UTILIZATION OF WASTE MARBLE POWDER AND SILICA FUME IN SELF-COMPACTING CONCRETE

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ABSTRACT. Marble industries are growing significantly as marble is used in the field of construction in monuments and sculptures as decorative and construction work at a larger scale. As the industries are growing, generation of waste marble is also increasing and causing major environmental impacts. Other side self-compacting concrete (SCC) is a revolutionary product which is not so much popular in the field of construction due to its higher production cost as it requires higher cement content. This study thus aims to utilize the waste marble powder in SCC as partial replacement of cement to lower down the cement content. In this study, fresh properties and compressive strength properties of SCC was studied by using waste marble powder and silica fume up to the amount of 30% and 5%, respectively, as replacement of cement. Result showed that replacement of cement with waste marble powder improves the fresh properties up to 20% and decreases compressive strength as compared to control mix. However, the incorporation of waste marble powder together with 5% silica fume content enhanced the compressive strength properties. It was thus concluded that the incorporation of marble powder together with silica fume improves fresh and compressive strength properties of SCC mixes as well as lower down the cost of SCC and CO_2 emission to environment.

Keywords: Marble Powder, Silica Fume, Self-Compacting Concrete, Fresh Properties, Compressive Strength

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INTRODUCTION

The demand for concrete production is increasing day by day as all countries are moving towards development. Construction and infrastructure are the backbone of the development. Thus, a huge growth is noticed in cement production industries [1]. Growth in cement production industries tends to emission of CO_2 to the environment which is responsible for the global warming. Marble industries are also growing with a noticeable rate [2]. Waste marble powder (WMP) generating from marble industries is responsible for many environmental and health related issues. One of the major handicaps faced in reinforced concrete construction practices is compaction and placement of the fresh concrete through confined spaces such as areas of congested reinforcement [3]. Many researchers investigated and invented the techniques to resolve above mentioned issues. Self-compacting concrete (SCC) is a revolutionary invention that can flow and settle into the heavily reinforced, narrow and deep sections by its own weight to completely fill the formwork without any internal or external mechanical energy. SCC is not so much popular in the construction industry because of its higher production cost. SCC has higher powder content which increases the cement demand thus, tends to higher cost of production [4]. A document having specification and guideline has been produced by EFNARC (European Federation of Producers and Contractors of Specialist Products for Structures) [5] which aims to provide a framework for the design and use of high-quality SCC in Europe based on the research findings combined with field experience. Thus, SCC can be cast without honeycombing where it is difficult to mechanically compact fresh concrete, such as underwater concreting, cast in-situ piles, and columns or walls with congested reinforcement. In addition, it can be pumped to great heights in high-rise buildings without segregation [6].

SCC has many advantages compared with normal concrete such as the reduction of construction time, reduction in labour crowd, equipment and noise in construction sites because of the abolition of vibrating equipment [7]. Having these advantages, SCC was used in the construction of significant structural applications such as Burj Khalifa (Dubai), National Museum of 21st Century Arts (Italy), Dragon Bridge (Spain), etc. [8]. SCC has the same ingredients as normal concrete except powder content. The key point for producing SCC depends on the mix proportions to obtain a highly fluid concrete while preventing bleeding and segregation during transportation and placing. Some guidelines were set for the proportioning of SCC including the reduction of water to powder ratio, controlling the total volume of coarse aggregate and its maximum particle size, increasing paste volume and using a superplasticizer. Viscosity modifying admixtures (VMA) is also incorporated to fine tune the balance between stability and deformability [9]. VMA are required to maintain the stability of the mix, hence reducing segregation and bleeding [10]. High powder content in the range of 500-600 kg/m^3 is often needed in SCC. However, high cement content increases heat of hydration, creep shrinkage and cost. Thus, mineral additives are required to satisfy the powder requirement in SCC. The commonly used mineral additives in SCC are industrial by-products such as limestone powder, fly ash and ground granulated blast furnace slag [8]. Similarly, the utilization of WMP as mineral additives in SCC, if it is proven by testing to be appropriate, may be an attractive solution to its disposal.In India about more than 2000 processing units all over Rajasthan are generating around 5-6 million tonnes of slurry every year which is dumped to open land [2]. The accumulation of this waste is imposing an alarming threat to eco-system, biological components of the environment and public health.

In recent years, some attempts have been made to assess the possibilities of utilizing WMP for soil stabilization, desulfurization process, in road embankments, asphalt, ceramics, thermoset resin composites, polymer-based composite materials [11]. Many researches are inclined towards the utilization of WMP in cementitious products to replace cement [12-13]. Some of the authors confirmed that the best results will be on percentage of MP as a partial replacement to cement in concrete is 10% [13]. Topcu et. al. [14] used WMP as filler and reported that the maximum and the optimum usage amount of WMP can be said as 200 kg/m^3 content in order to obtain best performance for both of fresh and hardened properties of SCC. Another author Mucteba [15] reported that incorporation of marble powder up to 20% of total binder in SCC increases the mechanical properties. Fresh and hardened properties of binary blend high strength SCC were also assessed and author recommended that cement can be replaced with Silica Fume (SF) to an extent of 10 to 15% in making SCC with good strength and reasonably eco-friendly green concrete by reducing CO2 emission [16-18].

RESEARCH SIGNIFICANCE

Using filling materials and mineral admixtures as replacing additives in SCC has a great tendency to fulfil the expectations in providing greater sustainability in the construction industry. The issues regarding the cost, recycling the industrial wastes and mechanical performance of concrete will therefore put a pressure on the utilization of such materials. The current study aims at highlighting the fresh and hardened characteristics of SCC produced with binary and ternary systems of Portland cement, WMP and SF. For this purpose, two series of concrete mixtures were designed with respect to the with and without SF, whereas WMP has partially replaced the total binder at the levels of 10%, 15%, 20%, 25% and 30%, by weight. Fresh properties of SCC were tested for flow and passing ability, whereas, compressive strength was measured for determination of the mechanical properties.

EXPERIMENTAL STUDY

Materials

The SCC mixtures were prepared with 43 Grade Ordinary Portland Cement (OPC) conforming to the requirements specified in IS 8112:1989 [19], the specific gravity was found to be 3.1, Fine aggregate (FA) confirming to zone II in the form of river sand and coarse aggregate (CA) having maximum size 10 mm was procured from a local dealer in Jaipur, Rajasthan, India. WMP obtained as a by-product of marble sawing and shaping from Vishwakarma Industrial Area Jaipur, Rajasthan, India. The specific gravity of FA, CA, SF and WMP was 2.64, 2.7, 2.22 and 2.69 respectively. To maintain the workability and reduce the water demand poly carboxylic ether (PCE) based admixture having specific gravity 1.07 was used.

Concrete mix proportioning and test specimen details

To study the effect of WMP replacement with cement at different percentage level with and without SF total twelve mixes having six binary and five ternary blends of SCC mixtures apart from a control mixture were designed and cast at a water to binder ratio (w/b) of 0.36. The control SCC mix was made with only OPC as the binder whereas the remaining mixtures incorporated binary (OPC + WMP, OPC + SF) and ternary (0PC + WMP + SF) blends in which the supplementary materials were replaced by equal amount of cement by weight. A constant replacement level of 5% by total weight of binder content was considered for SF, whereas the various replacement levels (10%, 15% 20%, 25% and 30%) were employed for WMP. Details of the concrete mixture proportioning are given in Table 1. To determine the mechanical properties of SCC, the compressive strength at 7 and 28 days were measured. A typical concrete mixture consisted of six cube specimens (100 X 100 X 100 mm) for compressive strength. Test specimens were casted without any compaction and vibration. After casting and surface finishing, all of the specimens were kept in laboratory for 24 h. Then, the specimens were demoulded and shifted to water for curing.

Table 1 Concrete Mix Proportioning

MIX	MIX-SYSTEM	W/B	Water Kg/m^3	Binder Kg/m^3	OPC Kg/m^3	SF Kg/m^3	WMP Kg/m^3	FA Kg/m^3	CA Kg/m^3	SP Kg/m^3
S0M0	Control	0.36	197	547	547	0	0	864	819	8.20
S0M10	Binary	0.36	197	547	492	0	55	864	819	6.56
S0M15	Binary	0.36	197	547	465	0	82	864	819	6.70
S0M20	Binary	0.36	197	547	437	0	110	864	819	6.84
S0M25	Binary	0.36	197	547	410	0	137	864	819	7.11
S0M30	Binary	0.36	197	547	383	0	164	864	819	7.11
S5M0	Binary	0.36	197	547	520	27	0	864	819	6.29
S5M10	Ternary	0.36	197	547	465	27	55	864	819	6.00
S5M15	Ternary	0.36	197	547	438	27	82	864	819	6.29
S5M20	Ternary	0.36	197	547	410	27	110	864	819	6.56
S5M25	Ternary	0.36	197	547	383	27	137	864	819	6.84
S5M30	Ternary	0.36	197	547	356	27	164	864	819	7.11

Testing Procedure

Fresh properties

After the mixing procedure was completed, the tests for fresh properties were conducted on each fresh SCC mix to determine T_{500} time, slump flow diameter, L-Box height ratio and V-funnel flow time as shown in figures. 1((a), (b) and (c)) respectively. Segregation and bleeding were also visually checked during the slump flow test. Workability of each SCC mix was controlled through the slump flow test. For that, slump flow diameters of all the mixtures were designed to be in the range of 700 ± 50 mm so as to satisfy the EFNARC [5] limitations. Slump flow, viscosity, and passing ability classes with respect to EFNARC are shown in Table-2.

Table 2 Slump flow, viscosity, and passing ability classes with respect to EFNARC

SLUMP FLOW CLASSES		
Class	Flow Diameter (mm)	
SF1	550-650	
SF2	660-750	
SF3	760-850	
VISCOSITY CLASSES		
Class	T_{500} time (S)	V-Funnel time (S)
VS1/VF1	≤2	≤8
VS2/VF2	>2	9-25
PASSING ABILITY CLASS		
PA1	≥0.8 with two rebars	
PA2	≥0.8 with three rebars	

2

(a) SlumpFlow

3

(b) L-Box

(c) V- Funnel

Figure 1 Fresh properties test apparatus

To maintain slump flow, trial mixes were produced till the desired slump flow was obtained by adjusting the dosage of the superplasticizer. Flowability of the SCC mixtures was examined through the V-Funnel test. L-box test was carried out as an indication of passing ability.

Hardened Properties

To determine the hardened properties of each SCC mix, compressive strength was measured according to IS 516 [20] by means of a 2000 kN capacity testing machine. The test was conducted on three 100 mm cubes at the ages of 7 and 28 days and the average of them was reported herein.

TEST RESULTS AND DISCUSSION

Fresh properties

To classify a concrete as SCC, the essential requirements for passing ability, filling ability and segregation resistance must be fulfilled. The concrete must be homogeneous at fresh state. Fresh properties of the concretes were carried out according to the limitations specified by EFNARC as reported in Table 2. It was observed that using WMP in all of the mixtures resulted in decreased amount of superplasticizer to achieve the target slump flow diameter (Table 1). It can stated that all of the mixtures conformed SF2 class in terms of slump flow according to the EFNARC [5]. SCC having SF2 class may be applied to construction of various normal structural members.

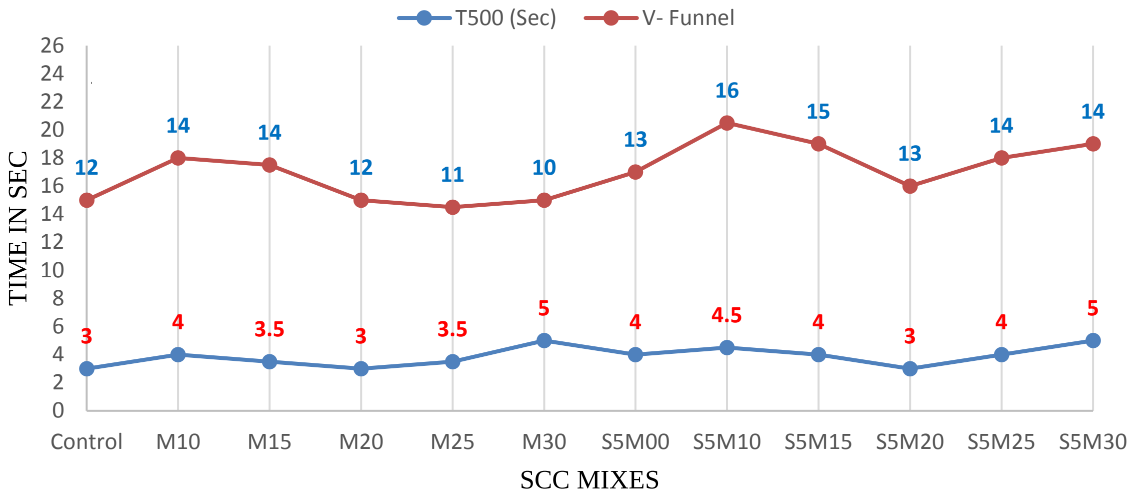

Figure 2 Variation of T_{500} time and V- Funnel time

It can be seen in figure 2 that slump flow durations of all concrete mixtures were within the range of 2–5 s. The mixture S0M20 had the lowest slump flow time, while, the highest was measured for S0M30 and S5M30 mixture. It can also be observed in figure 2 that the V-funnel time values for all the concrete mixtures were within the range of 9-16 s. The mixtures prepared with SF showed higher values of the V-funnel time compared to that of mixtures prepared without SF, this may be due to greater fineness of SF particles. However, the values of slump flow and V-funnel time confirmed VS2 and VF2 viscosity class respectively as per EFNARC limitations.

Variation in the L-box height ratio (h2/h1) is given in figure 3 to assess the passing ability properties considering the recommendations in Table I. Test results showed that the L-box height ratios ranged from 0.88 to 0.96 for all the SCC mixtures. The concrete mixtures having L-box height ratio between 0.8 and 1.0 is classified as PA2 in terms of passing ability.

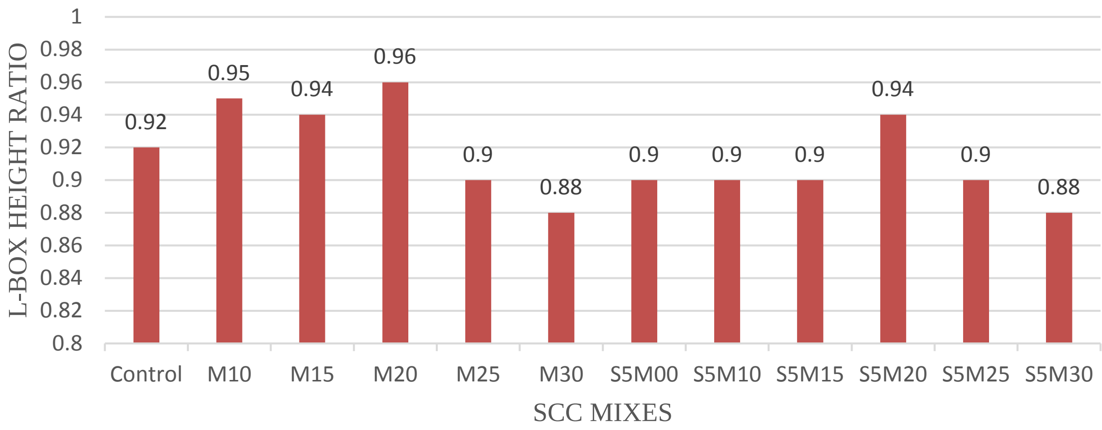

Figure 3 Variation in L-Box height ratio

Hardened Properties

Compressive strengths of SCC mixtures at 7 and 28 days are shown in figure 4 and figure 5 respectively. Considering the binary mixtures, it was observed that there was a sudden drop down in compressive strength at 10% replacement of WMP, however, it increased on further replacement of WMP up to 20%. After 20% replacement, the reduction in compressive strength was found. Moreover, the compressive strength of all binary SCC mixes was less than control mix except S5M0 mix at 7 days and S0M20 and S5M0 at 28 days. The decrease in compressive strength was due to the reduction in binder content as WMP is an inert and non-pozzolanic material. Replacement of cement with SF resulted in the higher compressive strength at 7 and 28 days. As marble powder plays the role of filler only instead of binder hence resulted poor compressive strength compared to control mix. Initially at 10% marble replacement, concrete mixture showed very less compressive strength (i.e. 13 and 10% less than control mix at 7 and 28 days respectively). This reduction in compressive strength showed that WMP primarily acts like inert filler. However, compressive strength slightly increased with further increment in the replacement level of WMP. Concrete mixture, at the 20% replacement level of WMP, showed significant performance and resulted an adequate compressive strength values as compared to other replacement levels of WMP. This is due to the physical nature of better packing and the denser matrix of particles. The increase in compressive strength can also be due to heterogeneous nucleation which leading to a chemical activation of the hydration of cement [21]. A similar trend was observed for ternary system mixtures. SCC mixes with OPC, WMP and SF showed satisfactory results except S5M10 and S5M30. All ternary mixes showed approximately equal or more compressive strength than control mix at 7 and 28 days. The maximum compressive strength was obtained by S5M0 among all the mixtures, however, the compressive strength obtained by S5M20 mix was higher than all other mixtures except S5M0. The mixture S5M20 allows the incorporation of 20% WMP which leads to economical SCC. 5% replacement of OPC with SF showed 20.83% increment in compressive strength. Similarly, 5% SF and 20% WMP replacement showed 18.75% increment in compressive strength and tends to save 25% cement in SCC.

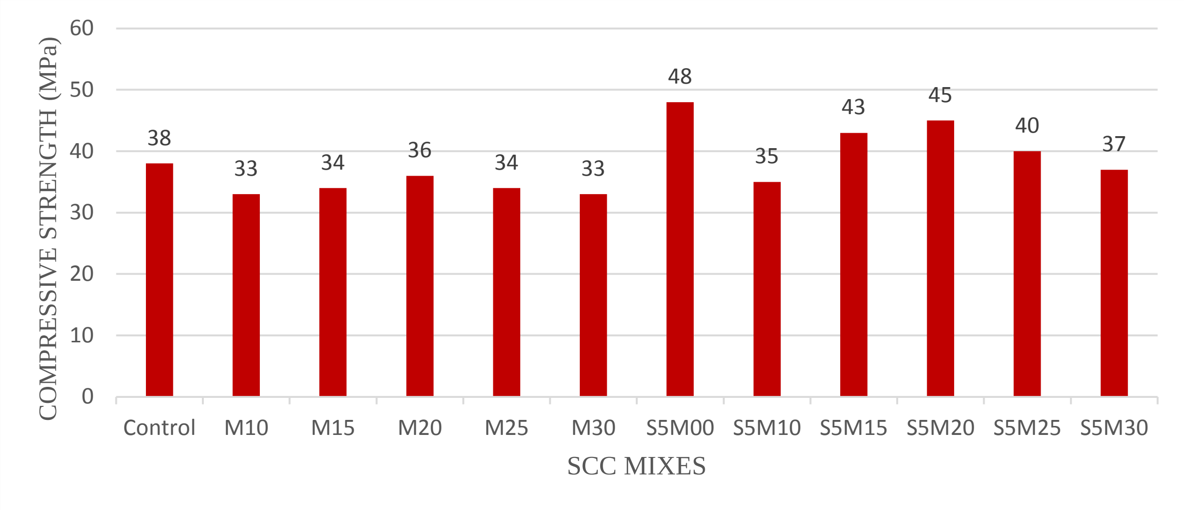

Figure 4 Variation in 7 days compressive strength

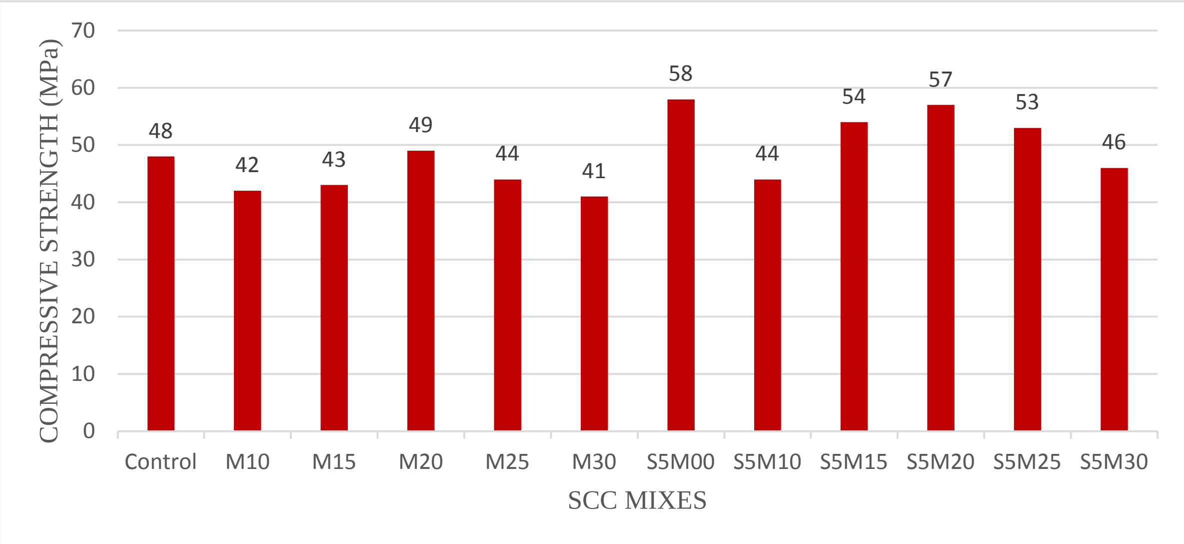

Figure 5 Variation in 28 days compressive strength

CONCLUSIONS

Waste marble powder generated from marble-processing industry could be used successfully as mineral additives in the production of SCC to increase its powder content without increasing cement content, which is useful from the environmental and economical points of view. The production of SCC without vibration reduces the noise and vibration on and near the construction sites where concrete is being placed, reduces the consumption of energy for operating the vibrators and offers safer and faster construction time. Based on experimental results of the current study, the following conclusions may be drawn:

1. The utilization of WMP as cement replacement decreases the admixture dosage compared to the control mix.
2. Binary and ternary mixes are possible to make SCC using waste marble powder and silica fume.
3. Incorporation of WMP in binary mixes (OPC + WMP) as cement replacement leads to the reduction in compressive strength.

4. Incorporation of SF in binary mixes (OPC + WMP) as cement replacement leads to increment in compressive strength.
5. WMP can be utilized in SCC as cement replacement up to 20% without compromising fresh and mechanical properties of SCC.

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