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Durability Assessment of M30 Grade NCC and SCC Incorporating Steel Fibers and Supplementary Cementitious Materials

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Abstract:
This study investigates the durability performance of M30 grade Normal Conventional Concrete (NCC) and Self-Compacting Concrete (SCC) incorporating a quaternary blend of Supplementary Cementitious Materials (SCMs)—Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), and Silica Fume—along with varying volumes of steel fibers (0.5%, 1.0%, 1.5%). Durability properties assessed include acid resistance, sulfate resistance, water absorption, and rapid chloride penetration. The results demonstrate that SCC outperforms NCC in terms of reduced permeability and better resistance to aggressive environments, particularly at higher steel fiber content. SEM and EDS analyses confirm a denser microstructure and stronger hydration products in SCC. The optimal performance was achieved with 1.5% steel fiber dosage combined with the quaternary blend.

Keywords: NCC, SCC, Durability, SCMs, Steel Fibers, Acid Resistance, Sulfate Resistance, Water Absorption, Chloride Penetration

I. Introduction

Durability is a critical factor in assessing concrete performance, especially for structures exposed to aggressive environments. The inclusion of SCMs such as Fly Ash, GGBS, and Silica Fume is known to enhance concrete's resistance to chemical attacks and permeability. Steel fibers further improve tensile behaviour and crack resistance. This study aims to evaluate and compare the durability of M30 grade NCC and SCC mixes enhanced with a quaternary SCM blend and varying steel fiber content.

II. Literature Review

Durability of concrete is a key area of research, especially in aggressive environments where acid, sulfate, and chloride attacks can significantly reduce structural lifespan. Several studies have demonstrated that incorporating Supplementary Cementitious Materials (SCMs) such as Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBS), and Silica Fume (SF) enhances resistance to chemical attack and reduces permeability due to pozzolanic activity and pore refinement. Self-Compacting Concrete (SCC), with its superior flowability and self-compaction, has been shown to produce a denser and more homogeneous matrix than conventional concrete. According to [Okamura and Ouchi, 2003], SCC significantly improves

durability by eliminating compaction-induced voids. Khushefati et al. (2020) reported lower chloride ion permeability in SCC mixes blended with silica fume and fly ash. The use of steel fibers in concrete improves toughness, crack resistance, and mechanical performance. Research by Li and Li (2016) demonstrated that steel fibers mitigate microcracking, reducing permeability and enhancing acid resistance. However, excessive fiber content may reduce workability, especially in SCC, which demands careful dosage optimization. Durability studies such as those by Naik et al. (2003) show that binary and ternary blends of SCMs significantly reduce weight and strength loss under acidic (HCl) and sulfate ($MgSO_4$) exposures. ASTM C642 and C1202-based investigations confirm that mixes with SF and GGBS exhibit the lowest water absorption and chloride penetration. Despite extensive research, comparative durability assessments between NCC and SCC using quaternary SCM blends and steel fibers remain limited. This study addresses this gap by evaluating the combined effect of SCMs and fibers on durability through HCl, $MgSO_4$ exposure, water absorption, and RCP.

III.Objectives of the Study

1. To evaluate the **durability performance** of M30 grade **Normal Conventional Concrete (NCC)** and **Self-Compacting Concrete (SCC)** using acid, sulfate, water absorption, and chloride resistance tests.
2. To investigate the effect of varying **steel fiber dosages** (0.5%, 1.0%, and 1.5%) on the durability of both NCC and SCC.
3. To assess the impact of **binary, ternary, and quaternary SCM blends** (Fly Ash, GGBS, and Silica Fume) on microstructural and durability characteristics.
4. To identify the **optimum combination of SCMs and steel fibers** for achieving maximum durability and long-term performance.

IV. Significance of the Study

This study contributes to sustainable construction by enhancing the durability of M30 grade concrete using steel fibers and supplementary cementitious materials (SCMs). By evaluating both Normal Conventional Concrete (NCC) and Self-Compacting Concrete (SCC), the research highlights the synergistic benefits of SCMs and fibers in improving resistance to acid and sulfate attack, reducing water absorption, and minimizing chloride ion penetration. The findings support the development of long-lasting, eco-friendly concrete suitable for aggressive environmental conditions.

V. Significance of Durability Studies

Durability studies are essential for evaluating the long-term performance of concrete structures exposed to aggressive environments such as acids, sulfates, and chlorides. These studies help identify material combinations that minimize deterioration, reduce maintenance costs, and extend service life. By incorporating **SCMs** and **steel fibers**, the resistance of concrete to chemical attack, water ingress, and ion penetration can be significantly improved. Understanding durability behavior also supports the development of **sustainable and high-performance concretes**, ensuring safety and reliability in critical infrastructure over time.

VI. Materials and Methods

- **Cement:** OPC 53 grade (IS 12269:1987)
- **Fine Aggregate:** River sand, specific gravity 2.65

- **Coarse Aggregate:** Crushed granite, 12.5 mm size, specific gravity 2.74
- **SCMs:**
  - Fly Ash: 10% (Class F)
  - GGBS: 15%
  - Silica Fume: 5%
- **Steel Fibers:** Crimped, 12 mm length, 0.3 mm diameter, aspect ratio 40
- **Water-Cement Ratio:** 0.40 (NCC), 0.44 (SCC)
- **Superplasticizer:** SP430 at 1.0% for NCC, 1.2% for SCC
- **VMA:** 0.15% for SCC
- **Mixes Tested:**
- F10G15SF5SF0.5
- F10G15SF5SF1.0
- F10G15SF5SF1.5

VII. Durability Tests Conducted

1 Acid Resistance Weight and strength loss were evaluated at 28 and 90 days after immersion in 5% H2SO4 solution. SCC mixes showed lower weight and strength losses than NCC. The best performance was seen in SCC with 1.5% fiber content.

2 Sulfate Resistance Specimens were immersed in 5% Na2SO4 solution. SCC mixes demonstrated lower deterioration rates compared to NCC, confirming higher sulfate resistance.

3 Water Absorption SCC exhibited significantly lower water absorption values (as low as 1.56%) compared to NCC (minimum 2.76%), indicating a denser matrix.

4 Rapid Chloride Penetration Test (RCPT) SCC mixes with 1.0% and 1.5% steel fibers showed low chloride ion penetrability (<2000 Coulombs), highlighting their superior impermeability.

5. SEM and EDS Analysis SEM micrographs showed a more compact and less porous structure in SCC. EDS results confirmed the presence of strong Ca, Si, and Al peaks in SCC, validating the formation of durable hydration products.

Durability Properties Of Normal Conventional (GROUP-II)

Table: 1 Acid Resistance

Mix ID	Weight Loss (%)*28 Days*	Weight Loss (%)*90 Days*	Strength Loss (%)*28 Days*	Strength Loss (%)*90 Days*
F10G15SF0.5	3.65	5.50	5.25	7.90
F10G15SF1.0	3.85	5.78	5.55	8.35
F10G15SF1.5	4.10	6.00	5.90	8.80
F10SF5SF0.5	3.70	5.60	5.30	7.80
F10SF5SF1.0	3.95	5.85	5.65	8.25
F10SF5SF1.5	4.20	6.10	6.00	8.70
G15SF5SF0.5	3.75	5.65	5.35	7.85
G15SF5SF1.0	4.00	5.90	5.70	8.30
G15SF5SF1.5	4.25	6.20	6.10	8.90

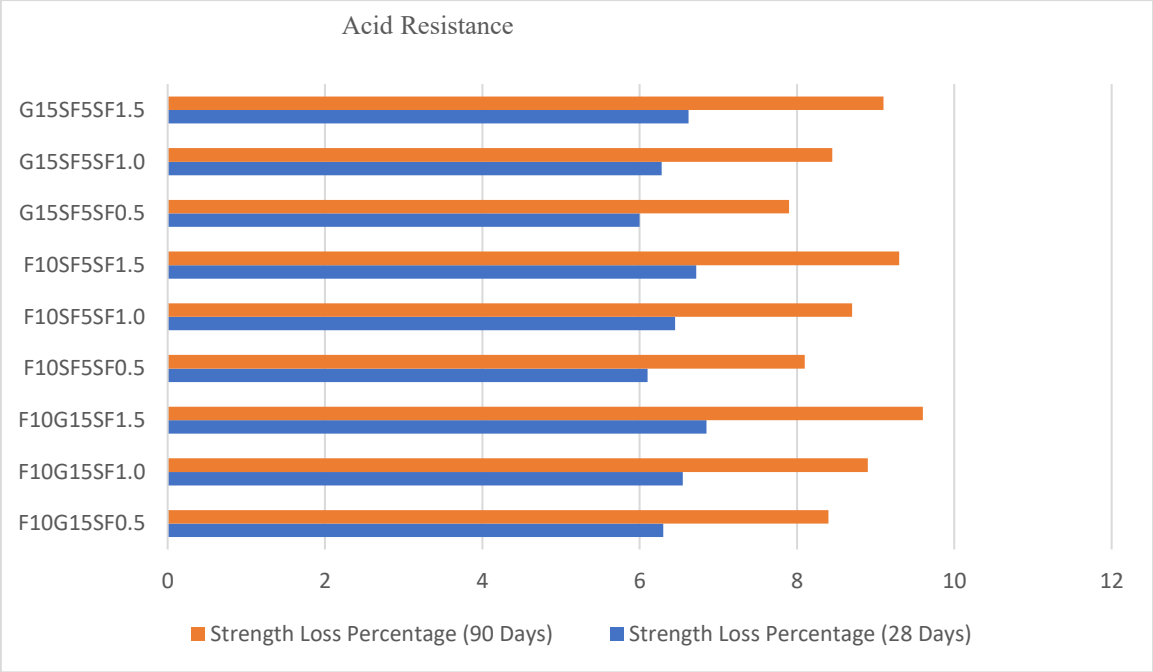


Fig: 1 Acid Resistance

Observations: from the above Table 1& figure 1

The acid attack test results for Group II mixes of M30 grade NCC indicate that **weight and strength loss increase** with higher steel fiber content across all combinations. Mixes with **0.5% steel fibers** consistently show better acid resistance. Among all, **F10G15SF0.5** exhibited the **lowest strength loss (7.90%)** and **weight loss (5.50%)** at 90 days, indicating the most resistance to acidic conditions. In contrast, **G15SF5SF1.5** showed the **highest losses**, with **6.20% weight loss** and **8.90% strength loss** at 90 days. This trend confirms that while SCMs improve durability, excessive steel fiber content (1.5%) may slightly reduce acid resistance due to possible fiber-induced microcracking. Overall, ternary blends with moderate fiber content (0.5%–1.0%) provide optimal durability under acid exposure.

Table 2: Sulfate resistance

Mix Type	Weight Loss (%) (28 Days)	Weight Loss (%) (90 Days)	Strength Loss (%) (28 Days)	Strength Loss (%) (90 Days)
F10G15SF0.5	3.45	5.10	4.80	6.50
F10G15SF1.0	3.70	5.40	5.10	6.90
F10G15SF1.5	4.00	5.70	5.40	7.50
F10SF5SF0.5	3.30	4.95	4.60	6.20
F10SF5SF1.0	3.55	5.25	4.95	6.60
F10SF5SF1.5	3.85	5.60	5.30	7.10
G15SF5SF0.5	3.20	4.80	4.50	6.00
G15SF5SF1.0	3.50	5.05	4.80	6.45
G15SF5SF1.5	3.80	5.40	5.10	6.90

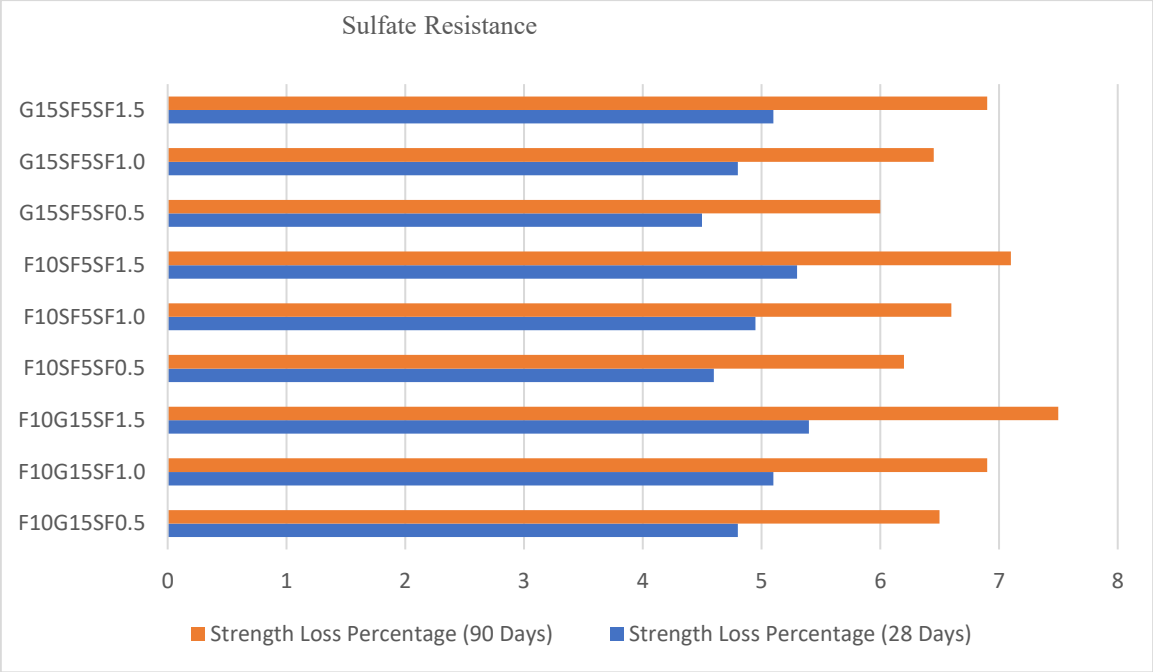


Fig: 2 Sulfate resistance

Observations: from the above Table 2 & figure 2

The sulfate attack results for Group II mixes reveal that **weight and strength loss increase with higher steel fiber content**, although all ternary blends performed better than typical control mixes. Among the tested combinations, **G15SF5SF0.5** demonstrated the **lowest weight loss (4.80%)** and **strength loss (6.00%)** after 90 days, indicating excellent sulfate resistance due to the combined effect of GGBS and silica fume. In contrast, mixes with 1.5% steel fibers, such as **F10G15SF1.5**, showed higher deterioration, with **5.70% weight loss** and **7.50% strength loss**. The results confirm that moderate steel fiber content (around 0.5%) in ternary blends enhances sulfate resistance, while excessive fiber content may slightly reduce durability due to possible microcracking or localized stress concentrations. Overall, ternary mixes with 0.5% fiber content, especially G15SF5SF0.5, provided the most durable performance under sulfate exposure

Table 3: Water Absorption Test

Mix	Water Absorption (%)
F10G15SF0.5	3.12
F10G15SF1.0	2.96
F10G15SF1.5	2.78
F10SF5SF0.5	3.28
F10SF5SF1.0	3.1
F10SF5SF1.5	2.85
G15SF5SF0.5	3.26
G15SF5SF1.0	3.05
G15SF5SF1.5	2.76

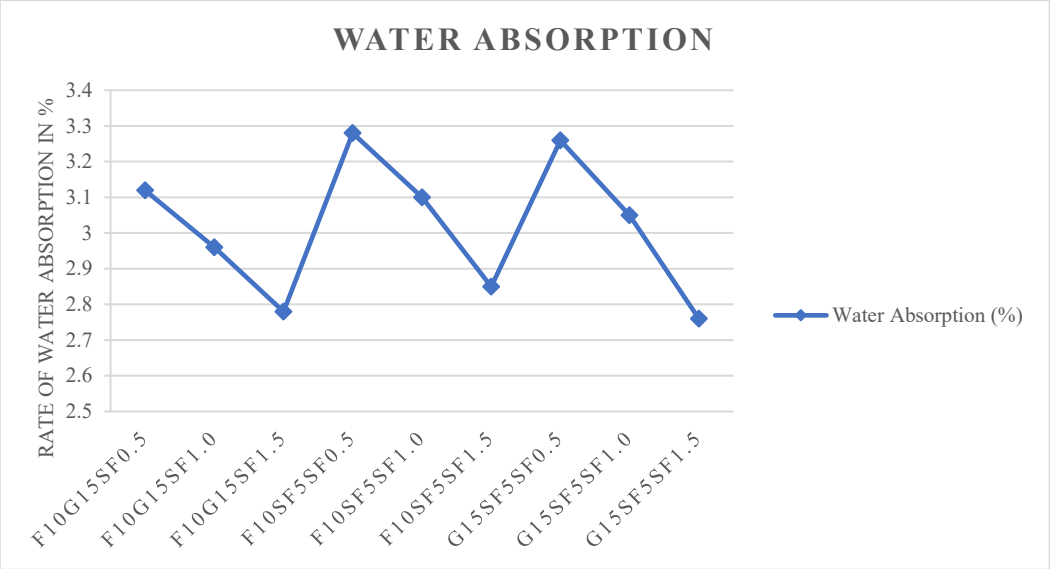


Fig: 3 Water Absorption

Observations: from the above Table 3& figure 3

The water absorption results for Group II M30 grade NCC mixes indicate a clear trend of **decreasing absorption with increasing steel fiber content**, suggesting improved density and reduced porosity. Among all mixes, **G15SF5SF1.5** showed the **lowest water absorption (2.76%)**, indicating the densest microstructure due to the combined effect of GGBS, silica fume, and higher fiber content. In contrast, **F10SF5SF0.5** exhibited the **highest absorption (3.28%)**, likely due to the presence of fly ash and lower fiber content. Overall, ternary blends with higher steel fiber dosages demonstrate better water-tightness, enhancing durability by minimizing moisture ingress.

Table 4: Rapid Chloride Test

Mix ID	Average Charge Passed (Coulombs)	Chloride Penetrability
F10G15SF0.5	2562	Moderate
F10G15SF1.0	2294	Low
F10G15SF1.5	2111	Low
F10SF5SF0.5	2487	Moderate
F10SF5SF1.0	2249	Low
F10SF5SF1.5	2084	Low
G15SF5SF0.5	2413	Moderate
G15SF5SF1.0	2197	Low
G15SF5SF1.5	2036	Low

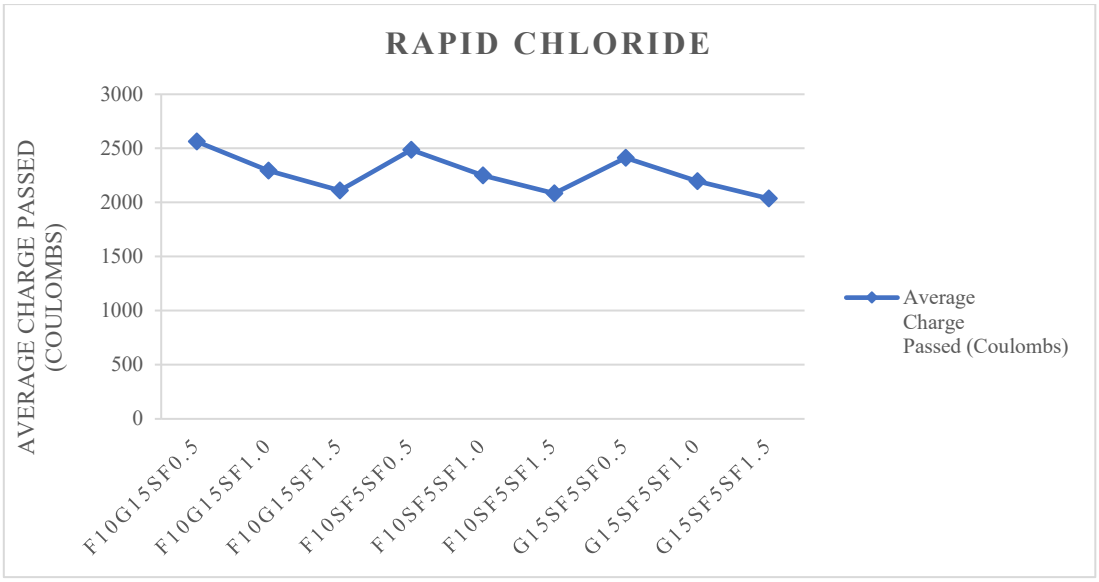
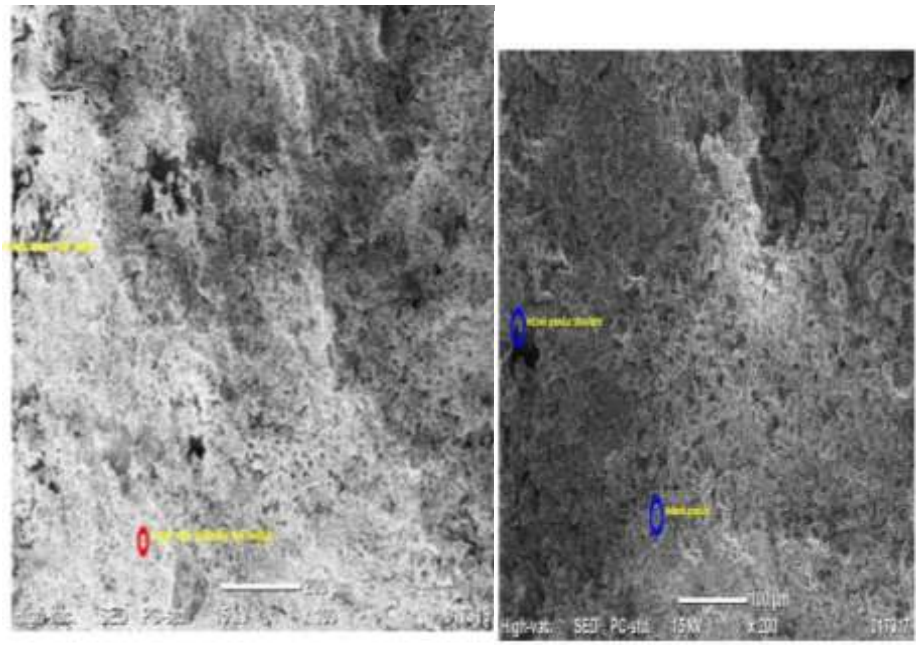


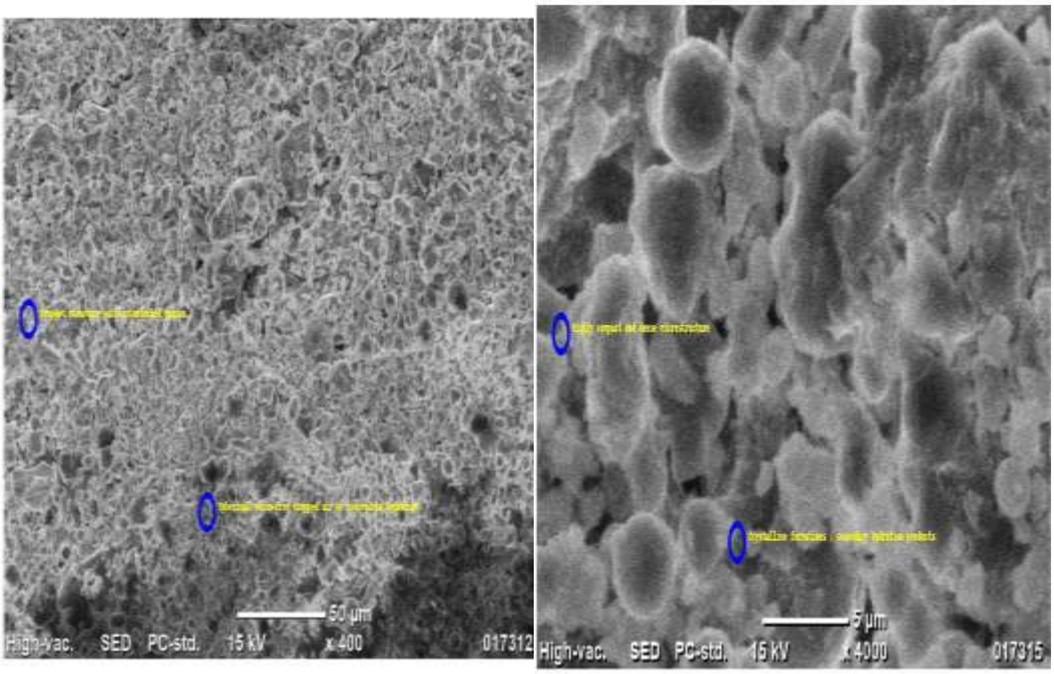
Fig: 4 Rapid Chloride

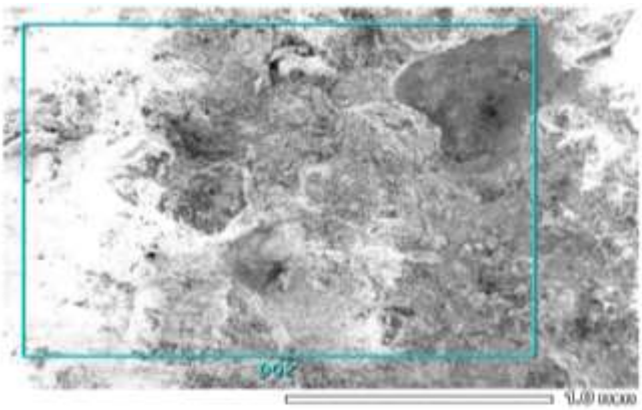
Observations: from the above Table 4 & figure 4

The RCPT results for Group II mixes indicate that **chloride ion penetrability decreases with higher steel fiber content**, reflecting enhanced durability. All mixes with **1.0% and 1.5% fibers** fall into the **low chloride penetrability** range, while those with **0.5% fibers** remain in the moderate range. The best performance was observed in **G15SF5SF1.5**, which recorded the **lowest charge passed (2036 Coulombs)**, followed closely by F10SF5SF1.5 and F10G15SF1.5. These results confirm that the combination of ternary SCMs (Fly Ash, GGBS, Silica Fume) with higher steel fiber content significantly improves the resistance of concrete to chloride ingress, thus enhancing its long-term durability in aggressive environments.

SEM ANALYSIS:







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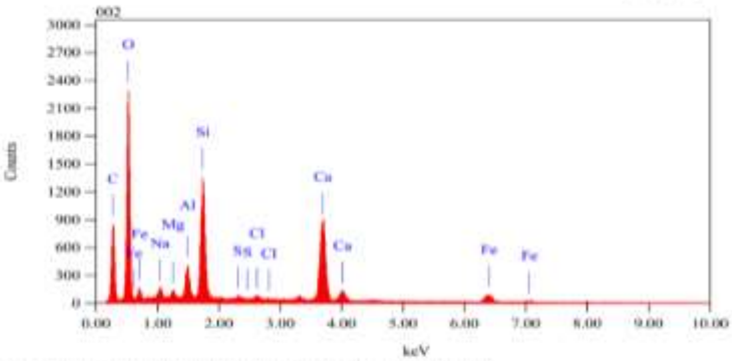

Acquisition Parameter

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Live Time	:	30.00 sec
Dead Time	:	2 %
Counting Rate	:	2344 cps
Energy Range	:	0 - 20 keV

ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.0430
Total Oxide : 24.0

Element	(keV)	Mass%	Sigma	Mol%	Compound	Mass%	Cation	K
C K	0.277	45.37	0.25	80.07	C	45.37	0.00	25.8925
O		21.33		ND		ND		
Na K	1.041	1.14	0.07	0.53	Na2O	1.53	0.89	1.6436
Mg K	1.253	0.72	0.07	0.63	MgO	1.19	0.53	1.0460
Al K	1.486	2.61	0.12	1.03	Al2O3	4.92	1.74	4.5169
Si K	1.739	9.55	0.24	7.28	SiO2	20.42	6.12	19.0435
S K	2.307	0.23	0.06	0.15	SO3	0.57	0.13	0.5239
Cl K	2.621	0.40	0.03	0.24	Cl	0.40	0.00	0.9575
Ca K	3.690	13.99	0.22	7.47	CaO	19.57	6.28	36.4513
Fe K	6.398	4.68	0.19	1.80	FeO	6.02	1.51	9.9289
Total		100.00		100.00		100.00	17.20	

The SEM images display a highly refined and compact microstructure, dominated by dense C-S-H gel formation resulting from the synergistic effect of GGBS and silica fume. The surface appears largely homogenous, with minimal porosity and absence of unreacted particles, indicating complete pozzolanic activity. The amorphous gel likely originates from silica fume's fine particles accelerating hydration, while GGBS contributes to a smoother, denser structure at later ages. The Interfacial Transition Zone (ITZ) seems well-developed, with tight bonding and reduced voids, suggesting superior mechanical strength and durability.

1. EDS shows presence of Ca, Si, Al, O, with dominant Calcium peaks indicating formation of CH and C–S–H.
2. The SEM image shows a less compact matrix with visible unreacted particles and voids — typical for normal cement concrete without mineral admixtures

Durability Properties Of Self-Compacting Concrete (GROUP-III)

Table 5: Acid Resistance

Mix ID	Weight Loss (%)28 Days	Weight Loss (%)90 Days	Strength Loss (%)28 Days	Strength Loss (%)90 Days
F10G15SF5SF0.5	3.25	5	5.3	8.1
F10G15SF5SF1.0	3.1	4.8	5	7.7
F10G15SF5SF1.5	2.9	4.5	4.7	7.2

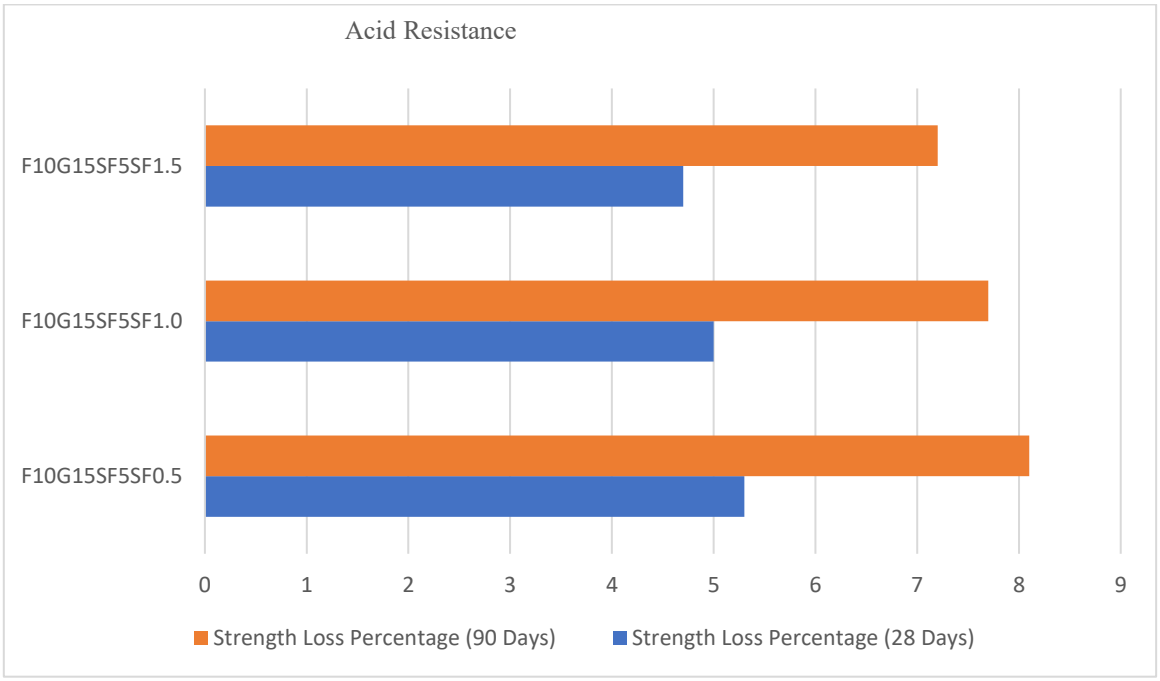


Fig: 5 Acid Resistance

Observations: from the above Table 5 & figure 5

The acid attack results for SCC (Group-III) show a decreasing trend in both weight and strength loss as the steel fiber content increases. At 90 days, weight loss drops from 5% to 4.5%, and strength loss reduces from 8.1% to 7.2% from 0.5% to 1.5% fiber content. This indicates that higher fiber content in quaternary blended SCC enhances resistance to acidic environments.

Table 6: Sulfate Resistance

Mix ID	Weight Loss (%)28 Days	Weight Loss (%)90 Days	Strength Loss (%)28 Days	Strength Loss (%)90 Days
F10G15SF5SF0.5	2.4	3.9	4.1	6.5
F10G15SF5SF1.0	2.2	3.7	3.8	6.1
F10G15SF5SF1.5	2.05	3.5	3.6	5.7

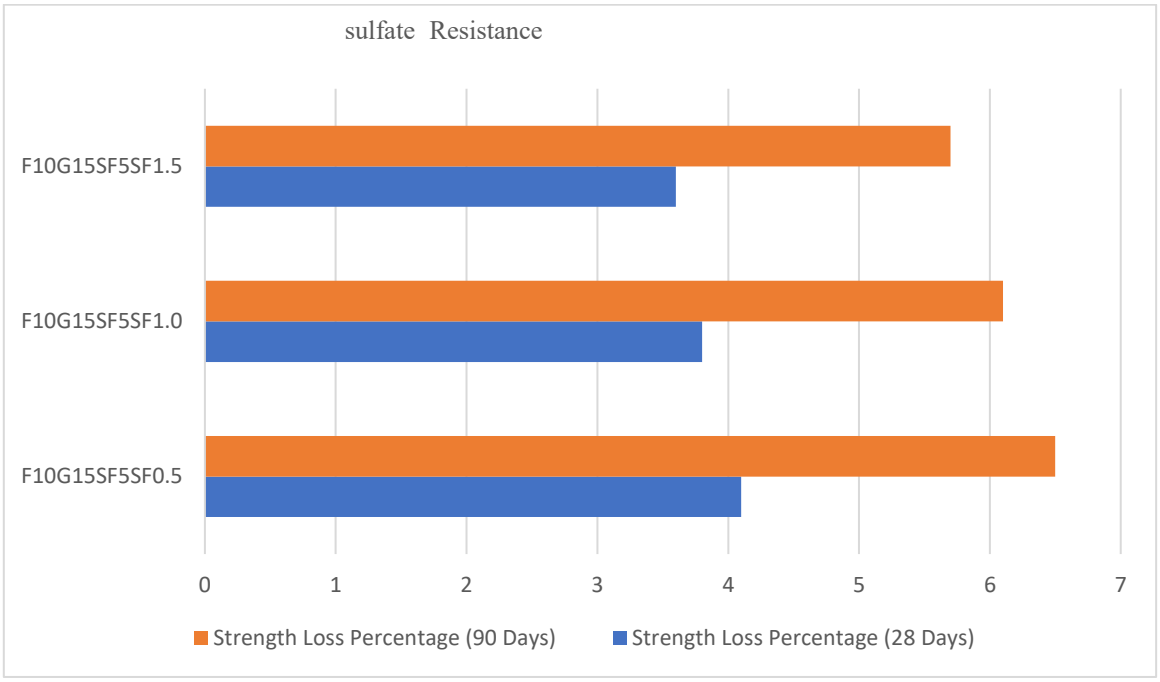


Fig: 6 Sulfate Resistance

Observations: from the above Table 6 & figure 6

The sulfate attack results for SCC (Group-III) demonstrate improved durability with increasing steel fiber content. At 90 days, weight loss decreases from 3.9% to 3.5%, while strength loss reduces from 6.5% to 5.7% as fiber content increases from 0.5% to 1.5%. This trend indicates enhanced sulfate resistance due to the denser matrix and crack-bridging effect of higher steel fiber dosage in quaternary blended SCC.

Table 7: Water Absorption Test

Mix	Water Absorption (%)
F10G15SF5SF0.5	1.75
F10G15SF5SF1.0	1.69
F10G15SF5SF1.5	1.56

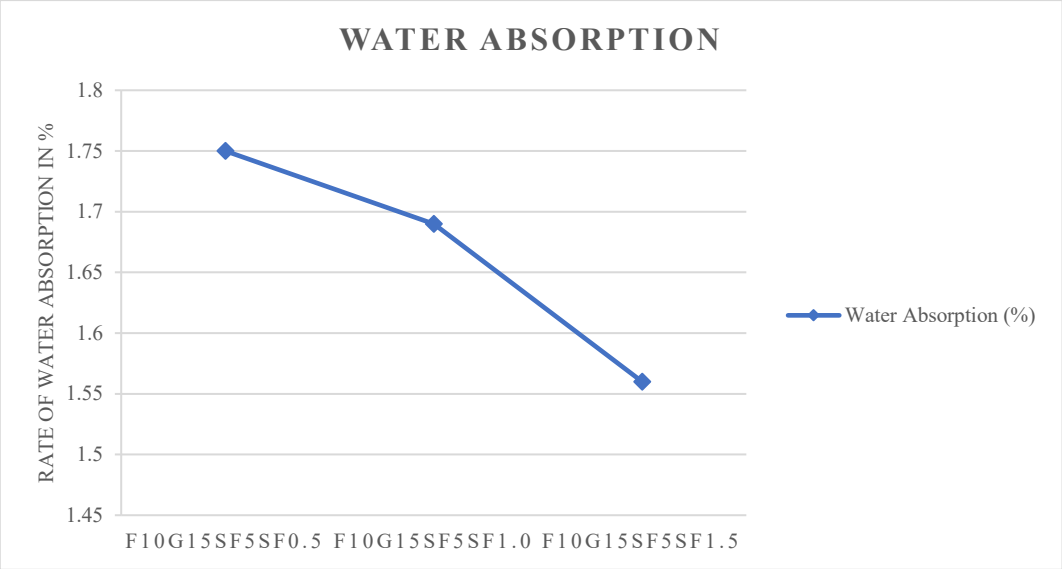


Fig: 7 Water Absorption

Observations: from the above Table 7 & figure 7

The water absorption results for SCC (Group-III) show a clear decreasing trend with increasing steel fiber content. The absorption drops from **1.75%** at 0.5% fiber content to **1.56%** at 1.5% fiber content. This indicates enhanced pore refinement and reduced permeability in quaternary blended SCC mixes, likely due to better fiber-matrix bonding and a denser microstructure.

Table 8: Rapid Chloride Test

Mix ID	Average Charge Passed (Coulombs)	Chloride Penetrability
F10G15SF5SF0.5	2265	Low
F10G15SF5SF1.0	2042	Low
F10G15SF5SF1.5	1847	Low

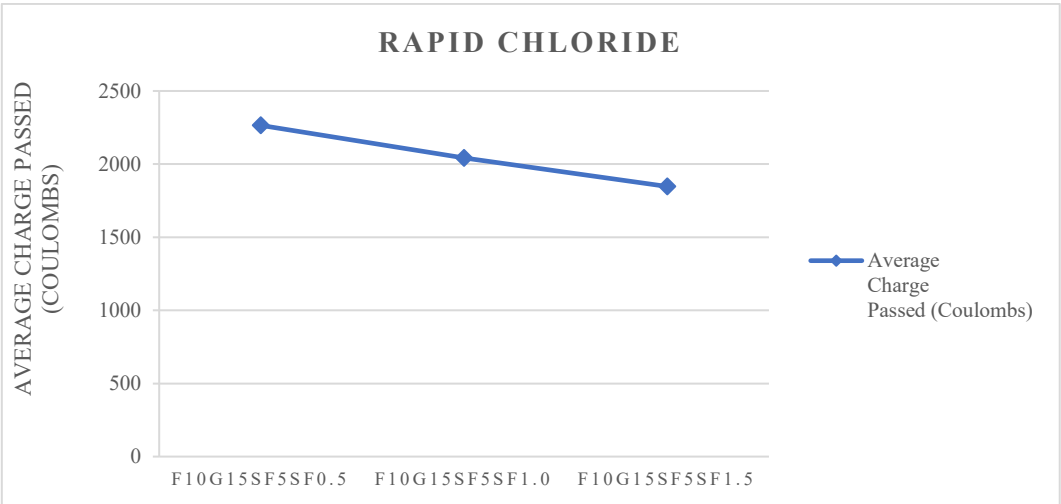
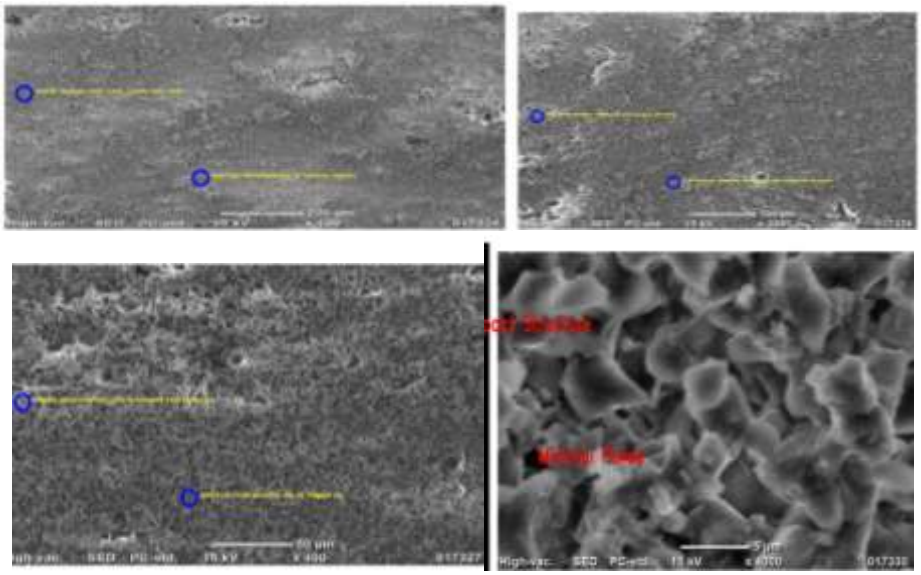


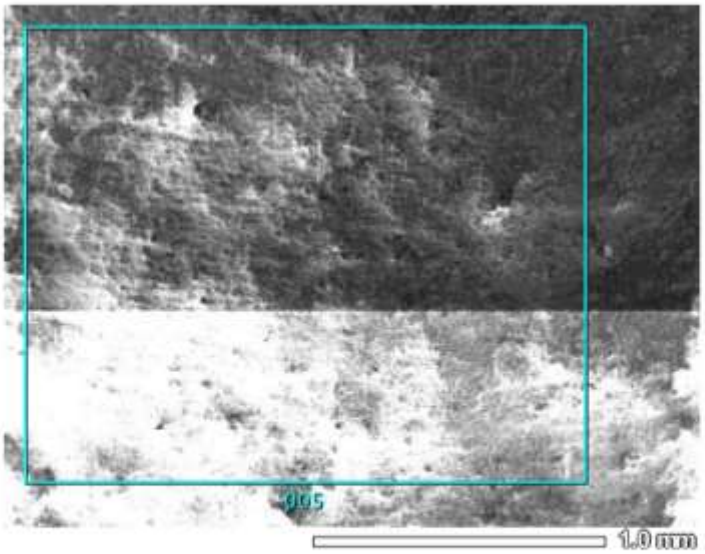
Fig: Rapid Chloride

Observations: from the above Table 8& figure 8

In Group-III SCC mixes, Rapid Chloride Test results showed low chloride penetrability for all blends. As steel fiber content increased from 0.5% to 1.5%, the charge passed decreased from 2265 to 1847 Coulombs, indicating improved durability and reduced permeability due to the combined effect of Fly Ash, GGBS, Silica Fume, and steel fibers.

SEM ANALYSIS:





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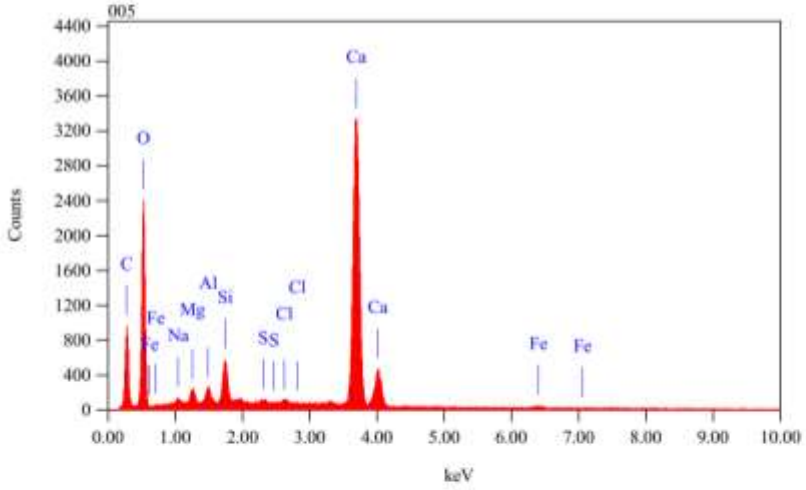

Acquisition Parameter

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Live Time	: 30.00 sec
Dead Time	: 3 %
Counting Rate	: 3773 cps
Energy Range	: 0 - 20 keV

ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.0358
Total Oxide : 24.0

Element	(keV)	Mass%	Sigma	Mol%	Compound	Mass%	Cation	K
C K	0.277	27.70	0.15	64.40	C	27.70	0.00	14.9372
O		22.88		ND		ND		
Na K	1.041	0.48	0.05	0.29	Na2O	0.64	0.35	0.4258
Mg K	1.253	1.36	0.08	1.56	MgO	2.25	0.94	1.2592
Al K	1.486	1.07	0.08	0.55	Al2O3	2.02	0.67	1.1877
Si K	1.739	3.02	0.13	3.00	SiO2	6.46	1.80	4.0051
S K	2.307	0.28	0.06	0.24	SO3	0.69	0.14	0.4504
Cl K	2.621	0.34	0.03	0.27	Cl	0.34	0.00	0.5797
Ca K	3.690	41.95	0.32	29.23	CaO	58.69	17.57	75.8342
Fe K	6.398	0.93	0.10	0.47	FeO	1.20	0.28	1.3207
Total		100.00		100.00		100.00	21.75	

The SEM analysis of the ternary blended concrete (Fly Ash + GGBS + Silica Fume) reveals a highly dense and compact microstructure. The combined pozzolanic reaction of fly ash and silica fume with the cement matrix results in abundant C–S–H gel formation, significantly reducing porosity. GGBS contributes to additional hydration products, while silica fume refines the pore structure due to its ultrafine particles. Fly ash fills the micro voids and provides a smoother matrix. The overall texture is more homogeneous with minimal unreacted particles and dense C–S–H zones, indicating superior strength, durability, and reduced permeability.

1. EDS reveals stronger Si and Al peaks, along with Ca, showing the influence of silica fume and GGBS/fly ash enhancing pozzolanic reactions.
2. The SEM structure is dense and homogeneous, with minimal pores, suggesting a well-hydrated, durable mix suitable for high-performance applications.

Conclusion

1. **Acid Resistance:**
   - In **NCC**, lower fiber content (0.5%) showed better acid resistance. Mix F10G15SF0.5 had the least strength loss (7.90%) at 90 days.
   - In **SCC**, durability improved with higher fiber content. F10G15SF5SF1.5 had the lowest strength loss (7.2%), indicating enhanced acid resistance due to denser microstructure.
2. **Sulfate Resistance:**
   - Similar trends were observed in sulfate exposure. In NCC, G15SF5SF0.5 exhibited the best sulfate resistance.
   - SCC with higher fiber content (1.5%) showed the least strength and weight loss, confirming better matrix integrity and crack control.
3. **Water Absorption:**
   - Water absorption reduced consistently with increasing fiber content in both NCC and SCC.
   - SCC mixes performed significantly better, with minimum absorption (1.56%) in F10G15SF5SF1.5, reflecting a highly dense matrix.
4. **Chloride Ion Penetrability (RCPT):**
   - All mixes with 1.0% and 1.5% fibers in both NCC and SCC demonstrated **low chloride penetrability**.
   - The best result was observed in SCC (F10G15SF5SF1.5) with only **1847 Coulombs**, ensuring superior resistance to chloride ingress.
5. **SEM and EDS Analysis:**
   - SEM images confirmed **dense microstructures** and **well-developed ITZ** in SCC due to the synergistic effect of SCMs.
   - EDS results showed high Ca, Si, and Al peaks, indicating effective pozzolanic reactions, especially in SCC mixes with quaternary blends.

References

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