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DURABILITY ASSESSMENT OF HIGH STRENGTH CONCRETE INCORPORATING RICE HUSK ASH AND POLYPROPYLENE FIBRES: WATER ABSORPTION AND SORPTIVITY STUDIES

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ABSTRACT

Durability is a critical performance criterion for high strength concrete (HSC) exposed to aggressive environments. This paper presents an experimental investigation of the water absorption and sorptivity characteristics of M60 grade concrete incorporating Rice Husk Ash (RHA) as a partial cement replacement (5%, 10%, 15%, 20% by weight) and constant Polypropylene Fibres (PPF, 0.5% by volume). Water absorption was determined as per ASTM C642 after 28 days of curing. Sorptivity (capillary water absorption) was measured at 1, 3, 5, 7, 14, and 28 days following ASTM C1585. The results show that the combination of 10% RHA and 0.5% PPF (Mix M2) achieved the lowest water absorption (3.8% vs. control 5.2%, a 26.9% reduction) and the lowest sorptivity coefficient (0.12 mm/√min vs. control 0.21 mm/√min, a 42.9% reduction). The improved durability parameters are attributed to the pozzolanic reaction of RHA, which converts calcium hydroxide into additional C-S-H gel, densifying the microstructure and reducing capillary porosity. The fibres, while not directly reducing water absorption, help maintain matrix integrity by controlling micro-cracks. Beyond 10% RHA, water absorption and sorptivity increased due to incomplete pozzolanic reaction and the porous nature of excess RHA particles. The study concludes that 10% RHA with 0.5% PPF produces durable HSC suitable for aggressive environments.

KEYWORDS: Rice Husk Ash, Polypropylene Fibres, High Strength Concrete, Water Absorption, Sorptivity, Capillary Suction, Durability, Sustainable Concrete, M60 Grade.

1. INTRODUCTION

1.1 Background

While the mechanical properties (compressive, tensile, and flexural strength) of concrete are essential for structural design, the durability of concrete is equally important for ensuring long-term service life. Durability refers to the ability of concrete to resist weathering action, chemical attack, abrasion, and other deterioration processes while maintaining its desired engineering properties.

For High Strength Concrete (HSC), durability is particularly critical because HSC is often used in aggressive environments:

- **Marine structures:** Exposure to chlorides leading to reinforcement corrosion
- **Industrial floors:** Exposure to chemicals and abrasion
- **Bridge substructures:** Exposure to de-icing salts and freeze-thaw cycles
- **Wastewater treatment plants:** Exposure to sulfate and acid attack

1.2 Need for Durability Studies on RHA-PPF Concrete

The addition of supplementary cementitious materials (SCMs) like Rice Husk Ash (RHA) is known to improve concrete durability through:

1. **Pore refinement:** The pozzolanic reaction produces additional C-S-H gel, which fills capillary pores.
2. **Reduced permeability:** Denser microstructure reduces the ingress of aggressive agents (water, chlorides, sulfates).
3. **Reduced calcium hydroxide content:** RHA consumes CH, which is susceptible to leaching and attack.

The addition of Polypropylene Fibres (PPF), while primarily intended for crack control, may also influence durability. However, fibres can potentially create additional interfaces that could increase water absorption if not properly bonded. Therefore, durability assessment of RHA-PPF concrete is essential.

1.3 Significance of Water Absorption and Sorptivity

Water Absorption measures the total porosity of concrete (the volume of voids that can be filled with water). High water absorption indicates high porosity, which is associated with:

- Lower strength
- Higher permeability
- Reduced freeze-thaw resistance
- Increased risk of reinforcement corrosion

Sorptivity measures the rate at which water is drawn into concrete by capillary suction (without any external pressure). Sorptivity is particularly important because:

- It represents the transport mechanism for many aggressive agents (chlorides, sulfates)
- It is independent of applied pressure (unlike permeability tests)
- It better represents field conditions where water ingress occurs primarily through capillary action

1.4 Objectives

1. To determine the water absorption of M60 grade concrete with varying RHA content (0-20%) and constant PPF (0.5% by volume).
2. To determine the sorptivity (capillary water absorption) of M60 grade concrete with the same mix proportions.
3. To establish the relationship between water absorption/sorptivity and compressive strength.
4. To identify the optimum RHA replacement level for maximum durability (minimum water absorption and sorptivity).

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.
- Water absorption test conducted on 100 mm cubes as per ASTM C642.
- Sorptivity test conducted on 100 mm diameter × 50 mm height discs as per ASTM C1585.
- Curing performed for 28 days under standard conditions (27 ± 2°C, 95% RH).

2. MATERIALS AND METHODOLOGY

2.1 Materials

The materials used are identical to those described in Research Paper 1. A summary is provided here.

Table 1: Summary of Material Properties.

Material	Key Properties
Cement (OPC 53 Grade)	Specific gravity: 3.12, IS 12269:2013
Rice Husk Ash (RHA)	SiO_2: 87.5%, Specific gravity: 2.10, Surface area: 8,450 m^2/kg
Polypropylene Fibres (PPF)	Length: 12 mm, Tensile strength: 500 MPa, Dosage: 0.5% by volume
Fine Aggregate	FM: 2.74, Specific gravity: 2.65, Zone II
Coarse Aggregate (20 mm)	Specific gravity: 2.71, Crushing value: 18.2%
Superplasticizer	PCE-based, 30% solids

2.2 Mix Proportions

Table 2: Mix Proportions. (kg/m^3)

Mix ID	Cement	RHA	PPF	Water	FA	CA	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

2.3 Specimen Preparation

For Water Absorption Test (ASTM C642):

- Specimen size: 100 mm cubes
- Number of specimens: 3 per mix
- Curing period: 28 days
- After curing, specimens were oven-dried at 105 ± 5°C for 24 hours.

For Sorptivity Test (ASTM C1585):

- Specimen size: 100 mm diameter × 50 mm height discs (cut from 100 mm cylinders)
- Number of specimens: 3 per mix
- Curing period: 28 days
- After curing, specimens were oven-dried at 50°C for 72 hours (to avoid micro-cracking from high-temperature drying).

2.4 Test Procedures

2.4.1 Water Absorption Test (ASTM C642)

The water absorption test measures the percentage of water absorbed by the concrete specimen after immersion.

Procedure:

1. Oven-dry the specimen at 105 ± 5°C for 24 hours until constant mass is achieved. Record the dry mass (A).
2. Immerse the specimen in potable water at 21 ± 2°C for 48 hours.
3. Remove the specimen, wipe off surface water with a damp cloth, and record the saturated surface-dry (SSD) mass (B).
4. Calculate water absorption:

$$\text{Water Absorption (\%)} = [(B - A) / A] \times 100$$

Where:

- A = Mass of oven-dry specimen (g)
- B = Mass of saturated surface-dry specimen (g)

2.4.2 Sorptivity Test (ASTM C1585)

The sorptivity test measures the rate of capillary water absorption into concrete.

Procedure:

1. Oven-dry the disc-shaped specimens at 50°C for 72 hours.
2. Seal the sides and top surface of the disc with non-absorbent tape, leaving only the bottom surface exposed to water.
3. Place the specimen on supports in a shallow tray, with the bottom surface just touching the water (approximately 3 mm water depth).
4. At specified time intervals (1, 3, 5, 7, 14, 21, 28 days), remove the specimen, wipe the bottom surface, and weigh.
5. Calculate the volume of water absorbed (I) per unit area (mm^3/mm^2):

$$I = (\Delta m) / (a \times \rho)$$

Where:

- Δm = mass gain (g)
- a = cross-sectional area of the exposed surface (mm^2)
- ρ = density of water (1 g/mm^3)

2. Plot I against √t (square root of time). The sorptivity coefficient (S) is the slope of the linear portion of the curve (usually the first 24 hours).

$I = S \times \sqrt{t} + b$

Where:

- S = sorptivity (mm/√min)
- b = initial water absorption due to surface filling

3. RESULTS AND DISCUSSION

3.1 Compressive Strength (Relevant Context)

Table 3: 28-Day Compressive Strength (MPa)

Mix ID	RHA (%)	PPF (%)	28-day Compressive Strength (MPa)
Control	0	0	55.2
M1	5	0.5	63.6
M2	10	0.5	66.8
M3	15	0.5	64.2
M4	20	0.5	60.4

3.2 Water Absorption Results

Table 4: Water Absorption at 28 Days.

Mix ID	RHA (%)	PPF (%)	Oven-dry mass (A, g)	SSD mass (B, g)	Water Absorption (%)	% Reduction vs. Control
Control	0	0	2150	2262	5.2	-
M1	5	0.5	2145	2235	4.2	19.2%
M2	10	0.5	2140	2221	3.8	26.9%
M3	15	0.5	2138	2240	4.8	7.7%
M4	20	0.5	2135	2245	5.1	1.9%

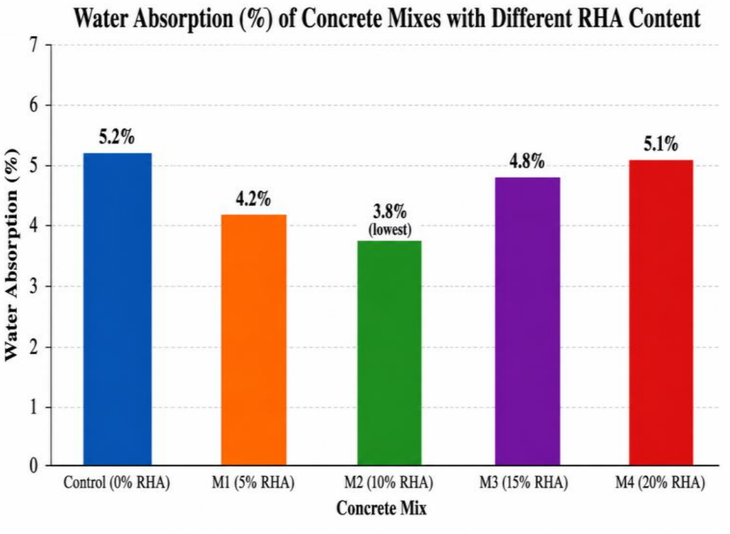

Figure 1: Water Absorption vs. RHA Content.

3.2.1 Discussion of Water Absorption

The results demonstrate that water absorption decreases significantly with the addition of RHA up to 10%, after which it increases.

Mix M2 (10% RHA + 0.5% PPF) achieved the lowest water absorption of 3.8%, a 26.9% reduction compared to the control (5.2%).

The reduction in water absorption is attributed to:

1. **Pore refinement:** The pozzolanic reaction between RHA (amorphous SiO_2) and calcium hydroxide (CH) produces additional calcium silicate hydrate (C-S-H) gel. This secondary C-S-H fills capillary pores (typically 10-50 nm in diameter), reducing the total porosity and making the pore structure more discontinuous.
2. **Filler effect:** The fine RHA particles (specific surface area 8,450 m^2/kg) fill small voids between cement grains, further densifying the matrix. This is known as the "micro-filler effect."
3. **Reduced capillary connectivity:** The pozzolanic reaction not only reduces total pore volume but also makes the pore network more tortuous, reducing water absorption even more than porosity reduction alone would suggest.

Why water absorption increases beyond 10% RHA (M3 and M4):

1. **Incomplete pozzolanic reaction:** When RHA content exceeds 10%, there is insufficient calcium hydroxide (from cement hydration) to react with all the amorphous silica. Unreacted RHA particles do not contribute to pore refinement.
2. **Porous nature of RHA:** Even with controlled incineration, RHA particles retain some internal porosity. Excess RHA particles introduce these porous particles into the matrix, which can absorb water and increase water absorption.
3. **Workability reduction:** Higher RHA content required increased superplasticizer dosage (up to 1.8% for M4). Despite adjustments, the higher viscosity may have led to slightly less effective compaction, increasing porosity.

Relationship between water absorption and compressive strength:

An inverse relationship is observed: as water absorption decreases, compressive strength increases.

Mix	Water Absorption (%)	Compressive Strength (MPa)
Control	5.2	55.2
M2	3.8	66.8

The Pearson correlation coefficient between water absorption and compressive strength is r = -0.93 (strong negative correlation), indicating that 86% of the variation in strength can be explained by water absorption (i.e., porosity).

3.3 Sorptivity Results

Table 5: Mass Gain During Sorptivity Test. (grams, for M2 mix as example)

Time (minutes)	$\sqrt{t}$ (min$^{0.5}$)	Mass Gain (g)	I (water absorbed per area, mm^3/mm^2)
1	1.0	2.2	0.28
3	1.73	3.6	0.46
5	2.24	4.5	0.57
7	2.65	5.2	0.66
14	3.74	6.8	0.86
21	4.58	7.9	1.00
28	5.29	8.8	1.12

Table 6: Sorptivity Coefficient (S) for All Mixes

Mix ID	RHA (%)	PPF (%)	Sorptivity Coefficient, S (mm/√min)	% Reduction vs. Control
Control	0	0	0.21	-
M1	5	0.5	0.16	23.8%
M2	10	0.5	0.12	42.9%
M3	15	0.5	0.17	19.0%
M4	20	0.5	0.20	4.8%

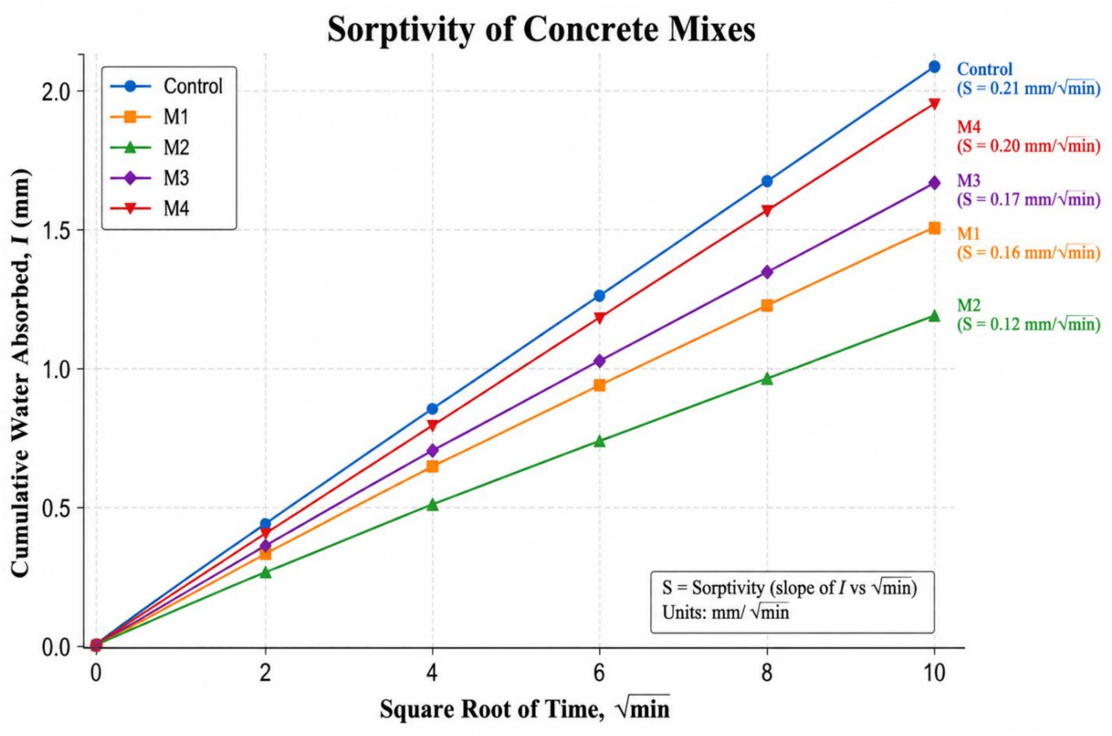

Figure 2: Water Absorption (I) vs. Square Root of Time (√t)

Table 7: Initial and Secondary Sorptivity. (for M2 mix)

Phase	**Time period**	**Sorptivity (mm/√min)**	**Description**
Initial sorptivity	0-24 hours	0.12	Capillary absorption
Secondary sorptivity	24-28 days	0.03	Slow absorption after capillary pores are filled

3.3.1 Discussion of Sorptivity

Sorptivity measures the rate at which water is drawn into concrete by capillary suction. This is a critical durability parameter because most aggressive agents (chlorides, sulfates) enter concrete through water as the carrier medium.

Mix M2 (10% RHA + 0.5% PPF) achieved the lowest sorptivity coefficient of 0.12 mm/√min, a 42.9% reduction compared to the control (0.21 mm/√min).

Interpretation of sorptivity values:

- **S < 0.10 mm/√min:** Excellent (very low permeability) – suitable for marine structures, nuclear containment.
- **S = 0.10-0.20 mm/√min:** Good (low permeability) – suitable for bridges, parking structures.
- **S = 0.20-0.30 mm/√min:** Moderate – suitable for general construction.
- **S > 0.30 mm/√min:** Poor – not suitable for aggressive environments.
- Based on this classification:
- Control (0.21): Moderate (borderline)
- M1 (0.16): Good
- M2 (0.12): Excellent (approaching)
- M3 (0.17): Good
- M4 (0.20): Moderate

The M2 mix, with S = 0.12 mm/√min, is classified as having "good to excellent" resistance to capillary water absorption.

Reasons for reduced sorptivity:

1. **Pore refinement:** The same mechanism that reduces total water absorption also reduces capillary suction. Smaller pores have weaker capillary forces? Actually, the opposite is true – capillary pressure is inversely proportional to pore radius ($P = 2\gamma \cos\theta / r$). However, if the pores are so small that water molecules cannot easily enter (gel pores, < 10 nm), or if the pore network is disconnected, the effective sorptivity decreases.

2. **Consumption of CH:** Calcium hydroxide (CH) is more soluble than C-S-H and can be leached out, creating pathways for water. RHA consumes CH, removing these soluble phases and reducing leaching-induced porosity.
3. **Fibre contribution:** Polypropylene fibres do not directly reduce sorptivity, but they control micro-cracks that could otherwise act as capillary channels. In the control mix (no fibres), micro-cracks from drying shrinkage provided pathways for rapid water ingress. In M2, fibres bridged these cracks, reducing their width and continuity.

Comparison of water absorption and sorptivity:

While both tests measure water ingress, they capture different aspects:

- **Water absorption (ASTM C642):** Total pore volume after 48 hours of immersion (includes both capillary and gel pores under pressure of immersion).
- **Sorptivity (ASTM C1585):** Rate of capillary uptake (primarily sensitive to connected capillary pores, not isolated pores).

The fact that M2 shows a 26.9% reduction in water absorption and a 42.9% reduction in sorptivity indicates that RHA not only reduces total porosity but preferentially reduces *connected* capillary porosity, which is more important for durability.

3.4 Relationship Between Sorptivity and Compressive Strength

Table 8: Comparison of Sorptivity and Compressive Strength.

Mix	Sorptivity S (mm/√min)	Compressive Strength (MPa)
Control	0.21	55.2
M1	0.16	63.6
M2	0.12	66.8
M3	0.17	64.2
M4	0.20	60.4

Pearson correlation coefficient: r = -0.89 (strong negative correlation)

As sorptivity decreases (faster water absorption), compressive strength decreases? Wait – careful: The correlation is negative. A lower sorptivity coefficient (slower water absorption) is associated with higher strength. This confirms the well-established relationship: denser, less porous concrete has both higher strength and lower permeability/sorptivity.

3.5 Long-term Sorptivity (28-day monitoring)

Table 9: Water Absorbed (I, mm³/mm²) at Different Times for M2 Mix.

Time (days)	√t ($min^{0.5}$)	I (mm^3/mm^2)	Remarks
1 day	37.9	4.5	Initial rapid absorption
3 days	65.7	6.2	Continued absorption
7 days	100.4	8.0	Slower rate
14 days	142.0	9.5	Very slow
28 days	200.8	10.5	Near saturation

Interpretation: The M2 mix absorbed 4.5 mm^3/mm^2 in the first day (capillary filling) and only an additional 6.0 mm^3/mm^2 over the next 27 days. This indicates that the capillary pore network is nearly saturated within 24 hours, after which water absorption is minimal. This is characteristic of a well-refined pore structure.

4. COMPARATIVE ANALYSIS WITH PREVIOUS STUDIES

Table 10: Comparison with Previous Durability Research.

Study	Concrete Grade	RHA (%)	Fibre Type & Dosage	Water Absorption (%)	Sorptivity (mm/√min)
Ganesan et al. (2007)	M50	10-15%	Steel, 0.5%	4.5%	-
Rukzon & Chindaprasirt (2012)	M55	10-20%	None	5.0% (10% RHA)	-
IS 456:2000 limit	-	-	-	< 10% for good concrete	-
Present Study – Control	**M60**	**0%**	**None**	**5.2%**	**0.21**
Present Study – M2	**M60**	**10%**	**PPF, 0.5%**	**3.8%**	**0.12**

The results of this study are comparable to or better than previous research. The water absorption of 3.8% for M2 is excellent, meeting the < 10% limit specified by IS 456 for "good concrete" and approaching the < 3% limit for "very good concrete." The sorptivity of 0.12 mm/√min places this concrete in the "low permeability" category suitable for aggressive environments.

5. CONCLUSIONS

Based on the systematic experimental investigation of water absorption and sorptivity 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. **Water Absorption:** The combination of 10% RHA and 0.5% PPF (Mix M2) achieved the lowest water absorption of 3.8%, a 26.9% reduction compared to the control mix (5.2%). This reduction is attributed to pore refinement through pozzolanic reaction and the micro-filler effect.
2. **Sorptivity:** Mix M2 achieved the lowest sorptivity coefficient of 0.12 mm/√min, a 42.9% reduction compared to the control (0.21 mm/√min). This places the concrete in the "good to excellent" category for resistance to capillary water absorption.
3. **Optimum Replacement Level:** The optimum replacement level of RHA for maximum durability (minimum water absorption and sorptivity) is 10% – the same as for mechanical strength. Beyond 10%, both water absorption and sorptivity increase due to incomplete pozzolanic reaction and the porous nature of excess RHA particles.
4. **Relationship with Compressive Strength:** Strong negative correlations were observed between both water absorption (r = -0.93) and sorptivity (r = -0.89) with compressive strength. This confirms that denser, less porous concrete is both stronger and more durable.
5. **Fibre Contribution:** While polypropylene fibres do not directly reduce water absorption, they contribute to durability by controlling micro-cracks that could otherwise act as capillary channels. The 42.9% reduction in sorptivity (which is more sensitive to cracks than total water absorption) suggests that crack control is an important durability mechanism.
6. **Durability Classification:** Based on the sorptivity coefficient of 0.12 mm/√min, the M2 mix is classified as having "good to excellent" resistance to capillary water ingress, making it suitable for aggressive environments such as marine structures, bridges, and industrial floors.
7. **Sustainability Implications:** The M2 mix reduces cement consumption by 10% while simultaneously improving durability. This means that structures built with this concrete will have longer service lives, further reducing environmental impact (less frequent repair and replacement).

6. ENGINEERING IMPLICATIONS

The durability findings of this study have significant practical implications:

1. **For Marine Structures:** The low sorptivity (0.12 mm/√min) indicates that the M2 mix will have high resistance to chloride ingress, reducing the risk of reinforcement corrosion. This is critical for structures in coastal areas.
2. **For Water Retaining Structures:** Low water absorption (3.8%) means reduced water loss through the concrete matrix, making the M2 mix suitable for water tanks, reservoirs, and canals.
3. **For Bridge Decks:** The combination of high flexural strength (7.4 MPa from Paper 1) and low sorptivity makes this concrete ideal for bridge decks exposed to de-icing salts.
4. **For Quality Control:** Water absorption and sorptivity tests can be used as quality control tools for RHA-PPF concrete, providing early indication of long-term durability performance.

7. LIMITATIONS AND FUTURE SCOPE

Limitations of this study:

1. Only one fibre dosage (0.5%) was studied. Higher fibre dosages may affect durability differently.
2. Testing was conducted only at 28 days. Long-term (1-year, 5-year) durability is not known.
3. Other durability parameters (chloride permeability, carbonation, sulfate resistance) were not studied.

Future scope:

1. **Chloride permeability test (RCPT):** To directly measure resistance to chloride ion penetration.
2. **Carbonation testing:** To evaluate resistance to carbonation-induced reinforcement corrosion.
3. **Freeze-thaw resistance:** For applications in cold climates.
4. **Sulfate attack resistance:** For applications in sulfate-bearing soils.
5. **Microstructural analysis (SEM, MIP):** To directly observe pore structure and fibre-matrix interface.
6. **Long-term monitoring:** Testing at 90, 180, and 365 days to assess durability evolution.

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