Study on Rheological & Mechanical Properties of SCM using Mineral Admixture as a Partial Replacement of Cement

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Abstract - *This paper presents an investigation on self-compacting Mortar (SCM) with three cementitious contents. The work involves three types of blends namely ternary & quaternary, the first &second consisted of different percentages of fly ash (FA), Metakaolin (MK) & Silica fume (SF) as a cement replacement [0-40,0-20 & 0-15 by weight %(wt.), respectively] and the third uses different percentages of fly ash (FA), metakaolin (MK) & silica fume (SF) with a total of ten ternary mixes, two quaternary mixes were designed. for each mix designed, the mini-slump and mini V-funnel tests are carried out on the fresh SCM, and nine cubes and prism specimens of each are cast and cured in water for 7,14 & 28 days and hardened properties of Mortar like compressive strength & flexural strength values are determined in the laboratory. The results show that ternary SCM mix with 20% of FA,10% MK (M1.2) and 10% MK, 5% SF and quaternary mix with 20% FA, 10% MK and 7.5 % SF gives values of compressive strength and flexural strength higher than reference mix at 28 Days of water curing.*

Key Words: *Self-compacting mortar, Ternary mix, quaternary mix, Compressive strength, Flexural strength*

1.INTRODUCTION

With the development of construction of megastructures, the world over, the need for self-compacting concrete (SCC) applications are increasing. Many sites have problems with congestion of reinforcement in principal 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 CO_2 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 Advantages and applications of SCM

- Mortar is consistent, stable, and easy to handle.
- More flowable and can access into narrow fills.
- Self-compacted with a good surface finish.
- Act as a binding agent to various structural fills
- Mortar is corrosion-resistant.
- Used in flooring tiles, roofing, and also for grout filling
- Mortar acts as a protective layer, used for waterproofing High strength
- High strength fiber reinforced SCM's are used to caste sheet piles.
- Used to develop kitchen work surfaces which is aesthetically good at appearance.
- Used in developing sinks, cupboards, and other interior and exterior designs.
- Used in filling cracks and joints.
- SCM's can be used in sprayed mortars.

- It is cost-effective, as cement content can be replaced with pozzolanic ashes.

2. OBJECTIVES OF THE PRESENT INVESTIGATION

- Based on literature study rheological and mechanical properties are studied in the laboratory with different admixtures.
- SCM mixes are developed in the in the laboratory. with industrial byproducts.
- Ternary & quaternary blended SCM mixes are developed in laboratory.
- Fresh properties are studied using mini v funnel & mini slump cone.
- Hardened properties like compressive & flexural strength are studied.

3. AIM AND SCOPE OF THE PRESENT STUDY

The aim of the present study is to produce green mortar by use of industrial by-products which are a threat to the environment on disposed of by any mode.

- Making use of these byproducts to produce binary, ternary & quaternary blends of SCMs to provide improved overall response.
- Using industrial waste as a partial replacement to cement to produce SCM mix.
- The aim was to explore Rheological & Mechanical properties and their comparison with reference SCM Mix.

4. METHODOLOGY

- Several literature reviews on the replacement of cement by mineral admixtures such as Fly ash, Silica fume, Metakaolin, etc. in SCC/SCM mixes are studied.
- In this investigation, cement mortar of 1:2 ratio is considered & Percentage of different admixture is determined referring to various research papers.
- Preliminary basic tests are conducted on material samples and are procured on satisfying the criteria given by the codes.
- Marsh cone test was employed in the laboratory to find the optimum dosage of superplasticizer (Master Glenium 8233).
- In this investigation, fresh properties are determined using mini slump and mini v funnel test & Hardened properties like compressive strength and Flexural strength are determined at 7,14,28 days of wet curing.

5. MATERIALS

5.1 Ordinary Portland Cement

Ordinary Portland Cement of Zuari brand of 43 grades confirming to IS: 8112-2013 & EN 197-1 was used in the present study. The properties of cement are shown in Table 1& 2.

5.2 Fly ash

Fly ash used was confirming to IS 3812 1981, EN 450 & was supplied by "JSW Cement". It is used as a partial replacement of cement up to 40% at an interval of 10%. The properties of Fly ash are shown in Table 1& 2.

5.3 Metakaolin

Metakaolin used was confirming to ASTM C 618 and was supplied by "JSW". The Metakaolin is used as a partial replacement of cement up to 20% at an interval 5%. The properties of Metakaolin are shown in Table 1& 2.

5.4 Silica fume

Silica Fume used was confirming to IS 15388 2003, IS 1727-1967, ASTM C 1240-14 & EN 13263 and was supplied by "LA GREENS". The Silica Fume is used as a partial replacement of cement up to 15% at an interval of 5%. The properties of Silica Fume are shown in Table 1& 2.

Fig -1: Samples of Mineral admixtures.

Table -1: Chemical Composition of Cementitious Materials

Chemical Composition	OPC	Fly ash	Metakaolin	Silica Fume
CaO	63.87	2.23	0.02	0.29
SiO_2	20.62	58.55	53.20	92.00
Al_2O_3	4.87	28.20	43.90	0.46
Fe_2O_3	3.35	3.44	0.38	1.60
MgO	1.54	0.32	0.05	0.28
K_2O	Nil	1.26	0.10	0.61

Na_2O	Nil	0.58	0.17	0.51
SO_3	2.50	0.07	Nil	0.19
LOI	1.50	4.17	0.50	1.00
Fineness (m2/Kg)	367	150-500 m^2/kg	700-900 m^2/kg	15000-30000 m^2/kg

5.5 Fine aggregates

Locally available M sand with 4.75mm maximum size was used as fine aggregate, and fine aggregate conformed to IS: 383-2016, EN 12620 & ASTM C 33 was used. The properties of fine aggregate are shown in Tab 2 &3.

Table -2: Physical Properties of Materials

Materials	Test conducted	Results	IS-Code
Cement (OPC 43)	Specific gravity	3.14	3.15
	Fineness (%)	5%	<10
	Normal consistency (%)	34	---
	Initial setting time (min)	95	30
	Final setting time (min)	360	600
	7days Compressive Strength (MPa)	25.4	26
	14days Compressive Strength (MPa)	39.45	38
	28days Compressive Strength (MPa)	43.4	43
Fly ash	Specific gravity	2.1	2.1-3.0
	Fineness (%)	7	<10
Metakaolin	Specific gravity	2.5	---
	Fineness (%)	8	10
Silica fume	Specific gravity	2.2	---
	Fineness (%)	8	10
Fine aggregate (M Sand)	Specific gravity	2.5	2.75
	Fineness modulus (%)	2.74	3.2
	Bulk Density (Kg/m^3)	1090	1250

Table -3: Sieve Analysis of Fine Aggregate

Sieve size	**Cumulative percent**		Specification (IS: 383-1970)
	Retained	**Passing**	**Zone II**
4.75 mm	0.8	99.2	90–100
2.36 mm	6.4	93.6	75–100
1.18 mm	44.4	56.6	55–90
600 µm	61.4	38.6	35–59
300 µm	81.6	18.4	8–30
150 µm	92.6	7.4	0–10

5.6 Superplasticizer

MasterGlenium SKY 8233 is an admixture based on modified polycarboxylic ether. This product has been developed primarily for applications in high performance and highly durable concrete. Table 2. Provides the physical and chemical properties of the admixture. Masterglenium SKY 8233 is Chloride free & low has low alkali content. It is compatible with all types and grades of cements.

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 PROPORTIONING

The quantity of cement, fine aggregates, water, and mineral admixtures (Fly ash, Metakaolin, Silica fume) for each batch of proportion is prepared as mentioned in the design.

Table -3: Mix proportions

Sl.No.	Mix id	Mix notation	OPC	FA	MK	SF
1	M0	100%C	100			
2	M1	60%C+40%F	60	40		
3	M2	85%C+15%S	85			15
4	M3	80%C+20%M	80		20	
5	M1.1	85%C+10%F+5%M	85	10	5	
6	M1.2	70%C+20%F+10%M	70	20	10	
7	M1.3	55%C+30%F+15%M	55	30	15	
8	M1.4	40%C+40%F+20%M	40	40	20	
9	M2.1	75%C+20%F+5%S	75	20		5
10	M2.2	60%C+30%F+10%S	60	30		10
11	M2.3	45%C+40%F+15%S	45	40		15
12	M3.1	85%C+10%M+5%S	85		10	5
13	M3.2	75%C+15%M+10%S	75		15	10
14	M3.3	65%C+20%M+15%S	65		20	15
15	M4.1	62.5%C+20%F+ 10%M+7.5%S	62.5	20	10	7.5
16	M4.2	35%C+30%F+ 20%M+15%S	35	30	20	15

7. RESULTS AND DISCUSSION

The present investigation deals with the study of developing Self-compacting mortars and these SCM's are replaced with admixtures obtained from industrial wastes to cement content at different percentages. SCM mixes were developed with keeping the overall powder content constant. The optimum dosage of SP is determined using marsh cone test & fresh properties are enhanced using mini-slump cone &

mini V funnel test, hardened properties i.e. Compressive strength, Flexural strength of all the mixes are determined.

7.1 Marsh cone test

Flow time of cement/mortar through marsh cone is indicator of viscosity, which depends upon cement super plasticizer compatibility. It is widely used to study cement superplasticizer compatibility and to determine optimum superplasticizer dosage of a specific cement-super plasticizer combination. Optimum dosage is the percentage of superplasticizer beyond which there is no significant increase in the fluidity of the mix

Table -4: Marsh cone test

Trial no.	W/C ratio	SP %	flow time S
1	0.35	0.6	92
2	0.35	0.8	57.2
3	0.35	1	28.51
4	0.35	1.2	26.68
5	0.35	1.4	24.53
6	0.35	1.5	23.39

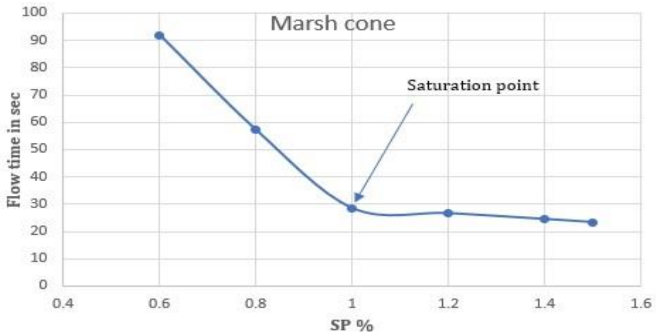

Chart -1: Marsh cone test SP% v/s time

A liter of slurry made with 2kg of cement powder and w/c ratio of 0.31 to 0.35 is tested varying the percentage of superplasticizer starting from 0.6%. it is observed that 1% of Superplasticizer optimum dosage for the above condition.

7.2 Fresh properties.

Fresh properties of all the designed mixes are determined in the laboratory by adjusting dosage of SP such that mini slump flow diameter of 240-260mm & mini v funnel flow time of 7-11 S. the results are tabulated in table-5

Table -5: Fresh properties

Mix Id	proportion	W/P	SP%	Slump In mm	V funnel Flow, sec
M0	1: 2	0.36	0.6	255	11
M1	1: 2	0.36	0.8	257	7
M2	1: 2	0.37	0.7	253	11
M3	1: 2	0.37	0.85	250	10
M1.1	1: 2	0.38	0.75	243	11
M1.2	1: 2	0.38	0.8	249	9
M1.3	1: 2	0.38	0.85	257	8
M1.4	1: 2	0.38	0.9	263	7
M2.1	1: 2	0.37	0.75	258	7
M2.2	1: 2	0.37	0.8	253	8.4
M2.3	1: 2	0.37	0.85	246	9
M3.1	1: 2	0.38	0.8	243	7
M3.2	1: 2	0.38	0.85	250	9
M3.3	1: 2	0.38	0.9	257	10
M4.1	1: 2	0.38	1.1	242	11
M4.2	1: 2	0.38	1.1	253	7

- Results show that reference mix(M0) has mini-slump flow diameter & mini v funnel flow time of 254mm,8Sec respectively, that satisfy EFNARC requirements for SCM with W/B ratio of 0.33 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.
- It is observed that SCM mix with FA and MK increases slump & decreases flow time on the increase of FA and MK content.
- It is observed that SCM with FA and SF decreases the slump & increases flow time on the increase of FA and SF content due to an increase of fineness of mineral admixtures.
- It is observed that SCM mix with FA, MK & SF requires more water due to increased fineness of mineral admixtures.

7.3 Hardened properties

The hardened properties investigated are compressive & Flexural strength. The SCM mixes with/without partial replacement of cement by mineral additives are tested at 7,14 &28 days. The results obtained are presented in Table 6

7.3.1 Compressive strength

The compressive strength development of Self-compacting mortar containing different percentages of FA, MK, SF at 7, 14, 28 days of curing, test specimen of 70.6*70.6*70.6mm and procedure are carried out following the guidelines of IS: 4031(part 6) 1988, ASTM C 109.

Chart -2: Mix v/s compressive strength

- It is observed from the results that the reference mix(M0) has a compressive strength of 43.4MPa.
- Results shows that binary mix(M3) with 20% Metakaolin gives strength more than reference mix(M0).
- It is observed that ternary SCM mix(M1.2) with 20% FA & 10% MK gives compressive strength of 41.8MPa, there is a decrease of 3.18% compared to reference mix.
- It is observed that ternary SCM mix(M2.1) with 20% FA & 5% SF gives compressive strength of 39.8MPa, there is a decrease of 8.27% compared to reference mix.
- It is observed that ternary SCM mix(M3.2) with 15% MK & 10% SF gives compressive strength of 49.8MPa, there is an increase of 14.74% compared to reference mix.
- It is observed that quaternary mix(M4.1) with 20% FA,10% MK and 7.5% SF gives compressive strength of 43.25MPa.

7.3.2 Flexural strength

The flexural strength development of Self-compacting mortar containing different percentages of FA, MK, SF at 7, 14, 28 days of curing, test specimen of 40*40*160mm and procedure are carried out following the guidelines of IS: 4031(part 6) 1988, ASTM C 348.

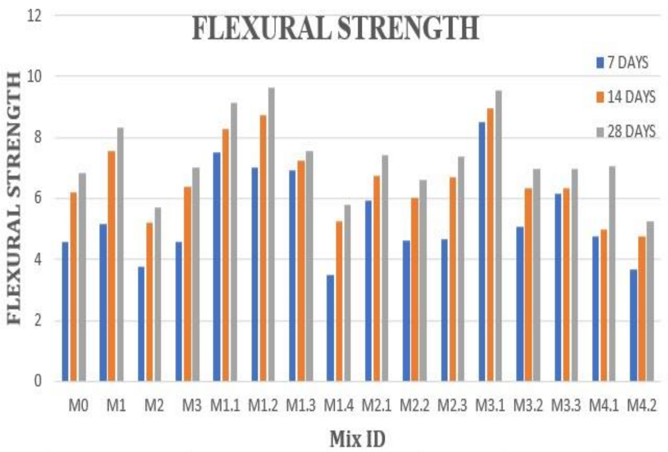

Chart -2: Mix v/s Flexural strength

- It is observed from the results that the reference mix(M0) has Flexural strength of 6.844MPa.
- Results shows that binary mix(M3) with 40% Metakaolin gives flexural strength more than reference mix(M0).
- It is observed from the results that ternary mix with FA and MK gives optimum results at 20% FA & 10% MK(M1.2).
- It is observed from the results that ternary mix(M2.1) with FA and SF gives Flexural strength of 7.41MPa. and an increase of 8.33% compared with the Reference mix is observed.
- It is observed from the experiment that a decrease in flexural strength on the increase of MK and SF.
- It is observed from the results that ternary mix(M3.1) with MK and SF gives Flexural strength of 9.53MPa. and increase of 39% compared with the Reference mix is observed
- Quaternary mix(M4.1) with 20% FA,10% MK and 7.5% SF gives Flexural strength of 5.483MPa, and a decrease of 19.83% is observed.

8. CONCLUSIONS

- The reference SCM mix(M0) shows good flow properties and hardened properties like compressive strength of 43.4 MPa, Flexural strength of 6.84 MPa.
- It is confirmed from the marsh cone test that flow rate becomes constant after 1% of Superplasticizer & hence it is the optimum dosage of superplasticizer for the brand of cement used.
- From the experimental results it is observed that there is a decrease of compressive and flexural strength on increase of percentage of cement replacement level above 35%.
- The ternary mix with 20% FA,10% MK (M1.2) and 30% FA,15% MK(M1.3) shows good flow properties and hardened properties compared to the reference mix(M0).
- The ternary SCM mix with cement replacement level 20% FA,10% SF(M2.2) shows good flow properties & hardened properties compared to reference mix(M0).
- The ternary SCM mix with cement replacement level 15% MK, 10% SF (M3.2) shows good flow properties & hardened properties compared to reference mix(M0).
- The Quaternary mix(M4.1) with 20% FA,10% MK & 7.5% SF shows good flow properties & hardened properties compared to the reference mix (M0).

9. SCOPE FOR FUTURE STUDY

The industrial byproducts such as FA, MK &SF are used as a partial replacement of cement in self-compacting mortars showed better results with good compressive strength. Further scope for extending the same work is reported below.

- The durability of SCM's against chloride and sulphate attacks can be studied to know the percentage of strength reduction as compared with the normal SCM's.

- Other industrial wastes like red mud and copper slag can be used to develop SCM.
- The properties of SCM can be studied from the replacement of natural sand with alternate materials. SCM without superplasticizer can be studied.
- Agro-based wastes like sawmill ash, jute ash, cotton stalk ash, etc. can be used in developing SCM.
- SCM with different curing conditions can be studied.
- Self-healing self-compacting concrete can be produced.

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