RHEOLOGICAL CHARACTERISTICS, MICROSTRUCTURAL PROPERTY AND COMPRESSIVE STRENGTH OF SELF-COMPACTING CONCRETE CONTAINING DHOLPUR SANDSTONE SLURRY AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT. This paper aims to find out the suitable use of Dholpur Sandstone Slurry (SS) for production in Self-Compacting Concrete (SCC) as partial replacement of cement. The surface of naturally occurred sandstone are refined by various scratchy treatment to give the proper profile. This process includes chamfering, cutting and polishing, which produces huge amount of SS. This SS is hazardous to the human life, aquatic life, Soil and water pollution, creates air contamination during traffic turbulence. Consequently, this stands the perilous waste obtained from the stone manufacturing process. SS is a non-pozzolanic material, which was used in the manufacture of SCC, as partial replacement of Cement at various percentages (5%, 10%, 15% & 20%) by weight of cement. The main concern in SCC is to prevent the concrete from Segregation & Bleeding during transportation & placing. To address this issue, Viscosity Modifying Agent (VMA) at a percentage of 0.1 by weight of cement is used. To achieve target strength and workability in SCC, water to powder ratio should be precise, for this purpose Polycarboxylate Ether based Superplasticizer (SP) is used at the rate of 1.35-1.55% by weight of cement. To gratify research objective, Rheological properties and Strength Characteristics of concrete were evaluated. Conventional SCC was also casted to compare the results. Rheological property was analysed by L-Box Test. To understand the workability of concrete Slump Flow Test and T_{500} test were performed. After acquiring acceptable results from fresh concrete tests, Compressive strength test was conducted on 100mm cubes at 7days & 28 days respectively. Density, Water absorption and voids of hardened concrete was performed at 28 days. Zeta Analysis (ZA), Scanning Electron Microscope (SEM) Test & X-Ray Diffraction (XRD) tests were performed on SS to evaluate the size, shape & chemical phase detection.

Keywords: Sandstone slurry (SS), Self-compacting concrete (SCC), Fresh properties, Compressive strength, Density, Water absorption

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List of Notations:

Sandstone Slurry (SS)
Self-Compacting Concrete (SCC)
Viscosity Modifying Agent (VMA)
Superplasticizer (SP)
Zeta Analysis (ZA)
Scanning Electron Microscope (SEM)
X-Ray Diffraction (XRD)
SCCP0 – SCC mix with 0% replacement of cement by SS
SCCP5 - SCC mix with 5% replacement of cement by SS
SCCP10 - SCC mix with 10% replacement of cement by SS
SCCP15 - SCC mix with 15% replacement of cement by SS
SCCP20 - SCC mix with 20% replacement of cement by SS

INTRODUCTION

Sandstone is one of the prime dimensional stone occurred from clastic sedimentary rock. This stone is cut and finished to specified sizes and shapes for using in Buildings, Monuments, Paving, Furniture and decorative objects. As per Indian Mineral Book (2015) [1], the value production of Quartzite & Sandstone in India is 6529443 (Rs'000) where Rajasthan produces 6517832 (Rs'000). Sandstone is exported not only in various states of India, but demand of sandstone is increases in overseas also. In Rajasthan, main resources are occurred from Karauli, Bhilwara, Jaisalmer, Jodhpur, Dholpur & Barmer.

During preparation of block squaring, Cutting of Stone Slab, Polishing & Chamfering process large & Medium size pieces, Dust, Debris & Slurry has been produced. The major concern is caused by two waste products i.e. Stone powder & Slurry. Slurry of Dholpur Sandstone is composed of a fine pink dusty residue of essentially siliceous in nature, which when mixed with water, create a pink slurry. This waste is very harmful for aquatic life when it is mixed with water. Due to the very fine particle size it is mixed with air and air gets contaminated. Visibility problems and mosquito effects also increased due to dumping of SS in open landfill.

In this work, Dholpur sandstone is used which is having more than 90% siliceous grains and classified under Quartz Arenites group. Stone like Arenites are having less than 15% clay matrix in between the framework grains.

Use of sandstone wastes in construction industry is negligible, than other stone wastes. Dry slurry powder has been used partially in replacement of total aggregate [2] Dholpur sandstone coarse aggregate is also used as replacement of natural coarse aggregate [3] and in making of conventional concrete. However, the use of Sandstone Slurry (SS) in Self-Compacting Concrete (SCC) is not yet discovered. Thus, partial replacement of cement along with SS in SCC may be a novel solution with respect to environmental problem of dumping sandstone wastes. Also, the use of SS may lower the demand for cement which reduces the cost of cement production and may help in reducing CO_2 emission from cement factories. Reduction in CO_2 emission may help to protect environment from global warming issues. The present study has attempted to develop SCC utilising SS as a Powder Content.

EXPERIMENTAL INVESTIGATIONS

Materials Used

SCC consists of Cement, Aggregate, Sandstone Slurry, Superplasticizer & Viscosity Modifying Agent (VMA). Portland Pozzolana Cement [Table 1] is used along with 10mm crushed natural angular Coarse aggregate [Table 2]. River Sand of Zone-III is used. Dry Sandstone Slurry Powder is used as partial replacement of cement, which is mostly passing through 90 mm sieve. Particle size distribution of sandstone slurry powder is in the range of 439 nm – 5209 nm as indicated in [Figure 1]. Shape of SS is angular as indicated in SEM image [Figure 2]. Chemical composition of SS is analysed through XRD analysis as indicated in [Figure 3]. Physical & Chemical properties of SS are indicated in [Table 3]. Second generation polycarboxylic ether-based SP is used which is developed using Nano-technology. Chloride free and organic VMA is used to refine the rheology of the mixes by increasing cohesiveness and eliminating bleeding.

Table 1 Physical Properties of Cement

PHYSICAL PROPERTY	PPC CEMENT	
	TEST RESULTS	IS 1489 (Part-1) – 1991 [4]
Colour	Grey (light)	-
Specific Gravity, g/cm^3	2.91	-
Initial Setting Time, minute	138	30, (Min$^{\underline{m}}$)
Final Setting Time, minute	251	600, (Max$^{\underline{m}}$)
3-day compressive strength, MPa	24.41	16
7-day compressive strength, MPa	25.08	22
28-day compressive strength, MPa	33.30	33

Table 2 Physical Properties of Coarse Aggregate & Fine Aggregate

PHYSICAL PROPERTY	AGGREGATE	
	COARSE*	FINE**
Specific Gravity	2.74	2.63
Water Absorption (%)	0.18	0.50
Fineness Modulus	5.94	2.61
Compacted Bulk Density (g/cc)	1.55	1.82
Percentage Voids after Compaction	43.74	30.93
Loose Bulk Density(g/cc)	1.36	1.70
Percentage Voids at Loose Condition	50.42	35.36

*Maximum nominal size of natural coarse aggregate is 10mm
**Fine aggregate is natural river sand of Zone-III

Table 3 Physical Properties of Sandstone Slurry

PHYSICAL PROPERTY	SANDSTONE SLURRY	CHEMICAL COMPOSITION	PERCENTAGE
Specific Gravity	2.62	O2 Si	99.40
Liquid Limit	28.20	Al0.33 Li0.33 O2Si0.67	0.60
Plastic Limit	19.76		

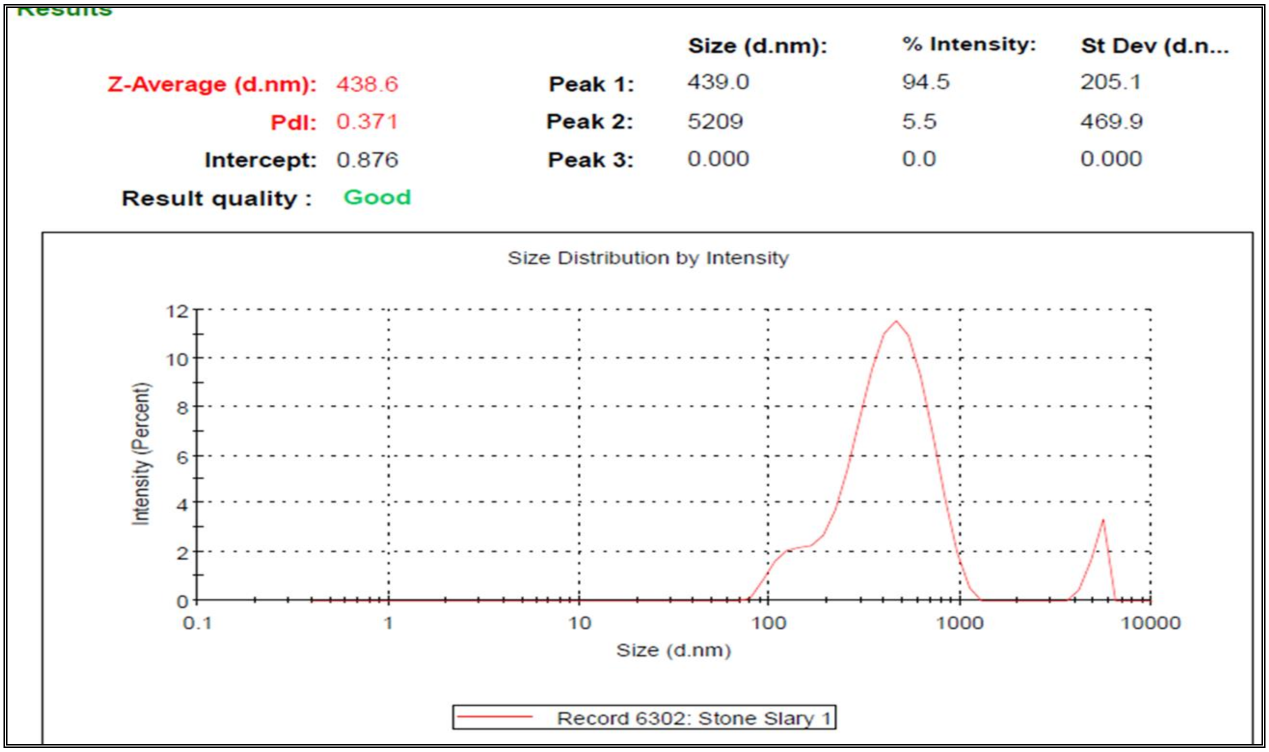

Figure 1 Size distribution of Sandstone Slurry

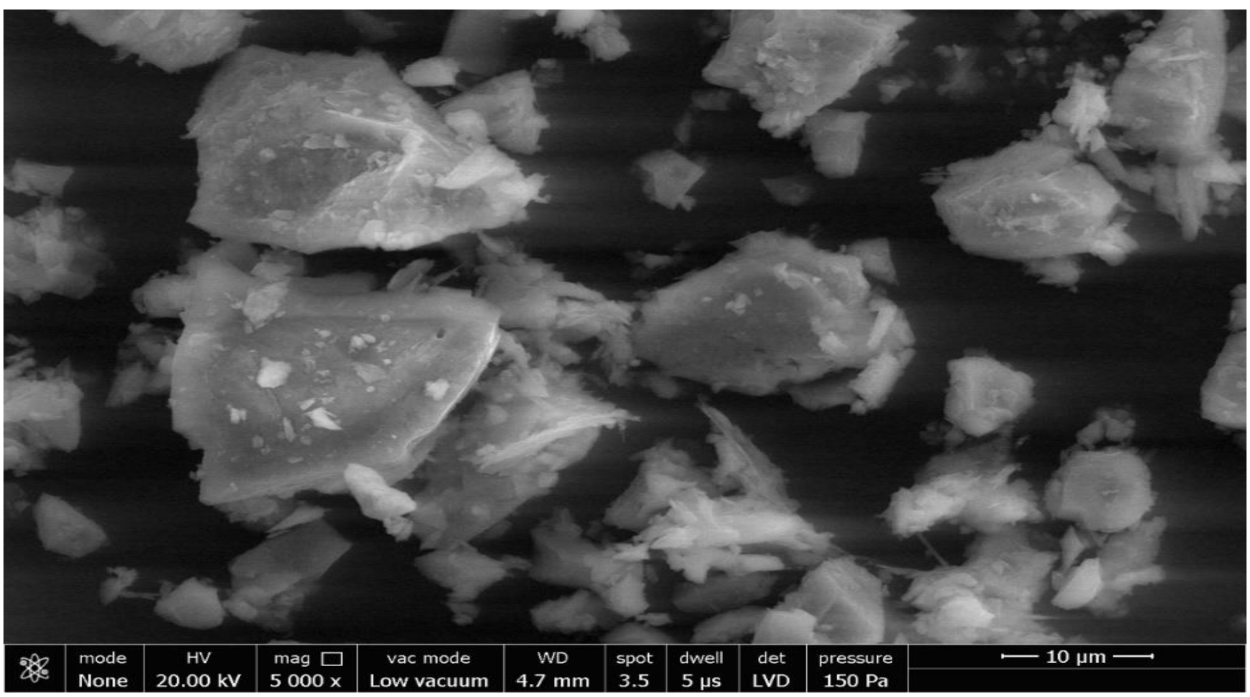

Figure 2 SEM Image of Sandstone Slurry

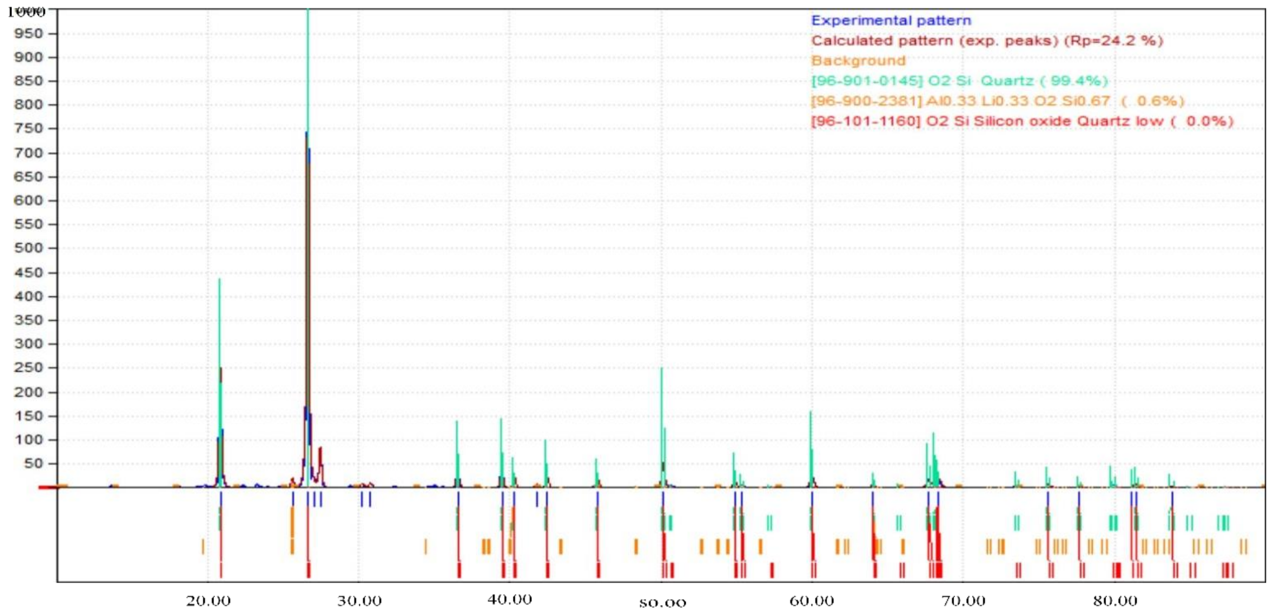

Figure 3 X-Ray diffraction pattern graph of Sandstone Slurry

Experimental Work

Present paper attempts to develop SCC mixes with replacing cement by SS in varying percentage of 5%, 10%,15% & 20% by weight of cement. Superplasticiser is used to maintain workability at lower Water/Binder ratio to achieve higher strength than designated characteristics strength. VMA is also used at a percentage of 0.10 by weight of cement to reduces bleeding and increases homogeneity to the mix. After mixing, fresh state of SCC was tested for Flowability, Passing Ability & Filling Ability as per EFNARC (2005) guidelines [5]. For all the mixes a slump value of 750-850 mm is targeted. Water Binder ratio and dosage of VMA kept constant for all the replacement levels, however superplasticiser dosage increased to achieve the targeted flow. Mix proportions are given in Table 4. Specimen for Compressive Strength were prepared by simply pouring the fresh concrete in to standard cubes (*) without vibration. The hardened specimens were tested for compressive strength at 7 & 28 days and Density, Water Absorption, Voids in hardened concrete tested at 28 days.

Table 4 Mix proportions for different SCC mixes, kg/m^3

MIX	CEMENT	SANDSTONE SLURRY	AGGREGATE		WATER	SP	VMA
			FINE	COARSE			
SCCP0	600	0	807	776	198	8.10	0.6
SCCP5	570	30	807	776	198	8.40	0.6
SCCP10	540	60	807	776	198	8.70	0.6
SCCP15	510	90	807	776	198	9.00	0.6
SCCP20	480	120	807	776	198	9.30	0.6

*****As per IS 516-1959, it is mentioned that for 10mm maximum nominal size of aggregate mould size is 100mm

Tests on Fresh Concrete

Various testing methods which are used to measure the workability of SCC are listed in Table 5. The Filling ability and stability of self-compacting concrete in the fresh state can be defined by four key characteristics. Each characteristic can be addressed by test methods as described in Table 5.

Table 5 Test methods for workability properties of SCC

CHARACTERESTIC	TEST METHODS PERFORMED
Flowability	Slump-flow test
Viscosity (assessed by rate of flow)	T500 Slump-flow
Passing ability	L-box test

Slump-flow test is a sensitive test that typically specifies for all SCC, as the initial check that the fresh concrete consistency meets the specification. T500 test provides information about segregation resistance of concrete and homogeneity of the mix. Flow time is the critical parameter to measure the viscosity of fresh concrete. The measured time describes the rate of flow. When the mix is having low viscosity initial flow of concrete is rapid, however, when the mix has high viscosity creep may continue for an extended time. SCC typically used for high-rise buildings where reinforcement placing is congested. To check the passing criteria through narrow reinforcement placing, passing ability test performed. The acceptance criteria are including no segregation of concrete ingredients. Segregation resistance is a measure of homogeneity. SCC can suffer from segregation and bleeding during placing and after placing but before stiffening. Segregation which occurs after placing, which is most dangerous for long slender structures, but even in slabs, it can lead to surface cracking & blow holes. Table 6 shows different properties of fresh SCC test results.

Table 6 Results for workability properties of SCC

TEST METHODS	SCCP0	SCCP5	SCCP10	SCCP15	SCCP20
Slump Flow **(**mm**)**	826.56	817.85	818.92	800.71	781.40
Slump flow time T500 (second)	2.23	1.91	1.62	1.43	1.30
L-Box **(**P2/P1**)**	1	1	1	1	1

The targeted slump flow was 800± 50, which is classified to SF3 (760 – 850 mm) as per EFNARC (2005). This flow is achieved with small maximum size of aggregates (less than 12.5 mm). It is useful for vertical applications in very congested structures, structures with complex shapes, or for filling under formwork. From, visual inspection it has been noticed that the surface

finish is very smooth. This finishing may come from small aggregate size and fine particle size of sandstone slurry.
Viscosity of SCC mixes was assessed by the T500 time during the slump-flow test. For every batch, after mixing viscosity tests were performed to confirm the uniformity of the SCC mix. As per, EFNARC (2005) Viscosity of SCC mixes were classified in 2 categories. For, T500 (sec) VS1 ≤ 2 sec and VS2 >2 sec. As per the result, it is noted that for Control SCC (SCCP0) the T500 flow time is greater than 2 sec (VS2). This result is indicating that with increasing flowtime it is more likely to exhibit thixotropic effects, it may be helpful in limiting the formwork pressure and improving the segregation resistance, but negative effects may experience with poor surface finish and blow holes. Another disadvantage is that, it is sensitive to stoppages or delays between successive lifts. For SCCP5, SCCP10, SCCP15 & SCCP20 the T500 flow time is less than 2 sec (VS1). EFNARC (2005) specifies that VS1 has good filling ability even with congested reinforcement. It is capable of self-levelling and generally has the best surface finish. However, it is more likely to suffer from bleeding and segregation. In this work, bleeding and segregation was not experienced due to the use of VMA. From the result of viscosity, we may conclude that introducing SS to SCC mix with replacement of cement provides better viscosity than control concrete. With the increment of SS percentage flow time for T500 reduced significantly.

To measure passing ability, L-Box test was performed with 2 rebar having 12mm dia at specified spacing of 80mm to 100mm. All SCC mixes were passed in between these rebars which categorise these mixes in Class PA1, which is typically used for housing and vertical structures.

From the above results of fresh concrete test, this may be concluded that SCCP0 is useful for construction of ramps, residential buildings and medium structures. SCCP5, SCCP10, SCCP15 & SCC20 are useful in making of Floor, Slabs, Tall & Slender structures [6].

Test on Hardened Concrete

Compressive strength

Compressive strength tests were carried out with cube size of 100 mm with varying percentage of SS. Compressive strength was done after 7 and 28 days of curing in accordance with IS 516:1959[7]. Surface water was removed with a dry cloth and the cubes were tested in surface dry condition. The variation in compressive strength for water binder ratio 0.33 is shown in Table 7.

In present study, targeted characteristics strength is 31.60Mpa. For, SCCP0 the achieved strength is 43.00 Mpa which is 26.50% more than desired and for maximum replacement of 15% SS, SCCP15 the achieved strength is 33.40Mpa which is 5.39% higher than target characteristics strength. At 20% replacement of cement with SS decreases the compressive strength value about 4.11%. As per EFNARC (2005), limit of total powder content is 600kg/cum. In SCC0 all the powder content is used as cement and for other replacement percentages cement has been replaced by SS. Due to the high cement content and lower dosage of SP, SCCP0 gives best results among all the replacements.

Table 7 Compressive Strength Test Results

MIX DESIGNATION	COMPRESSIEVE STRENGTH (MPa) (AVERAGE OF 3 SPECIMEN)	
	7 Day	28 Day
SCCP0	34.63	43.00
SCCP5	31.83	36.45
SCCP10	28.95	34.25
SCCP15	28.23	33.40
SCCP20	26.26	30.30

In later cases, cement content (i.e. powder contents) was reduced, and percentage of SP was increased which may result in lower strength than SCCP0, but higher than target characteristics strength. From the result it may be concluded that optimum use of SS up to 15% is recommended.

Table 8 Density & Water Absorption Calculation

FINDINGS	FORMULA USED
Water Absorption after immersion, %	$[(B^{*(2)} – A^{*(1)})/A] \times 100$
Water Absorption after immersion and boiling, %	$[(C^{*(3)} – A)/A] \times 100$
Bulk density, dry	$[A/(C-D^{*(4)})] \times þ^{*(5)} = g1^{*(6)}$
Bulk density after immersion	$[B/ (C – D)] \times þ$
Bulk density after immersion and boiling	$[C/ (C – D)] \times þ$
Apparent density	$[A/ (A – D) \times þ = g2^{*(7)}$
Volume of permeable pore space (voids, %)	$(g2 – g1)/g2 \times 100$
$A^{*(1)}$ = mass of oven-dried sample in air, g $B^{*(2)}$ = mass of surface-dry sample in air after immersion, g $C^{*(3)}$ = mass of surface-dry sample in air after immersion and boiling, g	$D^{*(4)}$ = apparent mass of sample in water after immersion and boiling, g $þ^{*(5)}$ density of water = 1 Mg/m3 = 1 g/cm3. $g1^{*(6)}$ = bulk density, dry, Mg/m3 $g2^{*(7)}$ = apparent density, Mg/m3

Density & Water Absorption

Density & Water Absorption test is done as per ASTM C 642 (2006) [8]. Concrete cubes of 100 mm size were oven dried in a ventilated oven at a temperature of 100 °C for 3-days and then weight (A) is taken when difference between two successive readings are 0.05%. Then it is immersed in water for 48 h in such a way that 50 mm water is maintained on the top of the surface of specimen. The specimen was taken out from the water and allowed to drain for 1 min by placing them on a dry cloth and final weight is taken immediately (B). Difference between two successive readings should be within 0.5% of the larger value. After taking the weight of cubes, cubes were boiled for 5 hrs and readings were taken after 16hrs of cooling at room temperature. Weight of specimen is noted as (C). Immediately, after taking weight of cubes, submerged weight of specimens was taken and recorded as (D). Density & Water absorption calculations for different level of replacement of sandstone slurry waste is shown in Table- 8 and evaluated result is shown in Table-9.

Table 9 Density & Water Absorption Test Results

MIX DESIGNATION	(I) (%)	(II) (%)	(III)	(IV)	(V) (%)	(VI)	(VII) %
SCCP0	3.28	2.72	2.35	2.42	2.41	2.51	6.38
SCCP5	3.18	2.39	2.35	2.41	2.40	2.47	5.47
SCCP10	2.79	2.07	2.31	2.38	2.36	2.43	4.79
SCCP15	2.48	2.04	2.29	2.36	2.34	2.42	4.78
SCCP20	2.45	2.00	2.26	2.30	2.28	2.40	4.75

(I)	Water Absorption after immersion, %
(II)	Water Absorption after immersion and boiling, %
(III)	Bulk density, dry
(IV)	Bulk density after immersion
(V)	Bulk density after immersion and boiling
(VI)	Apparent density
(VII)	Volume of permeable pore space (voids, %)

Particle size of sandstone slurry is 439nm-5209nm, which is finer than cement. Hence, it is helpful in particle packing in between concrete ingredients. In SCCP0 volume of void is 6.38% and water absorption is 3.28% while maximum increasing percentage of SS (SCCP20) reduces the volume of void to 4.75% and water absorption to 2.45%. In case of density of SCC, increasing replacement percentage of SS decreases the density of concrete. This is resulting due to lower specific gravity of SS than cement.

CONCLUSION

The shape of Sandstone Slurry is angular, due to this T_{500} flow time reduced.

Sandstone slurry increases the packing density of concrete due to its finer size than cement particles. Increasing in replacement percentage of sandstone slurry decreases density of concrete. This is happened due to less specific gravity of sandstone slurry.

From, Compressive strength test result, it may be concluded that up to 15% replacement of cement with sandstone slurry may be adopted after checking durability requirements.

It should be noted that, maximum strength attained with maximum cement content (600kg/cum) but target characteristic strength achieved with using (510kg/cum) 85% cement contents & 15% SS. The difference between cement content not only reduce the total material cost but also reduce the CO_2 emission, which is the prime reason of global warming.

Last but not the least the main benefit we get by using this stone waste in making concrete is to save environment from hazardous material and to minimize the pollution.

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