Experimental Investigation on Self-Compacting Mortar using GGBS and Alccofine

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Abstract - *The primary objective of the present work is to carry out an experimental investigation on rheological, mechanical and durability properties of SCM. A total of 18 mixes are proportioned where the control mix consists of 100% cement and rest of the mixes are proportioned with varying percentages of Ground Granulated Blast-furnace Slag (GGBS) and Alccofine used as partial replacement for cement. 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, sulphate resistance and sorptivity. The results show that M0 mix (100%C) is the most flowable mix with mini slump flow diameter of 257mm and mini V-funnel time of 7.6 sec. M13 mix (70%C + 20%G + 10%A) has the highest compressive and flexural strengths of 51.17 MPa and 8.83 MPa at 28 days of curing respectively. M4 mix (60%C + 40%G) has the lowest volume expansion against sulphate attack with a change in length of 0.026% at 11 weeks of immersion in sodium sulphate solution. M17 mix (50%C + 35%G + 15%A) has the lowest sorptivity coefficient of 0.37 x 10^{-3} cm/sec$^{0.5}$ at 90 days of curing.*

Key Words: Self-Compacting Mortar, Ground Granulated Blast Furnace Slag, Alccofine, Mini Slump Flow, Mini V-Funnel, Compressive Strength, Flexural Strength, Sulphate Resistance and Sorptivity.

1. INTRODUCTION

Self-compacting mortar (SCM) is considered as new technology product specially preferred for the rehabilitation and repair of reinforced concrete structures. By its high fluidity, great deformability and rheological stability, the self-compacting mortar is capable of ensuring the ability to be easily implemented without vibration. However, its formulation requires a large volume of fine materials with an adequate dosage of cement, which is necessary to ensure required workability and mechanical strengths. As cement manufacturing results in emitting tons of carbon dioxide into the atmosphere, the current environmental considerations encourage reducing the production of cement. So, it is essential to use admixtures to replace cement because of their great availability, moderate price and contribution to an economic sort to solve the problems related to the environment. The mechanical and durability characteristics of self-compacting mortars are similar to self-compacting concretes and could be utilized to study the SCC performance mechanisms. Mortar phase has similar properties to concrete and research on mortar is more controllable. In fact, assessing features of SCMs is an integral part of SCC design. Nowadays, most of the industrial wastes such as fly ash, silica fume, GGBS, etc. are used without being taken full advantages of their properties or disposed of rather than used. This study investigates the effects of supplementary cementitious materials mainly, GGBS and alccofine on SCM mixes prepared with suitable w/b ratio and SP dosage.

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 alccofine. A total of 18 mixes are proportioned including the control mix.

The mix ratio for all the mortar mixes is kept constant at 1:2. 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, sulphate resistance and sorptivity tests are performed on the mixes. The sulphate resistance test is carried out on prisms of size 25 x 25 x 285 mm at 28 days of curing. The sorptivity test is performed on cubes of size 70.6 x 70.6 x 70.6 mm at 90 days of curing.

2.1 Materials

An Ordinary Portland Cement (OPC) of grade 43 conforming to IS: 8112-2013 is used to produce SCM mixes. The physical and chemical properties of cement are presented in Table 1 and Table 2 respectively. Ground Granulated Blast-furnace Slag (GGBS) and alccofine 1203 are the mineral admixtures used as partial replacements for cement. GGBS conforms to IS: 16714-2018. The physical and chemical properties of GGBS are given in Table 3 and Table 4 respectively. Alccofine 1203 conforms to IS: 16715-2018. The physical and chemical properties of alccofine 1203 are presented in Table 5 and Table 6 respectively.

Table 1: Physical properties of cement

Test	Result
Fineness (Dry Sieving)	5 %
Soundness (Le-Chatelier's)	0.5 mm
Normal Consistency	33 %
Initial Setting Time	75 min
Final Setting Time	330 min
Bulk Density	1440 Kg/m^3
Specific Gravity	3.14

Table 2: Chemical properties of cement

Chemical composition	Percentage value of chemical composition
CaO	63.87
SiO_2	20.62
Al_2O_3	5.26
Fe_2O_3	3.50
MgO	1.54
K_2O	0.53
Na_2O	0.28
SO_3	2.50
Loss on ignition	1.90

Table 3: Physical properties of GGBS

Test	Result
Fineness	500 m^2/kg
Bulk Density	1100 kg/m^3
Specific Gravity	2.88
Color	Off-White

Table 4: Chemical properties of GGBS

Chemical composition	Percentage value of chemical composition
CaO	32.08
SiO_2	35.16
Al_2O_3	22.15
Fe_2O_3	2.50
MgO	4.31
K_2O	2.13
Na_2O	1.09
SO_3	--
Loss on ignition	0.58

Table 5: Physical properties of Alccofine 1203

Test	Result
Fineness	1200 m^2/kg
Bulk Density	680 kg/m^3
Specific Gravity	2.85
Color	Gray

Table 6: Chemical properties of Alccofine 1203

Chemical composition	Percentage value of chemical composition
CaO	32.44
SiO_2	34.52
Al_2O_3	22.36
Fe_2O_3	2.10
MgO	6.34
K_2O	--
Na_2O	--
SO_3	1.81
Loss on ignition	0.43

Manufactured sand (M-sand) is the fine aggregate used in the study. M-sand belongs to zone II and conforms to IS: 383-2016. The physical properties of m-sand are presented in Table 7. In addition, a polycarboxylates ether-based superplasticizer (SP) called MasterGlenium SKY 8233 is used to lower the water-binder (w/b) ratio and the properties are given in Table 8.

Table 7: Physical properties of m-sand

Test	Result
Specific Gravity	2.67
Water Absorption (%)	3.5
Moisture Content (%)	1.5
Bulking (%)	5.3

Loose Density (kg/lit)	1.634
Rodded Density (kg/lit)	1.854

Table 8: Properties of m-sand

Test	Result
Specific Gravity	1.08
pH	>6
Chloride ion content	<0.2%
Color	Light Brown Liquid

2.2 Mix proportions

A total of 18 mixes are prepared to observe the behavior of SCM in fresh and hardened states. The mix ratio and binder content are kept constant at 1:2 and 630 kg/m^3. So, the m-sand content remains constant at 1260 kg/m^3. Water-binder ratio and superplasticizer dosage are selected in such a way that the SCM mixes give a slump diameter of 240 – 260 mm and V-funnel time 7 – 11 sec. The binary and ternary mixes consist of various percentages of GGBS and alccofine replacing cement by weight. Percentage replacement of cement (C) by GGBS (G) and alccofine (A) in each mix with their designation is shown in Table 9. The variation of Marsh flow time for different SP dosages is shown in Fig. 1.

Table 9: Designation of mix proportions

Mix Designation	Mix Proportion
M0	100%C
M1	90%C + 10%G
M2	80%C + 20%G
M3	70%C + 30%G
M4	60%C + 40%G
M5	95%C + 5%A
M6	90%C + 10%A
M7	85%C + 15%A
M8	80%C + 20%A
M9	80%C + 15%G + 5%A
M10	80%C + 10%G + 10%A
M11	80%C + 5%G + 15%A
M12	70%C + 25%G + 5%A
M13	70%C + 20%G + 10%A
M14	70%C + 15%G + 15%A
M15	50%C + 45%G + 5%A
M16	50%C + 40%G + 10%A
M17	50%C + 35%G + 15%A

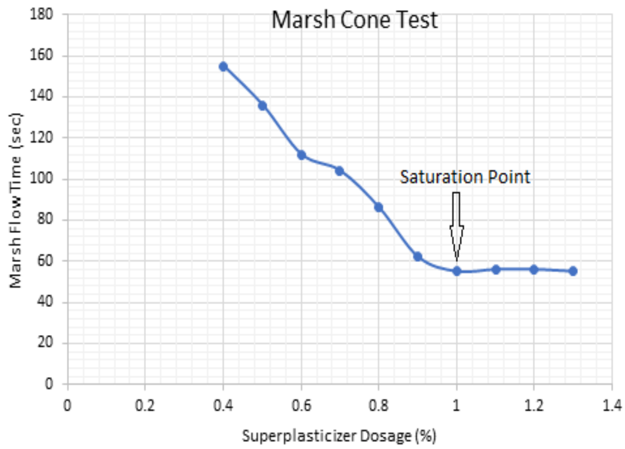

Fig. 1: Variation of Marsh flow time

The quantity of materials for each mix per m^3 is presented in Table 10.

Table 10: Design mix proportions of SCM

Mix	w/b ratio	SP (%)	Quantity (kg/m^3)				
			Water	SP	C	G	A
M0	0.40	0.7	252.0	4.41	630.0	--	--
M1	0.40	0.7	252.0	4.41	567.0	63.0	--
M2	0.41	0.7	258.3	4.41	504.0	126.0	--
M3	0.41	0.7	258.3	4.41	441.0	189.0	--
M4	0.41	0.8	258.3	5.04	378.0	252.0	--
M5	0.40	0.7	252.0	4.41	598.5	--	31.5
M6	0.41	0.7	258.3	4.41	567.0	--	63.0
M7	0.41	0.8	258.3	5.04	535.5	--	94.5
M8	0.41	0.8	258.3	5.04	504.0	--	126
M9	0.41	0.8	258.3	5.04	504.0	94.5	31.5
M10	0.41	0.8	258.3	5.04	504.0	63.0	63.0
M11	0.41	0.8	258.3	5.04	504.0	31.5	94.5
M12	0.41	0.9	258.3	5.67	441.0	157.5	31.5
M13	0.41	0.9	258.3	5.67	441.0	126.0	63.0
M14	0.41	0.9	258.3	5.67	441.0	94.5	94.5
M15	0.41	1.0	258.3	6.30	315.0	283.5	31.5

M16	0.41	1.0	258.3	6.30	315.0	252.0	63.0
M17	0.41	1.0	258.3	6.30	315.0	220.5	94.5

2.3 Production of test specimens

For this work, in all the mixes, cement, mineral additives and m-sand are first mixed for 1 minute. Then, SP and water are poured and mixed for an additional 4 minutes. The workability of fresh mortar is obtained immediately using mini slump cone and mini V-funnel test as per EFNARC 2005 standards. Mortars are cast into cubic molds with the dimensions 70.6 x 70.6 x 70.6 mm and prism molds with the dimensions 40 x 40 x 160 mm and 25 x 25 x 285 mm for mechanical and durability tests. Specimens are demolded after keeping in the casting room for 24 h and are cured in water at the temperature of 25 ± 3 °C till the desired age.

3. TEST METHODS

3.1 Rheological tests for fresh SCM

To evaluate the rheological properties of SCM, mini slump cone and mini V-funnel tests are performed. In mini slump cone test, the truncated cone is filled with mortar on a flat plate and lifted upwards. The diameter is evaluated by averaging the two vertical dimensions of the mortar spread. In mini V-funnel test, after fully filling the funnel with mortar, the bottom outlet is opened to allow the mortar to flow out. The V-funnel flow time is the time between the opening of the bottom outlet and the start of the funnel from the beginning of the light. The workability values of SCMs are considered according to EFNARC 2005 acceptance criteria with 240–260 mm and 7– 11 sec for mini slump flow diameter and mini V-funnel flow time, respectively.

3.2 Compressive strength test

The compressive strength test is conducted on cubic samples of size 70.6 x 70.6 x 70.6 mm that are cured in water for 7 and 28 days. The samples are placed at the loading platform of the compression testing machine and load is applied gradually at the rate of 350 kg/cm^2/min till the sample fails. This test is performed conforming to IS: 4031 (part 6)-1988.

3.3 Flexural strength test

The flexural strength test is conducted on prismatic samples of size 40 x 40 x 160 mm that are cured in water for 7 and 28 days. The samples are placed between the rollers of the flexure testing machine and are loaded between 2 – 6% of the computed ultimate load till the samples fail. This test is performed conforming to ASTM C348-21.

3.4 Sulphate resistance test

The sulphate resistance test is conducted on prismatic samples of size 25 x 25 x 285 mm that are cured in water for 28 days. The method involves the determination of length change of prismatic samples immersed in sodium sulphate (Na_2SO_4) solution of concentration 50 g/L. After 28 days of curing in water, three mortar specimens of each mix are measured for length using the length comparator and placed in sodium sulphate (Na_2SO_4) solution at 21 ± 2 °C. Changes of length of the specimens are measured after storage periods of 1, 2, 3, 4, 5, 6 and 11 weeks, respectively. This test is performed conforming to ASTM C1012-04.

3.5 Sorptivity test

The sorptivity test is conducted on cubic samples of size 70.6 x 70.6 x 70.6 mm that are cured in water for 90 days. At first, the specimens are put into oven at 110 ± 5 °C until a constant weight. In order to avoid evaporation and achieve uniaxial water flow, four sides of the samples are sealed with waterproofing sealant and the other opposite faces are released open. The initial weights of the specimens are measured as 0.01 g. Then, the surface of the specimen exposed to water at about 3–5 mm by putting it in a salver to provide water access to the inflow surface. The water absorption is determined at 5, 10, 30, 60, 180, 240, 360 and 1440 minutes. The sorptivity coefficients of the mixes can be calculated as the following formulation:

$$k = \frac{Q^2}{A^2 t}$$

where Q is the amount of water absorbed in cm^3, A is the cross-section area of specimen that is exposed to water in cm^2, t is time in sec, k is the sorptivity coefficient in cm/sec$^{0.5}$ and this value is calculated from the slope of the linear relation between Q/A and $\sqrt{t}$ by using the smallest squares method.

4. RESULTS AND DISCUSSION

4.1 Rheological properties of SCM

The results of mini slump cone and mini V-funnel tests are presented in Table 11. The mortars with more slump flow diameter and less V-funnel flow time have a higher flowability and workability. All the SCM mixes are designed to have a mini slump diameter of 250 ± 10 mm. This aim is achieved by the addition of adequate SP dosage to the mixes.

Table 11: Rheological properties of SCM

Mix	w/b ratio	SP (%)	Mini slump flow diameter (mm)	Mini V-funnel time (sec)
M0	0.40	0.7	257	7.6
M1	0.40	0.7	255	7.9
M2	0.41	0.7	251	8.5
M3	0.41	0.7	253	9.3
M4	0.41	0.8	251	9.5
M5	0.40	0.7	250	10.3
M6	0.41	0.7	246	9.8
M7	0.41	0.8	251	9.4
M8	0.41	0.8	242	10.6
M9	0.41	0.8	256	9.2
M10	0.41	0.8	253	8.5
M11	0.41	0.8	249	10.8
M12	0.41	0.9	255	8.3
M13	0.41	0.9	257	8.6
M14	0.41	0.9	252	9.1
M15	0.41	1.0	240	11.0
M16	0.41	1.0	246	10.5
M17	0.41	1.0	242	10.8

As it is clear from Table 11, slump flow diameters for SCMs are obtained between 240 and 257 mm which are acceptable according to SCM requirements mentioned in EFNARC. Increasing the admixture content in SCMs slightly decreased slump flow diameter. Higher the cement is replaced by GGBS and alccofine, lesser the slump flow diameter is achieved. This is due to the large specific surface area present in GGBS and alccofine particles that demand more water to be flowable. Compared to all the mixes, the control mix (100%C) is the most flowable mix with a slump flow diameter 257mm. The same conclusion is drawn from mini V-funnel test. It is observed that the control mix (100%C) has the lowest V-funnel time of 7.6 sec. As the fineness of the mix increased, the V-funnel time also increased. The SP dosage is also increased accordingly to overcome the viscosity of the mix and satisfy the EFNARC guidelines.

4.2 Compressive strength

The results of compressive strength test of SCM mixes are presented in Fig. 2. It is observed that the control mix M0 (100%C) has 7 days compressive strength of 33.27 MPa. Apart from M13 mix (70%C+20%G+10%A), the compressive strength of all other mixes falls below the control mix at 7 days. This is because the rate of hydration of GGBS and alccofine is slower compared to the rate of hydration of cement. Hence these admixtures gain strength in later stage. This is evident that the 28 days compressive strength of many binary and ternary mixes are higher than that of control mix. Among the binary mixes, M3 mix (70%C+30%G) has the highest strength of 50.10 MPa and M8 mix (80%C+20%A) has the lowest strength of 41.33 MPa at 28 days. Among the ternary mixes, M13 (70%C+20%G+10%A) mix shows the highest compressive strength of 51.17 MPa and M17 mix (50%C+35%G+15%A) has the lowest strength of 39.90 MPa at 28 days.

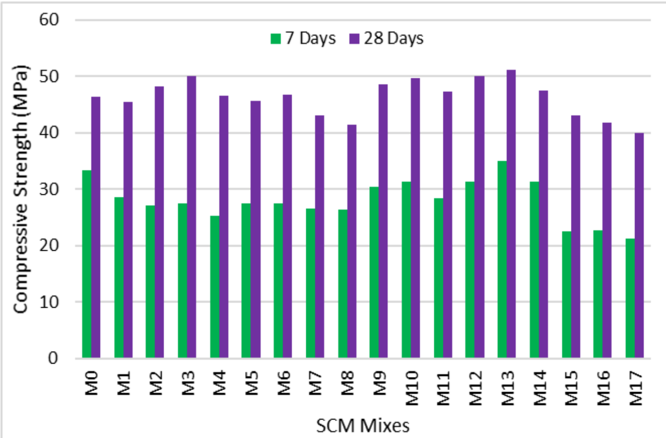

Fig. 2: Compressive strength of SCM mixes at 7 and 28 days of curing.

4.3 Flexural strength

The results of flexural strength test of SCM mixes are presented in Fig. 3.

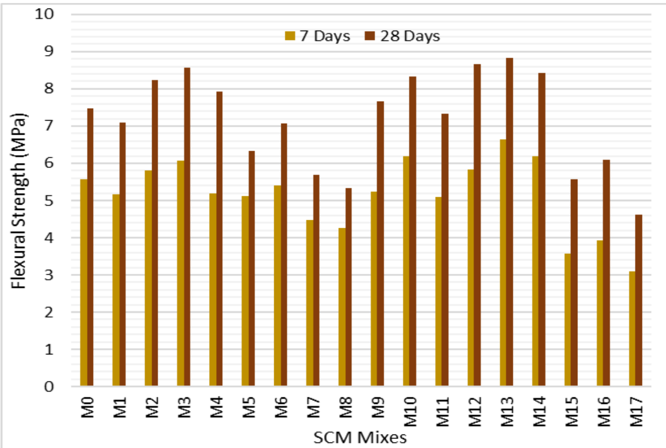

Fig. 3: Flexural strength of SCM mixes at 7 and 28 days of curing.

It is observed that the control mix M0 (100%C) has flexural strength of 5.57 and 7.47 MPa at 7 and 28 days of curing, respectively. Among the binary mixes, M3 mix (70%C+30%G) has the highest strength of 6.07 MPa and 8.57 MPa at 7 and 28 days, respectively. Among the ternary mixes, M13 mix (70%C+20%G+10%A) has the highest strength of 6.63 and 8.83 MPa at 7 and 28 days, respectively. M17 mix (50%C+35%G+15%A) has the lowest strength of 3.10 and 4.63 MPa at 7 and 28 days, respectively.

4.4 Sulphate resistance

The sulphate resistance test provides a good measure of relative performance of mortar in sulphate environment. The results of sulphate resistance test of SCM mixes are presented in Fig. 4 and Fig. 5. The control mix M0 (100%C) shows the most expansion to sulphate attack. After 11 weeks of immersion in sodium sulphate (Na_2SO_4) solution, M0 mix has 0.047% expansion which is the highest change in length compared to all the mixes. Among the binary mixes, M4 mix (60%C+40%G) shows the lowest expansion to sulphate attack with 0.026% change in length after 11 weeks of immersion. Among the ternary mixes, M13 mix (70%C+20%G+10%A) has the lowest expansion of 0.028% change in length after 11 weeks of immersion. It is also observed that there is formation of efflorescence on the surface of prismatic samples immersed in sodium sulphate (Na_2SO_4) solution.

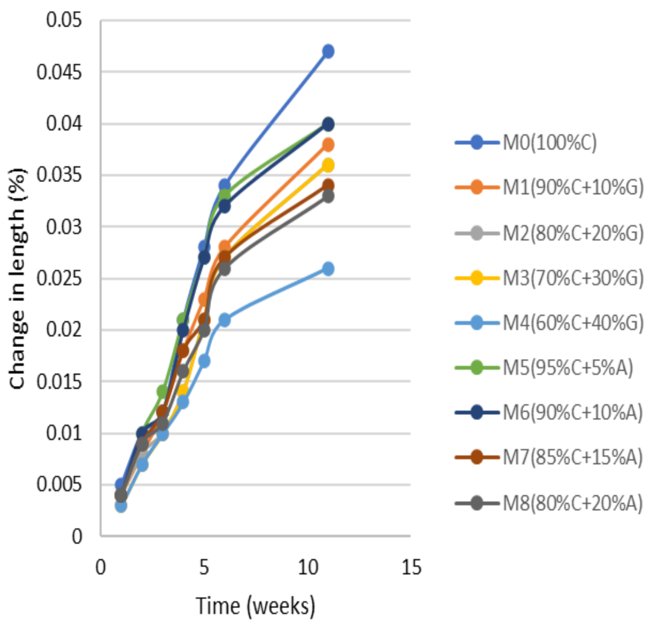

Fig. 4: Change in length (expansion) of samples due to sulphate attack (M0 to M8).

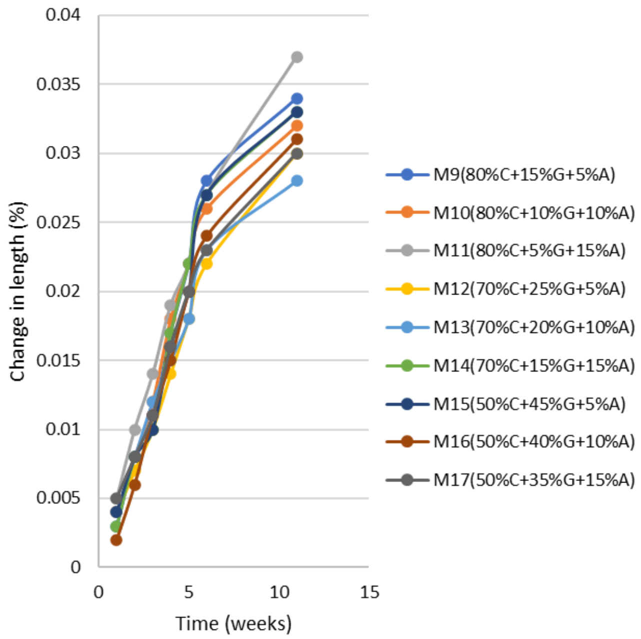

Fig. 5: Change in length (expansion) of samples due to sulphate attack (M9 to M17).

4.5 Sorptivity

The sorptivity test indirectly indicates the volume of voids present in the hardened mortar. The results of sorptivity test are obtained in the form of sorptivity coefficients. Higher the sorptivity coefficient, greater the porosity/permeability and lesser the durability of mortar. The sorptivity coefficients of SCM mixes are shown in Fig. 6.

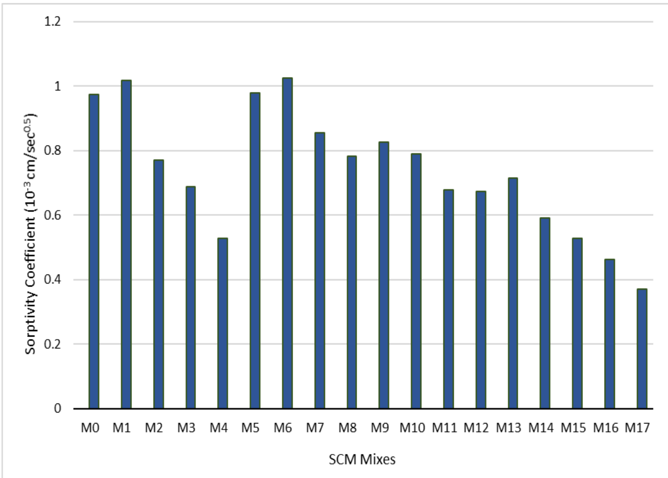

Fig. 6: Sorptivity coefficients of SCM mixes

It is observed that the control mix has the sorptivity coefficient of 0.9735 x 10^{-3} cm/sec$^{0.5}$. Among the binary mixes, M4 mix (60%C+40%G) has the lowest sorptivity coefficient of 0.5275 x 10^{-3} cm/sec$^{0.5}$ and M6 mix has the highest sorptivity coefficient of 1.025 x 10^{-3} cm/sec$^{0.5}$. Among the ternary mixes, M17 mix (50%C+35%G+ 15%A) shows the lowest sorptivity coefficient of 0.3706 x 10^{-3} cm/sec$^{0.5}$ and M9 mix (80%C+15%G+5%A) has the highest sorptivity coefficient of 0.8259 x 10^{-3} cm/sec$^{0.5}$. Except for M1, M5 and M6 mixes, all other mixes have lower sorptivity coefficients compared to the control mix.

5. CONCLUSION

Based on the results obtained from this study, the following conclusions can be drawn:

- As the GGBS and alccofine content in SCM mixes increases, the dosage of SP also increases. This is because the fineness of GGBS and alccofine increases the viscosity of the mix. GGBS and alccofine have large surface area which demands more water/SP content to maintain the rheological properties within the acceptable limits.
- As the GGBS and alccofine content increases, there is decrease in early strength (7 days) and increase in later strength (28 days). There can be up to 30% increase in strength when GGBS and alccofine mixes are cured for 90 – 120 days.
- This is because GGBS and alccofine react with calcium hydroxide [$Ca(OH)_2$] which is a by-product of hydration of cement to form C-S-H (calcium silicate hydrate) gel to increase the strength of the mix. So the strength gain depends on the time of availability of $Ca(OH)_2$.
- In binary mixes, replacement of cement by GGBS up to 30% by weight improves both mechanical and durability properties. When GGBS is used at 40% replacement, there is reduction in mechanical strengths due to slow rate of hydration.
- M3 mix (70%C+30%G) has compressive strength 7.9% and flexural strength 14.72% higher than the control mix. Also, has 36.17% decreased change in length subjected to sulphate attack and 29.34% lower sorptivity coefficient.
- In M4 mix (60%C+40%G), the change in length subjected to sulphate attack is reduced by 44.68% and sorptivity coefficient by 45.81% compared to the control mix. However, the compressive and flexural strengths are similar to the control mix.
- Alccofine at 10% replacement level in binary mixes, yields compressive and flexural strengths close to the control mix with more or less similar durability properties. When alccofine is used beyond 10% replacement level, similar to GGBS there is reduction in mechanical strengths due to the slow rate of hydration.
- In ternary mixes, replacement of cement by a combination of GGBS at 20% and alccofine at 10% yields better mechanical and durability properties.
- M13 mix (70%C+20%G+10%A) has compressive and flexural strengths 10.21% and 18.21% higher than the control mix. Also, has 40.42% decreased change in length subjected to sulphate attack and 26.62% lower sorptivity coefficient.
- GGBS and alccofine have higher silica content which means the calcium to silica (Ca/Si) ratio is lesser compared to the Portland cement. The C-S-H phase formed with low Ca/Si ratio is considered to improve the mechanical and durability properties.
- The control mortar mix M0 (100%C) is least resistant to sulphate attack. M4 mix (60%C+40%G) has the lowest expansion to sulphate attack with 44.68% lower change in length compared to M0 mix. This shows GGBS is resistant to sulphate attack and can be used as partial replacement of cement in sulphate environment.

REFERENCES

[1] Sara, Bachene, Adjoudj Mhamed, Boukendakdji Otmane, and Ezziane Karim. "Elaboration of a Self-Compacting mortar based on concrete demolition waste incorporating blast furnace slag." *Construction and Building Materials* 366 (2023): 130165.

[2] Xu, Rongsheng, Haoran Wang, Qingkun Zha, and Jian Lin. "Improving the carbonation resistance of alkali-activated slag mortars with different additives: experimental evaluations." *Construction and Building Materials* 366 (2023): 130197.

[3] Türk, Esra, Mehmet Karataş, and Murat Dener. "Rheological, mechanical and durability properties of self-compacting mortars containing basalt powder and silica fume." *Construction and Building Materials* 356 (2022): 129229.

[4] Marthish Babu, Bhavanishankar S. "Study on Fresh and Hardened Properties of Self-Compacting Mortar Containing GGBFS, Granite Powder and M-sand." *International Research Journal of Engineering and Technology (IRJET)*. 2022 Mar.

[5] Prithiviraj, Chidambaram, Packirisamy Swaminathan, Deivasigamani Ramesh Kumar, Gunasekaran Murali, and Nikolai Ivanovich Vatin. "Fresh and Hardened Properties

of Self-Compacting Concrete Comprising a Copper Slag." *Buildings* 12, no. 7 (2022): 965.

[6] Bhavanishankar S, Charan U T. "Experimental Investigation on SCM using Different Admixtures." *International Research Journal of Engineering and Technology (IRJET)*. Feb 2022.

[7] Zhao, Zengfeng, Adèle Grellier, Mohamed El Karim Bouarroudj, Frédéric Michel, David Bulteel, and Luc Courard. "Substitution of limestone filler by waste brick powder in self-compacting mortars: Properties and durability." *Journal of Building Engineering* 43 (2021): 102898.

[8] Hammat S, Menadi B, Kenai S, Khatib J, Kadri EH. "Properties of self-compacting mortar containing slag with different finenesses." *Civil Engineering Journal*. 2021 May 1;7(5):840-56.

[9] Soma Prasanth Reddy, Sashidhar C, Kavyateja BV. "A study on the performance of self-compacting concrete with fly ash and alccofine." *International Journal of Multidisciplinary Research (IJMR).* 2021 Sep 9.

[10] Al-Jaberi, Layth A. "Role of mineral admixtures in self compacting concrete: Scanning electron microscopy approach." *AIP Conference Proceedings*, vol. 2372, no. 1, p. 180005. AIP Publishing LLC, 2021.

[11] Tangadagi RB, Manjunatha M, Seth D, Preethi S. "Role of mineral admixtures on strength and durability of high strength self compacting concrete: An experimental study." *Materialia.* 2021 Aug 1;18:101144.

[12] Mehdizadeh B, Jahandari S, Vessalas K, Miraki H, Rasekh H, Samali B. "Fresh, mechanical, and durability properties of self-compacting mortar incorporating alumina nanoparticles and rice husk ash." *Materials*. 2021 Jan;14(22):6778.

[13] Hammat S, Menadi B, Kenai S, Khatib J, Kadri EH. "Properties of self-compacting mortar containing slag with different finenesses." *Civil Engineering Journal*. 2021 May 1;7(5):840-56.

[14] Kavyateja BV, Jawahar JG, Sashidhar C. "Durability performance of self compacting concrete incorporating alccofine and fly ash." *International Journal of Engineering.* 2020 Aug 1;33(8):1522-8.

[15] Si-Ahmed, Mohammed, and Said Kenai. "Behavior of self-compacting mortars based on waste brick powder." *Current Materials Science: Formerly: Recent Patents on Materials Science* 13, no. 1 (2020): 39-44.

[16] Kavyateja BV, Jawahar JG, Sashidhar C. "Effectiveness of alccofine and fly ash on mechanical properties of ternary blended self compacting concrete." *Materials Today: Proceedings.* 2020 Jan 1;33:73-9.

[17] IS: 8112-2013 – Specification for 43 grade ordinary Portland cement.

[18] IS: 4031 (part 6)-1988 – Standard methods of physical tests for hydraulic cement.

[19] IS: 383-2016 – Specification for coarse and fine aggregate for concrete.

[20] IS: 9103-1999 – Specification for concrete admixtures.

[21] IS: 16714-2018 – Specification for Ground Granulated Blast Furnace Slag for use in cement, mortar and concrete.

[22] IS: 16715-2018 - Specification for Ultrafine Ground Granulated Blast Furnace Slag for use in cement, mortar and concrete.

[23] ASTM C939-97 – Standard test method for flow of grout for preplaced aggregate concrete (Flow cone method).

[24] ASTM C348-21 – Standard test method for flexural strength of hydraulic cement mortars.

[25] ASTM C1012-04 – Standard test method for length change of hydraulic cement mortars exposed to a sulphate solution.

[26] ASTM 1585-04 -Standard Test Method for measurement of the rate of absorption of water by hydraulic cement. European Federation of National Associations Representing for Concrete 2005.