www.ijarp.com ISSN 2456-9992 Page: 01-14
International Journal Advanced Research Publications
Research Article
Volume: 02
Issue: 05

ENHANCEMENT OF COMPRESSIVE AND FLEXURAL STRENGTH OF HIGH STRENGTH CONCRETE USING RICE HUSK ASH AND POLYPROPYLENE FIBRES

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Article Received: 08 April 2026, Article Revised: 28 April 2026, Published on: 18 May 2026

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DOI: https://doi-doi.org/101555/ijarp.8652

ABSTRACT

High Strength Concrete (HSC) is essential for modern infrastructure, but its high cement content contributes significantly to CO_2 emissions, while its inherent brittleness limits performance under tensile and flexural stresses. This study investigates the combined effect of Rice Husk Ash (RHA) as a supplementary cementitious material and Polypropylene Fibres (PPF) as crack-arresting reinforcement in M60 grade concrete. RHA is a sustainable, agriculturally derived pozzolanic material produced by controlled incineration of rice husks, an abundant agricultural waste in India. A control mix (100% cement) and four blended mixes with varying RHA replacements (5%, 10%, 15%, 20% by weight of cement) and constant polypropylene fibre content (0.5% by volume of concrete) were prepared. The water-cement ratio was kept constant at 0.30. Compressive strength was evaluated at 7, 14 and 28 days on 150 mm cubes. Flexural strength was measured at 28 days on 100 × 100 × 500 mm beams under third-point loading. The results show that the optimum replacement level is 10% Rice Husk Ash with 0.5% Polypropylene Fibres. This mix achieved a 28-day compressive strength of 66.8 MPa (control: 55.2 MPa, +21.0%) and a flexural strength of 7.4 MPa (control: 6.1 MPa, +21.3%). Beyond 10% RHA, performance declined due to incomplete pozzolanic reaction and the porous nature of excess RHA particles. The study confirms that the combination of 10% rice husk ash and 0.5% polypropylene fibres produces M60 grade concrete that meets strength requirements and offers enhanced crack resistance.

KEYWORDS: High Strength Concrete, Rice Husk Ash, Polypropylene Fibres, Compressive Strength, Flexural Strength, M60 Grade, Sustainable Concrete, Pozzolanic Reaction

1. INTRODUCTION

1.1 Background

The construction industry is the backbone of modern infrastructure development, with concrete serving as the most widely consumed construction material globally. Approximately 30 billion tons of concrete are produced annually worldwide, consuming about 4 billion tons of cement. The production of Ordinary Portland Cement (OPC) is responsible for approximately 8% of global anthropogenic CO_2 emissions, with each ton of cement producing nearly 0.9 tons of CO_2.

High Strength Concrete (HSC), typically defined as concrete with compressive strength exceeding 60 MPa, has become increasingly important in high-rise buildings, long-span bridges, prestressed concrete structures, and other demanding applications. However, the production of HSC poses two significant challenges:

1. **High cement consumption leading to substantial carbon emissions:** HSC requires higher cementitious content (typically 450-550 kg/m^3) compared to normal strength concrete (300-350 kg/m^3), exacerbating its environmental footprint.
2. **Inherent brittleness resulting in poor tensile strength and crack resistance:** As concrete strength increases, its strain capacity decreases, making it more brittle and susceptible to sudden failure under tensile and flexural loads.

1.2 Need for Sustainable Alternatives

India is the second-largest producer of rice in the world, with annual production exceeding 120 million tons. This generates approximately 24 million tons of rice husk annually. Traditionally, rice husk is burned in open fields or inefficient boilers, causing severe air pollution and wasting a valuable pozzolanic resource. Rice Husk Ash (RHA), when produced through controlled incineration at temperatures between 600-700°C, yields amorphous silica content exceeding 85%, making it an excellent supplementary cementitious material (SCM).

Simultaneously, the use of polypropylene fibres (PPF) in concrete addresses the brittleness issue. These synthetic fibres are chemically inert, hydrophobic, and have high tensile strength (500 MPa). They act as micro-reinforcement, bridging cracks and providing post-cracking ductility.

1.3 Research Significance

The present study investigates the synergistic effect of RHA as a partial cement replacement and PPF as a reinforcing agent in M60 grade HSC. This combination addresses two critical sustainability challenges simultaneously: the utilization of agricultural waste (RHA) that would otherwise cause environmental pollution, and the reduction of cement consumption with its associated carbon emissions. Additionally, the use of PPF enhances the mechanical properties of concrete, particularly flexural strength, which is critical for structural applications such as beams, slabs, and pavements.

1.4 Objectives

1. To develop M60 grade HSC with partial replacement of cement by Rice Husk Ash (5%, 10%, 15%, 20%) and constant Polypropylene Fibres (0.5% by volume).
2. To evaluate the workability (slump) of fresh concrete.
3. To determine compressive strength (7, 14, 28 days) and flexural strength (28 days).
4. To identify the optimum replacement level of RHA for maximum strength enhancement in the presence of PPF.

1.5 Scope of Work

- Cement replaced by RHA at 5%, 10%, 15%, and 20% by weight of cement.
- Polypropylene fibres added at constant 0.5% by volume of concrete.
- Water-cement ratio maintained at 0.30.
- Superplasticizer (polycarboxylate ether) used to maintain slump of 100 ± 25 mm.
- Curing performed for 7, 14, and 28 days under standard conditions (27 ± 2°C, 95% RH).

2. MATERIALS AND METHODOLOGY

2.1 Materials

2.1.1 Cement

Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269:2013 was used. Table 1 presents the physical properties of the cement.

Table 1: Physical Properties of OPC 53 Grade.

Property	Value	IS 12269:2013 Requirement
Specific gravity	3.12	-
Fineness (retained on 90 µm sieve)	2.5%	< 10%
Initial setting time	45 minutes	> 30 minutes
Final setting time	280 minutes	< 600 minutes
28-day compressive strength (mortar)	36.2 MPa	> 53 MPa (for cement)

Note: The 28-day strength of cement is tested on standard mortar; concrete strength is different.

2.1.2 Rice Husk Ash (RHA)

Rice husk was collected from local rice mills in Lucknow, Uttar Pradesh. The husk was thoroughly washed with water to remove dust and impurities, then dried in sunlight. The dried husk was subjected to controlled incineration in a muffle furnace at 650°C for 2 hours to achieve complete combustion while preserving amorphous silica content. The furnace was slowly heated at a rate of 10°C per minute to avoid recrystallization. The resulting ash was grayish-white in color, ground in a ball mill to achieve fineness equivalent to cement, and sieved through 90 µm sieve.

Table 2: Chemical Composition of Rice Husk Ash.

Oxide	Percentage (%)
SiO_2	87.5
Al_2O_3	1.2
Fe_2O_3	0.8
CaO	0.9
MgO	0.5
SO_3	0.9
Loss on Ignition (LOI)	4.2

Physical properties:

- Specific gravity: 2.10
- Specific surface area: 8,450 m^2/kg
- Color: Grayish-white

2.1.3 Polypropylene Fibres (PPF)

Monofilament polypropylene fibres conforming to ASTM C1116 were used.

Table 3: Properties of Polypropylene Fibres.

Property	Value
Length	12 mm
Diameter	0.034 mm
Aspect ratio (length/diameter)	353
Tensile strength	500 MPa
Specific gravity	0.91
Melting point	160°C
Modulus of elasticity	3.5 GPa

The fibres were hydrophobic (water-repellent) and dispersed uniformly in the concrete mix during mixing. The dosage was maintained constant at 0.5% by volume of concrete, equivalent to approximately 1.8 kg/m³.

2.1.4 Fine Aggregate

Natural river sand conforming to IS 383:2016 (Zone II) was used.

Table 4: Properties of Fine Aggregate.

Property	Value
Fineness modulus	2.74
Specific gravity	2.65
Water absorption	0.82%
Grading zone	Zone II

2.1.5 Coarse Aggregate

Crushed granite aggregate of 20 mm nominal maximum size conforming to IS 383:2016 was used.

Table 5: Properties of Coarse Aggregate.

Property	Value
Specific gravity	2.71
Water absorption	0.58%
Crushing value	18.2%
Impact value	16.5%
Nominal size	20 mm

2.1.6 Superplasticizer

A polycarboxylate ether (PCE)-based high-range water-reducing admixture was used to maintain workability at the low water-cement ratio of 0.30. The superplasticizer had a specific gravity of 1.08 and solid content of 30%.

2.2 Mix Design

The mix design for M60 grade concrete was carried out following IS 10262:2019. The target mean strength was calculated as:

Target mean strength (f_t) = f_ck + 1.65 × S

Where:

- f_ck = characteristic compressive strength = 60 MPa
- S = standard deviation = 6 MPa (for M60 grade as per IS 10262:2019)

f_t = 60 + 1.65 × 6 = 69.9 MPa

The water-cement ratio was fixed at 0.30 based on preliminary trials. Total cementitious content was maintained at 480 kg/m³.

Table 6: Mix Proportions for M60 Grade Concrete. (kg/m³)

Mix ID	Cement	RHA	PPF	Water	FA	CA (20 mm)	SP (%)
Control	480	0	0	144	662	1145	0.8
M1	456	24	1.8	144	662	1145	1.0
M2	432	48	1.8	144	662	1145	1.2
M3	408	72	1.8	144	662	1145	1.5
M4	384	96	1.8	144	662	1145	1.8

Note: FA = Fine Aggregate, CA = Coarse Aggregate, SP = Superplasticizer (% by weight of cementitious material). PPF dosage is constant at 0.5% by volume of concrete (approximately 1.8 kg/m³).

2.3 Casting and Curing

Concrete specimens were cast in steel moulds and compacted on a vibrating table. After 24 hours, specimens were demoulded and transferred to a water curing tank maintained at 27 ± 2°C. Compressive strength specimens (150 mm cubes) were tested at 7, 14, and 28 days. Flexural strength specimens (100 × 100 × 500 mm beams) were tested at 28 days.

Specimen details:

- **Compressive strength:** 150 mm cubes (3 specimens per mix per age)
- **Flexural strength:** 100 × 100 × 500 mm beams (3 specimens per mix)
- **Total specimens:** 5 mixes × (3 ages × 3 cubes + 3 beams) = 60 specimens

2.4 Testing Methods

2.4.1 Compressive Strength Test (IS 516:2021)

The compressive strength test was conducted using a 2000 kN compression testing machine (CTM). The cube specimen was placed centrally on the lower platen of the machine. The load was applied at a constant rate of 140 kg/cm²/min (approximately 315 kN/min for a 150 mm cube) until failure.

Calculation:

Compressive Strength (MPa) = Maximum Load (N) / Cross-sectional Area (mm²)

For a 150 mm cube:

Area = 150 × 150 = 22,500 mm²

2.4.2 Flexural Strength Test (IS 516:2021 - Third Point Loading)

The flexural strength test was conducted using the third-point loading method (two-point loading). The beam specimen (100 × 100 × 500 mm) was placed on two supports with a span length of 400 mm. The load was applied at two points, each at a distance of 133 mm from the supports, using a load distribution system. The loading rate was maintained at 1.0 kN/min.

Calculation:

Flexural Strength (Modulus of Rupture) = $P \times L / (b \times d^2)$

Where:

- P = maximum load (N)
- L = span length (400 mm)
- b = width of specimen (100 mm)
- d = depth of specimen (100 mm)

For the given dimensions:

Flexural Strength = $P \times 400 / (100 \times 100^2) = P \times 400 / 1{,}000{,}000 = P / 2500$

(where P is in Newtons, result in MPa)

3. RESULTS AND DISCUSSION

3.1 Workability (Slump)

Table 7: Slump Values for Different Mixes.

Mix ID	RHA (%)	PPF (%)	Slump (mm)
Control	0	0	105
M1	5	0.5	95
M2	10	0.5	90
M3	15	0.5	85
M4	20	0.5	80

DISCUSSION:

The slump values decreased progressively as RHA content increased, from 105 mm (control) to 80 mm (M4). This reduction is attributed to the porous nature of RHA particles, which absorb water, and the increased surface area of RHA (8,450 m^2/kg compared to 320 m^2/kg for cement). However, all values fall within the target range of 100 ± 25 mm, indicating acceptable workability for structural concrete. The superplasticizer dosage was adjusted accordingly (0.8% for control, increasing to 1.8% for M4) to maintain workability.

3.2 Compressive Strength Results

Table 8: Compressive Strength Results. (MPa)

Mix ID	RHA (%)	PPF (%)	7-day Strength	14-day Strength	28-day Strength
Control	0	0	38.2	47.6	55.2
M1	5	0.5	43.2	53.4	63.6
M2	10	0.5	46.8	58.2	66.8
M3	15	0.5	44.6	55.4	64.2
M4	20	0.5	41.2	51.8	60.4

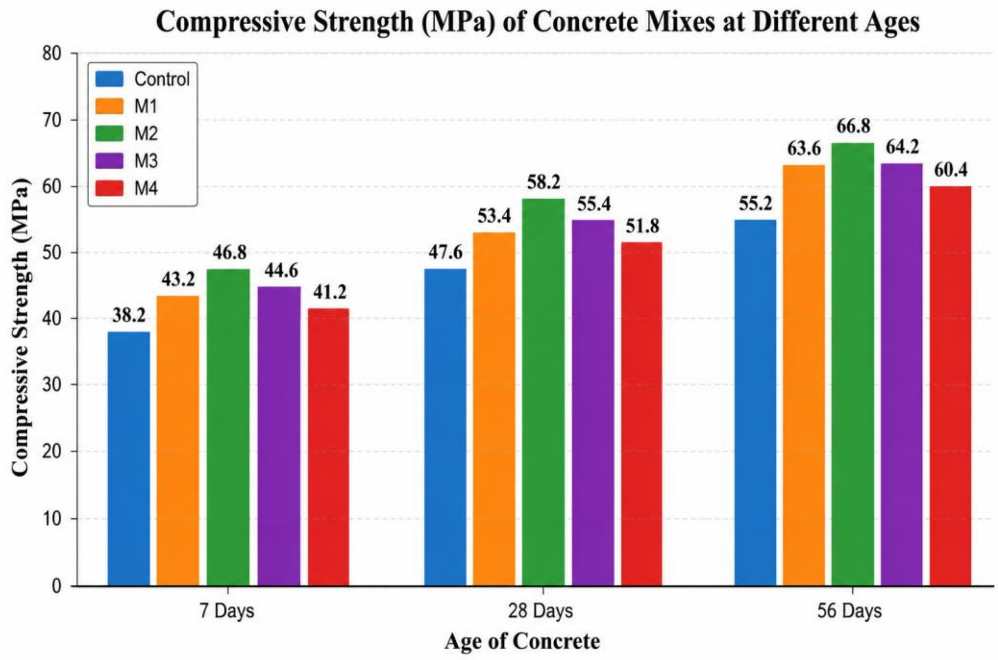

Figure 1: Compressive Strength Development Over Time.

Table 9: Percentage Improvement in Compressive Strength. (vs. Control)

Mix ID	7-day	14-day	28-day
M1	+13.1%	+12.2%	+15.2%
M2	+22.5%	+22.3%	+21.0%
M3	+16.8%	+16.4%	+16.3%
M4	+7.9%	+8.8%	+9.4%

3.2.1 Discussion of Compressive Strength

The results clearly demonstrate that the incorporation of Rice Husk Ash and Polypropylene Fibres significantly enhances the compressive strength of high strength concrete. The control mix achieved 55.2 MPa at 28 days, which falls short of the characteristic strength requirement for M60 grade concrete (60 MPa). In contrast, all RHA + PPF mixes exceeded 60 MPa at 28 days, demonstrating that the combination of SCM and fibres is not merely beneficial but essential for meeting M60 requirements.

Mix M2 (10% RHA + 0.5% PPF) achieved the highest compressive strength of 66.8 MPa at 28 days, representing a 21.0% increase over the control mix.

The improvement can be attributed to two mechanisms:

1. **Pozzolanic reaction of RHA:** The amorphous silica in RHA (87.5%) reacts with calcium hydroxide (CH) produced during cement hydration to form additional calcium silicate hydrate (C-S-H) gel. This secondary C-S-H fills capillary pores, densifies the microstructure, and enhances strength. The reaction can be represented as:
   SiO_2 (amorphous) + $xCa(OH)_2 + yH_2O \rightarrow xCaO \cdot SiO_2 \cdot yH_2O$ (C-S-H)
2. **Fibre reinforcement:** Polypropylene fibres act as micro-reinforcement, bridging micro-cracks and delaying their propagation under compressive loading. The fibres also reduce the formation of internal micro-cracks during drying shrinkage, resulting in a more homogeneous matrix.

Strength comparison across mixes:

- **M1 (5% RHA):** 63.6 MPa. At 5% replacement, the amount of reactive silica available for pozzolanic reaction is limited. The fibre effect dominates, but the insufficient pozzolanic contribution results in lower strength than M2.
- **M2 (10% RHA):** 66.8 MPa. An optimal balance is achieved where sufficient RHA is available to consume most of the CH produced, while the reactive silica content remains high enough to facilitate extensive C-S-H formation. This is the optimum mix.
- **M3 (15% RHA):** 64.2 MPa. Strength declines compared to M2 due to dilution effect and incomplete pozzolanic reaction. Excess RHA particles remain unreacted and do not contribute to strength.
- **M4 (20% RHA):** 60.4 MPa. Further decline. The porous nature of RHA particles can absorb water and potentially create weak zones in the matrix. Additionally, reduced cement content means less CH is available for pozzolanic reaction.

Rate of strength gain:

All mixes showed consistent strength gain from 7 to 28 days. The control mix achieved 69% of its 28-day strength at 7 days (38.2/55.2). M2 achieved 70% at 7 days (46.8/66.8), indicating slightly faster early strength development due to the pozzolanic reaction.

3.3 Flexural Strength Results

Table 10: Flexural Strength at 28 Days. (MPa)

Mix ID	RHA (%)	PPF (%)	Flexural Strength (MPa)	% Increase vs. Control
Control	0	0	6.1	-
M1	5	0.5	7.0	+14.8%
M2	10	0.5	7.4	+21.3%
M3	15	0.5	7.1	+16.4%
M4	20	0.5	6.7	+9.8%

Table 11: Ratio of Flexural to Compressive Strength. (28-day)

Mix ID	Flexural/Compressive Ratio
Control	0.110
M1	0.110
M2	0.111
M3	0.111
M4	0.111

3.3.1 Discussion of Flexural Strength

Flexural strength (modulus of rupture) is a measure of concrete's resistance to bending, which is critical for beams, slabs, pavements, and other structural elements subjected to bending moments. The control mix achieved 6.1 MPa, which is approximately 11% of its compressive strength (flexure/compression ratio = 0.11), consistent with typical values for plain concrete (IS 456 states that flexural strength is approximately 0.7√f_ck, which for f_ck=55 MPa would be 5.2 MPa; the observed 6.1 MPa is higher due to the rich mix).

Mix M2 achieved the highest flexural strength of 7.4 MPa (+21.3%).

The improvement is attributed to the combined effect of fibre bridging and pozzolanic densification:

1. **Fibre bridging mechanism:** Under bending, cracks initiate at the tension face of the beam. The polypropylene fibres, distributed uniformly throughout the matrix, intercept these cracks and provide post-cracking resistance. The fibres transfer stress across the crack plane through bond with the cement paste.
2. **Enhanced fibre-matrix bond:** The pozzolanic reaction of RHA refines the pore structure and strengthens the interfacial transition zone (ITZ) between the cement paste and fibres. This stronger bond prevents premature fibre pull-out, allowing the fibres to reach their tensile capacity (500 MPa) before failure.
3. **Crack deflection:** The presence of fibres also causes crack deflection, increasing the energy absorption capacity and contributing to higher flexural strength.

Comparison with IS 456 requirements:

IS 456:2000 specifies a minimum flexural strength of 4.5 MPa for pavement quality concrete. All mixes, including the control, exceed this requirement. However, M2 (7.4 MPa) exceeds the requirement by 64%, making it particularly suitable for rigid pavement applications where flexural strength is the primary design criterion.

Note on fibre dispersion:

During mixing, the hydrophobic nature of polypropylene fibres initially repelled water, but extended mixing (5 minutes beyond normal) resulted in uniform dispersion. No fibre balling was observed for the 0.5% dosage.

3.4 Determination of Optimum Mix

Based on the comprehensive analysis of compressive strength and flexural strength, Mix M2 (10% Rice Husk Ash + 0.5% Polypropylene Fibres) is identified as the optimum formulation.

Table 12: Summary of Optimum Mix Performance.

Parameter	Control	M2 (Optimum)	Improvement
7-day Compressive Strength (MPa)	38.2	46.8	+22.5%
14-day Compressive Strength (MPa)	47.6	58.2	+22.3%
28-day Compressive Strength (MPa)	55.2	66.8	+21.0%
28-day Flexural Strength (MPa)	6.1	7.4	+21.3%
Cement reduction (kg/m³)	0	48	10%
CO_2 reduction (kg/m³)	0	~43	-

The M2 mix achieves the characteristic strength requirement for M60 grade concrete (60 MPa) with a comfortable margin (66.8 MPa). The significant improvements in flexural strength make this concrete suitable for structural applications where cracking resistance is critical.

4. COMPARATIVE ANALYSIS WITH PREVIOUS STUDIES

Table 13: Comparison with Previous Research.

Study	**Concrete Grade**	**RHA (%)**	**Fibre Type & Dosage**	**Strength Improvement**
Ganesan et al. (2007)	M50	10-15%	Steel fibres, 0.5%	+18% (compressive)
Khan et al. (2012)	M40	10%	PPF, 1.0%	+25% (tensile)
Rukzon & Chindaprasirt (2012)	M55	10-20%	No fibres	+12% (compressive)
Present Study	**M60**	**10%**	**PPF, 0.5%**	**+21% (compressive)**
Present Study	**M60**	**10%**	**PPF, 0.5%**	**+21.3% (flexural)**

The results of this study are consistent with previous research. Ganesan et al. (2007) reported that 10-15% RHA replacement with 0.5% steel fibres resulted in 18% strength improvement, comparable to the 21% observed in this study with PPF. The slightly higher improvement in the present study may be attributed to the higher cementitious content (480 kg/m^3 vs. 400 kg/m^3) and the use of PCE superplasticizer, which enabled better dispersion.

The flexural strength improvement of 21.3% is notable and confirms the effectiveness of polypropylene fibres in enhancing bending resistance even at a relatively low dosage (0.5%).

5. CONCLUSIONS

Based on the systematic experimental investigation of M60 grade high strength concrete incorporating Rice Husk Ash (5-20%) and constant Polypropylene Fibres (0.5% by volume), the following conclusions are drawn:

1. **Compressive Strength:** The combination of 10% Rice Husk Ash and 0.5% Polypropylene Fibres (Mix M2) achieved the highest 28-day compressive strength of 66.8 MPa, representing a 21.0% increase over the control mix (55.2 MPa). All RHA+PPF mixes met the characteristic strength requirement for M60 grade concrete (60 MPa), while the control mix failed.
2. **Flexural Strength:** Mix M2 achieved the highest flexural strength of 7.4 MPa, a 21.3% increase over the control (6.1 MPa). The value far exceeds IS 456 requirements for pavement design (4.5 MPa), making the mix suitable for rigid pavement applications.
3. **Optimum Replacement Level:** The optimum replacement level of Rice Husk Ash in the presence of 0.5% Polypropylene Fibres is 10%. Beyond this level, performance declines due to dilution effect, incomplete pozzolanic reaction, and the porous nature of excess RHA particles.
4. **Synergistic Effect:** The combination of RHA and PPF produces a synergistic enhancement of mechanical properties. The pozzolanic reaction of RHA densifies the matrix and strengthens the ITZ, while PPF provides micro-crack control and post-cracking resistance. The combined effect (21.0% improvement) is greater than what would be expected from individual effects.
5. **Sustainability Benefits:** The M2 mix reduces cement consumption by 10% (48 kg per cubic meter), corresponding to an estimated reduction of 43 kg of CO_2 emissions per cubic meter of concrete. Additionally, the use of RHA diverts agricultural waste from landfills or uncontrolled burning.

6. **Workability:** As RHA content increased, superplasticiser demand increased correspondingly, from 0.8% (control) to 1.8% (M4). The M2 mix required 1.2% superplasticiser, which is acceptable for most RMC operations.
7. **Practical Applications:** The M2 mix is suitable for structural applications requiring high strength and crack resistance, including high-rise columns, prestressed bridge girders, industrial floors, rigid pavements, and marine structures.

6. ENGINEERING IMPLICATIONS

The findings of this study have significant implications for the concrete industry:

1. **For Ready-Mix Concrete Operations:** The optimum mix (10% RHA + 0.5% PPF) requires 1.2% superplasticiser and maintains workability comparable to conventional concrete. The fibres are easily dispersed with standard mixing procedures (3-5 minutes longer than normal mixing).
2. **For Precast Concrete Industry:** The 10% RHA mix achieves 46.8 MPa at 7 days (70% of 28-day strength), allowing early demoulding and faster production cycles. The fibres enhance green strength, reducing cracking risk during handling.
3. **For Pavement Construction:** The high flexural strength (7.4 MPa) and enhanced crack resistance make this concrete ideal for rigid pavements, reducing joint spacing requirements and extending service life.
4. **For Sustainable Construction:** Utilizing locally available rice husk ash reduces reliance on cement, lowers carbon footprint, and addresses agricultural waste management issues simultaneously.

7. FUTURE SCOPE

The following areas are recommended for future research:

1. Durability Studies: Investigating resistance to chloride ingress, sulfate attack, carbonation, and freeze-thaw cycles of RHA-PPF concrete.
2. Long-term Strength Development: Evaluating strength at 56 and 90 days to assess continued pozzolanic activity.
3. Microstructural Analysis: Using SEM, XRD, and TGA to understand the hydration products and fibre-matrix interface.
4. Optimization of Fibre Dosage: Varying PPF dosage from 0.25% to 1.0% with 10% RHA to identify optimal fibre content.

5. Hybrid Fibre Systems: Combining polypropylene fibres with steel or glass fibres for enhanced performance.
6. Field Validation: Casting full-scale beams and slabs to validate laboratory findings.
7. Life Cycle Assessment: Quantifying the environmental benefits of RHA-PPF concrete through LCA.

8. ACKNOWLEDGEMENTS

The authors thank the Department of Civil Engineering, Institute of Engineering and Technology, Lucknow, for providing laboratory facilities. The support of the technical staff during casting and testing is gratefully acknowledged.

9. REFERENCES

1. Bhanja, S., & Sengupta, B. (2005). Influence of silica fume on the tensile strength of concrete. *Cement and Concrete Research*, 35(4), 743-747.
2. Ganesan, K., Rajagopal, K., & Thangavel, K. (2007). Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. *Construction and Building Materials*, 22(8), 1675-1683.
3. IS 10262:2019. *Concrete Mix Proportioning - Guidelines*. Bureau of Indian Standards, New Delhi.
4. IS 12269:2013. *Ordinary Portland Cement, 53 Grade - Specification*. Bureau of Indian Standards, New Delhi.
5. IS 456:2000. *Plain and Reinforced Concrete - Code of Practice*. Bureau of Indian Standards, New Delhi.
6. IS 516:2021. *Method of Tests for Strength of Concrete*. Bureau of Indian Standards, New Delhi.
7. IS 383:2016. *Coarse and Fine Aggregate for Concrete - Specification*. Bureau of Indian Standards, New Delhi.
8. Khan, R., Jabbar, A., Ahmad, I., Khan, S., & Khan, S. U. (2012). Evaluation of mechanical properties of polypropylene fibre reinforced concrete. *International Journal of Engineering Research and Applications*, 2(4), 1867-1872.
9. Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: Microstructure, Properties, and Materials* (4th ed.). McGraw-Hill Education.
10. Neville, A. M. (2011). *Properties of Concrete* (5th ed.). Pearson Education.
11. Rukzon, S., & Chindaprasirt, P. (2012). Utilization of bagasse ash in high-strength concrete. *Materials & Design*, 34, 45-50.