BEHAVIOUR OF SELF COMPACTED SELF CURING KILN ASH CONCRETE WITH VARIOUS ADMIXTURES

M. S. Ravikumar[1], Selvamony C.[1], S. U. Kannan[1] and S. Basil Gnanappa[2]
[1]Sathyabama University, Chennai, India
[2]Moderator Gnanadhasan Polytechnic, Nagercoil, India
E-Mail: muthu9678@rediffmail.com

ABSTRACT

In recent years, self-compacting concrete (SCC) has gained wide use for placement in congested reinforced concrete structures with difficult casting conditions. For such applications, the fresh concrete must possess high fluidity and good cohesiveness. The use of fine materials such as kiln ash can ensure the required concrete properties. The initial results of an experimental program aimed at producing and evaluating SCC made with high-volumes of kiln ash are presented and discussed. Ten SCC mixtures and one control concrete were investigated in this study. Fresh properties, flexural and compressive strengths of self compacted concrete were determined. The use of SF in concrete significantly increased the dosage of superplasticiser (SP). At the same constant SP dosage (0·8%) and mineral additives content (30%), KA can better improve the workability than that of control and fine aggregate mixtures by (5 % to 45 %). However, the results of this study suggest that certain QD, SF and KA combinations can improve the workability of SCCs, more than QD, SF and KA alone. KA can have a positive influence on the mechanical performance at early strength development while SF improved aggregate-matrix bond resulting from the formation of a less porous transition zone in Concrete. SF can better reducing effect on total water absorption while QD and KA will not have the same effect, at 28 days.

Keywords: self-compacting concrete, limestone powder, silica fume, quarry dust, clinkers workability, strength, water absorption.

INTRODUCTION

Self-compacting concrete (SCC) was first developed in Japan as a mean to create uniformity in the quality of concrete by controlling the ever present problem of insufficient compaction by a workforce that was losing skilled labour and by the increased complexity of designs and reinforcement details in modern structural members. Durability was the main concern and the purpose was to develop a concrete mix that would reduce or eliminate the need for vibration to achieve consolidation. Self-compacting concrete achieves this by its unique fresh state properties. In the plastic state, it flows under its own weight and maintain homogeneity while completely filling any formwork and passing around congested reinforcement. In the hardened state, it equals or excels standard concrete with respect to strength and durability.

Although self-compacting concrete has been successfully used in Japan and European there has been some reluctance to employ it in Australia and as a consequence it has suffered very little development with local materials. The composition of concrete could sometime consist of more than one type of cement (i.e. special cement, like ultra-fine alumina cement) together with additions (i.e. silica fume, slag or kiln ash), aggregates (normal, lightweight and special types, fillers), admixtures such as superplasticiser (SP), air entrainers and viscosity modifying agents, The use of industrial by-products, such as KA, SF, QD offers a low-priced solution to the environmental problem of depositing industrial waste.

The viscosity of cement-based material can be improved by decreasing the water/ cementitious material ratio (w/cm) or using a viscosity-enhancing agent. It can also be improved by increasing the cohesiveness of the paste through the addition of filler, such as limestone (Ozawa *et al.*, 1995, Khayat 1999). However, excessive addition of fine particles can result in a considerable increase in the specific surface area of the powder, which results in an increase of water demand to achieve a given consistency. On the other hand, for a fixed water content, high powder volume increases interparticle friction due to solid–solid contact. This may affect the ability of the mixture to deform under its own weight and pass through obstacles (Nawa *et al.*, 1998).

The use of limestone powder can enhance many aspects of cement-based systems through physical or chemical effects. Some physical effects are associated with the small size of lime- stone particles, which can enhance the packing density of powder and reduce the interstitial void, thus decreasing entrapped water in the system. For example, the use of a continuously graded skeleton of powder is reported to reduce the required powder volume to ensure adequate deformability for concrete (Fujiwara *et al.*, 1996). Chemical factors include the effect of limestone filler in supplying ions into the phase solution, thus modifying the kinetics of hydration and the morphology of hydration products (Daimon and Sakai 1998). Partial replacement of cement by an equal volume of limestone powder with a specific surface area ranging between 500 and 1000 m^2/kg resulted in an enhancement in fluidity and a reduction of the yield stress of highly flowable mortar (Yahia *et al.*, 1999). Other investigations have shown that partial replacement of cement by an equal volume of limestone powder varying from 5% to 20% resulted in an enhancement of the fluidity of high-performance concrete having a W/C ratio ranging between 0·5 and 0·7 (Nehdi *et al.*, 1998). This improvement may be due to the increase in W/C or in paste volume. Indeed, for given water content, partial replacement of cement by an equal volume of a filler results in an increase in W/C. On the other hand, partial replacement of cement by an equal mass of limestone powder results in an increase of powder content, i.e. an increase in paste volume. For example, the partial substitution of cement by 40% (by mass of limestone filler) having a specific gravity of 2·7 yields to a 17% increase in powder volume.

The durability of a concrete repair can depend on many factors. Those most often considered are cement reactivity with environment, low permeability, diffusion coefficient of species such as sulfate ions and compressive strength. The water absorption is also very important factor effecting durability such as freezing and thawing. The use of mineral additives may provide a way of improving the durability of SCC depending on the type and amount of mineral additive used. In addition, in the absence of self-compactability the success of mortars depends on the compaction degree supplied at application site.

For improving strength and durability properties; limestone powders produce a more com-pact structure by pore-filling effect. In the case of SF and FA, it also reacts with cement by binding Ca $(OH)_2$ with free silica by a pozzolanic reaction forming a non-soluble CSH structure (O'Flaherty and Mangat; 1999).

The main objective of the present study was to investigate a suitable combination of KA, QD, SF and Steel fibres that would improve the properties of the SCCs more than when these materials would be used separately.

SELF-COMPACTING CONCRETE

A. Definition

The concrete that is capable of self-consolidation and occupying all the spaces in the formwork without any vibration is termed as Self-Compacting Concrete. The guiding principle behind the self-compaction is that "the sedimentation velocity of a particle is inversely proportional to the viscosity of the floating medium in which the particle exists".

B. Ingredients of SCC

The constituent material used for the production of SCC is discussed as follows:

i) Cement

Ordinary Portland Cement (53 grade) Dalmia cement conforming to IS 8112 was used. The different laboratory tests were conducted on cement to determine standard consistency, initial and final setting time, and compressive strength as per IS 4031 and IS 269-1967. The results are tabulated in Table-1. The results conforms to the IS recommendations.

Table-1. Properties of cement.

S. No.	Test conducted	Result
1	Standard consistency	32%
2	Initial setting time	150 minutes
3	Final setting time	330 minutes
4	7 day compressive strength	27.67 N/mm^2
5	21 day compressive strength	39.93 N/mm^2
6	28 day compressive strength	54.60 N/mm^2

ii) Fine aggregates

Natural sands, crushed and rounded sands, and manufactured sands are suitable for SCC. River sand of specific gravity 2.58 and conforming to zone II of IS 363 was used for the present study. The particle size distribution is given in Table-2.

Table-2. Sieve analysis of fine aggregate.

Passing through **IS sieve** (mm)	Retained on IS **sieve** (mm)	Cumulative % retained	% Passing
4.75	2.36	2.00	98.00
2.36	1.18	21.20	78.88
1.18	0.6	46.40	53.60
0.6	0.3	63.14	36.68
0.3	0.15	88.14	11.86

Fineness modulus = 3.06
Dry rodded Bulk density = 1.84g/cc

iii) Coarse aggregate

The shape and particle size distribution of the aggregate is very important as it affects the packing and voids content. The moisture content, water absorption, grading and variations in fines content of all aggregates should be closely and continuously monitored and must be taken into account in order to produce SCC of constant quality. Coarse aggregate used in this study had a maximum size of 20mm. Specific gravity of coarse aggregate used was 2.8. The particle size distribution is given in Table-3.

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Table-3. Sieve analysis of coarse aggregate.

Passing through IS sieve (mm)	**Retained on IS sieve** (mm)	**Cumulative % retained**	**% Passing**
20	12.5	100	100
12.5	10	7.5	92.5
10	4.75	30.01	69.99
4.75	Pan	90.45	9.55

Fineness modulus = 7.3
Dry rodded Bulk density = 1.66g/cc

iv) Water

Ordinary potable water available in the laboratory was used.

v) Chemical admixtures

Superplasticisers or high range water reducing admixtures are an essential component of SCC. Conplast SP 430 was used as superplasticiser and Structuro 485 was used as viscosity modifying agent and Concure was used as self curing admixture

vi) Kiln ash

A high quality kiln ash generally permits a reduction in water content of a concrete mixture, without loss of workability. Kiln ash obtained from India's cement Limited, Tirunelveli was used for the study. The chemical composition of kiln ash is given in Table-4.

VII) Rock dust

The granite fines obtained as by-product in the production of concrete aggregates are referred as quarry or rock dust [4]. Rock dust of specific gravity 2.37 passing through 150-micrometer sieve was used in this study. The chemical composition of rock dust is given in Table-5.

viii) Silica fume

Silica fume imparts very good improvement to rheological, mechanical and chemical properties. It improves the durability of the concrete by reinforcing the microstructure through filler effect and thus reduces segregation and bleeding. It also shows KAs in achieving high early strength. Silica fume of specific gravity 2.34 was used in this study. The chemical composition of Silica fume is given in Table-6.

Table-4. Chemical composition of kiln ash.

S. No.	**Component**	**Quantity** (%)
1	SiO_2	15-45
2	Al_2O_3	10-25
3	Fe_2O_3	4-15
4	CaO	15-40
5	MgO	3-10
6	SO_3	0-10
7	Na_2O	0-6
8	K_2O	0-4
9	LOI	0-5

Table-5. Chemical composition of rock dust.

S. No.	**Constituents**	**Quantity** (%)
1	SIO_2	70.74
2	Ai_2O_3	20.67
3	FE_2O_3	2.88
4	TIO_2	0.33
5	NA_2O	0.11
6	K_2O	0.19
7	MGO	1.57
8	MNO_2	0.01
9	CAO	0.2
10	ZNO	0.01
11	PB	625 PPM
12	CR	125 PPM
13	LOI	0.72

Table-6. Chemical composition of silica fume.

S. NO.	Constituents	Quantity (%)
1	SiO_2	91.03
2	Ai_2O_3	0.39
3	Fe_2O_3	2.11
4	CaO	1.5
5	LOI	4.05

Experimental investigation

Tests on fresh concrete were performed to study the workability of SCC with various proportions of rock dust and silica fume. The tests conducted are listed below:

i Slump flow test
ii V- funnel flow test
iii Orimet test
iv U-tube test
v J- Ring test
vi L-box test

The acceptance criteria for the fresh properties of SCC are listed in Table-7. Tests on hardened concrete were also conducted for mixes with various proportions of rock dust. An investigation for the optimum percentage of replacement of cement with rock dust was performed.

Table-7. Acceptance criteria for SCC.

S. No.	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump-flow	mm	650	800
2	T50 slump flow	Sec	2	5
3	J-ring	Mm	0	10
4	V-funnel	Sec	6	12
5	V-funnel at T5minutes	Sec	0	+3
6	L-Box	(h_2/h_1)	0.8	1.0
7	U-Box	(h_2/h_1)	0	30
8	Fill Box	%	90	100
9	GTM Screen stability test	%	0	15
10	Orimet	Sec	0	5

Mix proportion of SCC

There is no standard method for SCC mix design and many academic institutions, admixture, ready-mixed, pre cast and contracting companies have developed their own mix proportioning methods. Okamura's method, based on EFNARC specifications, was adopted for mixed design. Different mixes were prepared by varying the amount of coarse aggregate, fine aggregate, water powder ratio, super plasticisers and VMA. After several trials, SCC mix satisfying the test criteria was obtained. The details of the design mix are given in Table-8.

Table-8. Mix proportion for SCC.

Particulars	Quantity (kg/m^3)
Cement	531.05
Fine aggregate	702.61
Coarse aggregate	360.67
Super plasticizer (lt/m^3)	13.42
Viscosity modifying agent (lt/m^3)	4

RESULTS AND DISCUSSIONS

Test result on the effect of silica fume with kiln ash as a mineral admixture in the fresh and hardened properties of SCC by replacing 2.00 to 14.00 % of cement by kiln ash with silica fume, quarry dust by 5.00 to 25.00% of fine aggregates, steel fibres 2.00 to 30.00 % of coarse aggregates in various proportions and superplasticizer with viscosity modifying agent by adding 0.8% of water are discussed in following tables.

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Table-9. Test result on fresh concrete.

Identification	Replacement details %				Tests on fresh concrete					
	Ka	Sf	Qd	Sfb	Orimet	L-box	V-funnel	Slump flow	U-box	J-ring
SCC 1	4.00	6.00	25.0	16.0	2.1	2	13	700	14.5	5.4
SCC 2	4.00	7.00	25.0	17.0	2.1	2	13	700	14.1	5.1
SCC 3	4.00	8.00	25.0	18.0	2.1	2	13	700	14.1	5.1
SCC 4	4.00	9.00	25.0	19.0	2.1	2	16	694	14.1	5.1
SCC 5	4.00	10.0	25.0	20.0	2.1	2	16	694	14.1	5.1
SCC 6	5.00	1.00	25.0	21.0	2.1	2	16	694	14.1	5.1
SCC 7	5.00	2.00	25.0	22.0	2.1	1.8	16	694	13.7	5.1
SCC 8	5.00	3.00	25.0	23.0	2.1	1.8	16	694	13.7	4.8
SCC 9	5.00	4.00	25.0	24.0	2.1	1.8	16	688	13.7	4.8
SCC 10	5.00	5.00	25.0	25.0	2.1	1.8	18	688	13.7	4.8
SCC 11	5.00	6.00	25.0	26.0	2.1	1.8	18	688	13.5	4.8
SCC 12	6.00	1.00	25.0	27.0	2.2	1.5	18	685	13.5	4.8
SCC 13	6.00	2.00	25.0	28.0	2.2	1.5	18	685	13.5	4.5

Six standard cubes each for various percentages were tested to determine the 7- day, 21- day and 28- day compressive strength and results are given in Table-10. Graphs below shows the variation of cube compressive strength with various replacements of admixtures. It was found that the 7-day, 21- day and 28-day cube compressive strength increased with increase in various percentages of admixtures. More than 14% replacement of cement by kiln ash with silica fume showed very significant reduction in the compressive strength. Three cylinder samples were cast with different percentages of rock dust with steel fibres and tested to determine the 28-day cylinder compressive strength. The 28-day cylinder compressive strength decreased for all the mixes with increase in content of limestone powder with silica fume. Split tensile strength also decreased as the percentage replacement of cement with limestone powder increased and results are given in Table-10.

Table-10. Test results on hardened concrete.

Identification	Cube strength (N/mm^2)			Cylinder strength (N/mm^2)		
	7 Days	21 Days	28 Days	7 Days	21 Days	28 Days
SCC 1	21.68	43.37	46.2	4.23	5.1	5.7
SCC 2	22.64	43.44	48.2	4.37	5.3	5.9
SCC 3	24.16	43.57	47	4.38	5.49	5.88
SCC 4	24.79	43.64	47.43	4.48	5.59	5.95
SCC 5	24.81	43.66	49.8	4.55	5.66	6.5
SCC 6	24.78	42.55	48.6	4.58	5.76	6.17
SCC 7	24.7	42.55	47.06	4.50	5.7	6.13
SCC 8	24.69	42.53	46.43	4.453	5.68	6.03
SCC 9	24.66	42.32	46.26	4.36	5.65	5.94
SCC 10	24.62	41.87	45.83	4.30	5.62	5.87
SCC 11	24.59	41.76	45.13	4.27	5.58	5.80
SCC 12	24.2	40.3	42.3667	4.13666667	5.456666667	6.2
SCC 13	23.12	38.1	41.9667	4.02666667	5.2	6

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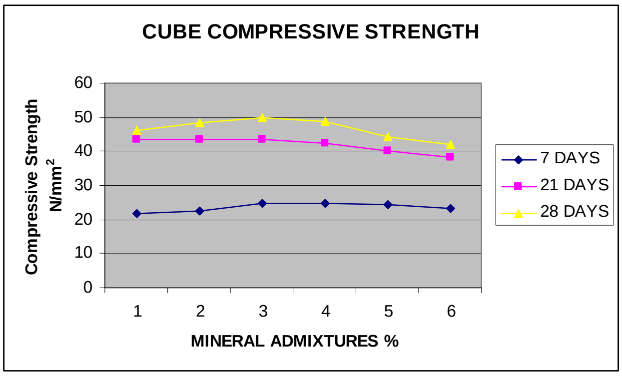

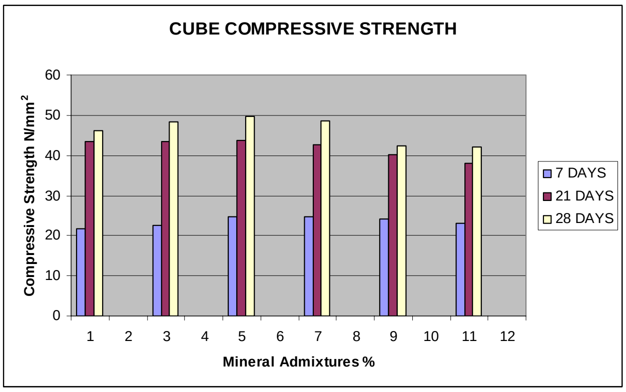

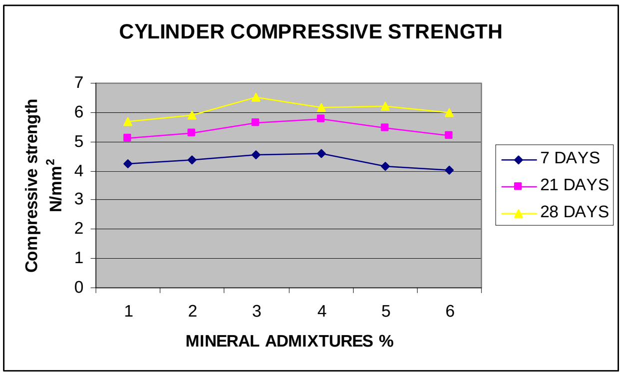

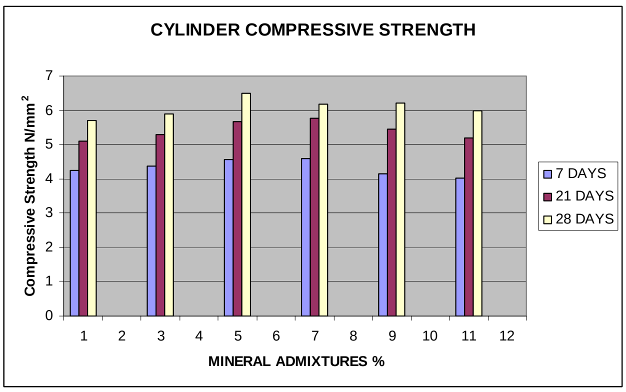

CONCLUSIONS

From the experimental investigation, it was observed that both admixtures affected the workability of SCC adversely. A maximum of 14% of kiln ash with silica fume, 25% of quarry dust and 20 % of steel fibres was able to be used as a mineral admixture without affecting the self-compactability. Silica fume was observed to improve the mechanical properties of SCC, while kiln ash along with quarry dust affected mechanical properties of SCC adversely.

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