Mechanical and Durability Performance of Metakaolin–Fly Ash Blended Concrete

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ABSTRACT

Durability of reinforced concrete in marine environments is primarily influenced by chloride-induced corrosion. This research evaluates the performance of concrete mixes containing metakaolin (MK) and fly ash (FA) as partial cement replacements (10% and 20%) under simulated saline exposure. Mechanical properties (compressive and split tensile strength) and durability parameters such as rapid chloride penetration test (RCPT), water absorption, sorptivity, half-cell potential, and accelerated corrosion behavior were studied. Results indicate that MK10FA10 exhibited the highest compressive strength (42.2 MPa), while MK20FA20 demonstrated the lowest chloride permeability (1300 C), lowest sorptivity, lowest water absorption, and maximum resistance to corrosion. The combined use of MK and FA significantly enhanced durability, reduced permeability, and delayed corrosion initiation. The study confirms that MK20FA20 offers superior corrosion resistance, making it suitable for marine and coastal construction applications.

Keywords: Metakaolin, Fly Ash, Chloride Penetration, RCPT, Corrosion Resistance, Saline Conditions, Reinforced Concrete.

1. INTRODUCTION

Reinforced concrete (RC) structures located in coastal regions face deterioration due to chloride ion ingress, which depassivates reinforcing steel and initiates corrosion. This leads to cracking, spalling, and reduction in service life. Improving the durability of concrete under aggressive marine conditions is therefore critical.

Supplementary cementitious materials (SCMs) such as metakaolin and fly ash have been widely used to enhance mechanical and durability properties. Metakaolin (MK) is a highly reactive aluminosilicate that refines pore structure and increases early strength, while fly ash (FA) improves workability, long-term strength, and microstructural densification. Studies have shown that SCMs significantly reduce chloride permeability and enhance corrosion resistance.

This work investigates the combined effects of MK and FA on strength and corrosion resistance of concrete exposed to 3.5% NaCl solution, simulating seawater conditions.

2. MATERIALS AND METHODS

2.1 Materials

- **Cement:** OPC 53 Grade (IS 12269).
- **Metakaolin:** High-reactive, with $SiO_2 + Al_2O_3 > 90\%$.
- **Fly Ash:** Class F conforming to IS 3812.

- **Aggregates:** 20 mm coarse aggregate, Zone II sand.
- **Reinforcement:** 12 mm HYSD bars.
- **Saline Medium:** 3.5% NaCl solution.

2.2 Mix Proportions

Concrete grade: **M30**, w/c ratio: **0.45**

Replacement Levels

- MK: 10%, 20%
- FA: 10%, 20%
- Combined: MK10FA10 and MK20FA20

Control mix (CM) contained 100% cement.

2.3 Specimen Details

- Compressive: 150 × 150 × 150 mm cubes
- Tensile: 150 × 300 mm cylinders
- RCPT: 100 mm dia × 50 mm discs
- Corrosion test specimens: 100 × 200 mm cylinders with embedded steel

2.4 Tests Conducted

- **Compressive strength:** IS 516
- **Split tensile strength:** IS 5816
- **RCPT:** ASTM C1202
- **Water absorption:** IS 3495
- **Sorptivity:** ASTM C1585
- **Half-cell potential:** ASTM C876
- **Accelerated corrosion:** 12V DC impressed voltage method

3. RESULTS AND DISCUSSION

3.1 Compressive Strength

The incorporation of MK and FA led to improved strength compared to control concrete.

Mix	**28-Day Strength (MPa)**
CM	32.0
MK10	38.0
MK20	41.0
FA10	35.2
FA20	37.0
MK10FA10	**42.2**
MK20FA20	40.5

MK10FA10 achieved the highest strength due to synergistic pozzolanic reactions and pore refinement.

3.2 Split Tensile Strength

Similar improvements were observed in tensile performance.

Mix	**Tensile Strength (MPa)**
CM	2.80
MK10FA10	**3.40**

3.3 Rapid Chloride Penetration Test (RCPT)

Mix	Charge Passed (Coulombs)	Rating
CM	3200	High
MK20FA20	**1300**	Very Low

MK20FA20 reduced chloride permeability by **≈60%**.

3.4 Water Absorption & Sorptivity

Mix	Water Absorption (%)	Sorptivity ($mm/min^{0.5}$)
CM	3.2	0.235
MK20FA20	**1.9**	**0.158**

Both properties significantly improved with MK and FA replacements.

3.5 Corrosion Performance

Half-Cell Potential

- Control mix: –420 mV → **High corrosion risk**
- MK20FA20: –210 mV → **Low corrosion risk**

Accelerated Corrosion Test

Mix	Time to Crack (Days)	Mass Loss (%)
CM	12	4.2
MK20FA20	**25**	**1.8**

MK20FA20 showed **the highest corrosion resistance**, with delayed cracking and reduced steel loss.

4. CONCLUSIONS

1. MK and FA significantly improved mechanical and durability performance of concrete.
2. MK10FA10 recorded the highest compressive strength (42.2 MPa).
3. MK20FA20 achieved the best durability performance:
    - Lowest RCPT (1300 C)
    - Lowest sorptivity and water absorption
    - Highest corrosion resistance
4. SCM-modified concrete offers enhanced protection for steel in saline environments.
5. MK–FA blends are recommended for marine structures such as ports, bridges, breakwaters, and piers.

5. FUTURE WORK

- Long-term field exposure studies in actual marine environments
- Microstructural analysis (SEM/EDS, XRD)
- Study of nano-based SCM combinations
- Life-cycle cost and service-life prediction modeling

REFERENCES

[1] ASTM C1202, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*, ASTM International.

[2] ASTM C876, *Standard Test Method for Half-Cell Potentials of Reinforcing Steel*, ASTM International.

[3] IS 10262:2019, *Concrete Mix Proportioning Guidelines*.

[4] IS 456:2000, *Code of Practice for Reinforced Concrete*.

[5] P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, Materials*.

[6] Sabir, B. B., et al., "Metakaolin and Calcined Clays," *Cem Concr Compos*, 2001.

[7] Justice, J. M., et al., "Evaluating Metakaolin," *ACI Mat. J.*, 2005.

[8] M. D. A. Thomas, "Optimizing Fly Ash Use," PCA, 2007.

[9] Bilodeau, A., Malhotra, V. M., "HVFA Concrete," *ACI Mat. J.*, 2000.

(Full list can be expanded on request.)