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STUDY ON RHEOLOGICAL AND MECHANICAL PROPERTIES PF SCM USING MINERAL ADMIXTURES AS A PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT

The investigation has been carried out to study the properties of self-compacting mortar containing different types of mineral admixtures such as GGBS & Metakaolin. For each mix, suitable w/b ratio and SP dosage are achieved by various trials. The mixes are tested for mini slump cone and mini-V-funnel in fresh state. The hardened mixes are tested for compressive strength, flexural strength, sorptivity and electrical resistivity test. To evaluate compressive and flexural strength at different ages, self-compacting mortar specimens are cast, cured, and tested for 7, and 28 days. specimens were cast, cured, and examined after 28 days to investigate the sorptivity and after that their compressive strength also examined. The electrical resistivity specimens are soaked in water for 90 days and after that 90days compressive strength also examined.

Conclusions are drawn based on the test results.

Keywords: Self-Compacting Mortar, Ground Granulated Blast Furnace Slag, Metakaolin, Mini Slump Flow, Mini V- Funnel, Compressive Strength, Flexural Strength, Sorptivity And Electrical Resistivity Test.

I. INTRODUCTION

With the development of construction of mega structures, the world over, the need for self-compacting concrete (SCC) applications are increasing. Many sites have problems with congestion of reinforcement in principle structural members. The design issues are compounded due to the high risk of the earthquake zone, vulnerability to cyclonic storms, and huge capacity addition of the plants to a very large scale. SCC has become the only choice in such difficult site environments. Ideally, the development of concrete mix where placing and compaction have minimal dependence on the Standard of workmanship available on a particular site should improve the true quality of the concrete in the final structure, and hence its durability.

This was an important driving force behind the development of self-compacting concrete (SCC). Self-compacting concrete is considered a breakthrough in concrete technology due to its improved performance and working environment. It has wide application from thin elements to bulk robust structures. SCC can be taken as the greatest technological advancement and most advanced development in concrete technology over the years. SCC is concrete of the future, as it will be substituting conventional concrete due to its distinct advantages.

Self-compacting Mortar has basic naturally available ingredients such as cement, sand, Superplasticizer, and water. After the water, cement is the 2nd most used material in the world. But this rapid production of cement creates two big environmental problems for which we must find out civil engineering solutions. The first environmental problem is the emission of CO2 emission is very harmful which creates lots of environmental changes. 1 ton of carbon dioxide is estimated to be released into the atmosphere when 1 ton of ordinary Portland cement is manufactured.

People working in the environmental field create awareness in the public about the energy sources like petrol, diesel is limited in earth crest and for the future generation, we have to save it or we have to find alternative energy sources. But the people working in the construction field are having the same awareness about line consumption. This is the second environmental problem related to the consumption of lime. As there is no alternative binding material that replaces the cement so the utilization of partial replacement of cement is well accepted for self-compacting mortar composites.

1.1. OBJECTIVES OF PRESENT STUDY

- Self-compacting mortar (SCM) mixes are being developed in the lab.
- In the lab, rheological and hardened characteristics of produced SCM mixtures were studied with several types of industrial waste material.

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- The characteristics of fresh mortar are determined using the Mini-slump cone and Mini-V-funnel tests.
- Compressive strength, and flexural strength tests are conducted to determine the properties of hardened Self compacting mortar.
- Sorptivity and electrical resistivity test are conduct to determine the durability properties of self-compacting mortar.

1.2. EXPERIMENTAL PROGRAM

The main purpose of this study is to investigate the rheological, mechanical and durability properties of SCM mixes with varying percentages of GGBS and metakaolin. A total of 16 mixes are proportioned including the control mix.

The mix ratio for all the mortar mixes is kept constant at 1:2.5 The w/b ratio and SP dosage are selected by evaluating the rheological properties of each mix conforming to EFNARC- 2005 guidelines. To evaluate the mechanical properties, the mixes are tested for their compressive strength and flexural strength. The compressive strength test is performed on cubes of size 70.6 x 70.6 x 70.6 mm at 7 and 28 days of curing. The flexural strength test is performed on prisms of size 40 x 40 x 160 mm at 7 and 28 days of curing. To evaluate the durability properties, sorptivity and electrical resistivity tests are performed on the mixes. The sorptivity test is performed on cubes of size 70.6 x 70.6 x 70.6 mm at 28 days of curing and epoxy coated compressive strength at 28days. electrical resistivity test is performed on cubes of size 70.6 x 70.6 x 70.6 mm at 90 days of curing Materials and compressive strength at 90days.

II. MATERIALS

Cement

Ordinary Portland cement of grade 43 is used, which is widely available in the local market. All of the cement used in the tests came from the same batch. The cement used was evaluated for various properties in accordance with IS: 4031-1988 and found to meet IS: 12269-1987 requirements. Table 1 and 5 depicts the physical characteristics.

Table 1: Physical Characteristics of cement

Sl. No	Properties	Test Results	Requirements as per IS :12269-1987
1	Normal consistency	32%	-
2	Specific gravity	3.128	-
3	Initial setting time	55 minutes	Not less than 30 min
	Final setting time	480 minutes	Not more than 600 min.
4	Soundness by LeChatelier	1.5 mm	Not more than 10 mm
5	Fineness of Cement	6%	Less than 10

Fine Aggregate

Locally available M-sand confirming to zone II. of IS: 383-1970. Table 2 and 5 shows characteristics of fine aggregate. The size of manufactured sand (M-sand) is less than 4.75mm.

Table 2: Properties of fine aggregates

Sl. No.	Property	Fine Aggregate
1	Specific gravity	2.75
2	Fineness modulus	2.88

Admixtures

A. Ground -Granulated Blast Furnace slag (GGBS)

The GGBS utilized complied with IS 16714 2018 and was provided by "JSW Cement." The GGBS is used as a partial substitute for cement. Tables 3 illustrate thecharacteristics of GGBS.

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Table 3: Physical properties of GGBS

Sl. No	Test	Result
1	Fineness	500 m^2/kg
2	Bulk Density	1100 kg/m^3
3	Specific Gravity	2.88
4	Color	Off-White

B. Metakaolin (MK)

M S Chemicals supplied the metakaolin (MK) that conformed to ASTM C 618. Metakaolin is used as a partial substitute forcement. Tables 4 and 5 demonstrate the characteristics of Metakaolin.

Table 4: Physical properties of MK

Sl. No	Test	Result
1	Fineness	1500 m^2/kg
2	Bulk Density	1100 kg/m^3
3	Specific Gravity	2.5
4	Color	Off-White

Table 5: chemical properties of Cementous materials

Sl. No	Chemical Composition	OPC	GGBS	MK
1	CaO	63.87	35.08	0.02
2	SiO2	20.62	32.97	53.20
3	Al2O3	4.87	17.97	43.90
4	Fe2O3	3.35	0.72	0.38
5	MgO	1.54	10.31	0.05
6	K2O	Nil	Nil	0.10
7	Na2O	Nil	Nil	0.17
8	SO3	2.50	0.72	Nil
9	Loss on ignition	1.50	0.58	0.50

Super plasticizer

Aura mix 300 plus is a modified polycarboxylic ether admixture. This product was created with the goal of being used in high-performance, highly durable concrete. The features of the admixture are listed in Table 6

Table 6: Properties Aura mix 300 plus

Particulars	Content
Chemical content	Polycarboxylic ether
Specific gravity	1.22
Compatibility	All types of cement
Color	Light yellow

III. MIX PROPORTIONS

In the current investigation, 240 specimens were cast from 16 SCM Mixes in the laboratory. The use of a 1:2.5 cement mortar is being examined. Mineral admixtures including GGBS and MK are utilized as admixtures, with M sand as the fine aggregate.

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Table 7: - Design mix proportions of scm

Mix id	Mix notation	Proportion	W/B ratio	SP %	Water	SP	OPC	GGBS	MK	MSAND
M0	100%C	1: 2.5	0.37	0.6	249.711	3.567	720.66	--	--	1783.65
M1	80%C+20%G	1: 2.5	0.37	0.7	285.383	6.342	475.638	317.092	--	1585.46
M2	70%C+30%G	1: 2.5	0.37	0.8	293.31	5.549	673.821	--	--	1585.46
M3	50%C+50%G	1: 2.5	0.38	0.9	293.31	6.738	634.184	--	158.546	1585.46
M4	95%C+5%M	1: 2.5	0.38	0.7	301.237	6.342	673.821	79.273	39.636	1585.46
M5	90%C+10%M	1: 2.5	0.38	0.8	301.237	6.342	554.911	158.546	79.273	1585.46
M6	85%C+15%M	1: 2.5	0.39	0.9	301.237	6.342	436.001	237.819	118.909	1585.46
M7	80%C+15%G+5%M	1: 2.5	0.38	0.85	301.237	6.342	317.092	317.092	158.546	1585.46
M8	80%C+10%G+10%M	1: 2.5	0.39	0.9	293.31	5.945	594.547	158.546	--	1585.46
M9	80%C+5%G+15%M	1: 2.5	0.39	1.0	293.31	6.342	475.638	237.819	--	1585.46
M10	70%C+25%G+5%M	1: 2.5	0.4	1.0	293.31	6.738	356.728	317.092	--	1585.46
M11	70%C+20%G+10%M	1: 2.5	0.4	1.05	301.237	6.342	673.821	--	79.273	1585.46
M12	70%C+15%G+15%M	1: 2.5	0.39	1.05	301.237	6.738	594.547	--	118.909	1585.46
M13	50%C+45%G+5%M	1: 2.5	0.39	1.1	301.237	7,134	515.274	--	158.546	1585.46
M14	50%C+40%G+10%M	1: 2.5	0.40	1.2	301.237	8.72	495.456	158.546	79.273	1585.46
M15	50%C+35%G+15%M	1: 2.5	0.40	1.2	301.237	8.72	277.455	237.819	158.546	1585.46

IV. RESULTS AND DISCUSSION

The current research project aims to investigate the properties of SCM mixes without and with mineral additives.SCM mixes were made with keeping the amount of mixing water and overall powder content constant (Portland cement and mineral additives). Mini-V-funnel and mini slump flow tests were performed to determine the workability of the fresh mortar. hardened properties like Compressive strength, flexural strength and drying shrinkage of all mixes are measured.

4.1Fresh Properties

Flow characteristics were determined by altering the amount of SP in each SCM mix. As a result, all of the combinations have slump flow diameter (240-260mm) and mini-v funnel flow time(7-11sec) that meet the EFNARC requirement.

Table 7:- Fresh properties of Self-compacting mortar mixes

Mix id	Mix notation	Proportion	W/B	SP%	Slump mm	V funnel Flow,sec
M0	100%C	1: 2.5	0.37	0.6	255	11
M1	80%C+20%G	1: 2.5	0.37	0.7	257	7
M2	70%C+30%G	1: 2.5	0.37	0.8	253	11
M3	50%C+50%G	1: 2.5	0.38	0.9	250	10
M4	95%C+5%M	1: 2.5	0.38	0.7	243	11
M5	95%C+10%M	1: 2.5	0.38	0.8	249	9

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M6	95%C+15%M	1: 2.5	0.39	0.9	257	8
M7	80%C+15%G+5%M	1: 2.5	0.38	0.85	263	7
M8	80%C+10%G+10%M	1: 2.5	0.39	0.9	258	7
M9	80%C+5%G+15%M	1: 2.5	0.39	1.0	253	8
M10	70%C+25%G+5%M	1: 2.5	0.4	1.0	246	9
M11	70%C+20%G+10%M	1: 2.5	0.4	1.05	243	7
M12	70%C+15%G+15%M	1: 2.5	0.39	1.05	250	9
M13	50%C+45%G+5%M	1: 2.5	0.39	1.1	257	10
M14	50%C+40%G+10%M	1: 2.5	0.40	1.2	242	11
M15	50%C+35%G+15%M	1: 2.5	0.40	1.2	241	12

- Results show that reference mix(M0) has mini-slump flow diameter & mini v funnel flow time of 255mm,11Sec respectively, that satisfy EFNARC requirements for SCM with W/B ratio of 0.37 and superplasticizer of 0.6%.
- It is observed that the rate of water demand increases with an increase in the replacement of cement by admixture content due to an increase in the fineness of cementitious materials.
- GGBS and metakaolin have large specific surface area compared to cement which creates more water demand to be flowable.
- M15 mix proves to be the least flowable mix having mini slump flow diameter of 241mm and mini-V-funnel time of 12 sec, marginally satisfying the EFNARC guidelines.

4.2 Hardened Properties

The compressive strength, flexural strength and drying shrinkage of SCM mixes with partial substitution of cementby GGBFS, MK, and SF at various ages are reported.

4.2.1 Compressive Strength

The compressive strength of self-compacting mortar with varying degrees of cement replacement with GGBS and MK is shown in the graph at 7and 28 days of curing. Cube of dimension 70.6x70.6x70.6 mm were used to cast SCM cubes. The compression strength on the mortar cube was evaluated according to IS: 4031(part 6) 1988.

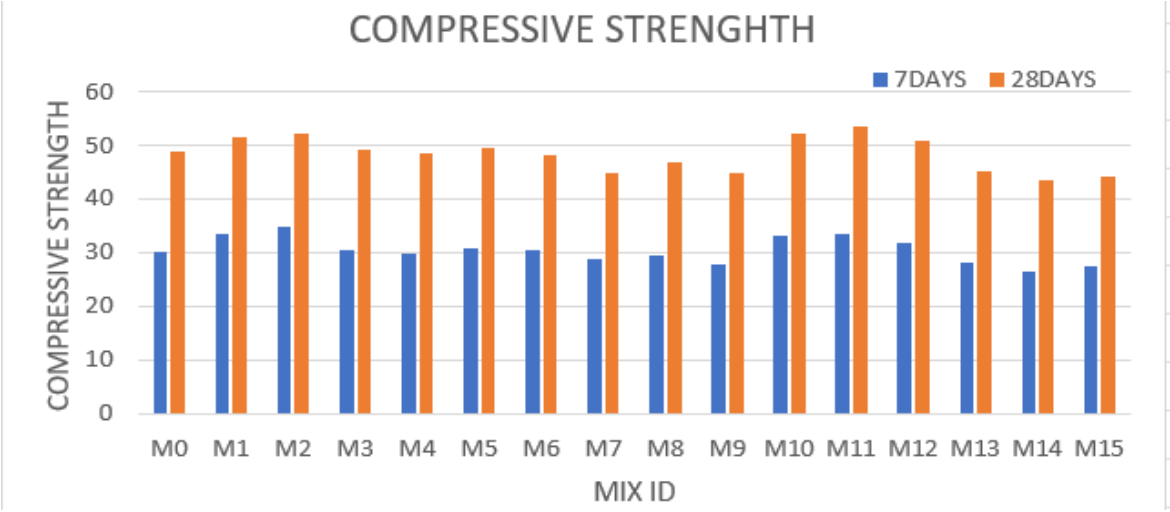

Chart 1: - Compressive strength vs 7and 28days

- At 7 and 28days of curing M0 mix (100C) has compressive strength of 30.25Mpa and 48.74Mpa
- Results show that binary mix with GGBS M2 gives compressive strength 7.2% more than reference mix(M0).
- Results show that binary mix with MK M5 gives compressive strength 1.86% more than reference mix(M0).
- It is observed that ternary SCM mix(M11) with 20% GGBS & 10% MK gives compressive strength of 51.37MPa, there is an increase of 5.39% compared to reference mix.

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- It is observed that ternary SCM mix(M14) with 40% GGBS & 10% MK gives Lowest compressive strength of 43.34MPa, there is a decrease of -11.07% compared to reference mix.

4.4.2 FLEXURAL STRENGTH

The Flexural strength development of Self-compacting mortar containing different percentages of GGBS and MK at 7 & 28 days of curing. test carried out following the Specimen (Prism) :160*40*40mm.

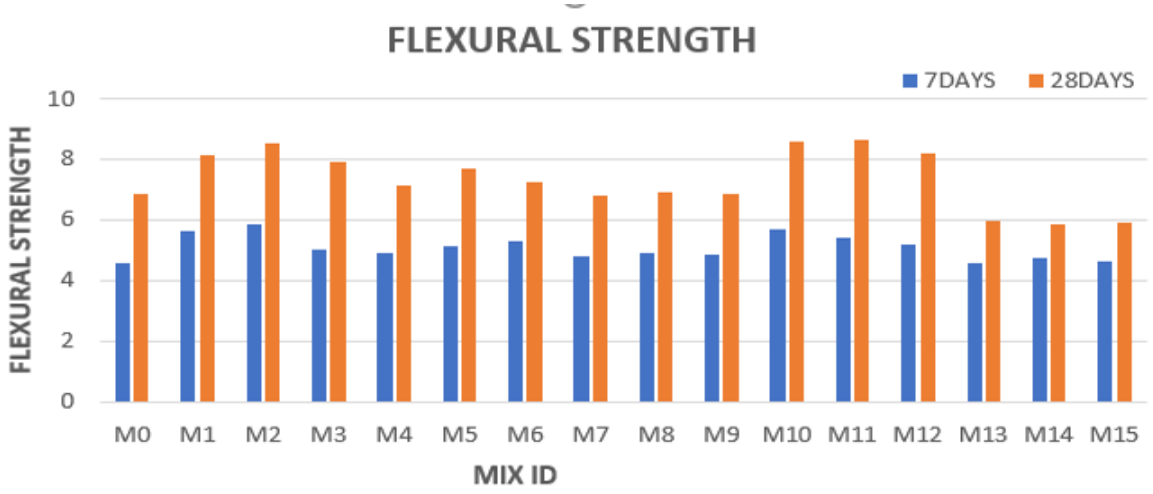

Chart 2: - Flexural strength vs 7and 28days

- It is observed from the results that the reference mix(M0) has Flexural strength of 5.47 and 6.83 MPa at 7 and 28days respectively.
- Results shows that binary mix with GGBS M2 gives Flexural strength 24.59% more than reference mix(M0).
- Results show that binary mix with MK M5 gives Flexural strength 12.0% more than reference mix(M0).
- It is observed that ternary SCM mix(M11) with 20% GGBS & 10% MK gives Flexural strength of 8.62MPa, there is an increase of 26.20% compared to reference mix(M0).
- It is observed that ternary SCM mix(M14) with 40% GGBS & 10% MK gives Lowest Flexural strength of 5.87MPa, there is a decrease of -14.05% compared to reference mix(M0).

4.4.3 SORPTIVITY TEST

Sorptivity is considered as a significant property of materials that indicates the tendency of a porous material to absorb and transmit water through the capillary. This test can be used for illustration of the volume of voids and as a complementary test for water absorption test. The sorptivity can be regarded as a criterion for capillary forces which can draw the applied liquid by the pore structure into the mortar. below the sorptivity coefficient of SCMs.

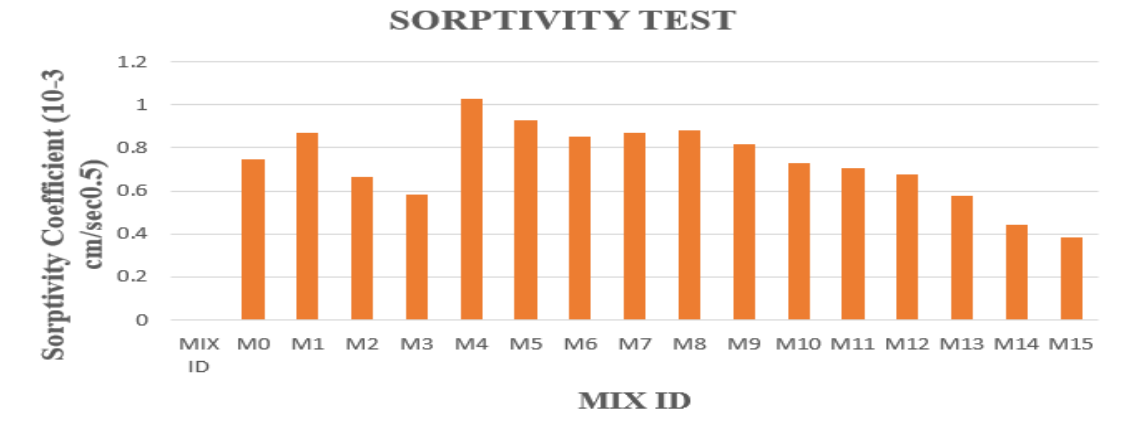

Chart 3: - mix vs sorptivity

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- The control mix M0 (100%C) has the sorptivity coefficient of .7459 x 10^{-3} cm/sec$^{0.5}$ at 90 days of curing.
- Among binary mixes with GGBS M1 mix (80%C+20%G) has the highest sorptivity coefficient of 0.8708 x 10^{-3} cm/sec$^{0.5}$.
- Among binary mixes with MK M4 mix (95%C+5%MK) has the highest sorptivity coefficient of 0.1.0294 x 10^{-3} cm/sec$^{0.5}$.
- Among binary mixes with MK and GGBS M3 mix (50%C+50%G) has the lowest sorptivity coefficient of .5840 x 10^{-3} cm/sec$^{0.5}$.
- Among ternary mixes, M8 mix (80%C+10%G+10%MK) shows the highest coefficient of 0.8842x 10^{-3} cm/sec$^{0.5}$ and M15 mix (50%C + 35%G + 15%MK) has the lowest sorptivity coefficient of 0.3840 x 10^{-3} cm/sec$^{0.5}$.

4.4.31 COMPRESSIVE STRENGTH

The compressive strength of self-compacting mortar cubes epoxy coated with varying degrees of cement replacement with GGBS and MK is shown in the graph at 28 days of curing. Cube of dimension 70.6x70.6x70.6 mm were used to cast SCM cubes. The compression strength on the mortar cube was evaluated according to IS: 4031(part 6) 1988.

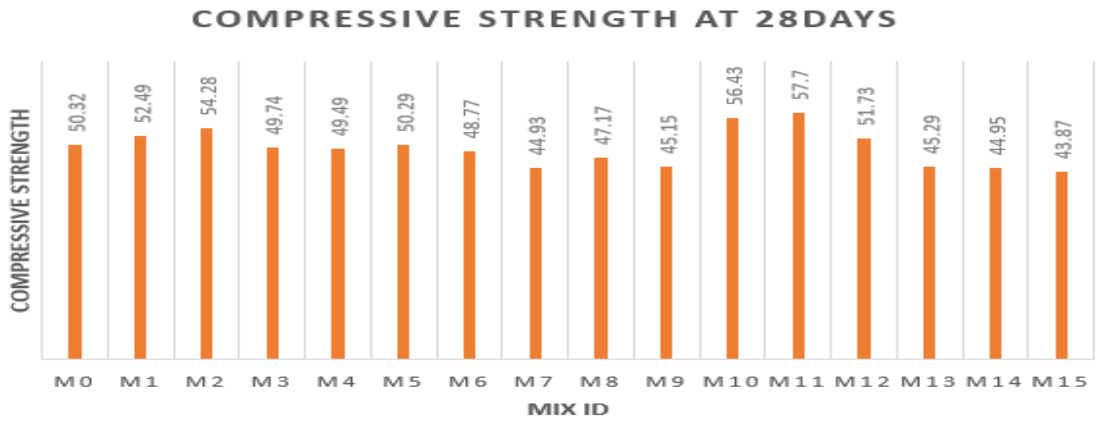

Chart 4: - mix vs compressive strength at 28days

- At 28days of curing M0 mix (100C) has compressive strength of 50.32Mpa
- Results show that binary mix with GGBS M2 gives compressive strength 7.86 more than reference mix(M0).
- It is observed that ternary SCM mix(M11) with 20% GGBS & 10% MK gives compressive strength of 57.70MPa, there is an increase of 14.66% compared to reference mix.
- It is observed that ternary SCM mix(M15) with 35% GGBS & 15% MK gives Lowest compressive strength of 43.87MPa, there is a decrease of -12.81% compared to reference mix(M0).

4.4.4 ELECTRICAL RESISTIVITY TEST

The Electrical resistivity of the 50.26 mm cube specimens with saturated dry surface was measured using a two-point uniaxial method. The durability of mortar can be evaluated by measuring its electrical resistivity. For each mix of mortar cubes were tested at a voltage of 9V and 15V after the 90days curing.

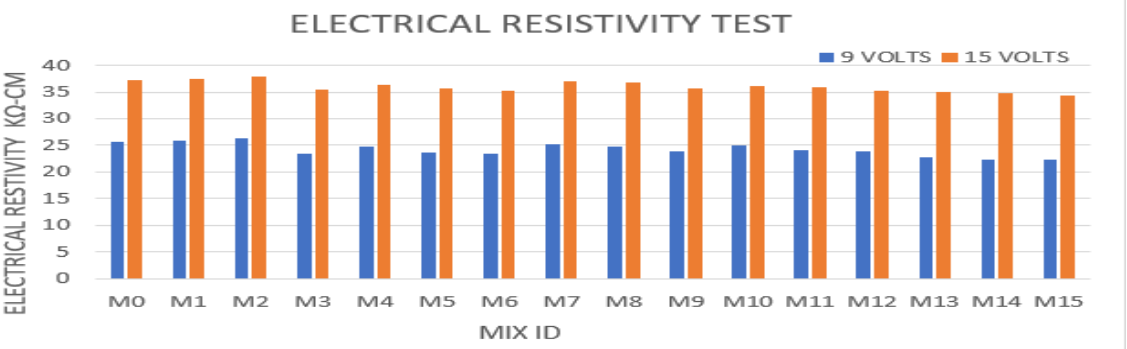

Chart 5: - mix vs electrical resistivity of 9 and 15 volts

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- It is observed from the results that the reference mix(M0) has Electrical resistivity of 25.7 and 37.19 kΩ-cm for the 9 and 15 direct current volts respectively.
- Results shows that binary mix with GGBS M2 gives Electrical restivity 1.90% more than reference mix(M0).
- Results show that binary mix with MK M 6 gives Electrical restivity 5.48% less than reference mix(M0).
- It is observed that ternary SCM mix(M15) with 35% GGBS & 15% MK gives of 7.58% less compared to reference mix(M0).
- It is observed replacing more 30% mineral admixtures the electrical resistivity of mortar samples decreases due the grain size of the minerals.

4.4.4.1 COMPRESSIVE STRENGTH

The compressive strength of self-compacting mortar with varying degrees of cement replacement with GGBS, and MK is shown in the graph at 90 days of curing after the electrical resistivity test. Cube of dimension 70.6x70.6x70.6 mm were used to cast SCM cubes. The compression strength on the mortar cube was evaluated according to IS: 4031(part 6) 1988.

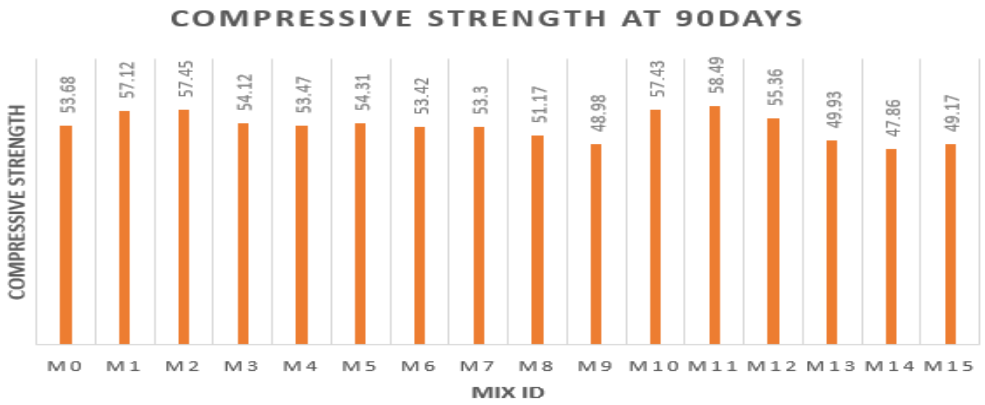

Chart 5: - mix vs compressive strength at 90 days

- At 90days of curing (M0) mix (100C) has compressive strength of 53.68Mpa.
- Results show that binary mix with GGBS (M2) gives compressive strength 9.44% more than reference mix(M0).
- Results show that binary mix with MK (M5) gives compressive strength 1.17% more than reference mix(M0).
- It is observed that ternary SCM mix(M11) with 20% GGBS & 10% MK gives compressive strength of 50.73MPa, there is an increase of 8.96% compared to reference mix. And ternary SCM mix (M14) with 40 GGBS & 10% MK there is a decrease of -10.84% than reference mix

V. CONCLUSION

- From the experimental results addition of mineral additives need more water and super plasticizer to achieve the rheological properties of the mortar with in the acceptable limits. This because of surface area and fine grain size of minerals.
- The reference SCM mix(M0) shows good flow properties and hardened properties like compressive strength of 48.74 MPa, Flexural strength of 6.83 MPa, sorptivity 0.7459 x 10-3 cm/sec0.5 & Electrical restivity of 37.9kΩ-cm.
- The binary mix with GGBS (M2) as shows good hardened properties of compressive strength 9.44% and flexural strength 24.59% more than reference mix(M0).
- The binary mix with MK (M5) as shows good hardened properties of compressive strength 4%, flexural strength 12.44% more than reference mix(M0).
- The ternary mix (M12) as shows good hardened properties of compressive strength 12.42% and (M11) flexural strength 26.20% more than reference mix(M0).
- The binary mix with GGBS (M1) as shows good sorptivity coefficient 0.8708x10-3cm/sec0.5 more than reference mix(M0).
- The binary mix with MK (M4) as shows good sorptivity coefficient 1.0294x

- 10-3cm/sec0.5 more than reference mix(M0).
- The ternary mix (M15) as shows lowest sorptivity coefficient 0.3840x
- 10-3cm/sec0.5.
- We observed from results M4 and M1 apart from the these two all the sorptivity coefficient is less than control mix (M0).
- The epoxy coated compressive strength of cube At 28days of curing M0 mix (100C) has compressive strength of 50.32Mpa
- It is observed that ternary SCM mix(M11) with 20% GGBS & 10% MK gives highest compressive strength of epoxy coated cube 57.70MPa and The SCM mix (M15) with 35% GGBS and 15% MK IS highest decrease of -12.81% compared to reference mix(M0).
- Results shows that binary mix with GGBS and MK M2 gives Electrical restivity 1.90% more than reference mix(M0). And Other binary mixes resistivity is less than reference mix (M0).
- Results shows that from all mixes M15 (50C+35GGBS+15MK) gives lowest Electrical restivity 7.58% compare to reference mix(M0).
- At 90days of curing (M0) mix (100C) has compressive strength of 53.68Mpa.
- It is observed that ternary SCM mix(M11) with 20% GGBS & 10% MK gives compressive strength of 50.73MPa, there is an increase of 8.96% compared to reference mix. And ternary SCM mix (M14) with 40% GGBS & 10% MK there is a decrease of -10.84% than reference mix(M0).

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