Experimental Investigation on SCM using Different Admixtures

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Abstract - *The characteristics of selfcompacting mortar (SCM) containing various types of mineral admixtures, such as GGBS, MK, and SF, were investigated. Mineral admixtures are waste byproducts of particular industries that are difficult to dispose of and constitute a harm to the environment. These ingredients can be utilized to make concrete and mortar, reducing the need for cement.*

The development of a self-compacting mortar is required for the investigation of self-compacting concrete proportions. The motor study has recently become more significant in crack repair, structural rehabilitation, retrofitting, pointing, and plastering operations.

A reference self-compacting mortar with 100 percent cement was created in the present study while preserving good flowability and stability. 15 mortar mixers with varied ratios of GGBS, metakaolin (MK), and silica fume (SF) with cement by weight were developed to evaluate the influence of mineral additive on self-compacting mortar. Self-compacting mortar's fresh properties, such as the min- slump flow test and the mini-V funnel test, are explored, as well as its hardened properties, such as compressive, flexural strength, and drying shrinkage. Self-compacting mortar specimens are cast, cured, and tested for 7, 14, and 28 days to determine compressive and flexural strength at various ages. The drying shrinkage specimens are soaked for three days in water before being air dried for the remaining days and for 30 days, the test is repeated every five days. The test outcomes are used to draw a conclusion.

Key Words: Self Compacting Mortar, Compressive Strength, Drying Shrinkage, Flexural Strength, Fresh Properties

1. INTRODUCTION

Ordinary Portland cement was used as a binding material in construction until 1924. Both Portland and masonry cement-based mortars have extremely high compressive strengths, and the consequent deformability. Lime with water increases the vapor transmission rate of mortar; a sufficiently high rate is often recommended to allow moisture stored in the brickwork to move through the joints without creating frost or salt crystallization damage. As technology progresses, construction costs rise due to increased demand for concrete ingredients, and so these materials become more expensive.

Ordinary Portland cement, fine aggregate, and sufficient water make up the cement mortar. It binds the sand grains and the stone or brick surfaces together in such a way that the adjacent elements form a continuous structure with strong resistance to loads from above and below. Mortar is the adhesive that holds a brick wall together. It must be sturdy, long-lasting, able to maintain the wall intact, and offer a water-resistant barrier after application.

The main resolution of this research is to learn about the rheological and strength features of Self-Compacting Concrete. Mortar is defined as "a highly flowable, and stable concrete and mortar that can spread readily into place and finish the formwork without any consolidation or significant separation." Another specification defines SCC and mortar as "flowing concrete without segregation and bleeding, capable of filling voids and dense reinforcing or inaccessible cavities without hindrance or blockage.

It is also necessary to utilize viscosity altering admixtures in order to create an optimal mix design of SCC or SCM (VMA). [2002], VMAs increase the viscidness of the SelfCompacting Concrete and prevent segregation. Trial batches should be carried out in collaboration with the admixture supplier in order to determine the exact combination of admixtures and other concreting materials required to maximize the element in terms of both engineering performance and cost efficiency.

2. 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.
- The characteristics of fresh mortar are determined using the Mini-slump cone and Mini-V-funnel tests.
- Compressive strength, drying shrinkage, and flexural strength tests are conducted to determine the properties of hardened SCM mortar.

3. SCOPE OF PRESENT STUDY

The fundamental issue is that traditional building materials are decreasing, so we are looking for alternatives, which brings us to the decision to use GGBS, MK, and SF.

- Making use of industrial unused items that are causing environmental issues due to their inability to be safely disposed of without causing harm to society.

- Using industrial waste as a cement substitute to make a cost-effective SCM mix.
- Because it is a byproduct and waste, using it properly to some extent contributes to a greener environment while also ensuring that the strength of the concrete is not compromised by the usage of admixtures.

4. METHODOLOGY

- Several literature reviews on the use of mineral admixtures (Fly ash, GGBS, Silica fume, Metakaolin, etc.) to substitute cement in SCC/SCM mixes are studied.
- Calculate the amounts of material necessary for various mix proportions, and conduct various preliminary material tests prior to casting.
- For the current investigation, cement mortar in the ratio of 1:2 is being considered. Mineral admixtures such as GGBS, Silica fume, and Metakaolin are used as admixtures, and M sand is used as fine aggregate.
- To find the appropriate dosage of superplasticizer (Master Glenium 8233) for cement paste, the marsh cone test was employed.
- The rheological properties of SCM mixes were determined using a mini slump flow diameter and a mini v funnel flow duration for all mortar mixes.
- After 7, 14, and 28 days of curing, the hardened properties of all SCM mixtures, such as compressive and flexural strengths, were determined.
- To analyze the durability attributes of all SCM mixtures, a 30-day drying shrinkage test is performed

5. MATERIALS

5.1 Ordinary Portland Cement

In the current investigation, ordinary Portland Cement of Zuari brand of 43 grades conforming to IS: 8112-2013 & EN 197-1 was employed. Tables 1 and 2 demonstrate the characteristics of cement.

5.2 Ground Granulated Blast Furnace Slag

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 1 and 2 illustrate the characteristics of GGBS.

5.3 Metakaolin

M S Chemicals supplied the metakaolin (MK) that conformed to ASTM C 618. Metakaolin is used as a partial substitute for cement. Tables 1 and 2 demonstrate the characteristics of Metakaolin.

5.4 Silica Fume

LAGREENS offered the Silica Fume (SF) that met IS 15388 2003, ASTM C 1240-14, and EN 13263. Silica fume is used as a partial substitute for cement. Tables 1 and 2 show the characteristics of Silica Fume.

Table -1: Chemical Composition of Cementitious Materials

Chemical Composition	OPC	GGBS	MK	Silica Fume
CaO	63.87	35.08	0.02	0.29
SiO2	20.62	32.97	53.20	92.00
Al2O3	4.87	17.97	43.90	0.46
Fe2O3	3.35	0.72	0.38	1.60
MgO	1.54	10.31	0.05	0.28
K2O	Nil	Nil	0.10	0.61
Na2O	Nil	Nil	0.17	0.51
SO3	2.50	0.72	Nil	0.19
Loss on ignition	1.50	0.58	0.50	1.00

5.5 Fine Aggregate

M sand in accordance with IS: 383-2016 was utilised. Table 2 shows the parameters of fine aggregate.

Table -2: Physical Properties of Materials

Materials	Test conducted	Results	Code Specifications
Cement	Specific gravity	3.15	3.15 (IS 4031 Part11:1988)
	Fineness (Dry Sieving) (%)	6	Max 10 (IS 4031 Part1:1996)
	Normal consistency (%)	33	25%-35% (IS 4031 Part4:1988)
	Initial setting time (min)	95	Min 30 (IS 4031 Part5:1988)
	Final setting time (min)	360	Max 600 (IS 4031 Part5:1988)
	7-days Compressive Strength (Mpa)	29.56	Min 26 (IS 8112:2013)
	14-days Compressive Strength (Mpa)	39.87	Min 38 (IS 8112:2013)
	28-days Compressive Strength (Mpa)	45.47	Min 43 (IS 8112:2013)
GGBS	Specific gravity	2.84	-
	Fineness (Dry Sieving) (%)	5	Max 10 (IS 4031 Part1:1996)
Metakaolin	Specific gravity	2.5	-
	Fineness (Dry Sieving) (%)	3.2	Max 10 (IS 4031 Part1:1996)
Silica Fume	Specific gravity	2.2	-
	Fineness (Dry Sieving) (%)	2.5	Max 10 (IS 4031 Part1:1996)

Fine aggregate	Specific gravity	2.5	2.75 (IS2386 Part3:1963)
	Fineness modulus (%)	2.74	3.2 (IS383:2016)
	Bulk Density (Kg/m³)	1090	1250 (IS383:2016)

5.6 Superplasticizer

Master Glenium SKY 8233 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 3.

Table -3: Properties of Master Glenium 8233

Particulars	Content
Chemical content	Polycarboxylic ether
Specific gravity	1.08
Chloride content	<0.2%
Solid content	35.46%
Compatibility	All types of cement
PH	7.02
viscosity	50-150s

6. MIX PROPOTIONING

In the current investigation, 315 specimens were cast from 15 SCM Mixes in the laboratory. The use of a 1:2 cement mortar is being examined. Mineral admixtures including GGBS, Silica fume, and Metakaolin are utilized as admixtures, with M sand as the fine aggregate.

Table -4: Mix proportions

SL. NO	Mix notation	Mix proportions	OPC	GGBS	MK	SF
1	M0	100% C	100			
2	M1	70%C + 30%G	70	30		
3	M2	80%C + 20%M	80		20	
4	M3	85%C + 15%S	85			15
5	M4	80%C + 10%G + 10%M	80	10	10	
6	M5	65%C + 20%G +15%M	65	20	15	
7	M6	50%C + 30%G + 20%M	50	30	20	
8	M7	85%C + 10%G + 5%S	85	10		5
9	M8	70%C + 20%G +10%S	70	20		10
10	M9	55%C + 30%G + 15%S	55	30		15
11	M10	85%C + 10%M + 5%S	85		10	5
12	M11	75%C + 15%M +10%S	75		15	10
13	M12	65%C + 20%M + 15%S	65		20	15
14	M13	67.5%C + 15%G +10%M + 7.5%S	67.5	15	10	7.5
15	M14	35%C + 30%G + 20%M + 15%S	35	30	20	15

7. 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.

7.1 Fresh 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 -5: Fresh Properties

SL. NO	Mix Notation	W / P	SP (%)	Mini Slump Flow Dia (mm)	Mini V-funnel flow time (sec)
1	M0	0.37	0.6	254	8.1
2	M1	0.38	0.6	248	9
3	M2	0.38	0.7	252	11
4	M3	0.38	0.7	250	10.15
5	M4	0.38	0.7	257	7.4
6	M5	0.38	0.8	260	7.1
7	M6	0.38	0.8	249	11
8	M7	0.38	0.9	256	10.4
9	M8	0.38	0.9	251	8
10	M9	0.38	0.9	247	9.2
11	M10	0.38	0.8	253	8.4
12	M11	0.38	0.8	249	11
13	M12	0.38	0.9	241	11
14	M13	0.38	1	251	10.5
15	M14	0.38	1	242	11

➢ 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 and mini-v funnel flow times that meet the EFNARC requirement.

- Reference SCM mix (M0) with 0.37 w/p and 0.6 percent SP gives 254mm mini slump flow diameter and an 8.1sec mini v funnel flow time that meets EFNARC guidelines.
- Addition of mineral additive needs extra water to get same workability as reference mortar mix.
- As the percentage of cement replacement increases, so does the demand for superplasticizer.
- In comparison to MK and GGBFS, SF necessitates a greater amount of superplasticizer. Finer the material the more SP required.
- MK raises the viscosity of the SCM mix. (As MK content increases, so does the flow time.)
- SCM mixes with cement replacement levels of 15% GGBS, 10% MK, and 7.5 % SF (M13) and 30% GGBS, 20% MK, and 15% SF (M14) require higher SP (1 percent SP and 0.38w/p) to achieve workability that meets EFNARC standards.

7.2 Hardened Properties

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

7.2.1 Compressive Strength

The compressive strength of self-compacting mortar with varying degrees of cement replacement with GGBS, MK, and SF is shown in the graph at 7, 14, and 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.

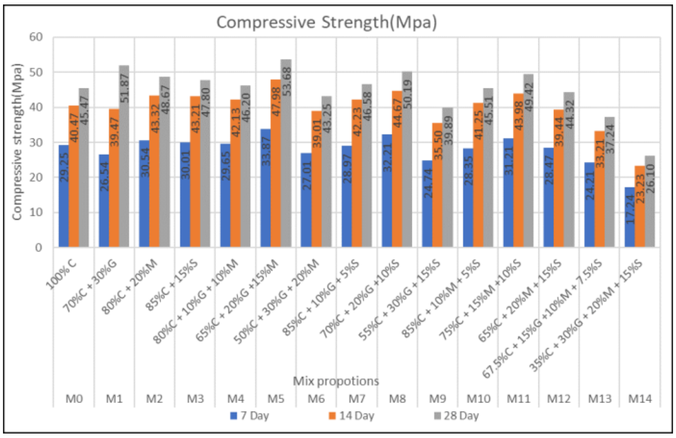

Chart -1: Compressive Strength VS 7,14&28 Days

- At 28 days, the reference SCM mix has a compressive strength of 45.47 MPa.
- The early strength gain of the binary SCM mix with GGBS is lower than that of the reference mix, but the strength gain with age is more than that of the reference mortar (M0).
- A binary SCM mix with SF and MK has a higher initial strength development than a reference mortar (M0).
- After 28 days, the SCM mix containing 20% GGBS and 15% Metakaolin (M5) has a maximum compressive strength of 53.68 MPa, which is 18.06 percent higher than the reference SCM mix (M0).
- Mixes containing 30% GGBS (M1), 20% GGBS and 10% SF (M8), 15% MK and 10% SF (M11), 20% MK (M2), 15% SF (M3), 10% GGBS and 5% SF (M7), 10%GGBS & 10% MK (M4) and 10%MK & 15%SF (M10) have compressive strengths 14.08 percent, 10.38 percent, 8.69 percent, 7.04 percent, 5.12 percent, 2.44 percent, 1.61 percent, and 0.09 percent more than a reference mix (M0).
- Based on the results obtained, the SCM mix with a cement replacement level of 30% GGBS, 20% Metakaolin, and 15% SF (M14) has the lowest compressive strength of 26.10MPa after 28 days, which is 42.06 percent less than the reference SCM mix (M0).
- Mixes with cement replacement of 15% GGBS, 10% MK, and 7.5 % SF (M13), 30% GGBS and 20% MK (M6), 30% GGBS and 15% SF (M9), and 20% MK and 15% SF (M12) have compressive strengths 21.11 percent, 4.88 percent, 12.27 percent, and 2.53 percent respectively, less than a reference mix M0.
- Binary SCM mixes with cement replacement levels of 30% GGBS (M1), 20% MK (M2), and 15% SF (M3) have higher compressive strength than the reference SCM mix (M0).
- In tertiary SCM mixes comprising GGBS and MK, a cement replacement level of 20 % GGBS and 15 % MK (M5) produces a good compressive strength.
- Tertiary SCM mixes incorporating GGBS and SF achieve good compressive strength at a cement replacement ratio of 20% GGBS and 10% MK (M8).
- In tertiary SCM mixes, MK and SF at a cement replacement level of 15 percent MK and 10 percent SF (M11) produce better compressive strength.

7.2.2 Flexural Strength

The Flexural strength of self-compacting mortar with varying degrees of cement replacement with GGBS, MK, and SF is shown in the graph at 7, 14, and 28 days of curing. Prism of dimension 40*40*160 mm were used to cast SCM mixes. The flexural strength of the mortar sample was determined accordance with ASTM C 348 02.

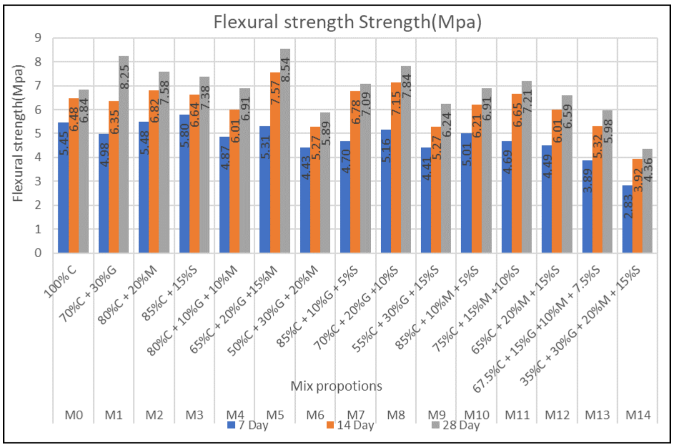

Chart -2: Flexural Strength VS 7,14&28 Days

- At 28 days, the reference SCM mix has a flexural strength of 6.84 MPa.

- The early strength gain of the binary SCM mix with GGBS is lower than that of the reference mix (M0), but the strength gain with age is more.
- A binary SCM mix with SF and MK has a higher initial strength development than a reference mortar (M0).
- After 28 days, the SCM mix containing 20% GGBS and 15% Metakaolin (M5) has a maximum flexural strength of 8.54 MPa, which is 24.85 percent higher than the reference SCM mix (M0).
- Mixes containing 30% GGBS (M1), 20% GGBS and 10% SF (M8), 20% MK (M2), 15% SF (M3), 15% MK and 10% SF (M11), 10% GGBS and 5% SF (M7), 10%GGBS & 10% MK (M4) and 10%MK & 15%SF (M10) have flexural strengths 20.61 percent, 14.62 percent, 10.82 percent, 7.89 percent, 5.41 percent, 3.65 percent, 1.02 percent, and 1.02 percent more than a reference mix (M0).
- Based on the results obtained, the produced SCM mix with a cement replacement level of 30% GGBS, 20% Metakaolin, and 15% SF (M14) has the lowest flexural strength of 4.36MPa after 28 days, which is 36.26 percent less than the reference SCM mix (M0).
- Mixes with cement replacement of 30% GGBS and 20% MK (M6), 15% GGBS, 10% MK, and 7.5 % SF (M13), 30% GGBS and 15% SF (M9), and 20% MK and 15% SF (M12) have flexural strengths 13.89 percent, 12.57 percent, 8.77 percent, and 3.65 percent respectively, less than a reference mix M0.
- Binary SCM mixes with cement replacement levels of 30% GGBS (M1), 20% MK (M2), and 15% SF (M3) have higher flexural strength than the reference SCM mix (M0).
- In tertiary SCM mixes comprising GGBS and MK, a cement replacement level of 20 % GGBS and 15 % MK (M5) produces a good flexural strength.
- Tertiary SCM mixes incorporating GGBS and SF achieve good flexural strength at a cement replacement ratio of 20% GGBS and 10% MK (M8).
- In tertiary SCM mixes, MK and SF at a cement replacement level of 15 percent MK and 10 percent SF (M11) produce better flexural strength.
- The flexural strength of quaternary SCM mixtures containing 15% GGBS, 10% MK, and 7.5 % SF (M13) and 30% GGBS, 20% MK, and 15% SF (M14) is lower than that of the reference mix.

7.2.3 Drying Shrinkage Strength

The graph demonstrates the drying shrinkage of self-compacting mortar with varying degrees of cement substitution utilizing GGBS, MK, and SF. For the first three days, the specimens were cured in water before being air dried for the remaining days. The test is conducted at an interval of five days for a total of thirty days. A rectangular prism measuring 285*25*25mm was used to cast SCM specimens. According to ASTM C 596 01 or IS 4031 part 10 1988, the drying shrinkage of the mortar sample was measured.

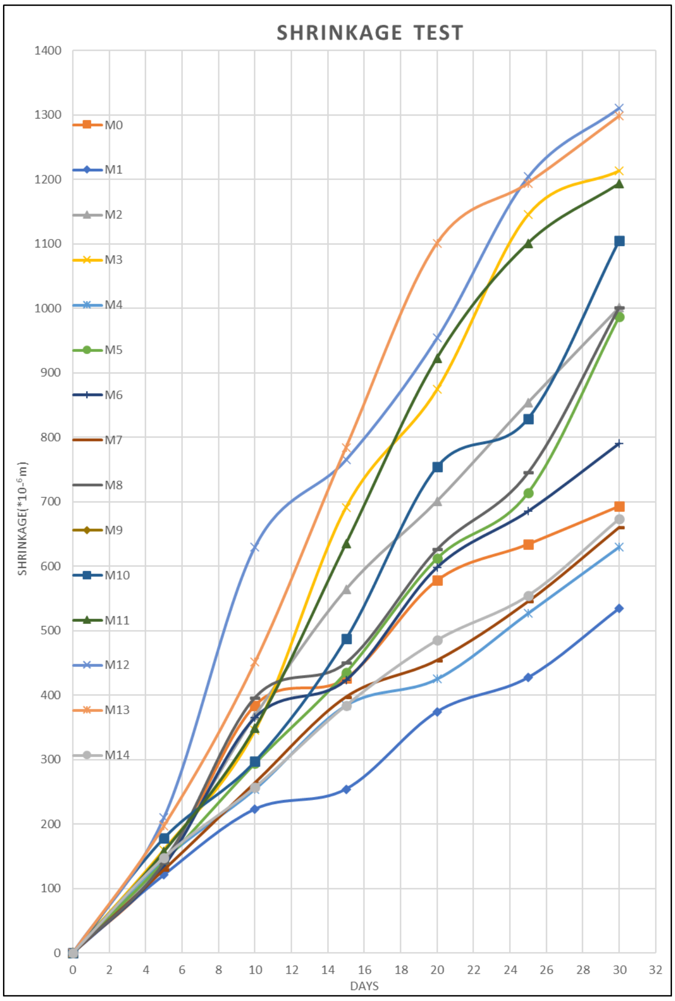

Chart -3: Drying Shrinkage VS Days

- At 30 days, the Drying shrinkage of the reference SCM mix has found to be 693µm.
- In the early stages of testing, all combinations of SCM mixes exhibit a similar trend in drying shrinkage results.
- The graph demonstrates that the SCM mix with a cement replacement level of 30% GGBS (M1) had a lower drying shrinkage (534µm) than the reference SCM mix (M0) at 30 days.
- Based on the results obtained, the SCM mix with a cement replacement level of 20% MK and 15% SF (M12) had the maximum drying shrinkage of 1311µm after 30 days.
- Based on the graph, we can deduce that all SCM mixes comprising 5% SF and 5% MK had greater drying shrinkage.
- SCM mixes containing 30 % GGBS (M1), 10% MK (M4), 10% GGBS and 5% SF (M7), and 30 % GGBS, 20 % MK, and 15 % SF (M14) as cement substitutes had lower drying shrinkage than the normal SCM mix (M0) and rest of the mixes shows more drying shrinkage.
- A decreasing drying shrinkage trend is observed as the content of GGBS replacement with cement is increased.
- Because SF and MK have a higher fineness than cement, the drying shrinkage tendency of SF and MK increases as the content of SF and MK increases.

- In general, drying shrinkage increases as the quantity of finer material increases.

8. CONCLUSIONS

- In comparison to the reference mix (M0), the binary SCM mix with 30% GGBS has higher flowability features, as well as good compressive strength and lowest drying shrinkage qualities.
- In comparison to the reference mix (M0), the binary SCM mix with 20% MK and 15% SF exhibits increased flowability and compressive strength but much higher drying shrinkage.
- The tertiary SCM mix with the addition of GGBS and Metakaolin at a cement replacement level of 20% GGBS and 15% Metakaolin has superior flowability and mechanical qualities but somewhat increased drying shrinkage when compared to the reference mix (M0).
- The tertiary SCM mix with GGBS and Silica fume at a cement replacement level of 20% GGBS and 10% Silica fume has better flowability and mechanical properties than the reference mix (M0), but has significant drying shrinkage.
- The tertiary SCM mix with the addition of Metakaolin and Silica fume at a cement replacement level of 15% Metakaolin and 10% Silica fume exhibits higher flowability and mechanical characteristics, but increased drying shrinkage, when compared to the reference mix.
- The quaternary SCM combination (GGBS+MK+SF) has the lowest mechanical properties, requires more SP to have adequate flowability, and has considerably higher drying shrinkage than the reference mix (M0).
- In general, as quantity of finer material increases drying shrinkage also increases.

9. SCOPE FOR FUTURE STUDY

Industrial byproducts such as GGBS, Metakaolin, and Silica fume demonstrated superior results with good compressive and flexural strength and drying shrinkage when used as a partial replacement for cement in self-compacting mortars. The scope for extending the same work is also reported below.

- The resistance of SCM mixes to chloride and sulphate attacks can be investigated to determine the percentage of strength variation when compared to standard SCMs.
- SCM mixes can also be made from other materials, such as fly ash, rice husk, red mud, and copper slag.
- The SCM mixtures can also be tested under different curing conditions to assess the effect on strength properties.
- The dry densities of SCM mixes with various admixtures can be investigated.
- Saw mill ash waste, jute ash, cotton stalk ash, and other agricultural wastes can be utilized to make self-compacting mortars.

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