 kN/m³, 3.21 kN/m³, 3.85 kN/m³ for CNS respectively, highlighting their roles in bridging micro-cracks and improving ductility in sustainable concrete composites.

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6.4 Flexural Strength

Table 9. Flexural Strength of M30 Grade Concrete (in kN/m³)

% of Material	PPF 7 Days	PPF 28 Days	CSA 7 Days	CSA 28 Days	Nano Silica 7 Days	Nano Silica 28 Days
0	1.64	2.7	1.39	2.45	1.55	2.61
0.5	1.81	2.97	1.56	2.72	1.72	2.88
1	2.06	3.38	1.81	3.13	1.97	3.29
1.5	1.98	3.26	1.73	3.01	1.89	3.17
2	1.93	3.12	1.68	2.87	1.84	3.03

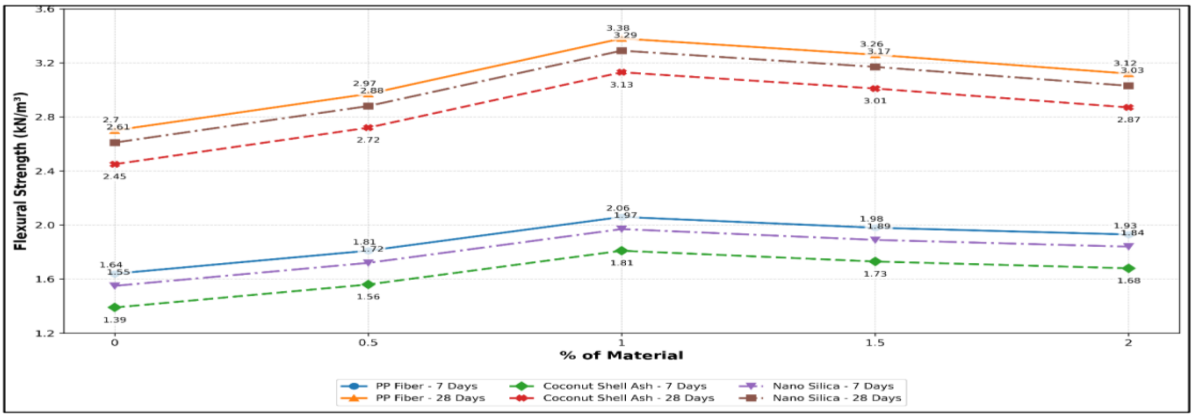

Fig. 10: Flexural Strength of M30 Grade (in kN/m³)

Inference: Polypropylene fiber yields the highest flexural capacities, peaking at 1% dosage with 2.06 MPa (7 days) and 3.38 MPa (28 days), beyond which diminishing returns occur due to excessive fiber volume. Coconut shell ash and nano silica also enhance flexural performance optimally at 1%, registering maxima of 1.81 MPa / 3.13 MPa and 1.97 MPa / 3.29 MPa respectively, thereby validating their utility as sustainable admixtures for improved crack resistance and load-bearing in flexural members.

6.5 Durability Tests

Table 10. Acid Attack Resistance for Polypropylene Fiber

Mix Designation	Dry Weight W1 (kg)	Weight after immersion W2 (kg)	% Weight Loss
MD 0% PF	8.468	8.386	0.96
MD 0.5% PF	8.419	8.327	1.09
MD 1% PF	8.376	8.273	1.22
MD 1.5% PF	8.230	8.102	1.55
MD 2% PF	8.167	8.012	1.89

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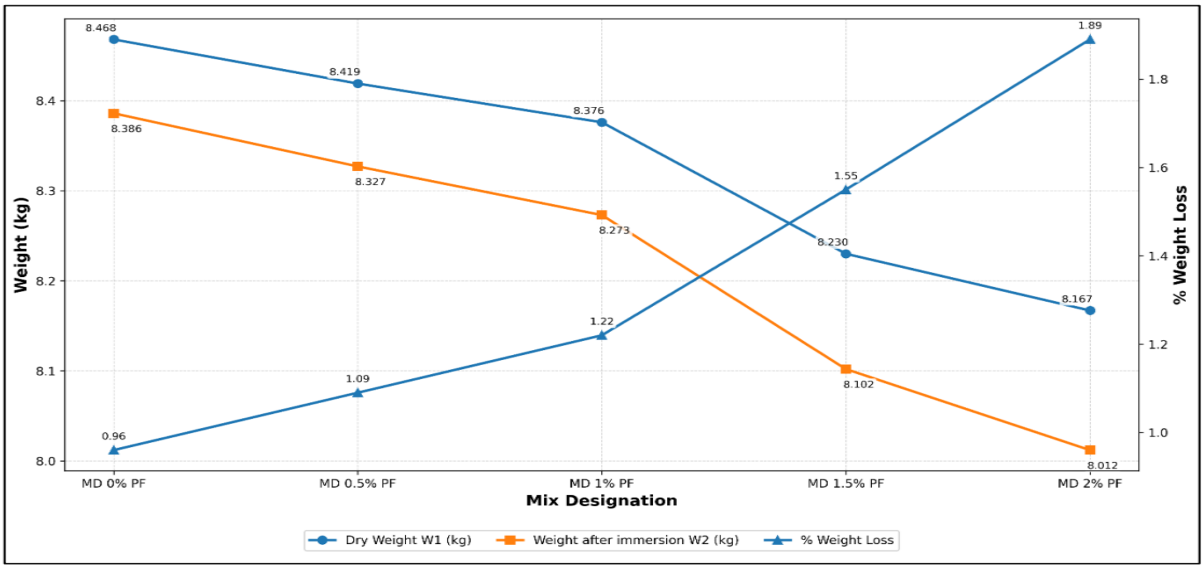

Fig. 11: Acid Attack Resistance for Polypropylene Fiber

Table 11. Acid Attack Resistance for Coconut Shell Ash

Mix Designation	Dry Weight W1 (kg)	Weight after immersion W2 (kg)	% Weight Loss
MD 0% CSA	8.166	8.084	0.96
MD 0.5% CSA	8.117	8.025	1.09
MD 1% CSA	8.074	7.971	1.22
MD 1.5% CSA	7.928	7.800	1.55
MD 2% CSA	7.865	7.710	1.89

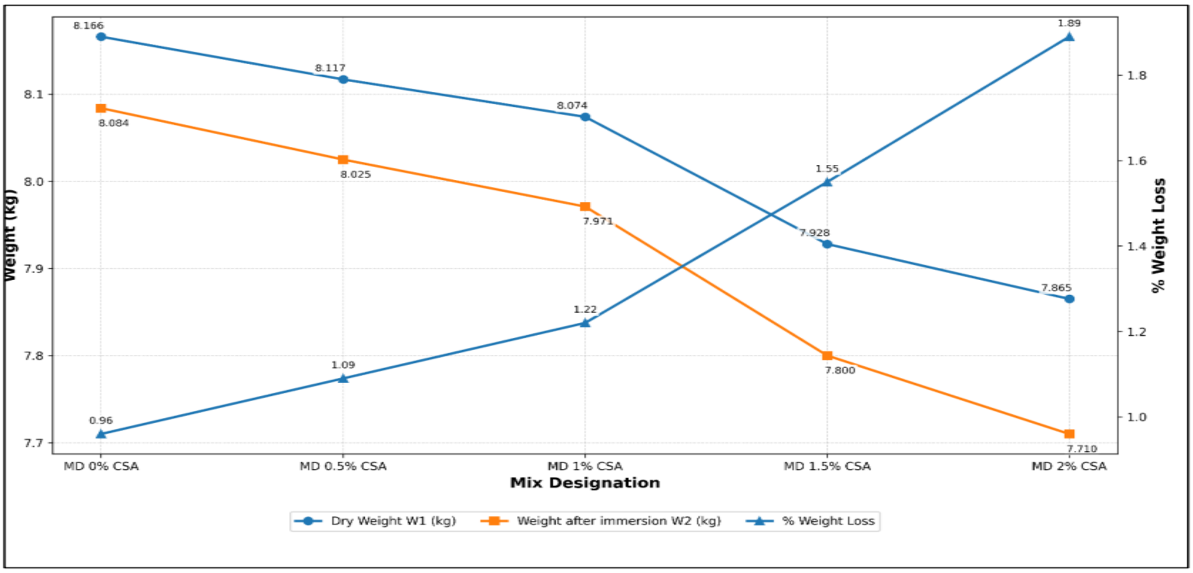

Fig. 12: Acid Attack Resistance for Coconut Shell Ash

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Table 12. Acid Attack Resistance for Nano Silica

Mix Designation	Dry Weight W1 (kg)	Weight after immersion W2 (kg)	% Weight Loss
MD 0% NS	8.277	8.195	0.96
MD 0.5% NS	8.228	8.136	1.09
MD 1% NS	8.185	8.082	1.22
MD 1.5% NS	8.039	7.911	1.55
MD 2% NS	7.976	7.821	1.89

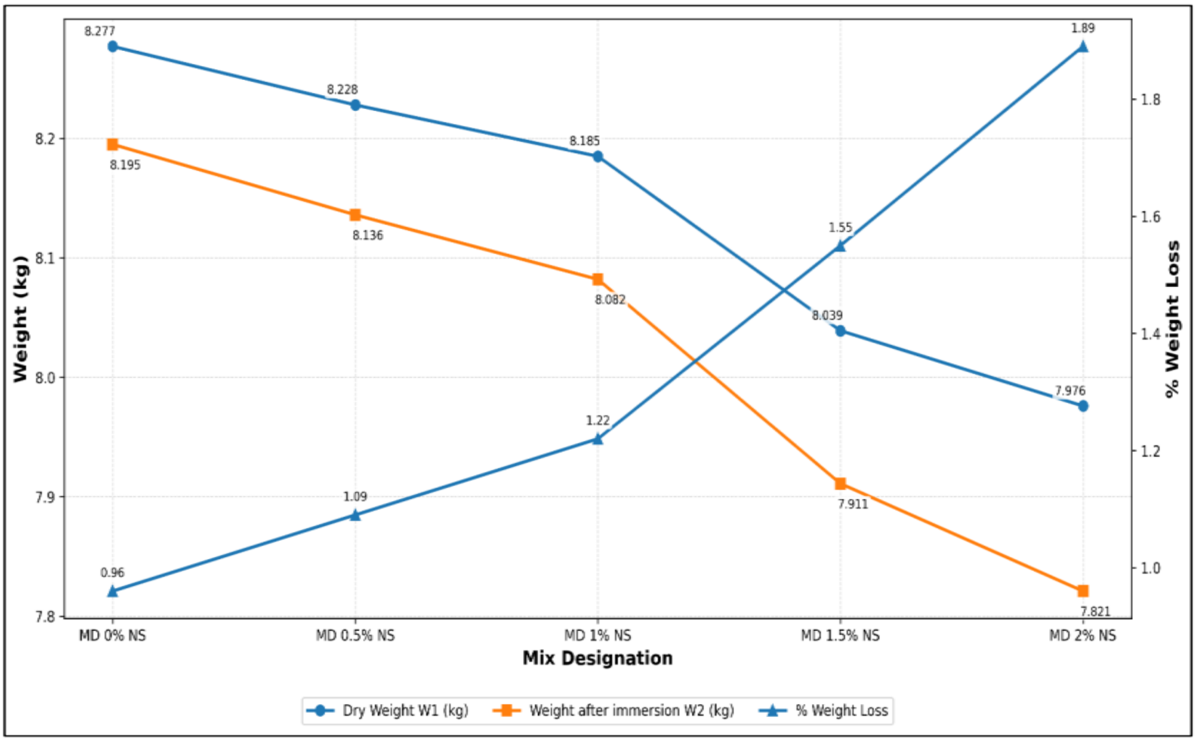

Fig. 13: Acid Attack Resistance for Nano Silica

Inference – Acid Attack Resistance: The tables present a comprehensive evaluation of concrete durability against acid attack. Across PF-modified mixes—from MD 0% PF (W1: 8.468 kg, W2: 8.386 kg, loss: 0.96%) to MD 2% PF (W1: 8.167 kg, W2: 8.012 kg, loss: 1.89%)—a systematic escalation in mass reduction is evident, attributable to increased fiber-matrix interfacial porosity and potential microcracking under chemical assault, with optimal resistance at lower dosages. CSA and NS variants exhibit parallel degradation profiles, transitioning from baseline losses near 0.96% to approximately 1.9% at 2% incorporation, wherein CSA's fine pozzolanic particulates may densify the matrix while NS's reactivity refines pore networks, collectively curtailing penetration of aggressive ions and underscoring their synergistic potential in sustainable, acid-resistant concretes. This progressive weight loss trend, consistently below 2%, aligns with IS 456 provisions for durable concrete in corrosive environments.

7. CONCLUSIONS

The present experimental investigation was carried out to evaluate the performance of M-30 grade concrete in which cement was partially replaced by polypropylene fiber (PPF), coconut shell ash (CSA), and colloidal nano silica (CNS) in varying proportions. Based on the extensive laboratory testing conducted on workability, mechanical strength, and durability, the following conclusions are drawn:

1. Workability (Slump Cone Test):

The slump values declined consistently with the increase in the percentage of all three replacement materials. PPF, owing to its fibrous nature, reduced workability from 80 mm (0%) to 70 mm (2%). CSA and CNS, being finer pozzolanic materials with high specific surface areas, also caused a reduction in slump, indicating a higher water demand. This reduction, however, remained within manageable limits and can be offset by the use of suitable superplasticizers.

2. Compressive Strength:

All three materials enhanced the compressive strength up to a certain optimal dosage, beyond which a decline was observed.

- For PPF, the peak 28-day compressive strength of 36.79 kN/m³ (≈36.79 MPa) was achieved at 1.5% replacement, which is about 12.6% higher than the control mix (32.67 kN/m³).
- For CSA, the maximum compressive strength of 34.71 kN/m³ was obtained at 1.5%, corresponding to a 13.5% improvement over the control (30.59 kN/m³).
- For CNS, the optimum was also at 1.5%, yielding 35.51 kN/m³, which is 13.1% higher than the control (31.39 kN/m³).

The improvement is attributed to fiber crack-bridging, pozzolanic C-S-H gel formation, and nano-filler effects refining the microstructure.

3. Split Tensile Strength:

The tensile strength increased notably at lower dosages, with the most significant enhancement recorded at 1% for all three materials.

- PPF gave a peak 28-day split tensile strength of 4.12 kN/m³ (≈4.12 MPa), 23.7% higher than the control.
- CSA achieved 3.14 kN/m³ at 1% (control: 2.35 kN/m³), an increase of 33.6%.
- CNS reached 3.85 kN/m³ at 1% (control: 3.06 kN/m³), an increase of 25.8%.

The high elongation and crack-arresting nature of PPF, and the micro-filling action of CSA and CNS, contributed to the improved tensile resistance.

4. Flexural Strength:

The flexural behavior mirrored the tensile trend, with optimum enhancement at 1% replacement.

- PPF concrete recorded a 28-day flexural strength of 3.38 kN/m³ (≈3.38 MPa), which is 25.2% above the control.
- CSA and CNS registered peak values of 3.13 kN/m³ and 3.29 kN/m³, corresponding to improvements of 27.8% and 26.1% respectively over the control mixes.

The substantial improvement is particularly valuable for pavement and slab applications where bending stresses dominate.

5. Acid Attack Resistance:

The percentage weight loss of cubes immersed in sulphuric acid solution increased gradually with the replacement level, indicating a slight reduction in acid resistance at higher dosages. However, even at 2% replacement, the maximum weight loss was limited to 1.89%, which is well below the alarming limit. The dense CSH matrix formed due to pozzolanic reactions and the hydrophobic nature of PPF helped in restricting acid ingress.

6. Optimum Replacement Levels:

Considering the combined performance across all mechanical and durability parameters, the optimum replacement levels are identified as:

- Polypropylene Fiber: 1–1.5% by weight of cement
- Coconut Shell Ash: 1–1.5% by weight of cement
- Colloidal Nano Silica: 1–1.5% by weight of cement

At these dosages, concrete can achieve substantial improvements in strength (12–34% over conventional M-30) without compromising durability.

7. Sustainability and Economic Benefits:

The successful use of agricultural waste (CSA) and reduced cement content contributes to lowering CO_2 emissions, saving natural resources, and promoting a circular economy in the construction industry.

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