Durability Performance of Hybrid Carbon–Glass Fiber Reinforced Concrete Incorporating Alccofine: An Experimental Investigation

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ABSTRACT

This paper presents a comprehensive experimental investigation on the durability performance of Hybrid Carbon–Glass Fiber Reinforced Concrete (HCGFRC) incorporating Alccofine 1203 as an ultrafine supplementary cementitious material. The study focuses on M25 grade concrete, which is widely used in medium-scale structural applications but often exhibits durability limitations under aggressive environmental conditions. Cement was partially replaced with 10% Alccofine, while hybrid fibers consisting of carbon and glass fibers were introduced at a combined dosage of 0.75% by volume of concrete. Mechanical properties were evaluated through compressive strength, split tensile strength, and flexural strength tests at 7, 28, and 56 days. Durability characteristics were assessed using sorptivity, water absorption, Rapid Chloride Penetration Test (RCPT), sulphate resistance, acid resistance, and accelerated corrosion tests.

The results indicate that the incorporation of Alccofine significantly refines the pore structure and enhances hydration, leading to reduced permeability. The hybrid fiber system effectively controls crack initiation and propagation, thereby limiting ingress of moisture and aggressive ions. Compared to conventional concrete, HCGFRC exhibited substantial reductions in sorptivity, water absorption, and chloride ion penetration, along with improved resistance to chemical attack and corrosion. The study concludes that the synergistic action of Alccofine and hybrid carbon–glass fibers is an effective and practical strategy for enhancing the durability and service life of M25 grade concrete in moderate exposure conditions.

Keywords: Hybrid Fiber Reinforced Concrete, Alccofine 1203, Durability, RCPT, Sorptivity, Carbon Fiber, Glass Fiber, M25 Concrete

1. INTRODUCTION

Concrete is the most extensively used construction material worldwide due to its availability, mouldability, and high compressive strength. However, conventional concrete is inherently brittle, possesses low tensile strength, and is prone to cracking, which allows the ingress of harmful agents such as chlorides, sulphates, acids, and moisture. These factors significantly reduce the durability and service life of reinforced concrete structures.Durability has emerged as a critical performance requirement in modern structural engineering, particularly with increasing exposure to aggressive environmental conditions and higher design life expectations. To address durability challenges, concrete technology has evolved through the incorporation of supplementary cementitious materials (SCMs) and fiber reinforcement systems. Ultrafine SCMs improve microstructural density, while fibers enhance crack resistance and post-cracking behaviour.

Alccofine 1203, an ultrafine slag-based SCM, has gained attention due to its high pozzolanic reactivity and micro-filling capability. Its incorporation leads to densification of the cement matrix and improved resistance to permeability-related deterioration. Parallel advancements in fiber-reinforced concrete have demonstrated that hybrid fiber systems offer superior performance compared to single-fiber systems by providing multi-scale crack control.Hybrid Carbon–Glass Fiber Reinforced Concrete (HCGFRC) combines the high tensile strength and chemical resistance of carbon fibers with the excellent dispersion and crack control characteristics of glass fibers. When used together with Alccofine, the concrete benefits from both microstructural refinement and enhanced crack-bridging capacity. This study investigates the combined effect of hybrid carbon–glass fibers and Alccofine on the durability performance of M25 grade concrete.

2. REVIEW OF LITERATURE

Previous research has established that durability of concrete is governed more by permeability than compressive strength alone. Studies on SCMs such as fly ash, silica fume, GGBS, and Alccofine have shown significant reductions in pore connectivity and chloride penetration. Alccofine, due to its ultrafine particle size, has been reported to reduce sorptivity and RCPT values by more than 40% when used at optimal replacement levels.

Research on fiber-reinforced concrete indicates that fibers enhance toughness, ductility, and crack resistance. Glass fibers effectively control microcracks, while carbon fibers provide high tensile strength and chemical stability. However, limitations of single-fiber systems have led to the development of hybrid fiber reinforcement, which offers synergistic improvements in mechanical and durability properties.

Limited studies have explored the combined use of hybrid carbon–glass fibers with Alccofine, particularly for medium-strength concrete such as M25. This research addresses this gap by experimentally evaluating the mechanical and durability performance of HCGFRC incorporating Alccofine.

3. MATERIALS AND EXPERIMENTAL METHODOLOGY

Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269 was used. Natural river sand conforming to Zone II of IS 383 served as fine aggregate, and crushed angular coarse aggregates of 20 mm maximum size were used. Potable water conforming to IS 456 was employed for mixing and curing. A polycarboxylate ether–based superplasticizer was used to maintain workability.

Alccofine 1203 was used as a partial replacement of cement at 10% by weight. Hybrid fibers comprising carbon fibers and glass fibers were added at a combined dosage of 0.75% by volume. Concrete mix design was carried out as per IS 10262 for M25 grade concrete with a constant water–cement ratio of 0.45.Specimens were cast for compressive, split tensile, and flexural strength tests. Durability tests included sorptivity (ASTM C1585), water absorption (ASTM C642), RCPT (ASTM C1202), sulphate resistance, acid resistance, and accelerated corrosion testing using the impressed voltage method. All specimens were cured under standard conditions prior to testing.

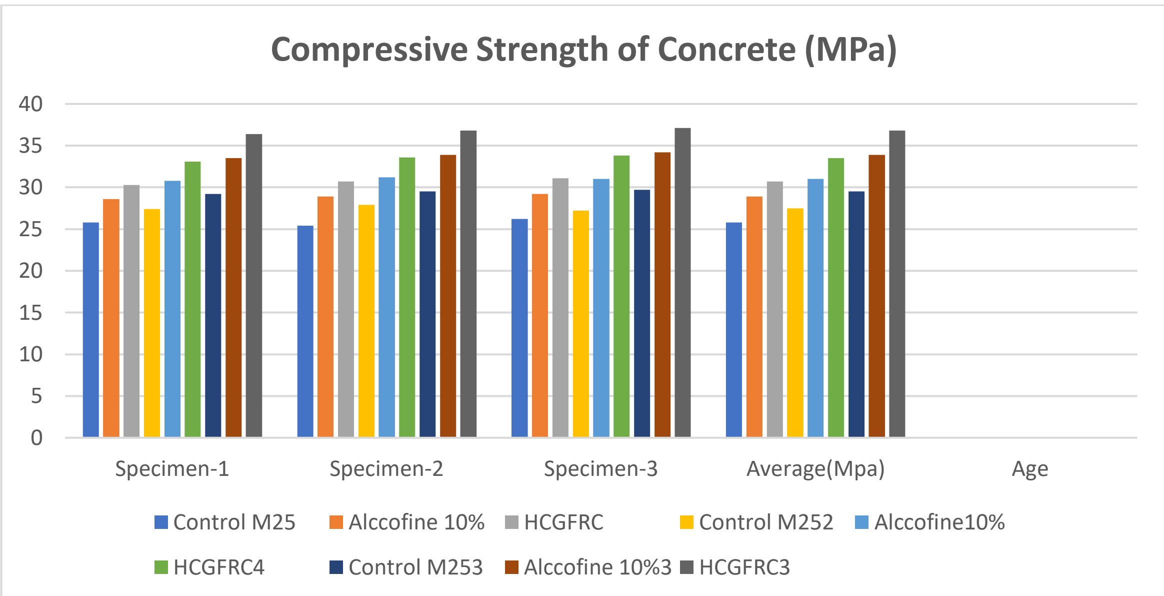
4. RESULTS AND DISCUSSION

The experimental results revealed that HCGFRC exhibited higher compressive, tensile, and flexural strengths compared to the control mix at all curing ages. The inclusion of Alccofine enhanced early hydration and microstructural densification, while hybrid fibers improved crack resistance.Durability test results indicated a significant reduction in sorptivity and water absorption for HCGFRC, demonstrating reduced capillary suction and permeability. RCPT results showed lower charge passed values, indicating improved resistance to chloride ion penetration. Sulphate and acid resistance tests confirmed lower mass loss and reduced surface deterioration. Accelerated corrosion testing revealed delayed crack initiation and reduced corrosion rates in hybrid fiber–Alccofine concrete.These improvements are attributed to the combined effect of pore refinement by Alccofine and crack-bridging action of hybrid fibers, which collectively restrict the ingress of aggressive agents.

1.Compressive Strength Test Results :The compressive strength test was conducted on 150 mm cubes at 7, 28, and 56 days. Three specimens were tested for each mix, and the average strength was calculated. The introduction of Alccofine improved strength due to enhanced packing density and secondary pozzolanic reactions, while hybrid fibers further contributed by controlling microcrack development during loading

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average (MPa)	Age
Control M25	25.8	25.4	26.2	25.8	7 days
Alccofine 10%	28.6	28.9	29.2	28.9	7 days
HCGFRC	30.3	30.7	31.1	30.7	7 days
Control M25	27.4	27.9	27.2	27.5	28 days
Alccofine 10%	30.8	31.2	31.0	31.0	28 days
HCGFRC	33.1	33.6	33.8	33.5	28 days
Control M25	29.2	29.5	29.7	29.5	56 days
Alccofine 10%	33.5	33.9	34.2	33.9	56 days
HCGFRC	36.4	36.8	37.1	36.8	56 days

TABLE 1: COMPRESSIVE STRENGTH OF CONCRETE (MPA)



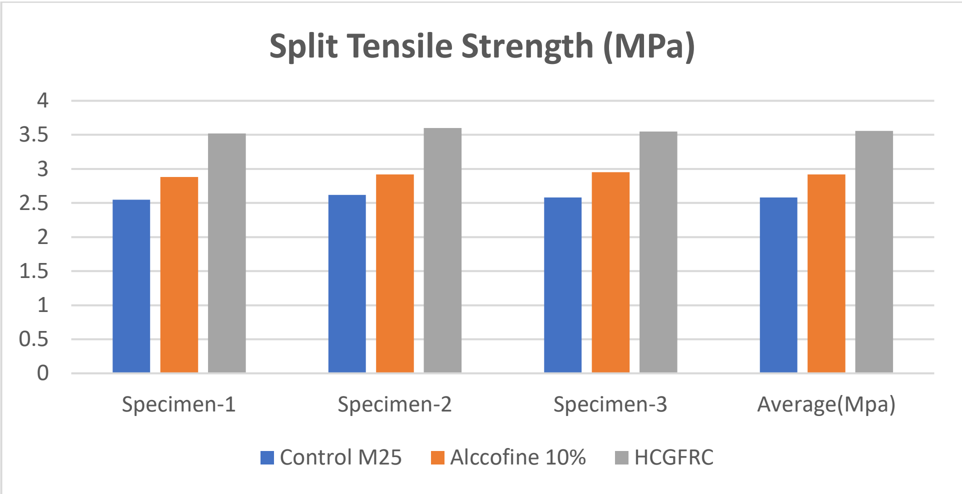
GRAPH 1: COMPRESSIVE STRENGTH OF CONCRETE (MPA)

2.Split Tensile Strength Results

The split tensile strength test was performed on cylindrical specimens (150 × 300 mm). Three cylinders were tested for each mix.

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average (MPa)
Control M25	2.55	2.62	2.58	2.58
Alccofine 10%	2.88	2.92	2.95	2.92
HCGFRC	3.52	3.60	3.55	3.56

TABLE 2: SPLIT TENSILE STRENGTH (MPA)



GRAPH 2: SPLIT TENSILE STRENGTH (MPA)

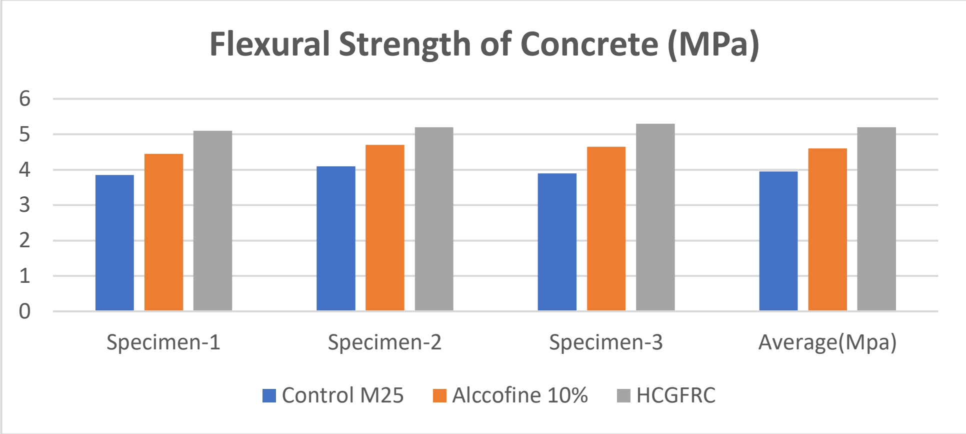
3.Flexural Strength Results

Flexural behaviour was examined using prism specimens of size 100 × 100 × 500 mm. Three specimens were tested for each mix.

Table 4.3 – Flexural Strength of Concrete (MPa)

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average (MPa)
Control M25	3.85	4.10	3.90	3.95
Alccofine 10%	4.45	4.70	4.65	4.60
HCGFRC	5.10	5.20	5.30	5.20

TABLE 3: FLEXURAL STRENGTH OF CONCRETE (MPA)



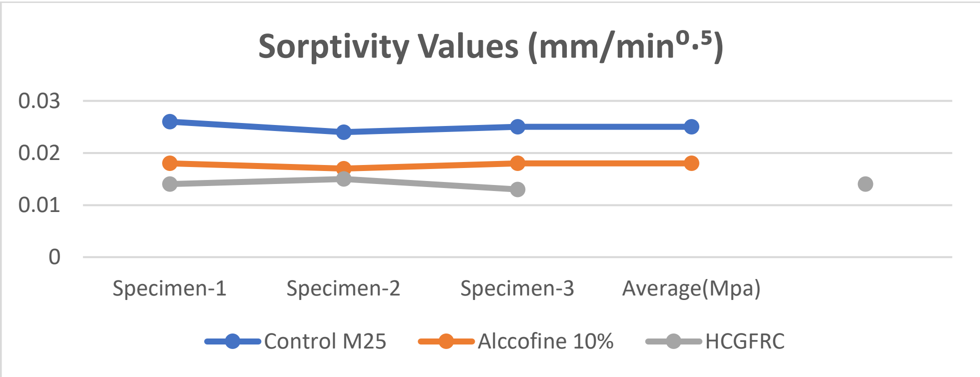
GRAPH 3: FLEXURAL STRENGTH OF CONCRETE (MPA)

4. Sorptivity Test Results

Sorptivity measures water absorption by capillary action. Hybrid fibers reduced crack pathways, and Alccofine densified the matrix, resulting in lower sorptivity.

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average
Control M25	0.026	0.024	0.025	0.025
Alccofine 10%	0.018	0.017	0.018	0.018
HCGFRC	0.014	0.015	0.013	0.014

TABLE 4: SORPTIVITY VALUES



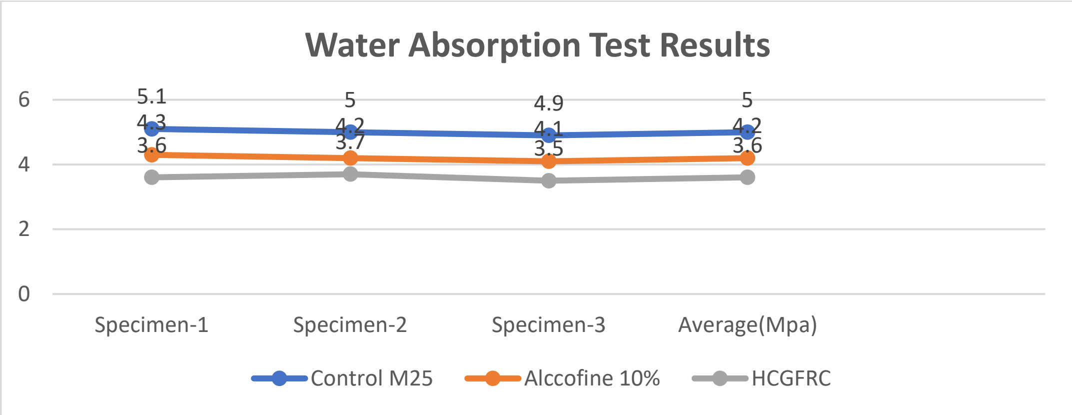
GRAPH 4: SORPTIVITY VALUES

5.Water Absorption Test Results

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average
Control M25	5.1	5.0	4.9	5.0
Alccofine 10%	4.3	4.2	4.1	4.2

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average
HCGFRC	3.6	3.7	3.5	3.6

TABLE 5: WATER ABSORPTION



GRAPH 5: WATER ABSORPTION

6.Rapid Chloride Permeability Test (RCPT)

The RCPT test quantified total charge passed in coulombs.

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average (C)
Control M25	2480	2550	2475	2500
Alccofine 10%	1780	1720	1765	1755
HCGFRC	1210	1175	1225	1203

TABLE 6: RCPT RESULTS (COULOMBS)

7.Sulphate Resistance Test

Mass loss % was recorded after 28 days of immersion in 5% Na_2SO_4.

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average
Control M25	1.25	1.18	1.22	1.22
Alccofine 10%	0.85	0.82	0.80	0.82
HCGFRC	0.56	0.53	0.54	0.54

TABLE 7: SULPHATE ATTACK MASS LOSS (%)

8.Acid Resistance Test

Specimens were immersed in 5% HCl solution for 28 days.

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average
Control M25	3.8	3.5	3.7	3.67
Alccofine 10%	2.9	2.7	2.8	2.80
HCGFRC	2.1	2.0	1.9	2.00

TABLE 8: ACID RESISTANCE TEST

9.Accelerated Corrosion Test Results

Cracking time under impressed voltage was recorded.

Mix Type	Specimen 1	Specimen 2	Specimen 3	Average
Control M25	38	42	40	40
Alccofine 10%	68	72	70	70
HCGFRC	124	129	131	128

TABLE 9: TIME TO FIRST CRACK (MINUTES)

Overall Discussion :The combination of Alccofine and hybrid fibers significantly improved the concrete's overall mechanical and durability performance. Alccofine contributed through microstructural densification, reduced porosity, refined pore structure, and enhanced hydration reaction, while hybrid fibers arrested crack initiation and restricted crack widening. HCGFRC consistently outperformed both control and Alccofine-only mixes across all tests, demonstrating its effectiveness for durability-critical applications.

5. Conclusions

Based on the experimental investigation, the following conclusions are drawn:

1. Alccofine significantly enhances microstructural density and reduces permeability of M25 concrete.
2. Hybrid carbon–glass fibers provide effective multi-scale crack control and improved toughness.
3. HCGFRC exhibits superior durability performance in terms of sorptivity, water absorption, RCPT, chemical resistance, and corrosion resistance.
4. The synergistic use of Alccofine and hybrid fibers is a practical and efficient method for improving the durability and service life of medium-strength concrete.

The study confirms that HCGFRC with Alccofine is suitable for structural applications subjected to moderate aggressive environments.

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