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INVESTIGATIONS ON SELF-COMPACTED SELF-CURING CONCRETE USING LIMESTONE POWDER AND CLINKERS

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ABSTRACT

Self-Compacting concrete is a type of concrete that gets compacted under its self-weight. It's commonly abbreviated as SCC and defined as the concrete which can placed and compacted into every corner of a formwork; purely means of it's self-weight by eliminating the need of either external energy input from vibrators or any type of compacting effort. Self compactability and stability are susceptible to ternary effects of chemical and mineral admixture type and their content. 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. Fresh properties, flexural and compressive strengths and water absorption properties of 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%), 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. LP 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 LP 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

The use of self-compacting concrete (SCC) is spreading world wide because of its very attractive properties in the fresh state as well as after hardening. The use of SCC will lead to a more industrialized production, reduce the technical costs of in situ concrete constructions, improve the quality, durability and reliability of concrete structures and eliminate some of the potential for human error. It will replace manual compaction of fresh concrete with a modern semi-automatic placing technology and in that way improve health and safety on and around the construction site. However, this type of concrete needs a more advanced mix design than traditional vibrated concrete and a more careful quality assurance with more testing and checking, at least in the beginning, when using SCC. It is possible to improve the mechanical properties of concrete by using chemical, mineral, polymer and fibre additives. For instance, producing of SCCs with the use of chemical additives, decreasing shrinkage and permeability and using mineral additives increased compressive strength. As it is well known, there are a wide range of cementitious mortars based on cement and components similar to those of concrete. 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 lime stone powder), 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 LP, 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) $_{2with}$ free silica by a pozzolanic reaction forming a non-soluble CSH structure (O'Flaherty and 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.

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 materials 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.

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.

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.

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.

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.

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.

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

Table-2. Sieve analysis of fine aggregate.

Passing through IS sieve (mm)	**Retained on IS seive** (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

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

Table-4. Chemical composition of lime stone powder.

S. No.	Constituents	Quantity (%)
1	CAO	52·35
2	SiO_2	0·45
3	Al_2O_3	0·33
4	Fe_2O_3	0·14
5	MgO	1·05
6	Na_2O	0·06
7	K_2O	0·02
8	SO_3	52·35
9	Cl	0·45

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 INVESTIGATIONS

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:

- Slump flow test
- V- funnel flow test
- Orimet test
- U-tube test
- J- Ring test
- 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.

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-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 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	5

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 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.

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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

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 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-10. Test result on hardened concrete.

Identification	Cube strength (N/mm^2)			Cylinder test (N/mm^2)		
	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

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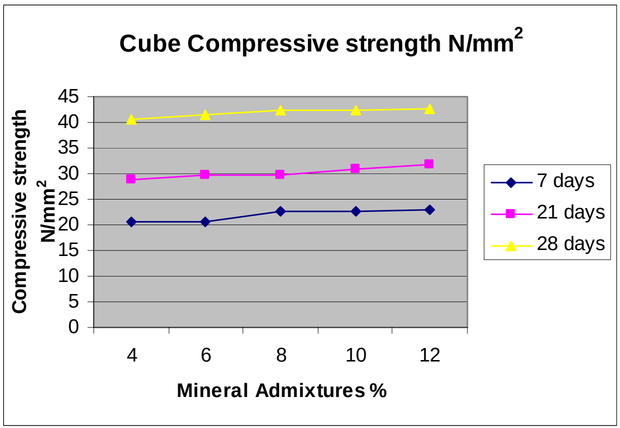

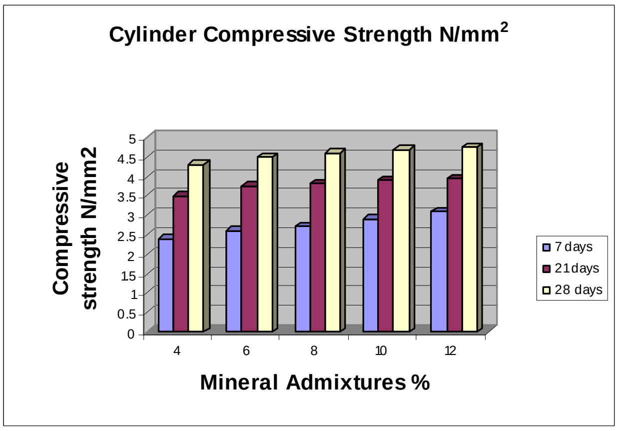

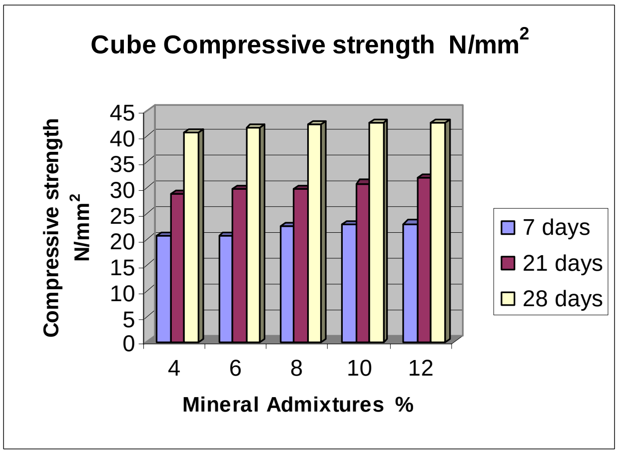

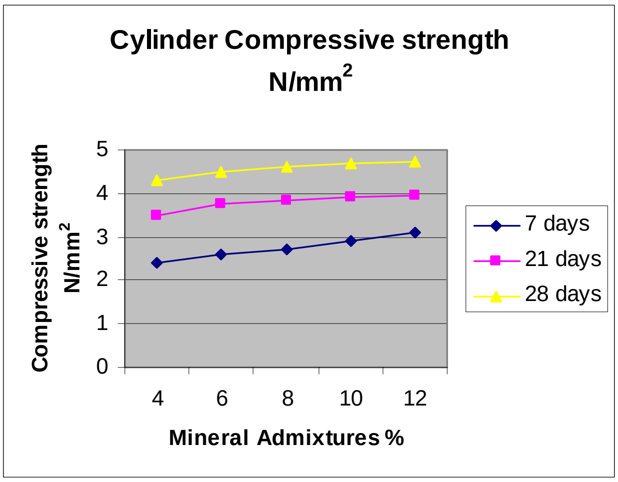

CONCLUSIONS

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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