Mechanical properties of self-compacting concrete containing sandstone slurry

R C Gupta, P Basu and S Agrawal
Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur-302017, India
Email: rcgupta.ce@mnit.ac.in; sprarthitas@gmail.com; 2016uce1174@mnit.ac.in

Abstract. India embraces wide variety of dimensional stones. It includes granite, marble, sandstone, limestone and slate. Amid all the states, Rajasthan is known as mineral majestic of India, with an abundance of important stones. Rajasthan produces more than 90% of sandstone of all over the country. The total quantity of mined out sandstone is 200.27 million tons per year, out of which 110.25 million tons are accounted as waste during various manufacturing and processing stages of sandstone. An experimental work has been conducted to manufacture self-compacting concrete (SCC) with dry sandstone slurry (DSS) and study the properties of SCC. Seven SCC mixes have been prepared with various percentages of sandstone slurry (i.e. 0, 5, 10, 15, 20, 25 and 30 percent) as partial replacement of pozzolana portland cement (PPC). Compressive, flexure and tensile strength of all SCC mixes up to 180 days curing age and abrasion resistance after 28 days curing age have been found out and presented in this paper. The conclusion of this study draws an idea about the use of SCC mixes made with DSS are in favor of using DSS up to 10% for reinforced cement concrete work and up to 20% for plain cement concrete work.

1. Introduction
India is the largest producer of natural stone in the world. This country accounts for about 27 percent of the world's total natural stone production [1]. Rajasthan is situated in the western region of the country with an area of 3,42,238 km², which makes this state as the largest state and second most mineral-rich state in India. It has a wide range of mineral deposits containing 64 different types of major and minor minerals and producing an annual revenue of more than 6000 million Indian Rupees [INR] [2]. There are 3403 mining leases for major minerals, 11861 mining leases for minor minerals and 18249 quarry licenses in the state [3]. The quantity of stone export has been observed significant growth and it rises to almost 50 percent in a year 2011–12 [4]. The rapid flow in exports of sandstone in the last two decades has led to increasing numbers of sandstone quarrying and processing units. There are several stages through which sandstone wastes are generated. From table 1, it is visible that after mining, almost 50% of the dimensional sandstone ends up as waste. This extreme mining of dimensional stone has been originated a severe environmental influence. After drying, these slurry results in air pollution. Fine particles get entrained into the atmosphere due to turbulence from the highway traffic. Which not only reduces visibility but also creates respiratory problems. It has excellent nuisance value as it gets airborne even with a mild breeze and settles down in areas far away from the source. During the execution process of sandstone, numerous sandstone quarry workers expire from silicosis, a deadly but avoidable lung disease. It is due to the inhalation of dust containing crystalline silica during mining and processing [5]. Cutting and polishing waste discarded into nearby
roads and dry rivers. In the rainy season, it makes the road surface slippery, which is dangerous for traffic. Disposal by dumping into rivers or sea is not safe, as it creates silting and a host of other problems for human and aquatic life. Therefore, it is essential to find an alternative use of DSS to safeguard the environment.

Table 1. Output of Mined-Out Sandstone Reserves in Rajasthan, India[6].

| Sandstone waste generated [thousands of tons] |       |
|---------------------------------------------|-------|
| Mined out reserves                          | 200,272 |
| Mine waste @ 25% of mine production         | 50,068  |
| Sandstone production as per DMG Rajasthan*a | 150,205 |
| Dressing waste                              | 22,531  |
| Processing + Polishing waste                | 37,651  |
| Dressing waste + Polishing                  | 60,182  |
| Total waste                                 | 110,250 |

*aDepartment of mines and geology (DMG) Rajasthan

2. Materials and experiments

2.1. Raw materials

In this investigational work, PPC has been used as a prime binder and partially replaced with DSS. The PPC used is as per IS 1489:1991 (part 1) [7] and DSS has been used after sieving through 90-micron sieve. Physical properties of PPC & DSS are shown in table 2. The particle size distributions for PPC & DSS (as obtained from mastersizer-3000) are presented in figure 1. Nearby river sand and crushed angular basalt rock (10mm maximum nominal size) have been used as fine and coarse aggregate respectively, and their physical properties are indicated in table 3. Sieve analysis has been performed as per IS 2386:1963 (part 1) [8] and its gradation has been designated as per IS 383:1970 [9]. Polycarboxylic ether (PCE) based superplasticizer (SP) as per IS 9103:1999 [10] and chloride free viscosity modifying agent (VMA) as per European Guidelines for Self-Compacting Concrete: Specification (EFNARC) Guidelines [11] have been used.

Figure 1. Particle size distribution curve of DSS and PPC
2.2. Mix proportions
Seven SCC mixes have been made in different proportion of PPC and DSS, by maintaining water/binder (w/b) ratio as 0.33 for 0, 5, 10, 15 and 20 percent replacement and 0.35 for 25 and 30 percent replacement level. Quantity of fine aggregate, coarse aggregate and VMA are 807, 776 & 0.60 kg/m$^3$ respectively. The detail mix proportions, along with fresh property test results, are presented in table 4.

**Table 2. Physical property of PPC and DSS.**

| Description                        | Test results | Description                        | Test results |
|------------------------------------|--------------|------------------------------------|--------------|
| Colour                             | Grey         | Colour                             | Pink         |
| Specific gravity [g/cm$^3$]         | 2.91         | Specific gravity, [g/cm$^3$]       | 2.62         |
| Specific surface area [m$^2$/kg]   | 730.80       | Specific surface area [m$^2$/kg]   | 968.70       |
| Initial setting time [Minutes]     | 138.00       | Liquid limit (WL) [%]              | 28.20        |
| Final setting time [Minutes]       | 251.00       | Plastic limit (WP) [%]             | 19.76        |
| 3-day comp. strength, [MPa]        | 24.41        | Shrinkage limit [%]                | 27.11        |
| 7-day comp. strength, [MPa]        | 28.08        | Shrinkage ratio                    | 1.51         |
| 28-day comp. strength, [MPa]       | 37.30        | Volumetric shrinkage               | 1.24         |

**Table 3. Physical properties of coarse and fine aggregates.**

| Physical property                      | Coarse aggregate | Fine aggregate |
|----------------------------------------|-------------------|----------------|
| Specific gravity [g/cm$^3$]            | 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 the loose condition| 50.42             | 35.36          |

**Table 4. Mix proportions and fresh property of self-compacting concrete.**

| Mix   | Quantity (kg/m$^3$) | Fresh property |
|-------|---------------------|----------------|
|       | Water   | Powder  | SP  | Slump flow (mm) | T$_{500}$ (sec) |
|       | PPC     | DSS     |     |                 |                |
| DSS0  | 198     | 600     | 0   | 8.10             | 826.56         |
| DSS5  | 198     | 570     | 30  | 8.40             | 818.92         |
| DSS10 | 198     | 540     | 60  | 8.70             | 810.85         |
| DSS15 | 198     | 510     | 90  | 9.00             | 800.71         |
| DSS20 | 198     | 480     | 120 | 9.30             | 784.28         |
| DSS25 | 210     | 450     | 150 | 9.60             | 781.40         |
| DSS30 | 210     | 420     | 180 | 9.90             | 766.87         |
2.3. Laboratory testing program

2.3.1. Slump-flow and $T_{500}$ test. The sampling and testing of fresh properties of self-compacting concrete have been conducted by following EN 12350-1 [12] and EN 12350-2 [13]. Test procedure is as follows: The fresh concrete is transferred into a cone which is used for slump test. When the top-level of slump cone is filled with concrete it is withdrawn upwards and the time from slump cone lifted upwards to when it flows and reaches a diameter of 500 mm is noted and is the $T_{500}$ time. The maximum diameter of the slump flow is then measured with right angles, and the average reading is pointed out as the slump-flow reading [14].

2.3.2. Compressive strength test. This test has been conducted as per IS 516:1959 [15] on concrete cubes of 100 mm size after 7d, 28d, 90d and 180 days of curing. Gradual increasing load at the rate of 140 kg/cm$^2$/minute is applied till the specimen fails. The maximum load is noted at which the specimen failed. The compressive strength is considered by dividing the load at the failure by the cross-sectional area of the sample.

2.3.3. Flexural strength test. This test has been conducted as per IS 516:1959 [15] on beam size 100 mm x 100 mm x 500 mm after designated curing time. Two-point loading set up is used, and the load is applied at the location of L/3 distance apart. The loading rate has been kept at 180 kg/minute. The load is applied gradually until the specimen reaches its failure load, and the load is recorded. Flexure strength is known as modulus of rupture.

2.3.4. Split tensile strength test. This test has been conducted as per DIN 1048:1991 (Part 5) [16] on concrete cube specimen of 150 mm size. After specified curing days, cubes are taken out, and surface water has been wiped off with a dry cloth, for further testing process.

2.3.5. Abrasion resistance test. The abrasion test has been performed after 28-day of curing as per Indian Standard IS 1237:1980 [17]. Three 100 mm concrete cube specimens of each mix are oven dried at temperature 110 ± 5 °C for 24 h. After specimens cool down to room temperature, initial weight (W1) has been measured and after completion of the test, final weight (W2) has been taken. The change in thickness is calculated with the use of formula [Eq. 1] mentioned below:

$$ t = \frac{W_1 - W_2}{W_1 \times A} $$  \hspace{1cm} (1)

Where, $V_1$ is the initial volume of the specimen in mm$^3$ and A is the surface area of the specimen in mm$^2$.

3. Result and discussions

3.1. Slump-flow and $T_{500}$ test

The targeted slump flow was 800 ± 50 mm, which is classified to slump flow class 3 (SF3) (760 – 850 mm) as per EFNARC (2005). From slump flow result figure 2 it is noticed that the maximum slump flow diameter has been achieved at 0% replacement level and minimum slump flow diameter has been at 30% replacement level. In the present study, PPC has been used, which contains fly ash in it. Sandstone slurry particles are angular in shape. The increment of DSS increases the number of angular particles, which resist the movement of concrete flow. The almost similar trend of result has been reported by V. Corinaldesi [18], where Fly Ash (FA), Limestone powder (LP) and Rubber powder (RP) was used as mineral addition. The result showed that, increases in flow diameter of SCC due to the increment of FA having rounded particles. Whereas, LP and RP were in angular in size, which restricts the flowability of concrete.
3.2. Compressive strength test
The compressive strength test results have been based on 7d, 28d, 90d and 180 days strength test and results are presented in figure 3. At 7d, as the quartz sandstone slurry replacement gets increased, the substantial decrease in compressive strength has been noticed. This could be attributed to delay in cement hydration at the initial stage of curing due to the higher replacement level of quartz sandstone slurry. After 90 days, significant strength gain has been observed and this is due to the continued pozzolanic reaction. This strength gain may also have been associated with filling up of pore spaces in the concrete with the product of hydration. As per Uysal et al. [19], larger specific surface area and siliceous property of waste material may be acted as nucleation sites for the early reaction products. As, PPC cement was used, which is having class F, fly ash and addition of DSS, which is having more than 90% of SiO$_2$, increases the silica content in SCC. The SiO$_2$ consumes the early formed Ca (OH)$_2$. Which is parting lesser amount in future ages for fly ash and it is causing early compressive strength. Therefore, it provides better strength at early stages to the cement due to the formation of silicates. This nucleation, accelerating the hydration process and significantly increase the C$_3$S content. As a result, the increase in compressive strength of the concrete has been observed in the early stage.

3.3. Flexure strength test
The flexure strength test performed at 28d, 90d and 180 days and results are shown in figure 4.
At 0% replacement of DSS, flexure strength has been observed maximum with cement content 600 kg/m$^3$. At 30% replacement level of DSS lowest strength has been achieved where cement content is 420 kg/m$^3$. The almost the same pattern has been reported in Dina M. Sadek [20]. They reported that strength reduction in control self-compacting concrete is related to the less cement content, poor workability and consequently weak compactness of SCC.

3.4. Tensile strength test
The tensile strength test results have been determined at 28d, 90d and 180 days and presented in figure 5. Tensile strength shows good result for all the replacement level of DSS. This is in line with Dina M. Sadek report [20]. Wherein, they stated that using of waste stone powders as mineral additives in SCC enhances its physical, mechanical properties and durability-related properties compared with the control mix of the same cement content.

3.5. Abrasion resistance test
The wear and tear of concrete occurs due to abrasion under different loading conditions. The results obtained for different replacement level of DSS in SCC are shown in figure 6. With the incorporation of 30% sandstone slurry, depth of wear increases up to 1.93 mm, which shows an increment of 0.95 mm with respect to control SCC mix sample. As per IS 1237:1980, permissible wear of the individual specimen for using in general purpose tiles is 4 mm and for heavy duty floor tiles is up to 2.5 mm. For all the SCC mix depth of abrasion is within the permissible limit. However, this developed SCC has good abrasion resistance.

4. Conclusions
The following conclusions can be drawn based on the above study: 1) All SCC mixes are classified in SF-3 category. This concrete may be beneficial for vertical applications in very congested structures and structures with complex shapes. 2) Due to the angular shape of sandstone slurry viscosity of SCC was increased and all the SCC mixes are classified into VS1 class, except DSS30 which contains 30% of dry sandstone slurry. 3) From strength parameter, it is visible that up to 10 per cent replacement level of DSS compressive strength, flexure strength and tensile strength parameters show excellent results. It happens due to enough quantity of binder content is present in the mixes. The sandstone slurry particle size is less than cement so better packing in between concrete constituents may be one of the reasons for achieving good strength. This mix can be used for reinforced concrete work. 4) Further increment of sandstone slurry up to 20%, concrete strength decreased, although it could be useful for plain cement concrete applications. 5) Depth of wear of concrete was increased with the increment of dry sandstone slurry percentages. However, for all the SCC mixes depth of wear lies within the permissible limit of standard code.
References

[1] Madhavan P and Dr. Raj S *Budhpura ground zero sandstone quarrying in India* Study commissioned by India Committee of the Netherlands, Mariaplaats 4e, 3511 LH Utrecht The Netherlands (2005) p.1-32

[2] Information on, http://www.dmg-raj.org/why-rajasthan.html

[3] Information on, http://resurgent.rajasthan.gov.in/focus-sectors/minerals-ceramics

[4] Crimes S B, Marshall S and Taylor K *Rajasthan stone quarries promoting human rights due diligence and access to redress in complex supply chains* (2016) p.1–67

[5] Lahiri-Dutt K *Digging to survive women’s livelihoods in South Asia’s small mines and quarries* South Asian Surv. 15 (2008) p.217–44

[6] Kumar S, Gupta R C, Shrivastava S and Csetenyi L J *J. Mater. Civ. Eng.* 29 (2017)

[7] IS 1489 (part-1): 2015 *Portland pozzolana cement-specification Part-1 fly ash-based* Bureau of Indian Standards New Delhi India (2015)

[8] IS 2386 (Part I):1963 *Method of Test for aggregate for concrete Part I - Particle size and shape* Bureau of Indian Standards New Delhi India (1963) (Reaffirmed 2002)

[9] IS 383: 1970 *Specification for coarse and fine aggregates from natural sources for concrete* Bureau of Indian Standards New Delhi India (1970)

[10] IS 9103: 1999 *Specification for concrete admixtures* Bureau of Indian Standards New Delhi India (1999)

[11] EFNARC, EFCA *Guidelines for viscosity modifying admixtures for concrete* Viscosity Modifying Admixtures Concr (2006)

[12] BS EN 12350-1:2009 *Testing fresh concrete - Part 1: Sampling* (2009)

[13] BS EN 12350-2:2000 *Testing fresh concrete Part 2: Slump* (2000)

[14] The European Project Group *the European guidelines for self-compacting concrete: specification, production and use* Eur. Guidel. Self-Compact. Concr. (2005) 63

[15] IS 516: 2018 *Method of tests for strength of concrete* Bureau of Indian Standards New Delhi India (2018)

[16] DIN 1048: 2016 *Determination of permeability of concrete* German Standard (2016)

[17] BIS 1237: 2012 *Cement concrete flooring tiles specification* Bureau of Indian Standards New Delhi India (2012)

[18] Corinaldesi V and Moriconi G *Constr. Build. Mater.* 25 (2011) 3181–86

[19] Uysal M, Yilmaz K and Ipek M *Constr. Build. Mater.* 27 (2012) 263–70

[20] Sadek D M, El-Attar M M and Ali H A *J. Clean. Prod.* 121 (2016) 19–32