EXPERIMENTAL STUDY ON PERFORMANCE OF SCC CONTAINING STONE DUST AND MINERAL ADMIXTURE

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ABSTRACT. The high flowability of self-compacting concrete (SCC) demands use of more fines aggregates and less coarse aggregate content. Sand content balances the volumes of other constituents. Sand ratio (ratio of fine aggregate to total aggregate, S/A) is an important parameter to decide the rheological properties of self-compacting concrete. Therefore present investigation was planned to develop different grades of SCC varying from M20 to M50 with high volume of sand content using superplasticiser and viscosity modifying agent. Concrete was tested to qualify the fresh properties of SCC by conducting horizontal slump flow test fabricated in accordance with EFNARC recommendations. Effect of replacement of 15%, 25%, 35%, 45% and 50% of sand with stone dust on the performance of various mixes was studied. Also, effect of replacement of 10%, 20%, 30% and 40% of cement with fly ash as mineral admixture on the fresh and mechanical properties of SCC was studied. It has been observed from the study that it is possible to develop SCC of various grades even at higher fine aggregate to total aggregate ratio (S/A) of 0.57 with the help of superplasticiser and VMA. The combination of SCC mix with 45% sand replacement with stone dust and 20% cement replacement with fly ash has resulted significance improvement in all fresh properties test and also shown maximum gain of 28.57% in compressive strength at the age of 28 days when compared with plain SCC mixes without stone dust and fly ash replacement.

Keywords: Self-compacting Concrete, Stone Dust, Fly ash.

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INTRODUCTION

In India developing SCC on mass scale using silica fume, blast furnace Slag and metakaolin are not economical due to enhanced cost of procurement of these supplementary mineral admixture. Belite cement which was initially used in Japan for SCC is still in its beginning stage in India and again costly being exclusively imported material [13-16]. The only cement widely used across the country is ordinary portland cement. Recently cost of sand has also increased manifold. On this score, for checking the heat of hydration in SCC development and to counter the price rise of basic concrete making material in the country other means too needs to be identified. This situation compel towards the use of more extra fine material i.e. high percentage of fly ash as replacement of cement and high percentage of stone dust as replacement of sand, which serves two purposes. One is to keep the heat liberation in SCC under control with OPC and other to utilise the waste to minimise environmental pollution.

General Requirements of SCC in Deciding Mix Proportions

In designing SCC mix it requires some specific considerations for mix proportioning to achieve the desired rheological properties. SCC mix should be designed for a combination like filling ability, resistance to segregation, and ability to pass through and around congested reinforcement without blockage.

In the design of SCC mix, the relative proportions of key ingredients may be considered by volume rather than by mass. A high content of fine materials and superplasticiser are necessary to achieve self-compacting properties [11]. The mix should have sufficient flowability along with adequate stability. Okamura and Ozawa [16] have proposed a mix proportioning system in which coarse aggregate and fine aggregate contents are fixed and self-compatibility is to be achieved by adjusting the water/powder ratio and superplasticiser dosage. Some common aspects of SCC mixture proportioning methods are as follows:

- Water content: 170 to 176 kg/m3 Su et al. [17]. It should not exceed 200 kg/m3 as per EFNARC guidelines [2,3].
- Cement content: 350 to 450 kg/m3 [2]
- Total powder content (i.e., cement + filler): 400 to 600 kg/m3 [2],
- Dosage of superplasticiser: 1.8% of the total powder content (by mass). However, the recommended dosage varies from product to product [17]
- Water/powder ratio: 0.80 to 1.10 (by volume) [2]. A water/powder ratio in the range of 0.30 to 0.38 (by mass) for tropical Middle East conditions [12, 4].
- Coarse aggregate content: 28 to 35% by volume of the mix, i.e., 700 to 900 kg/m3 of concrete [2, 3].
- The sand content balances the volume of other constituents. The sand content should be greater than 50% of the total aggregate content [12, 4].Sand ratio (i.e. volume ratio of fine aggregate to total aggregate) is an important parameter in SCC and the rheological properties increase with an increase in sand ratio. Sand ratio should be taken in the range of 50 to 57% and
- The aggregate packing factor: 1.12 to 1.16 [17].

Adjustment of SCC Mixes

Laboratory trials should be used to verify properties of the initial mix composition. If necessary, adjustment to the mix compaction should be made. Once all requirements of SCC are fulfilled, the mix should be tested at full scale at the concrete plant or at site. In the event that satisfactory performance cannot be obtained, then consideration should be given to fundamental redesign of the mix. Depending upon the apparent problem, the following course of action might be appropriate.

- Using additional or different types of filler, if available.
- Modifying the proportions of the sand or coarse aggregate.
- Adjusting the dosage of superplasticiser and the viscosity modifying agent.
- Using alternative type of superplasticiser and VMA, more compatible with local materials.

RESEARCH SIGNIFICANCE

The significant studies on using high volume stone dust as replacement of normal sand in development of various grades of SCC are rarely reported in India. Therefore the present work has been planned to explore the use of stone dust a waste material in the development of SCC along with fly ash and study its performance in fresh and hardened stage. It is expected that the finding of the proposed research programme will help in understanding the performance of SCC under different conditions and explore the use of SCC containing stone dust and mineral admixture in construction industry.

EXPERIMENTAL PROGRAMME

Design of SCC Mix Proportions

The present study employed an iteration approach to develop specific SCC mixes. The initial mix composition for ordinary M20, M25, M30, M35, M40, M45 and M50 grades were arrived in accordance with IS 10262-1982 and SP23-1983 assuming compacting factor equal to 1. The new information given in IS:456-2000 has also been incorporated. The mix proportioning of normal concrete so obtained are presented in Table 5 and are modified for SCC in the following Phases:

Phase -1. Increasing the percentage of fine aggregate by absolute volume method.

Phase -2. By replacing the increased sand content with Stone dust

Phase -3. By partial replacement of cement with fly ash.

- In each phase, water content obtained was kept constant as obtained in conventional mix design of concrete and should not exceed 210 liters/m^3.
- Optimum dosage of superplasticiser is arrived through marsh cone test and mortar flow test.
- The dosage of VMA is fixed through trial mix to adjust the rheology of mix.
- In each phase all the mixes were tested to full fill the requirements of SCC i.e. slump flow test, J ring test, U- box test, V-funnel test and L-box test. But results are reported here only for horizontal slum flow test.

- If slight bleeding is observed in the test, then a marginal increase in fine aggregate content may be made and further trials may be performed. If the bleeding still persists, then dosage of superplasticiser may be slightly decreased.
- The coarse aggregate content is reduced by increasing the fine aggregate by absolute volume method.
- Even though the mix proportion have been arrived at, trial mixes are necessary to fine tune the dosage of the superplasticiser and VMA and also to identify and correct any problems in the rheological behaviour of SCC mix taking in to consideration the demands of the projects.
- Once SCC of desired strength has achieved, the effect of varying percentages of replacement of sand with crusher stone dust was carried out in 2^{nd} phase of study up to the optimization level.
- In 3^{rd} phase efforts were made to develop SCC with the less content of cement by the replacement of cement with fly ash up to the optimization level.
- The criteria for adjudging the performance of SCC in 2^{nd} and 3^{rd} phase was to qualify minimum horizontal slump of at least 600mm along with other tests and to attain the desired minimum compressive strength at the age of 28days curing for respective grades.

The qualified control SCC mixes so obtained containing optimised stone dust are shown in Table 6.

MATERIAL USED

Cement

Ordinary Portland cement (OPC) of 43 grade confirming to IS: 8112-1989 was used for all the mixes. It was fresh and without any lumps. The cement was tested as per IS: 4031-1988 and test results are given in Table 1 along with the reference value of the physical properties of the cement confirming to Indian standard IS: 8112-1989.

Aggregates

Locally available river sand was used as fine aggregate and crushed stone aggregates of maximum nominal sizes of 10mm and 20mm in proportion of 50:50 were used as coarse aggregates in the study. The aggregates were obtained from crusher at Burj Kotian near Chandimandir, Panchkula in Haryana. Aggregates were then washed to remove dust, dirt and then dried to surface dry condition The particle size physical properties of river sand and coarse aggregates are presented in Table 2.

Table 1 Physical properties of cement used

PHYSICAL PROPERTY TESTED	UNIT	OBSERVED VALUE	IS:8112-1989 SPECIFICATION
Specific Gravity	-	3.14	-
Soundness (Le Chatelier test)	Mm	2.3	10 (maximum)
Fineness (retained on 90-μm sieve	Mm	7.5	10mm
Normal Consistency(% of cement by weight)	%	28%	-
Setting Times			
Initial setting time	minutes	85	30 (minimum)
Final setting time		205	60 (maximum)
Compressive strength			
3-days		25.4	23.0 (minimum)
7-days	Mpa	35.40	33.0 (minimum)
28-days		45.2	43.0 (minimum)

Table 2 Physical properties of coarse and fine aggregates

CHARACTERISTICS	RESULTS OBTAINED	
	COARSE AGGREGATE	FINE AGGREGATE
Grading Zone	---	Grading Zone III (IS: 383-1970)
Fineness Modulus	6.52	2.12
Specific Gravity	2.66	2.62
Water Absorption (%)	0.6%	0.8 %
Free surface moisture Content (%)	0.0%	0.0 %

Stone Dust

Aggregate crushers produce significant amounts of crusher dust during the process of producing of 20-10 mm nominal size aggregate, normally known as stone dust. Utilization of this stone dust, a waste material has not been made in concrete. The reason for this is the greater specific surface area and the associated increase in the water demand of concrete. However, with the availability of high range water reducers i.e. Superplasticiser, the increase water demand of the crusher dust can be accommodated without increasing water cement ratio. In the development of SCC stone dust is procured from Burj Kotian near Chandimandir, Panchkula in Haryana, locally situated stone crushers. It is then washed, dried and sieved with 150 micron sieve. The specific gravity of stone dust was found to be 2.50.

Fly Ash

Fly ash used in the present study was procured from Guru Gobind Singh Thermal Power Plant, Ropar, Punjab. The physical and chemical properties of fly ash used satisfied the requirement of IS: 3812-2003 and ASTMC-618 and are given in Table 3.

Table 3 Physical properties of fly ash

CHARACTERISTICS	TEST RESULTS
Color	Grey
Specific gravity	2.05
Surface area(cm^2/gm) (by Blaine's air permeability method)	4680
Lime Reactivity- average compressive strength obtained at the age of 7 days (MPa)	5.98
Bulk density (kg/m^3)	1000
Compressive strength at 28 days as percent of strength of corresponding plain cement mortar concrete	90.95
% particle retained on 45 micron IS: Sieve (wet sieving)	19.8
Soundness by Autoclave test expansion of Specimen in percent	0.5
CHEMICAL PROPERTIES (%AGE BY MASS)	
Silica(SiO_2)	56.32
Alumina (Al_2O_3)	30.87
Iron Oxide (Fe_2O_2)	4.94
Calcium Oxide (CaO)	1.58
Magnesium Oxide (MgO)	0.70
Loss on Ignition(% by mass)	4.55
Reactive silica	22.4
Total sulphur SO_3)	0.41
Available alkalies (as Na_2O)	0.6

Superplasticiser

Different bases of new generation Superplasticiser or high range water reducing agents (HRWRA) have different water reduction capabilities. The advantages of this water reduction can be taken either to increase the strength as in high strength concrete or to obtain a better flowability as in case of self-compacting concrete (SCC). The mechanism of action varies, depending upon individual bases. The major mechanism is absorption of superplasticiser by the cement particles, which leads to electrostatic repulsion.

In the present study Modified Polycarboxylate Ether (PCE) based superplasticiser which has been developed for the production of SCC, pumped concrete, high performance concrete obtained from “SIKA Chemicals Pvt. Ltd. were used. Different properties of used superplasticiser are listed in Table 4.

Viscosity Modifying Agent (VMA)

Admixtures that modify the cohesion of SCC without significantly altering its fluidity are called viscosity-modifying agents (VMA). These admixture are used in SCC to minimize the effect of variations in moisture content, ensures the homogeneity reduces the tendency of variation of highly fluid mix to segregate. The properties of VMA used in the present study are listed in Table 4.

Table 4 Properties of superplasticiser and viscosity modifying agent

CHARACTERISTICS	SUPERPLASTICISER	VMA
Type	Modified Polycarboxylate	Polymer solution
Color	Light Yellowish	Colorless liquid
Specific gravity at 30°C	1.08 ± 0.01	-
Density	-	1.0 kg/Ltr

Water

Tap water as available in the laboratory which was fit for drinking was used for developing various mixes of concrete.

Table 5 Mix Proportions for Normal Concrete as per IS Code Method

GRADE	WATER (litres)	CEMENT (kg)	FA (kg)	CA (kg)	SAND CONTENT BY ABSOLUTE VOLUME (%)	FA/P
M20	208.95	358.55	564.77	1193.29	32.5	1.575
M25	208.5	428.69	515.66	1184.18	30	1.202
M30	208.2	469.52	494.0	1171.00	30	1.053
M35	208.2	480.97	490.92	1165.32	30	1.021
M40	200.67	530.00	403.11	1230.30	25	0.761
M45	201.39	545.00	400.07	1220.630	25	0.734
M50	201.30	561.18	396.66	1210.59	25	0.707

Mix designation are represented by S#F*Qx, where ‘S’ stand for SCC, ‘#’ represent different replacement level of stone dust with fine aggregate, ‘F’ stands for fly ash, ‘*’ represent different replacement level of fly ash with cement, ‘Q’ represents type of SCC mix selected from trials mixes for further study and ‘x’ stands for grade of concrete i.e. M20, M30, M50 etc. The results obtained for fresh and hardened properties are presented and explained under results and analysis.

At each replacement level of fine aggregate with stone dust, fresh properties of SCC were measured. It was observed from the fresh properties that the horizontal slump flow for all the mixes increased up to 45 percent replacement level of fine aggregate with stone dust but decreased with further increase to 50%. Similarly there was significance increase in compressive strength at age of 28 days up to 45% replacement level of fine aggregate with stone dust for all SCC mixes but no further increase was observed to 50 %. Therefore the mixes presented in Table 8 containing content of stone dust @ 45% and fulfilling the fresh properties of SCC and having maximum compressive strength were used for further investigation by replacing cement content with different percentage (10%, 20%, 30% and 40%) of fly ash keeping coarse aggregate content, total fine aggregate (fine aggregate + stone dust), water content, dosage of superplasticiser and VMA constant.

Table 6 Composition of Control SCC Mixes without Stone Dust and Fly Ash

SCC MIX	CEMENT, kg/m^3	FA kg/m^3	CA, kg/m^3	WATER, $Litres/m^3$	SP, Lit.	VMA, Lit.	FA/A Ratio	FA/P Ratio	W/P Ratio
S0F0M20	358.55	1007.8	742.49	209.8	5.91	1.79	57.57	2.810	0.585
S0F0M25	428.69	940.63	751.86	209.32	6.24	2.14	55.57	2.273	0.488
S0F0M30	469.52	888.79	770.23	209.0	6.86	2.34	53.57	1.895	0.445
S0F0M35	480.97	883.65	765.78	208.94	7.09	2.4	53.57	1.769	0.434
S0F0M40	530.00	838.48	787.38	202.31	7.76	2.65	51.57	1.582	0.382
S0F0M45	545.00	831.90	781.20	202.21	7.72	2.72	51.57	1.526	0.371
S0F0M50	561.17	793.32	807.08	202.07	7.98	2.8	49.57	1.414	0.360

Where, W/P= Total water to powder (cement + fly ash) ratio, FA/P=total fines (sand +stone dust) to total aggregate ratio

Table 7 Composition of SCC mixes containing optimised stone dust i.e. @ 45% stone dust

SCC MIX	CEMENT, kg/m^3	FA, (kg/m^3)		CA, kg/m^3	WATER, $LITRES/m^3$	SP, Lit.	VMA, Lit.	FA/A Ratio
		SAND	STONE DUST					
S45F0M20	358.55	564.36	443.43	742.49	209.8	5.91	1.79	57.57
S45F0M25	428.69	526.76	413.87	751.86	209.32	6.24	2.14	55.57
S45F0M30	469.52	497.73	391.06	770.23	209.0	6.86	2.34	53.57
S45F0M35	480.97	495.00	388.65	765.78	208.94	7.09	2.4	53.57
S45F0M40	530.00	469.55	368.93	787.38	202.31	7.76	2.65	51.57
S45F0M45	545.00	465.87	366.03	781.20	202.21	7.72	2.72	51.57
S45F0M50	561.17	444.26	349.06	807.08	202.07	7.98	2.8	49.57

RESULTS AND DISCUSSION

Effect of Stone Dust and Fly Ash on Slump Flow of SCC

Slump flow test is suitable to assess the horizontal free flow of SCC in the absence of obstructions. The slump flow test results for replacement of varying percentage of fine aggregate with stone dust are shown in figure 1.

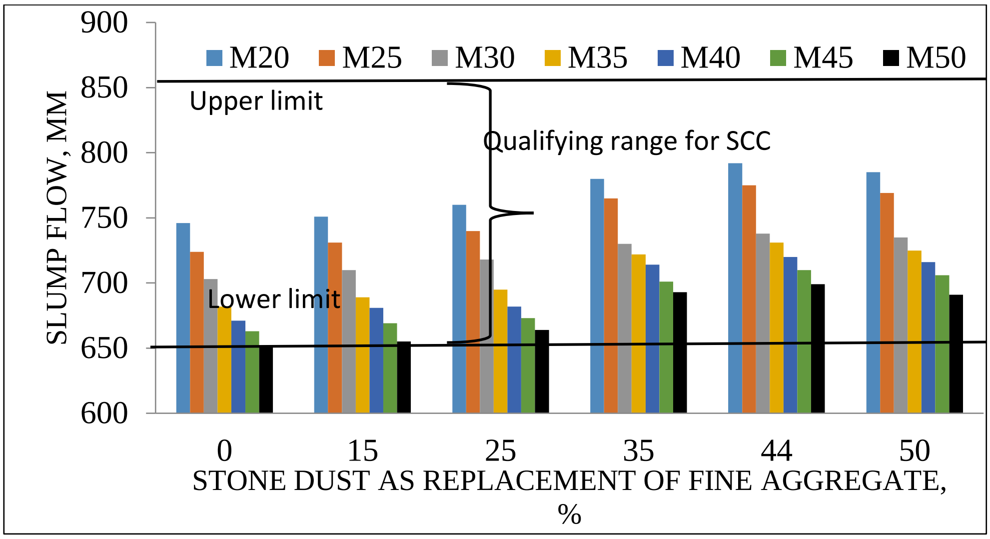


Figure 1 Effect of stone dust on horizontal slump flow of SCC

The value of slump flow for all the mixes were found to be in the range of SCC specified by various researchers [5-10,18]. An average increase of 45mm was measured over the plain SCC mixes for all the grades containing stone dust. It is observed from the test results that horizontal slump flow value has increased with the increase in stone dust replacement level up to 45% and decreased with the further increase in stone dust to 50%.

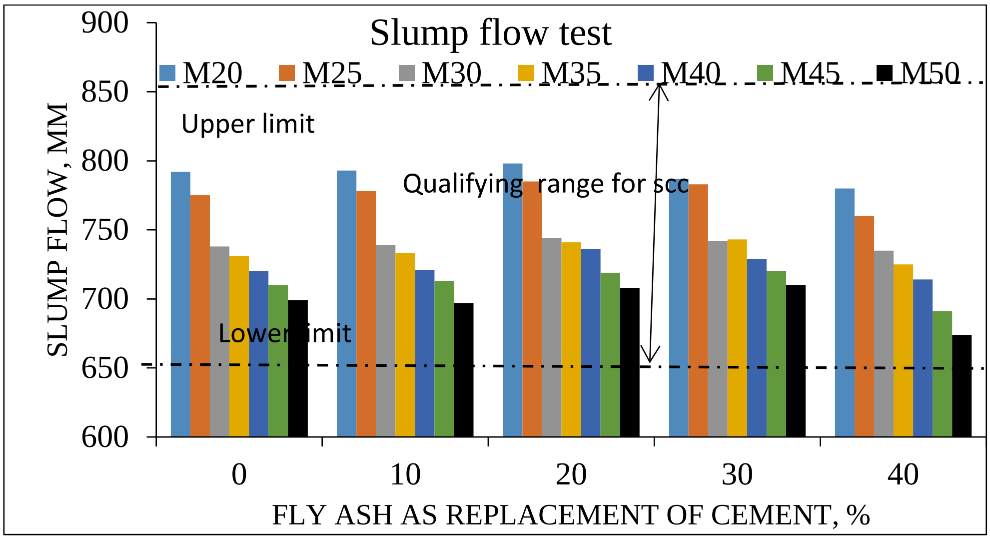


Figure 2 Effect of fly ash on the slump flow properties of SCC

Similarly slump flow for mixes containing 45% stone dust and varying percentage of replacement of 0%, 10%, 20%, 30% and 40% cement with fly ash are presented in figure 2 for various grades of SCC. It is found that the slump flow value has an average increase of 9.4mm for SCC mixes containing 20% fly ash and 45% stone dust replacement level over SCC @0% fly ash, whereas in comparison with plain SCC mixes without stone dust the overall average increase has reached to 55.57mm. This may be due to the fact that fly ash being lighter in weight, which in turn producing increased lubricating effect on the ingredients of concrete and helps in achieving a free flowing concrete with closer packing of particles. Fly ash also reduces the heat of hydration and loss of water during chemical reaction of cement, which results in increased workability. Apart from this, fly ash also acts as a dispersing agent for cement coated water particles. It releases the water entrapped between various cement particles, hence making that water available for increasing workability of SCC mix.

With further increase in cement replacement from 20% to 30% and 40% with fly ash, a decreasing trend were observed reducing to the minimum of 670mm slump value but still the slump value for these mixes falls within the limiting criteria of 600-850mm horizontal diameter. This can be attributed to the fact that when a through mixture of cement, sand, fly ash, stone dust and water is made, the calcium ions of stone dust react with the increased amount of reactive silica of sand or alumina or both present in fly ash which consume more water and reduce the slump flow than mixes containing 20% fly ash replacement.

Although increasing trend were observed in slump flow value for all SCC mixes with stone dust replacement up to 45% and fly ash replacement level up to 20% but slump flow value for lower grades of SCC were noted higher than SCC of higher grades. For example for SCC M20 and SCC M25 grade, slump flow value were found to be 792mm and 775mm for mixes containing 45% of fines replaced with stone dust but for higher grade of SCC mixes of M30 to SCC M50, slump flow value were found to be low. Similarly horizontal slump flow value for mixes of same grade of SCC M20 and SCC M25 with 45% stone dust and 20% fly ash were noted to be 798mm, and 785mm respectively which is on higher side of limiting range of qualifying criteria for SCC whereas, for higher grade of SCC M30 to SCC M50, slump value were noted to be at lower side of qualifying criteria for SCC.

Mechanical Performance

Phase-1 of the study which resulted in optimization of ingredient for arrival of various grades of SCC on the basis of 28days compressive strength and simultaneously qualifying for 600mm slump flow as per EFNARC guidelines [2,3]. Specimens of phase-2 and phase-3 of the experimentation were tested for the mechanical performance of SCC mixes containing varying percentage replacement of 0%, 15%, 25%, 35%, 45% and 50 % of fine aggregate with stone dust and compressive strength, containing 45% optimized stone dust as replacement of fine aggregate and 10%, 20%, 30% and 40% partial replacement of cement with fly ash respectively and shown in Table 8.

Plain SCC developed using higher content of sand although attains the desired compressive strength at 28 day curing but at lower side. Simultaneously flowing properties were just at the passing criteria. Cohesiveness and segregation were also observed due to increase in sand content. Moreover with the use of more sand content, the compressive strength of SCC has reduced up to 31.98% and 23.81% over conventional concrete at the age of 7days and 28 days respectively.

This decrease in compressive strength was obvious with the increase in volume of fine aggregate and decrease in volume of coarse aggregate in the mix with the constant cement and water content. Use of superplasticiser and VMA not only increased workability in fresh state but also helped in maintaining the minimum desired compressive strength at different ages.

Table 8 Comparison of compressive strength of various SCC mixes

MIX	28 DAYS COMPRESSIVE STRENGTH OF CONCRETE, N/mm^2										
	NOR-MAL	PLAIN/ CONT-ROL SCC	SCC WITHOUT FLY ASH AND STONE DUST@					SCC CONTAINING STONE DUST AND ASH@			45% FLY
			15%	25%	35%	45%	50%	10%	20%	30%	40%
M20	34.40	26.21	28.22	30.49	31.18	30.42	29.19	31.03	33.70	29.99	27.99
M25	36.90	32.67	34.67	33.80	34.65	35.36	33.50	35.41	36.97	32.12	30.47
M30	46.21	39.06	40.26	40.60	43.73	45.64	46.17	48.36	46.44	40.83	36.53
M35	48.43	42.96	42.87	45.78	46.67	48.79	53.53	50.94	50.26	45.46	42.66
M40	54.52	48.85	50.32	51.56	54.44	55.56	55.50	58.56	55.84	48.97	44.42
M45	59.92	54.85	53.55	55.57	56.72	58.49	56.54	60.51	57.27	53.74	50.22
M50	68.12	60.23	61.32	63.85	64.75	65.45	63.78	65.76	62.66	59.62	57.69

Compressive Strength of SCC Mixes Containing Stone Dust

The effect of stone dust on the strength resumption was studied in the increment of 15% 25%, 35%, 45% and then at 50% as replacement of sand content. The optimum gain in flow properties was observed for 45% replacement level of stone dust for all SCC grade and for all testing ages. A maximum of 26.98% gain was observed for SCC mix containing @ 45 % stone dust. Due to increase in stone dust, the quantity of gel formation is also increased leading to an increase in strength up to some extent of sand replacement

But when 50% sand content was replaced, there was decrease in strength as compared to 45% replacement level. This decrease may be due to the fact that cement particle available at this stage becomes insufficient to utilize all the lime particles in stone dust thereby gel formation becomes insufficient to bind all the lime particle resulting decrease in strength of SCC. Also some of the stone dust fines content at this percentage act as weak filler in SCC mixture, which results in decrease in strength.

M. Rame Gowda et al [8] recommended 70% replacement of quarry dust (Granite dust) with fine aggregate without much alteration in compressive strength. Based on the results of the present study on use of stone dust, we can assume that replacing fine aggregate with stone dust is ideal at 45% without the use of fly ash.

Effect of Fine Aggregate to Total Aggregate Ratio (S/A) on Compressive Strength of Plain SCC

Figure 3 shows the relationship between compressive strength at various ages of plain SCC mixes with varying fine aggregate to total aggregate ratio. It can be concluded from the figure 3 that the compressive strength decreases with the increase in fine aggregate to total aggregate (S/A) ratio. This relationship is ideal for estimation of sand content in the development of SCC mix for desired strength of M20 to M50 grade at 28days of water curing under the scope of the study.

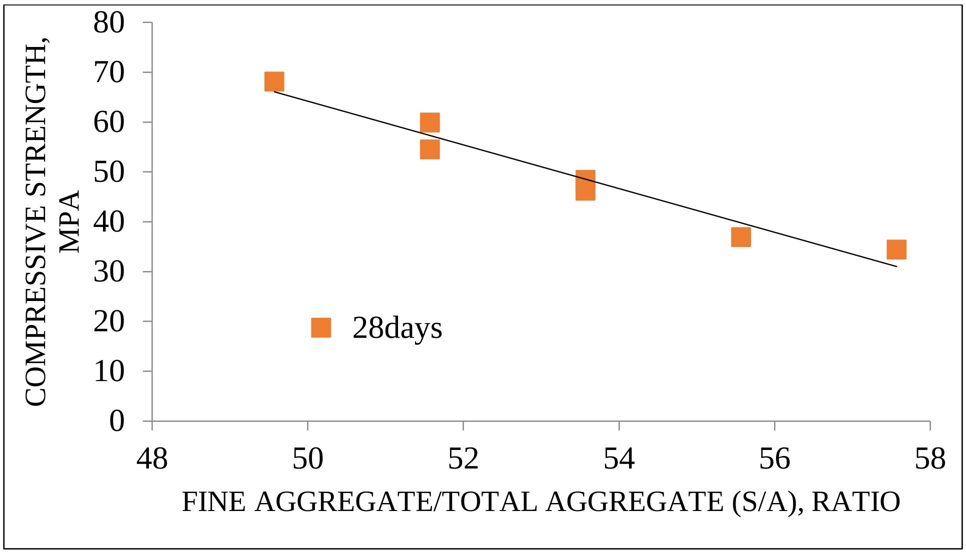
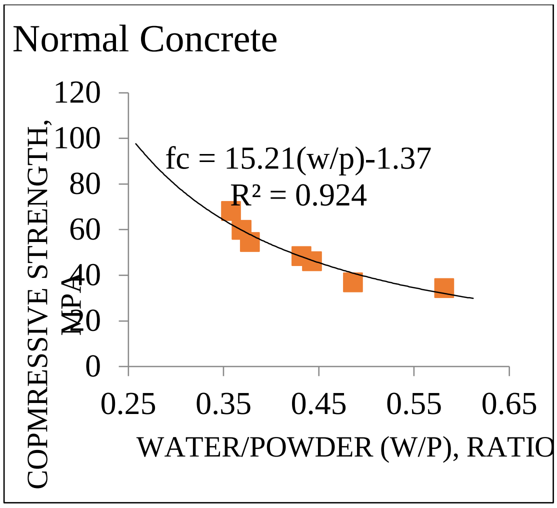


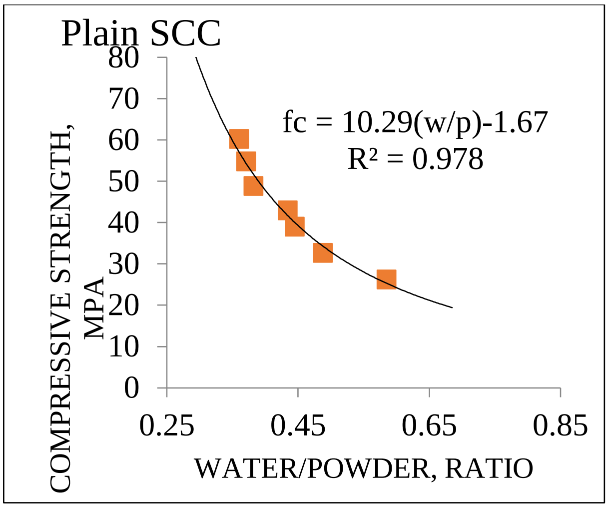
Figure 3 Effect of S/A ratio on compressive strength of plain SCC mixes

Effect of W/P Ratio on Compressive Strength of SCC Containing Stone Dust

Figure 4 (a) to 4(f) gives the relationship between compressive strength and water to powder ratio for the normal concrete mixes, plain SCC mixes and SCC mixes with varying %age of stone dust at the age of 28days. It is observed from the figures that compressive strength (fc) of plain SCC decreases with the increase in W/P ratio but on lower side than normal concrete at all testing ages. The power equation have been found fit to predict the compressive strength, fc for different ages for normal and plain SCC mixes and are placed at the respective curve. The regression coefficient for the predicted equations depicts very good relationship between the two variables of SCC mixes over normal concrete.



(a)



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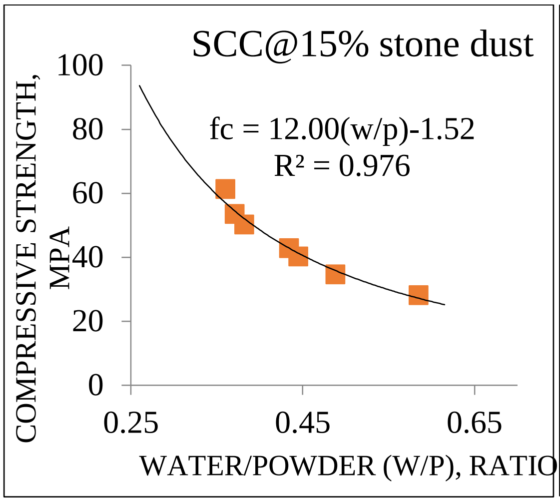

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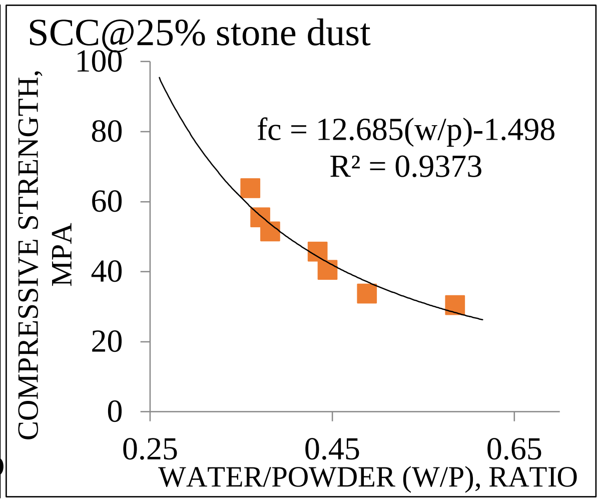

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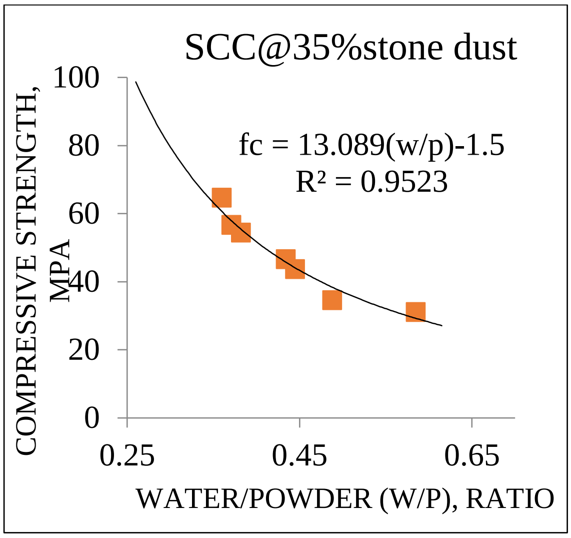

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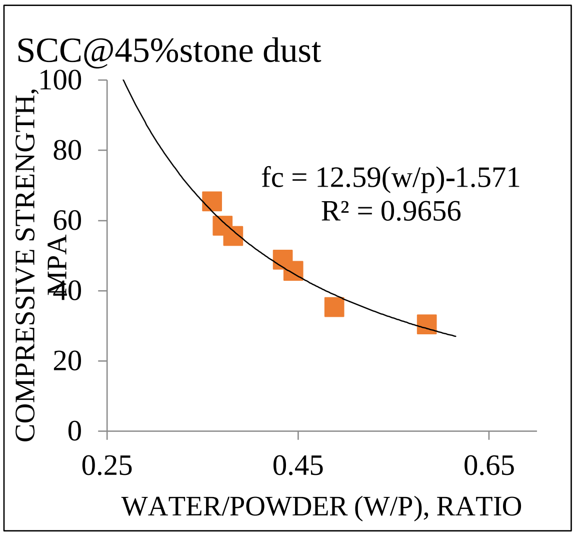

(f)

Figure 4: Effect of W/P ratio on the Compressive Strength of Normal and SCC Mixes with and without Stone Dust.

Effect of fly ash on the compressive strength of SCC

Table 8 shows the compressive strength results of SCC mixes containing 10%, 20%, 30% and 40% replacement of cement with fly ash at 28 days of moist curing. As the content of cement replaced with fly ash in SCC mixes @10 %, compressive strength decreased when compared with the corresponding tested periods of normal concrete. When compared with plain SCC mixes which are without stone dust and without fly ash, increase in compressive strength was observed.

All SCC mixes with 20% fly ash as replacement of cement shown improvement in compressive strength over normal concrete almost at all the ages. This improvement was more significant when compared with plain SCC mixes at corresponding age.

At 30% replacement of cement replaced with fly ash, a precipitous decrease of 5-16% in compressive strength was observed in comparison with plain SCC mixes. This decrease was more prominent in SCC mixes at 40% cement replaced with fly ash. In comparison to normal concrete and plain SCC the strength was even lesser for the corresponding grade.

The compressive strength is lower at the initial ages of 28 days is due to the reason of reduction of quantity of cement by the replacement with fly ash, resulting in weakening the cohesion of cement paste and adhesion to the aggregate particles. As approximately 75% strength rendering primary mineralogical phases is developed at the ultimate hydration of OPC [1]. The balance $Ca(OH)_2$, whose contribution for strength is insignificant as the fly ash replaced with cement do not contribute for chemical reaction. This is because of the fact that sufficient cementious action of fly ash is not activated at the initial stages and thus the uncreative quantity of fly ash at this stage reflects insignificant effect.
This decrease may be due to the fact that lime available for pozzolanic reaction at this stage becomes insufficient to utilize all the fly ash particles, thereby gel formation becomes insufficient to bind the entire fly ash particle resulting in decrease in strength of SCC. Also some of the stone dust fines content at this percentage act as weak filler in SCC mixture, which results in decrease in strength.

Effect of W/P Ratio on Compressive Strength of SCC with Fly Ash

Figure 5 (i) to 5 (iv) shows the variation in compressive strength with the water to powder ratio (W/P) for SCC mixes with 45% sand replacement with stone dust and with varying percentages of cement replaced with fly ash.
It is observed that w/p ratio has great impact on the compressive strength of SCC. Gradual strength development is observed with the reduction in w/p ratio for all SCC mixes. For example for SCC mixes containing 45% stone dust and 0% replacement of cement with fly ash, an increase in compressive strength of 16.24% to 115.15% for 28days was observed at when water to powder ratio was reduced from 0.585 to 0.36.

SCC mixes with 10% and 20% cement replacement with fly ash shown little improvement in compressive strength over SCC mixes without fly ash with the decrease in water to powder ratio. For example compressive strength of SCC mixes having 10% cement replacement with fly ash increased from 14.12% to 111.92% at 28days with w/p ratio reduced from 0.585 to 0.36. Similarly for SCC @ 20% fly ash compressive strength increased from 9.7% to 85.83% at 28days.

With the further increase in fly ash replacement level of 30% and 40%, the decreasing trend in increase in compressive strength was observed with the reduction in water to powder ratio. That means 20% cement replacement with fly ash is sufficient to develop sustainable SCC mixes.

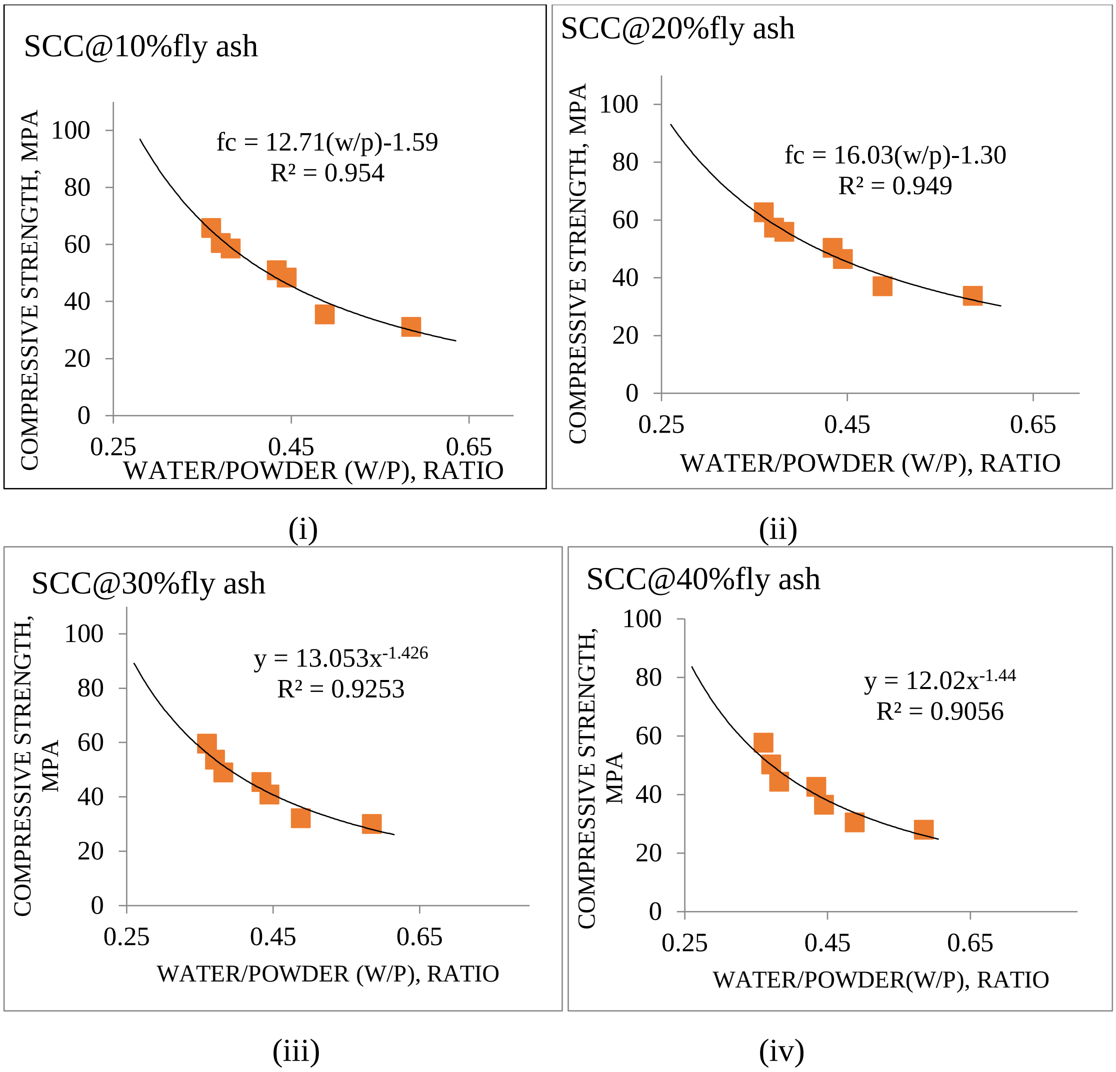

Figure 5 Effect of w/p ratio on the compressive strength of SCC mixes containing 45% of stone dust at varying % age of fly ash.

The power equations were developed from the relationship between two variables to predict the compressive strength of SCC mixes at 28days for different percentages replacement of cement with fly ash. The regression coefficient, R^2 for the predicted equations indicates that the predicted power equation are in good agreement with experimental data and can be used to predict the w/p ratio for desired compressive strength.

CONCLUSIONS

On the basis of present study the following conclusions are drawn:

- ✓ SCC of M20 to M50 grades concrete can successfully be developed without the use of any mineral admixture even at higher fine aggregate to total aggregate (FA/A) ratio of 0.57 with the help of superplasticiser and VMA.

- ✓ To maintain the rheology of the mix and to avoid segregation, the viscosity modifying agent (VMA) can be added @0.50% of total powder content in the mix within the scope of the present study.

- ✓ Utilization of stone crusher dust, a waste material has shown great potential in the development of SCC without increase in water, cement and superplasticiser dosage in concrete. It has not only improved the fresh properties but also enhanced strength properties of SCC. Although fine aggregate at 50% replacement with stone dust have shown satisfactory performance but maximum gain in compressive strength of 27% at 28days over plain SCC mix was observed at optimum level of 45% replacement of fine aggregate with stone dust for all the grades of SCC.

- ✓ All the test results on fresh properties of SCC mixes with and without stone dust has found to be satisfactory for all the grades within the qualified range of individual test. It was possible to develop SCC using stone dust as replacement of sand and fly ash replacement of cement within a range of slump flow of 650mm -800mm.The best value of slump flow test was found to be for SCC mix with 45% fine aggregate replacement with stone dust and 20% cement replacement with fly ash.

- ✓ SCC containing 45% of stone dust as replacement of sand and with 20% of cement with fly ash have shown maximum gain of 28.57% in compressive strength at the age of 28 days when compared with plain SCC without stone dust and fly ash replacement.
- ✓ Empirical equations have been developed from the test results at 28 days for SCC mixes containing various replacement level of fine aggregate with stone dust and cement with fly ash to predict the w/p ratio for desired compressive strength. These equations can be used as reference to proportion the SCC mixes with stone dust and fly ash for the desired strength of SCC within the scope of this study.

- ✓ The Iteration approach adopted in the present study have minimized the trials to develop SCC mixes using stone dust and fly ash as replacement of fine aggregate and cement respectively for desired compressive strength. This can serve as guidelines forthe designer of SCC in the construction industry.

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