DEVELOPMENT OF HIGH STRENGTH SELF-COMPACTED SELF-CURING CONCRETE WITH MINERAL ADMIXTURES

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Abstract

Conventional concrete is the most widely used construction material throughout the world because of its versality, mouldability, durability, and resistance to fire and energy efficiency. However, its major disadvantages like poor tensile strength, limited ductility and little resistance to cracking resists its use as a structural material. Hence, in order to overcome these difficulties several new materials have been developed in the recent past. Admixtures are ingredients other than water, aggregates, hydraulic cement and fibers that are added to the concrete batch immediately before or during mixing. Mineral admixtures are usually added to concrete in larger amounts to enhance the workability of fresh concrete; to improve resistance of concrete to thermal cracking, alkali-aggregate expansion and sulphate attack and to enable a reduction in cement content. The objective of this study is to evaluate the effectiveness of various percentages of mineral admixtures in producing SCC. In this study, the effect of replacing the cement, coarse aggregate and fine aggregate by limestone powder (LP) with silica fume, quarry dust and clinkers respectively and their combinations of various proportions on the properties of SCC has been compared. The use of SF in Concrete signi◦cantly increased the dosage of superplasticiser (SP). At the same constant SP dosage (0 8%) and mineral additives content (30%), LP 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 LP combinations can improve the workability of SCCs, more than QD, SF and LP alone.

Keywords: Self-compacting Concrete; limestone powder; Silica Fume; Quarry Dust; Clinkers

I. INTRODUCTION

Self-Compacting Concrete (SCC) is the concrete that can be compacted into every corner of the formwork by means of its self-weight only. SCC was developed by Professor Okamura in 1986 for the first time in the world and has been spread to all over the world as the original of Japan. Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. Self-compacting concrete (SCC) is 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 India and as a consequence it has suffered very little development with local materials.

Therefore, it is essential to have proper mix design. Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier demoulding and faster use of elements and structures. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction.

The durability of a concrete repair can depend on many factors. Those most often considered are cement reactivity with environment, low permeability, diffusion coef◦cient 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 compact structure by pore-◦lling effect. In the case of SF and FA, it also reacts with cement by binding Ca(OH)2with free silica by a pozzolanic reaction forming a non-soluble CSH structure (O'Flaherty & Mangat 1999). The main objective of the present study is to investigate a suitable combination of LP, QD ,SF and Clinkers that would improve the properties of the SCCs more than when these materials would be used separately.

II. 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 are discussed as follows:

1) 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. Results

Sl.No	Test Conducted	Result
1	Standard consistency	32%
2	Initial Setting Time	150 minutes
3	Final setting time	330 minutes
4	3 day compressive strength	27.67 N/nm^2
5	7 day compressive strength	39.93 N/nm^2
6	28 day compressive strength	54.60 N/nm^2

2) 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. Fine aggregate Particle Size Distribution

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

3) 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.

Table 3. Coarse aggregate Particle Size Distribution

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..1	69.99
4.75	Pan	90.45	9.55

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

4) Water: Ordinary potable water available in the laboratory was used.

5) 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

6) Lime stone powder: A high quality lime stone powder generally permits a reduction in water content of a concrete mixture, without loss of workability.

Lime stone powder obtained from India's cement Limited, Tirunelveli was used for the study. The chemical composition of lime stone powder is given in Table 4.

Table 4. Chemical composition of Lime stone powder

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..1	69.99
4.75	Pan	90.45	9.55

7) 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.

Table 5. Chemical composition of Rock dust

Sl.No	Constituents	Quantity (%)
1	Silica(SIO_2)	70.74
2	Aluminum Dioxide (Ai_2O_3)	20.67
3	Ferric Oxide(Fe_2O_3)	2.88
4	Titanium Dioxide (TiO_2)	0.33
5	Sodium Oxide (Na_2O)	0.11
6	Potassium Oxide (K_2O)	0.19
7	Magnesium Oxide (MgO)	1.57
8	Manganese Dioxide (MnO_2)	0.01
9	Calcium Oxide (CaO)	0.2
10	(Zinc Oxide (ZnO)	0.01
11	Lead (Pb)	625ppm
12	Chromium (Cr)	125ppm
13	Loss on Ignition (LOI)	0.72

8) 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 helps 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.

III. 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

Table 6. Chemical composition of Silica fume

Sl.No	Constituents	Quantity (%)
1	Silica(SIO_2)	91.03
2	Aluminum Dioxide (Ai_2O_3)	0.39
3	Ferric Oxide(Fe_2O_3)	2.11
4	Calcium Oxide (CaO)	1.5
5	Loss on Ignition (LOI)	4.05

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

Sl.No	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump-flow	Mm	650	800
2	T_{50} slump flow	sec	2	5
3	J-ring	mm	0	10
4	V-funner	sec	6	12
5	V-Funnel at T_5 minutes	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	15

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

IV. RESULTS AND DISCUSSION

Test result on the effect of silica fume with lime stone powder as a mineral admixture in the fresh and hardened properties of SCC by replacing 2.00 to 14.00 % of cement, quarry dust by 5.00 to 45.00% of fine aggregates, Clinkers 2.00 to 20.00 % of coarse aggregates in various proportions and superplasticizer with Viscosity Modifying Agent by adding 0.8% of water are discussed in following tables.

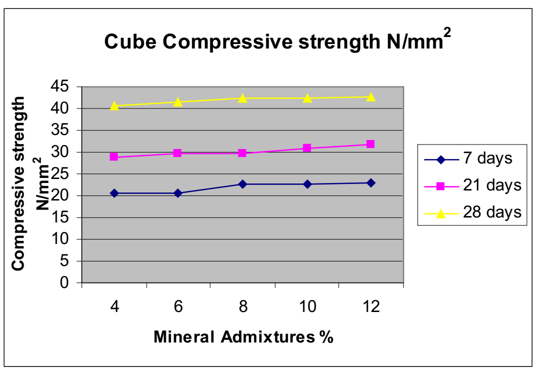
Six standard cubes each for various percentages were tested to determine the 7- day, 21- day and 28- day compressive strength and results are given in Table 10. Figure.1(a-d) below shows the variation of cube compressive strength with various replacements of admixtures. It was found that the 7-day, 21- day and 28-day cube compressive strength increased with increase in various percentages of admixtures. More than 8% replacement of cement by lime stone powder with silica fume showed very significant reduction in the compressive strength. Three cylinder samples were cast with different percentages of rock dust with clinkers 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 9. Test Result on Fresh Concrete

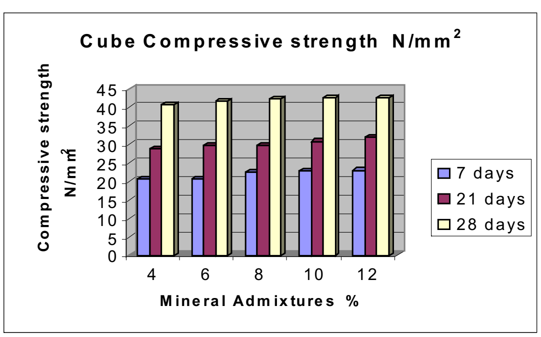
Identification	Replacement details %				Tests on fresh concrete					
	LP	SF	QD	CL	Orimet	L Box	V Funnel	Slump Flow	U Box	J Ring
SCC 1	2.00	1.00	5.00	2.00	4.7	0.80	7.2	650	30	10
SCC 2	2.00	2.00	10.0	4.00	4.3	0.82	7.4	656	26	9.8
SCC 3	3.00	3.00	15.0	6.00	4.1	0.82	7.5	658	24	9.6
SCC 4	4.00	4.00	20.0	8.00	3.9	0.84	7.5	664	21	9.5
SCC 5	5.00	5.00	25.0	10.0	3.8	0.85	7.7	668	20	9.3
SCC 6	6.00	6.00	25.0	12.0	3.6	0.87	7.8	672	18	9.1
SCC 7	7.00	1.00	30.0	14.0	3.1	0.88	7.9	675	16	9.0
SCC 8	8.00	2.00	35.0	16.0	3.1	0.88	8.1	682	15	8.8
SCC 9	9.00	3.00	40.0	18.0	2.9	0.92	8.3	688	12	8.5
SCC 10	10.0	4.00	45.0	20.0	2.8	0.94	8.4	696	10	8.4

Table 10. Test Result on Hardened Concrete

Identification	Cube Strength (N/mm²)			Cylinder Test (N/mm²)		
	7 Days	21 Days	28 Days	7 Days	21 Days	28 Days
SCC 1	20.5	28.8	40.7	2.4	3.5	4.3
SCC 2	20.7	29.6	41.6	2.6	3.75	4.5
SCC 3	22.6	29.8	42.3	2.7	3.82	4.6
SCC 4	22.7	30.8	42.5	2.9	3.9	4.68
SCC 5	23.0	31.8	42.6	3.1	3.94	4.74
SCC 6	23.4	33.2	43.7	3.3	4.1	4.81
SCC 7	24.0	34.7	45.0	3.4	4.2	4.92
SCC 8	23.8	34.5	44.7	3.1	4.0	4.72
SCC 9	23.6	34.1	44.3	3.0	3.7	4.61
SCC 10	23.1	34.0	44.0	2.8	3.5	4.58



(a)



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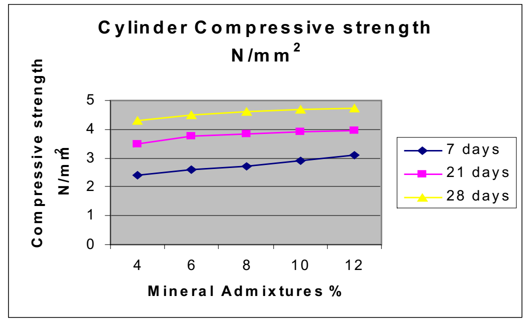

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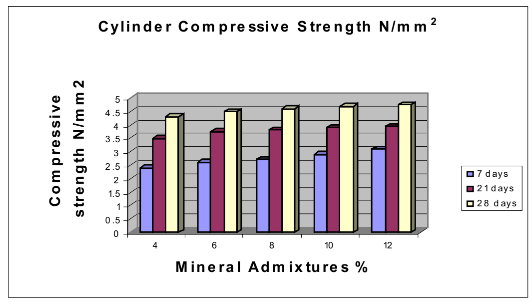

(d)

Fig.1.(a,b,c & d) Cube/Cylinder Compressive Strength of SCC with various admixtures

V. CONCLUSION

From the experimental investigation, it was observed that both admixtures affected the workability of SCC adversely. A maximum of 8% of lime stone powder with silica fume, 30% of quarry dust and 14 % of clinkers 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 lime stone powder along with quarry dust affected mechanical properties of SCC adversely.

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