EXPERIMENTAL INVESTIGATION ON THE EFFECT OF METAKAOLIN AND IRON SLAG ON THE DURABILITY OF SELF COMPACTING CONCRETE

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ABSTRACT

Due to the shortage and high price of river sand led to the use of M sand in construction. Based on the experimental results conducted on SCC to determine the mechanical properties of concrete, cement replaced with metakaolin at 15% ad Iron slag at 20% as a replacement material for fine aggregate give the better results In this study durability properties of SCC like sulphate resistance, acid resistance, water absorption, electrical resistivity and rapid chloride penetration test were conducted on SCC with 15% metakaolin and 20% iron slag as a partial replacement of cement and fine aggregate respectively.

Keyword – *Self compacting concrete, metakaolin, iron slag, compressive strength, split tensile strength, flexural strength etc.*

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1. INTRODUCTION

Cement is the most commonly used material in concrete. Use of concrete is increasing day by day due to increase in the construction works. Usually Concrete is compacted by vibrations in order to expel entrapped air, making it denser and homogeneous because compaction is necessary to produce durable concrete. Full compaction is difficult due to heavy reinforcement, as a result self-compacting concrete (SCC) was developed. Self-compacting concrete (SCC) can be defined as a concrete which can be placed with its own weight with or without vibration. It facilitates and ensures proper filling and good structural performance of heavily reinforced congested members.

The optimization of self-compacting concrete mixtures aims at the reduction of the paste volume and consequently the reduction of the production cost. The cement and fine aggregate are the most reliable materials used for concreting, plastering and masonry work. The main problems such as acute shortage, high price and enormous usage of M sand in the construction. Iron slag can be used as an alternative to M sand since iron slag is produced in large quantity all over the world. About 17 thousand tons of iron slag is produced annually in India. Large volume of iron slag disposed off in open land in near-by areas which can cause great threat to living beings. Use of iron slag in the preparation of concrete is the good remedy to its disposal. With continuous increase in the production of iron slag, it is necessary and appropriate to use it in concrete rather than disposal.

Due to their high pozzolanic activity and filling effect, SCMs can lead to the production of a more consistent, cohesive and dense concrete, which exhibits enhanced mechanical characteristics and reduced permeability. Among other cementitious materials, such as silica fume, granulate blast-furnace slag and fly ash, that are frequently used for the production of concrete, metakaolin is a material with a feasible growing implementation in the concrete industry. Metakaolin is a thermally activated pozzolanic material that is obtained by the calcination of kaolinitic clay at moderate temperatures ranging from 650 to 800 ^{0}C. The main characteristic of metakaolin is its high reactivity with calcium hydroxide, $Ca(OH)_2$, and its ability to accelerate cement hydration. Compared to other SCMs, like silica fume or fly ash, the pozzolanic action of metakaolin is expected to be more significant due to its high concentration of silica and alumina. Additionally to the sustainable performance enhancement of concrete, through its improved durability, metakaolin is also considered as a sustainable and environmental-friendly material, due to the limited CO_2 emissions during its production process. Thus, when it is used as a replacement material of Portland cement, a significant reduction of the total CO_2 emissions is achieved. The major disadvantage of metakaolin is the high cost of production, compared to cement.

2. Material Properties and Experimental Investigation Sub Title-1

2.1 Cement

A cement is the binder substance that used in construction which hardens and adheres to other materials, binding them together. Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete. In this study OPC 53 grade was used. 53 grade cement provides long lasting durability due to the presence of high Tri Calcium Silicate (C_3S) content. As per the Bureau of Indian standards (BIS) IS 12269 1987 (reaffirmed 2008), grade of cement highlights the minimum compressive strength that is expected to attain within 28 days. The main characteristics of cement (53 Grade) used are given in the table 1.

Table -1: Properties of cement

Sl.No.	Characteristics	Values obtained
1	Specific gravity	3.15
2	Standard consistency	32%
3	Fineness of cement	5%
4	Initial setting time (min)	35
5	Final setting time(hr)	10

2.2. Fine Aggregate (M-Sand)

Fine aggregate is a reliable material used for concreting, plastering and masonry work. The main problem of fine aggregate is acute shortage, high price and enormous usage of sand in the construction. The manufactured sand (M-sand) is a better substitute to river sand because it has no silt or organic impurities and is mostly well graded. M-sand with proper gradation shall be used in this project for casting the concrete. As per IS 383:1970 (reaffirmed 2016) the size of fine aggregate should ranges from 4.75mm to 75µ and shall have a maximum water absorption of 2.3%. For the preparation of SCC the fine aggregate content will be more compared to coarse aggregate. The tests done on M-sand are water absorption test and specific gravity test.

Table -2: Properties of fine aggregate

Sl.No.	Characteristics	Values obtained
1	Specific gravity	2.73
2	Water absorption	2.0 %

2.3. Coarse Aggregate

The coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. Coarse aggregates consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm and generally between 9.5 mm and 37.5 mm. Crushed stone is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. The aggregates are usually washed and graded at the pit or plant. Some variation in the type, quality, cleanliness, grading, moisture content, and other properties is expected. The sieve analysis, specific gravity and water absorption tests are done on coarse aggregate.

Table -3: Properties of coarse aggregate

Sl.No.	Characteristics	Values obtained
1	Specific gravity	2.80
2	Water absorption	0.4 %

2.4. Iron slag

Iron slag is screened to remove the oversized particle and material passing through 4.75 mm sieve was used in manufacturing of concrete. The major chemical compounds in iron slag are. Iron slag is brittle and lighter than river sand. River sand and iron slag were dried in oven at 100 ^{0}C for 24 h and then cooled down to room temperature before using in concrete.

Fig -1: Iron slag

Specific gravity : 2.52

2.5 Metakaolin

Metakaolin (MK) is a pozzolanic material. It is obtained by the calcination of kaolinitic clay at a temperature ranging between 500 °C and 800 °C. The raw material input in the manufacture of metakaolin ($Al_2 Si_2 O_7$)is kaolin. Metakaolin on reaction with $Ca(OH)_2$, produces CSH gel at ambient temperature and reacts with CH to produce alumina containing phases, including C_4AH_{13}, C_2ASH_8 , and C_3AH_6. In this study the metakaolin was obtained from English India Clay Limited industries (EICL), Trivandrum.

Specific gravity : 2.60

3. MIX DESIGN

The mix design of SCC shows a rapid difference between normal concrete and SCC. SCC has more fine aggregate content than coarse aggregate to compact by its own self weight. The fresh and hardened properties of SCC was affected by the addition of mineral admixture. The size of specimen to find compressive strength and split tensile strength are of 150 x 150 x 150 mm cubes and 150 mm diameter x 300 mm length cylinder respectively. The size of specimen used to find the flexural strength are of 100 x 100 x 500 mm prisms. Fly ash was added as a replacement material for cement at a concentration of 20% in order to reduce the cement content while preparing conventional SCC.

Table -4: Mix design of SCC

Material	Cement	Fine aggregate	Coarse aggregate	Water	Fly ash
Quantity(Kg/m^3)	472	858	783	200	118
Ratio	1	1.754	1.65	0.423	0.25

4. EXPERIMENTAL INVESTIGATION

Various tests were done for the constituent materials of SCC and the test results obtained for the same. In this study the results and discussion of the durability tests conducted on SCC modified with metakaolin and iron slag are presented**.**

4.1 Durability Test

4.1.1 Sulphate resistance test

The durability tests was conducted only on SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate. The effect of sulphate attack on the concrete was identified in terms of loss in compressive strength and weight loss at 28 and 56 days of exposure. Loss in compressive strength due to exposure in sodium sulphate for 28, 56 days 90 days and is shown in table 5, table6 and table 7

Table- 5: Loss in compressive strength by Sodium Sulphate exposure in 28 days

Specimen	Compressive strength at 28 days of curing (N/mm^2)		
	Water cured	Na_2SO_4 cured	Loss (%)
SCC MK 0	50.22	48.56	3.30
1SCC MK 15 I 20	57.28	55.76	2.65

Table -6: Loss in compressive strength by Sodium Sulphate exposure in 56 days

Specimen	Compressive strength at 56 days of curing (N/mm^2)		
	Water cured	Na_2SO_4 cured	Loss (%)
SCC MK 0	51.96	49.75	4.25
SCC MK15 I 20	58.43	56.28	3.68

Table 7 :Loss in compressive strength by Sodium Sulphate exposure in 90 days

Specimen	Compressive strength at 90 days of curing (N/mm^2)		
	Water cured	Na_2SO_4 cured	Loss (%)
SCC MK 0	51.54	48.45	6.05

SCC MK15 I 20	58.36	55.27	5.29

It can be seen that the strength attained by all the mixes get decreased by the immersion of specimen into sodium sulphate solution. Conventional self compacting concrete and self compacting concrete containing 15% metakaolin and 20% iron slag showed strength reduction of 3.30% and 2.65% at 28 days exposure. Loss in compressive strength of SCC is higher for control specimen compared to SCC with 15% metakaolin as a partial replacement of cement and 20% iron slag as a partial replacement material for fine aggregate compared to control specimen. A gain of 0.65% is obtained on SCC with 15% metakaolin as a partial replacement of cement and 20% iron slag as a partial replacement material for fine aggregate compared to control specimen on 28 days of sodium sulphate exposure.

While at 56 days exposure condition conventional SCC and SCC with 15% metakaolin and 20% iron slag had a reduction in strength at 4.25% and 3.68% respectively. It can be seen that compressive strength of conventional concrete get reduced with sulphate exposure than SCC with optimum metakaolin and iron slag based on maximum strength criteria. A gain of 0.57% is obtained on SCC with 15% metakaolin as a partial replacement of cement and 20% iron slag as a partial replacement material for fine aggregate compared to control specimen on 56 days of sodium sulphate exposure. This could be due to the improved impermeability and the reduction in porosity of the concrete mix by the combined void filling characteristics of metakaolin.

At 90 days of sodium sulphate exposure there is a loss of 6.05% in compressive strength for control specimen and 5.29% loss in compressive strength for SCC with 15% metakaolin as a partial replacement of cement and 20% iron slag as a partial replacement material for fine aggregate. A gain of 0.76 % is obtained on SCC with 15% metakaolin as a partial replacement of cement and 20% iron slag as a partial replacement material for fine aggregate compared to control specimen on 90 days of sodium sulphate exposure. Figure 2 gives the graphical representation of the loss in compressive strength of specimens due to sodium sulphate exposure

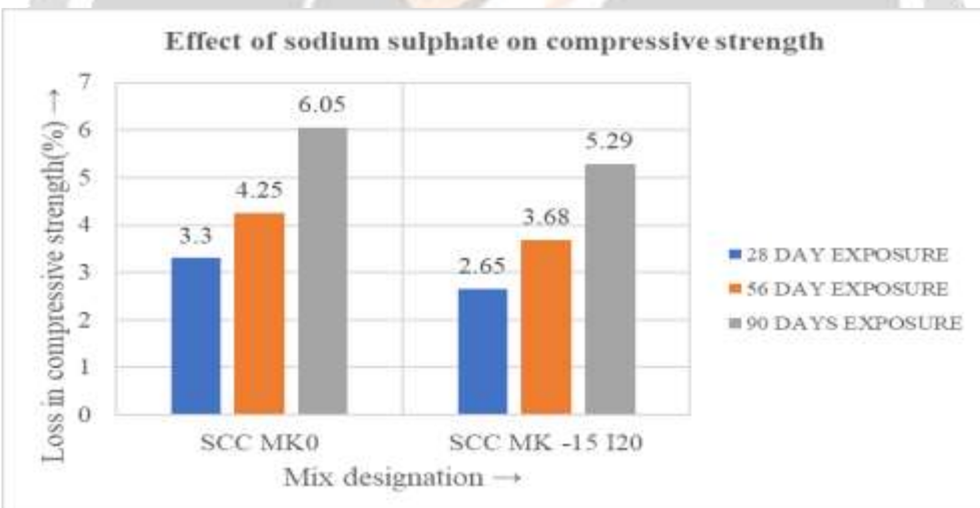

Fig 2 Loss in compressive strength by Sodium Sulphate exposure

Table -8: Loss in weight by Sodium Sulphate exposure

Specimen	Initial weight after 28 days water curing (kg)	After 28 days of curing in Na_2SO_4		Initial weight after 28 days water curing (kg)	After 56 days of curing in Na_2SO_4		Initial weight after 28 days water curing (kg)	After 90 days of curing in Na_2SO_4	
		Weight (kg)	Loss (%)		Weight (kg)	Loss (%)		Weight (kg)	Loss (%)
SCCMK 0	8.530	8.490	0.47	8.560	8.470	1.05	8.510	8.390	1.41
SCC MK-15 I20	8.780	8.750	0.34	8.730	8.660	0.80	8.760	8.650	1.25

It can be seen that strength development of all mixes get decreased by the immersion into sodium sulphate. The conventional SCC undergone 0.47% weight loss while comparing SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate undergone a weight loss of 0.34% on 28 days. At 56 days of exposure there is a loss of 1.05% for control specimen and 0.80 % for SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate. The conventional SCC undergone 1.41% weight loss while comparing SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate undergone a weight loss of 1.25% on 90days. Figure 4.9 showed the loss in weight of sodium sulphate exposure.

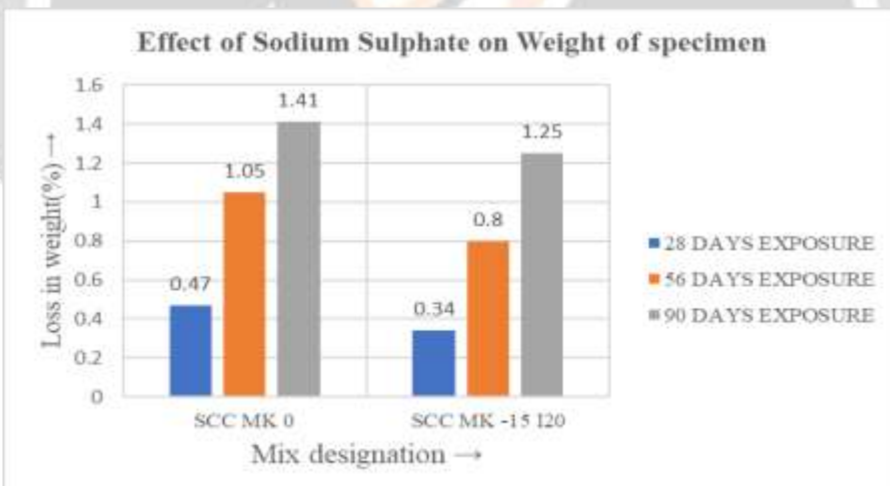

Fig 3 Loss in weight by sodium sulphate exposure

4.1.2 Acid Resistance Test

The effect of acid on the concrete was identified in terms of loss in compressive strength and weight loss at 28, 56 and 90 days of exposure. Loss in compressive strength due to exposure in sodium hydrochloric acid for 28, 56 and 90 days is shown in Table 9,10 and 11.

Table 9: Loss in compressive strength by Hydrochloric acid exposure in 28 days

Specimen	Compressive strength at 28 days of curing (N/mm^2)		
	Water cured	Acid cured (HCl)	Loss (%)
SCC MK 0	50.22	48.46	3.50
SCC MK15 I 20	57.28	54.85	4.24

Table -10: Loss in compressive strength by hydrochloric acid exposure in 56 days

Specimen	Compressive strength at 56 days of curing (N/mm^2)		
	Water cured	Acid cured (HCl)	Loss (%)
SCC MK 0	50.80	48.60	4.34
SCC MK15 I 20	57.08	54.10	5.22

Table 11: Loss in compressive strength by hydrochloric acid exposure in 90 days

Specimen	Compressive strength at 90 days of curing (N/mm^2)		
	Water cured	Acid cured (HCl)	Loss (%)
SCC MK 0	50.35	47.80	5.06
SCC MK15 I 20	57.68	54.15	6.12

It can be seen that strength development of concrete get decreased due to the acid exposure. For conventional SCC there is a loss of 3.50% in compressive strength and for SCC with 15% metakaolin and 20% iron slag, there is a loss of 4.24% in compressive strength. There is a difference of 0.74% in loss % while comparing conventional SCC and SCC with 15% metakaolin and 20% iron slag on 28 days.

While at 56 days there is a difference of 0.88% in loss percentage while comparing conventional SCC and SCC with 15% metakaolin and 20% iron slag on 56 days. The loss in compressive strength will be due to reaction of acid with iron slag in concrete. At 90 days of exposure there is a difference of 1.06% in loss percentage while comparing control specimen and SCC with 15% metakaolin which is used as a partial replacement material for cement and 20% iron slag which is used as a partial replacement material for fine aggregate on 90 days. The compressive strength get decreased when exposed to acid environment. It may be due to the reaction iron slag with acid. Figure 3 gives the graphical representation of the loss in compressive strength of specimens due to hydrochloric acid exposure

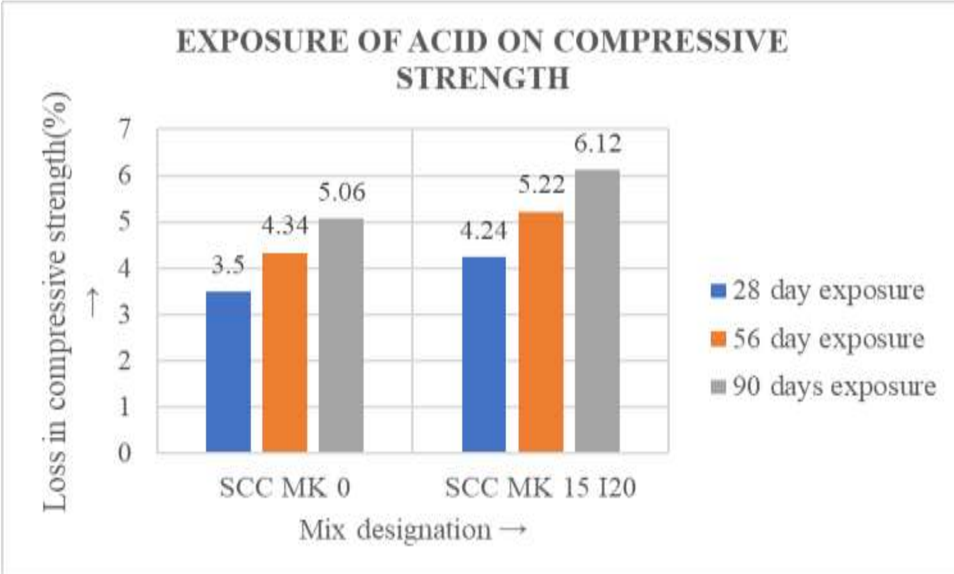

Fig 3 Loss in compressive strength by acid exposure

Table -12: Loss in weight by HCL exposure

Specimen	Initial weight after 28 days water curing (kg)	After 28 days of curing in Na_2SO_4		Initial weight after 28 days water curing (kg)	After 56 days of curing in Na_2SO_4		Initial weight after 28 days water curing (kg	After 90 days of curing in Na_2SO_4	
		Weight (kg)	Loss(%)		Weight (kg)	Loss (%)		Weight (kg)	Loss (%)
SCCMK 0	8.545	8.495	0.585	8.530	8.460	0.82	8.540	8.430	1.29
SCC MK15 I20	8.595	8.533	0.72	8.585	8.495	1.05	8.600	8.460	1.63

The conventional SCC undergone 0.82% weight loss, while SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate have a weight loss of about 1.05%. There is a difference of 0.23% in weight loss while comparing control specimen and SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate on 56 days. At 90 days weight loss for control specimen is 1.29% and SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate is 1.63%. The weight loss is higher for SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate may be due to the presence of iron slag which is coarser than M sand. Figure 4 showed the loss in weight of hydrochloric acid exposure.

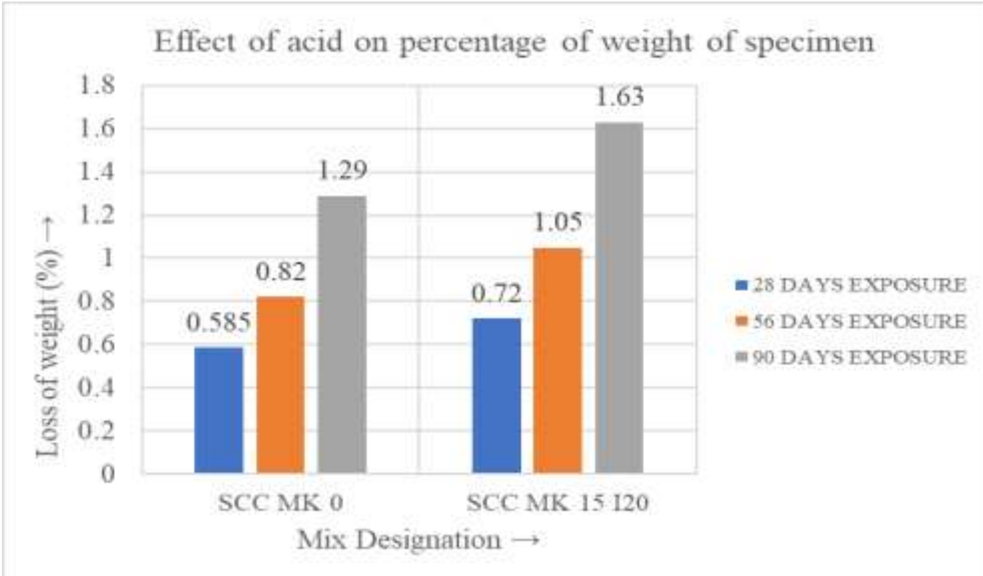

Fig 4 Loss in weight by Hydrochloric acid exposure

4.2.8. Water Absorption

The water absorption values of conventional SCC and SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate at 28, 56, 90 days were found out. Table 14 shows the water absorption results at 28, 56, 90 days

Table -14: Water absorption results

Mix designation	Water absorption (%) at 28 days	Water absorption(%)at 56 days	Water absorption(%)at 90 days
SCC MK 0	1.19	1.35	1.60
SCC MK 15 I20	1.26	1.42	1.75

The water absorption of conventional self-compacting concrete is increased due to the addition of iron slag and metakaolin. There is an increase of 0.07% in water absorption for SCC with 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate at 56 days and 0.15% increase at 90 days. This could be due to the presence of voids occurred due to the addition of iron slag which is coarser than M sand. Fig 5.shows the water absorption.

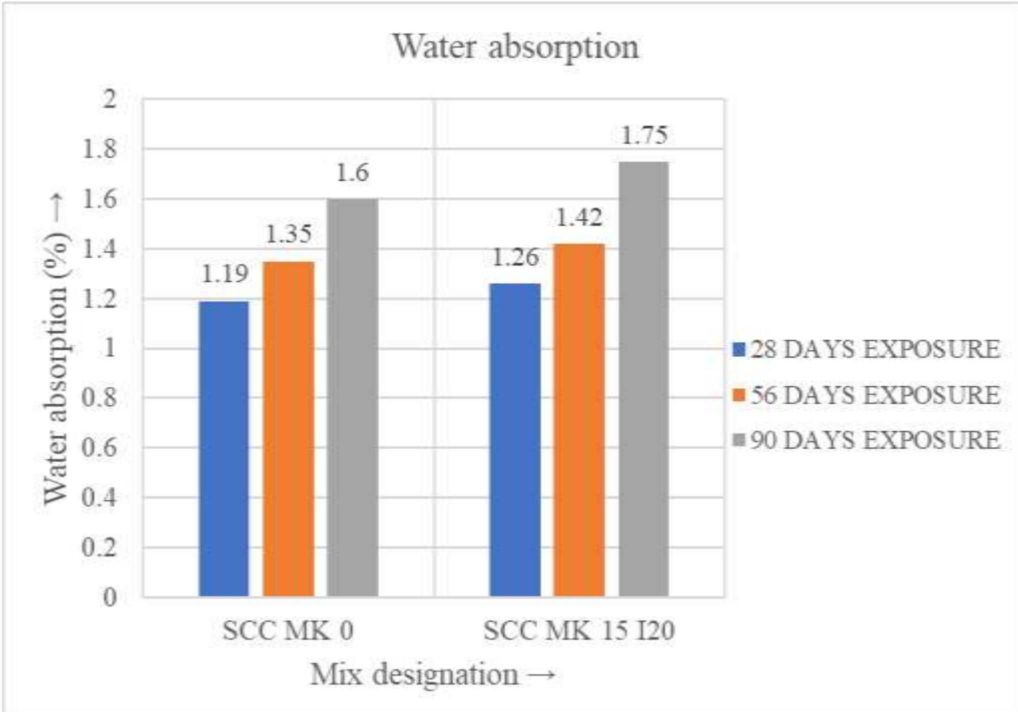

Fig 5 Water absorption

4.2.9 Electrical resistivity

Electrical resistivity were evaluated on conventional self-compacting concrete and self-compacting concrete containing metakaolin and iron slag. Table 15 shows the electrical resistivity at 56 days.

Table -15: Electrical resistivity

Specimen	Electrical resistivity on Dry condition(MΩ)	Electrical resistivity on Wet condition (MΩ)
SCC MK 0	2.0	1.2
SCC MK 15 I20	1.4	0.8

Electrical resistivity gives a direct interpretation on corrosion risk. As electrical resistivity increases corrosion risk get decreased. Electrical resistivity of conventional SCC is high compared to SCC with 15% metakaolin and 20% iron slag due to the presence of iron slag. The electrical resistivity of SCC containing 15% metakaolin and 20% iron slag is 33% less compared to control specimen. Electrical resistivity of SCC MK 15 I20 is decreased due to the presence of iron slag which is a good conductor of electricity.

4.2.10 Rapid chloride penetration test

Concrete specimens after 56 days was subjected to rapid chloride permeability test. And the test results are shown in table 16

Table -16: Rapid chloride permeability test

Specimen	Charge passed(Columbs)	Chloride permeability
SCC MK0	2597.3	Moderate
SCC MK15 I20	4568.4	High

Both conventional SCC have moderate chloride ion permeability and SCC with 15% metakaolin and 20% iron slag have high chloride ion permeability as per ASTM 1202 standard. Rapid chloride permeability of SCC with 15% metakaolin and 20% iron slag have high value compared to control specimen. The chloride permeability of SCC with 15% metakaolin and 20% iron slag have high value may be due to the presence of iron slag which reacts with chlorine. Fig 6 gives rapid chloride permeability test results of concrete.

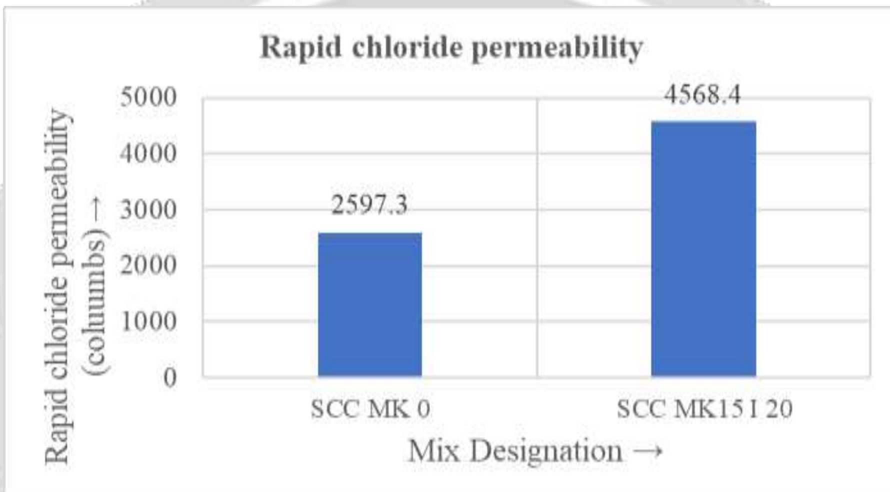

Fig 6. Rapid chloride permeability

5 CONCLUSION

Based on the experimental investigation conducted in this work, the following conclusions were drawn.

- The SCC containing 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate are more durable with respect to sulphate resistance, and lee durable with respect to acid resistance when compared to conventional SCC.
- The electrical resistivity of M40 grade equivalent SCC containing 15% metakaolin as partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate was low compared to control specimen. This may be due to the presence of iron slag which is a good conductor of electricity.
- The chloride penetration on M40 grade equivalent SCC containing 15% metakaolin as partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate was high as compared to control specimen.
- Inclusion of metakaolin at 15% as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate on SCC gives a self compacting concrete equivalent to M50 grade.

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