Role of Supplemental Cementitious Materials on the Strength Characteristics of Green Concrete Specimens

A.R. Dar
Department of Civil Engineering, National Institute of Technology Srinagar, J&K, India
E-mail: abdulrashid@nitsri.net

Abstract. Numerous natural waste materials possessing cementitious property are available in abundance. This study presents an experimental investigation on self-consolidating concrete (SCC) by partially replacing natural sand with waste marble powder (WMP), and partially substituting cement by waste limestone dust (WLSD), along with saccharum officinarum molasses as an admixture. Evaluation of relevant material properties of such mixes, both in wet and hardened state was the primary aim of this study. Initially conventional mix of self-consolidating concrete was developed by adopting saccharum officinarum molasses as the only admixture. Later other mixes were prepared by replacement of sand by WMP ranging from 8-40% together with a uniform 5% replacement of cement by WLSD. Furthermore, ultrasonic pulse velocity, drying shrinkage and standard consistency tests of the concrete were conducted. The replacement of sand and cement by industrial by-products partially has shown considerable enhancement in relevant properties of the above new concrete mixes rightly called as green concrete. Keywords: self-consolidating concrete, industrial waste products, saccharum officinarum molasses, plasticity, hardened properties

1. Introduction
Concrete’s versatility as a construction material is amply visible by its huge consumption worldwide, thus making it the world’s second largest material consumed, after water. However, its production has adversely affected the environment, leaving a huge void for the environmentalists as well as the construction engineers, to find its suitable and sustainable alternative. Different industrial by-products with certain cementitious properties can be utilized most effectively for the development of green concrete [1-3], and will also provide a suitable alternative to the fast depleting concrete constituents, particularly sand. This will not only help in sustainable disposal of such industrial wastes [4-9] but also promote substantially the environmental friendly construction. By increasing the proportion of marble dust in concrete, increase in the compressive resistance and abrasion strength was observed [10]. This improvement was the highest at 10% replacement, without affecting the concrete characteristics [10]. The adoption of waste foundry sand as a partial sand replacement improved the compressive resistance by 20% [11]. At higher sand replacements, reduction in the resistances was observed [11]. The partial use of waste marble powder was seen to directly affect the compaction capability of SCC through workability tests [12].

The present study focuses on the evaluation of material properties of green concrete both in plastic and hardened state, prepared by partially replacing sand by WMP from 8-40% at a uniform 5% replacement of cement by WLSD. Furthermore, ultrasonic pulse velocity, drying shrinkage and standard consistency tests of the concrete were conducted.
2. Experimental study

2.1. Materials Used

2.1.1. Cement

OPC bearing the trade name Khyber cement of grade 43, conforming to BIS: 8112-1989 [13] was used in this study. The normal consistency of cement was found to be 31.45%.

2.1.2. Fine aggregates

The fine aggregates were taken from Ganderbal area of Jammu & Kashmir confirming to zone-II of IS: 383-1970 [14].

2.1.3. Coarse aggregate

The course aggregates of 20mm (nominal size) used in this study were taken from a small scale industry unit situated at Khrew, Jammu & Kashmir confirming to IS: 383-1970 [14].

2.1.4. Waste marble powder

The waste marble powder was obtained from a local factory located at Rangreth in Jammu & Kashmir. It was obtained in wet form and was dried in sunlight, followed by sieving (using IS 4.75mm sieve) before mixing.

2.1.5. Waste limestone dust

Limestone dust taken from a small factory located at Shalteng in Jammu & Kashmir was used in this study.

2.1.6. Admixture

In this study Saccharum officinarum and sulphonated naphthalene formaldehyde as admixture were adopted in dosages of 0.8% and 0.5% respectively by weight of cement.

2.1.7. Water

Throughout the investigation, potable water was used for mixing and curing of concrete specimens.

2.2. Mix design

M-35 grade of SCC was adopted for all tests in this study. EFNARC specification and guidelines [15] were followed for conducting tests on fresh and hardened concrete. The SCC mix design is given in Table-1. A fixed quantity of water as 160 lt/m³ and admixture as 4.85 kg/m³ was uniformly adopted in all the mixes.

Table 1 Mix design for M35 grade SCC

| S.No. | Designation | % LSD (with cement) | % WMP (with sand) | Cement (kg/m³) | Aggregate (kg/m³) |
|-------|-------------|---------------------|-------------------|----------------|-------------------|
|       |             | %                    | %                 |                | Fine | Coarse |
| 1.    | X0          | 0                    | 0                 | 395.00         | 772.4 | 1055.78 |
| 2.    | X1          | 5                    | 19.5              | 61.79          | 710.6 | 1055.78 |
| 3.    | X2          | 5                    | 19.5              | 123.58         | 375.25 | 648.8 | 1055.78 |
| 4.    | X3          | 5                    | 19.5              | 185.37         | 375.25 | 587.1 | 1055.78 |
| 5.    | X4          | 5                    | 19.5              | 247.16         | 375.25 | 525.2 | 1055.78 |
| 6.    | X5          | 5                    | 19.5              | 308.95         | 375.25 | 463.4 | 1055.78 |

3. Results and discussion

Based on the relevant tests conducted on fresh and hardened state of various concrete samples prepared in this study, the following test results along with technical discussion are described as under:

3.1. Fresh properties

To evaluate the workability characteristics, numerous workability tests were conducted out as per the guidelines brought out by EFNARC [15], and their results are given in Table-2.

Table 2 Test Results of fresh SCC
Mix % of WMP in SCC Slump Test Slump Flow T5 (Sec) V-Funnel J-Ring U-Box
Limiting Value (EFNARC, 2002) 650-800 2-5 6-12 3-10 0-30
X0 0% 676 4.4 10.5 9.9 21
X1 8% 692 4.1 9.8 9.3 25
X2 16% 697 3.7 10.2 8.7 26
X3 24% 711 3.2 9.6 7.8 28
X4 32% 718 2.9 8.9 6.9 30
X5 40% 732 2.3 8.8 5.4 27

3.2 Drying Shrinkage
Three prisms were casted for conducting drying shrinkage test on different mixes of SCC for different percentages of sand replacement by WMP, and the test results are shown in Figure 1.

3.3 Plastic Density
Just after the batching, the plastic density test on fresh concrete was conducted, and the results of the tests are shown in Figure 2.

3.4 Compressive Strength Test
Figure 3 shows the compressive strength variation for different SCC mixes for 7 days and 28 days. It can be observed that the incorporation of WMP along with added admixtures led to the improvement in the compressive strength of SCC mixture till X3 mix only. Further addition of WMP lead to the drop in the compressive strength as shown in Figure 3.

3.5 Flexural Strength Test
Figure 4 shows the variation in flexural strength for different SCC mixes for 7 days and 28 days. It can be observed that the incorporation of WMP along with added admixtures led to the increase in the compressive strength of SCC mixture till X2 mix only. Further addition of WMP lead to the drop in the compressive strength as shown in Figure 4. Furthermore, this variation was more distinct in the 28 days strength compared to the 7 days strength.

3.6 Split Tensile Strength
Figure 5 shows the flexural strength variation for different SCC mixes for 7 days and 28 days. It can be observed that the incorporation of WMP along with added admixtures led to the improvement in the compressive strength of SCC mixture till X3 mix only. Further addition of WMP lead to the drop in the compressive strength as shown in Figure 5. Furthermore, this variation was more distinct in the 28 days strength compared to the 7 days strength. Also, the rate of increase in the split tensile strength up to X3 mix was lesser than the drop in the split tensile strength, post X3 mix, particularly for 28 days strength.

3.7 Ultrasonic pulse velocity
The test in ASTM C 597-02 [16] was adopted for the determination of pulse velocity through concrete, and the test results are given in Figure 6.
4. Conclusions and recommendations
Following conclusions are drawn from this study:

- The replacement of sand with WMP in the range of 8-24% enhances hardened properties of SCC. However, any further WMP leads to drop in the strength when compared to conventional concrete.
- Incorporation of WMP improves the passing and filling ability of SCC through numerous workability tests.
Due to the cementitious characteristics of WMA, it can sustainably replace cement for achieving economical as well as environment friendly construction.

The disposal issues of industrial by-products like WLSD & WMP can be tackled efficiently through their efficient adoption as natural aggregate and cement replacement alternatives.

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