Self Compacting Concrete: Use of Waste Marble Powder as Filler Material

Asif Hameed[1], Asad-ullah Qazi[1], Safeer Abbas[1] and Abdul Rehman[2]

1. *Department of Civil Engineering, University of Engineering and Technology Lahore, Pakistan*
2. *Graduate Student, Department of Civil Engineering, University of Engineering and Technology Lahore, Pakistan*

* **Corresponding Author:** E-mail: *asifhameed@uet.edu.pk*,

Abstract

Self compacting concrete (SCC) is a type of concrete which can flow and spread through reinforcement and narrow sections which fills the empty spaces completely without any mechanical vibration. This type of concrete requires large quantity of powder, for which either fine pozzolanic (e.g. fly ash, ground granulated blast furnace slag and silica fume etc) or non-pozzolanic additions (crushed limestone or sand stone etc) are used. The composition of this blend of cement and filler material is significant in SCC, as high amount of cement with lower water content may cause autogenous shrinkage. Therefore, the use of non-pozzolans material with cement needs to be investigated. The concrete industry is among the largest consumer of raw materials. Limestone fillers are generally used in concrete. As marble stone is of limestone origin i.e. marble is formed by metamorphism of limestone. The effect of addition of non-pozzolans powder waste from marble industry is studied for its suitability in SCC. This was done keeping in view the requirement of fines in SCC and to find an effective utilization of waste marble powder (WMP). For this, five different SCC mixes were prepared, one without WMP and four other with varying amounts of WMP. These mixes in fresh state were tested for their flowability, passing-ability and segregation resistance. Hardened concrete was tested for compressive and flexural strengths. It was found that the locally available WMP can be effectively used as filler in developing SCC. Furthermore, it can be concluded that the addition of WMP up to 15% by cement weight can lead to a desirable SSC properties.

Key Words: Self compacting concrete, waste material, lime stone, flowability

1. Introduction

Concrete is the most commonly used construction material worldwide. The durability, economy and quality of construction make concrete a popular choice as a construction material. However concrete requires proper compaction which is done using vibrators, making concrete to reach every corner of formwork. To overcome problems due to improper vibration with decreasing skill of labor, self compacting concrete (SCC) was first developed in 1988 (Okamura and Ouchi, 2003). SCC is highly fluid concrete which flows around reinforcement and reaches each place inside the formwork and can be compacted under its own weight without any need of a vibrator. It is amongst the most revolutionary development in the field of concrete. Furthermore, SCC has made a remarkable impact on concrete construction industry especially in precast concrete industry (Hameed *et al*., 2012). The need of SCC arose due to the lack of skilled labor in this huge construction industry. Moreover, the SCC is the current need of construction industry which overcomes the requirement of skilled labor leading to economical and durable structures.

Professor Hajime Okamura is the pioneer in the field of SCC and proposed the necessity of such type of concrete in 1986 to achieve durable concrete (Okamura and Ouchi, 2003). Figure 1 shows the obvious benefits and reasons for SCC requirement in construction industry.

Compact ability is to prepare a high fluid concrete with excellent segregation resistance. These properties are of vital importance, particularly when the concrete has to flow through the bars of reinforcement or in case of thin sections where the concrete has to reach each place without any vibration.

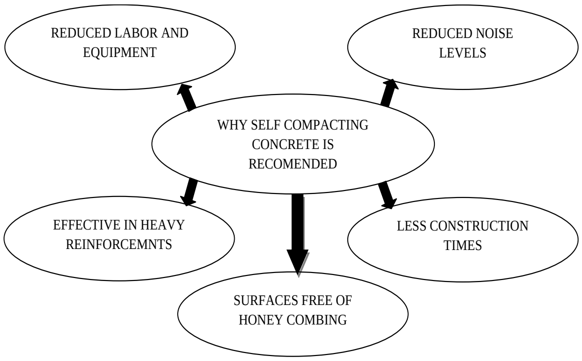

Fig. 1 Need of SCC

The main ideology behind the development of self The main ideology behind the development of self compact ability is to prepare a high fluid concrete with excellent segregation resistance. These properties are of vital importance, particularly when the concrete has to flow through the bars of reinforcement or in case of thin sections where the concrete has to reach each place without any vibration.

In literature, SCC is recognized by three distinct but related properties i.e. flowability, passing-ability and segregation resistance. Flowability is the property of concrete which makes it to flow under its own weight, passing-ability is to pass between the reinforcing steel and reaching every narrow section of formwork and segregation resistance is essential in both the cases when concrete flows and passes through narrow places. This can be accomplished using higher powder content and lower coarse aggregate content in the concrete mix (Figure 2). It was found that in case of higher coarse aggregate content, there is a greater susceptibility of inter particle collision. More the inter particle collision more is the friction and therefore large amount of energy is consumed when the concrete flows. So if this part of energy is saved, more energy will be available for concrete to flow. Consequently lower coarse aggregate content is leading to a more deformable concrete. Also, viscosity is an important factor in SCC. Higher powder contents, lower water cement ratios and use of a super plasticizer are employed for achieving the required properties. Viscosity should be such that the concrete is highly deformable, preventing localized stress concentrations with segregation resistance (Okamura and Ouchi, 2003). An increased amount of fines is very important for achieving a cohesive mix. The amount of fines is typically increased by employing various industrial by products with or without some chemical reactivity. Mostly these additions are characterized by their pozzolanic activity. Coarse aggregates occupy 70% volume of the whole concrete mix. However, in case of SCC, it was advised to limit the coarse aggregate up to 50%. Furthermore, it was recommended to use coarse aggregate with a particle size not exceeding 20 mm (Okamura and Ouchi, 2003).

Fillers in SCC are either pozzolanic additions e.g., silica fume, fly ash and ground granulated blast furnace slag or inert fillers like crushed limestone and sand stone. These filler materials can also help in reducing autogenous shrinkage. One of the waste material locally available is marble powder which is a granular metamorphic rock formed by metamorphism of limestone and dolomite. During cutting and sawing process of marble, a huge amount of waste is produced in form of fine powder and slurry. It is believed that 70% of the original stone is wasted in form of stone fragments, powder and slurry (Aukor and Qinna, 2008). About 25% of this waste is fine powder or dust and can be used as filler. This can reduce the waste deposits of marble powder leading to overcome the huge burden on environment (Binici *et al*., 2007).

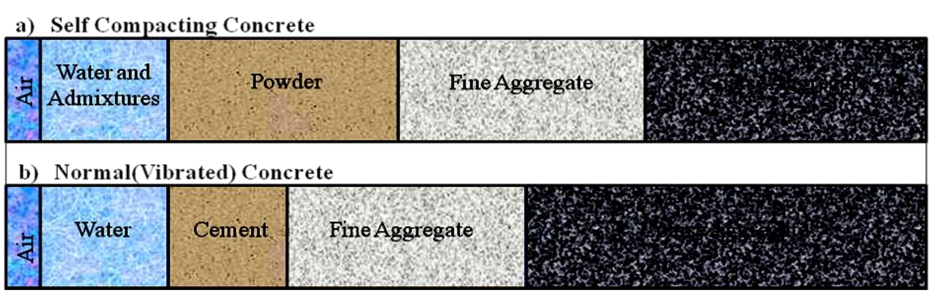

Fig. 2 Mix Composition of SCC (Okamura and Ouchi, 2003)

2. Research Significance and Objectives

SCC is gaining popularity all over the world. However in Pakistan its use is not common. Lack of research in our region is a factor due to which SCC has not gained confidence in its use. Various researchers internationally have used waste marble powder (WMP) in developing SCC, aiming to reduce burden on waste dump sites besides achieving good quality SCC. Therefore, WMP can be employed for SCC which will also provide a solution for environmental degradation caused by marble wastes. So, keeping in view the work of several other scientists worldwide, this research will focus on the use of WMP in SCC using locally available materials in Pakistan. The objective of this study is to investigate the effectiveness of WMP in SCC and to get the most favorable amount of WMP that can be effectively used in developing SCC.

3. Mixture Composition and Proportions

In order to examine the properties of fresh and hardened SCC using WMP, a control concrete mix fulfilling the requirements of self compactability was prepared following ACI 237R (2007) and EFNARC (2002) guidelines. The effect of addition of WMP is studied by replacing cement content with varying amounts of marble powder. Fine aggregate conforming to grading requirements of ASTM C 33 was used in this research work. A mixture of sand from two quarry sites i.e. Lawerancepur sand and Chenab sand was used. The fine aggregate was proportioned as 90% Lawerancepur sand and 10% Chenab sand. This was done keeping in view the well gradation requirements of ASTM C 33 (Table 1). Crushed stone from Margalla quarry was used as coarse aggregate. Table 2 shows sieve analysis results of coarse aggregates used. This was selected due to its angular particle shape and also its abundant availability in local building materials market. Crushed stone with particle size below 19 mm was collected for research work. This collected material was further separated into two fractions i.e. particles of size range 19 mm to 12 mm and other with particle size lesser than 12 mm to particles retained on No. 4 sieve. Considering the grading requirements, 20% of total aggregates were with particle size range 19 mm to 12 mm, and 80% were below 12 mm. The properties of the constituent materials are given in Table 3. Marble cutting and sawing waste was collected from local processors of marble stone. The collected waste consisted of particles of various sizes. The fraction passing #100 sieve was used in this research work. This fraction was used keeping in view the fineness requirements of powder content and maximum utilization of possible powder waste produced during marble processing.

Table 1: Gradation of fine aggregate

Sieve Size		Weight Retained (grams)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing	% passing ASTM C-33 Limits	
No.	mm						
3/8	9.5	0	0	0	100	100	100
4	4.75	12	1.2	1.2	98.8	95	100
8	2.36	40	4	5.2	94.8	80	100
16	1.18	258	25.8	31	69	50	85
30	0.6	346	34.6	65.6	34.4	25	60
50	0.3	236	23.6	89.2	10.8	5	30
100	0.15	77	7.7	96.9	3.1	0	10
200	0.075	5	0.5	97.4	2.6	0	0
Pan	0	0	0	97.4	2.6	0	0

Table 2: Gradation of coarse aggregate

Sieve No		Weight Retained (grams)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing	% passing ASTM C-33 Limits	
No	Size (mm)						
¾	19	0	0	0	100	100	100
½	12.5	48.00	2.4	2.4	97.6	90	100
3/8	9.5	775.00	38.75	41.15	58.85	40	70
¼	4.75	897.00	44.85	86	14	0	15
3/16	2.4	244.00	12.2	98.2	1.8	0	5
Pan	0	36.00	1.8	100	0		

Table 3: Properties of constituent materials

	Lawerancepur Sand	Chenab Sand	Coarse aggregate	Cement ASTM Type I
Bulk Density (kg/m^3)	1735.7	1600	1535.7	---
Bulk Specific Gravity (SSD)	2.71	2.77	2.64	3.14
Water Absorption	1.47 %	1.55%	1.19	---
Fineness Modulus	2.76	2.43	3.28	---

Table 4: Mix Proportions

Constituent Materials	**Quantities (kg/m^3)**				
	SCC	**5MP**	**10MP**	**15MP**	**20MP**
Cement	500	475	450	425	400
Silica Fume	25	25	25	25	25
Marble Powder	0	25	50	75	100
Total Powder	525	525	525	525	525
Water	187.5	189.75	191.55	193.4	195.25
Fine Aggregate (Lawerancepur)	873.90	864.38	855.96	847.41	838.87
Fine Aggregate (Chenab)	97.10	96.04	95.15	94.16	93.2
Coarse Aggregate (19 to 12 mm)	600	600	600	600	600
Coarse Aggregate (< 12 mm)	150	150	150	150	150
Super Plasticizer	10.0	9.5	9.0	8.5	8.0
VMA	7.5	7.1	6.8	6.4	6.0
w/c (weight)	0.375	0.399	0.426	0.455	0.488
w/p (volume)	1.10	1.10	1.10	1.10	1.10

A control mix was prepared keeping in view ACI 237 (2007) and EFNARC (2002) guidelines (Table 4).

Various trial mixes were tested for optimize mix design which satisfy the performance requirement of SCC mix. Five different mixes were prepared. Cement was replaced with WMP by 0%, 5%, 10%, 15% and 20% of its weight. The mixes were designated as SCC, 5MP, 10MP, 15MP and 20MP, respectively. In all these mixes, the dosage of admixtures was kept constant with respect to weight of cement. However, the water-cement ratio by weight exceeded the ACI 237 limit i.e. 0.45 as the water powder ratio was kept constant and the cement contents were decreased with the addition of WMP.

4. Testing of Fresh Concrete

The fresh concrete was tested following ACI 237R (2007), ASTM standards and EFNARC (2002). Concrete mixes were tested for flowability, passing-ability and segregation resistance. These three are although distinct but are interlinked characteristics. The tests performed on fresh concrete are Slum flow test, J Ring test, L Box test, Column segregation test and V Funnel test.

4.1 Slump Flow Test

In this test, the horizontal spread of concrete was measured when the standard slump cone filled with concrete was lifted upwards. The concrete was allowed to flow on a flow table, and the spread of concrete was measured when the concrete ceased to flow (Figure 3). The time taken by concrete to reach a horizontal spread of 500 mm was also recorded. This test was performed following EFNARC (2002) and ACI 237R (2007) guidelines for SCC. All the freshly prepared mixes were tested for slump flow.

The results of slump flow test are shown in Figure 4. EFNARC (2002) suggests that for SCC, the slump flow should be between 650 to 800 mm. Concrete having slump flow less than 650 mm is less flowable and may require vibration for complete filling. ACI 237; however, says that a concrete having a slump flow value of 550 mm and above may be considered as self consolidating.

Fig. 3 Slump Flow test

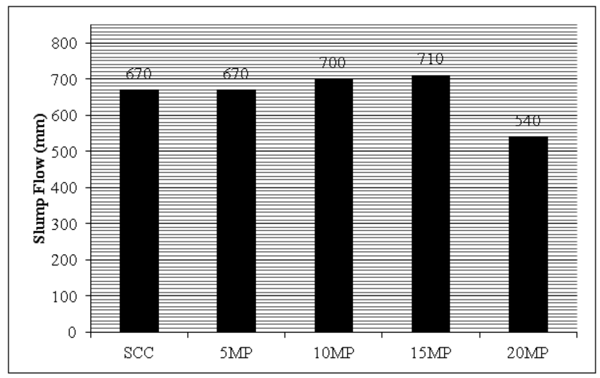

Fig. 4 Slump Flow Test Results

The slump flow of all mixes was within the ACI and EFNARC limits except the 20MP mix (i.e. 540 mm). The time taken by concrete to reach a slump flow of 500 mm was also recorded and designated as T_{50} cm slump flow (Figure 5). ACI 237 and EFNARC (2002) both states 2 to 5 seconds as satisfactory range. All mixes satisfied the above mentioned limits except 20MP (i.e. 6 seconds).

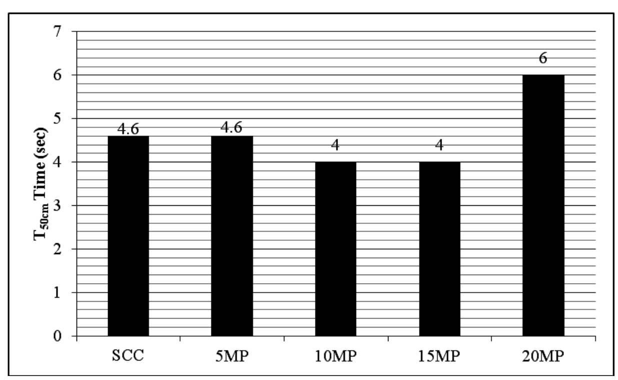

Fig. 5 T_{50}cm Slump Flow Test Results

4.2 J-Ring Test

This test is used to determine the passing-ability of concrete. In this test, the concrete is allowed to flow through a ring of reinforcing bars. Slump cone is fitted with the ring of reinforcing bars around the base of slump cone. The slump cone is lifted and concrete passes through the ring of reinforcing bars. The spread of concrete after passing through the J ring and the heights of concrete just inside and outside of the ring are measured (Figure 6).

This test was done in accordance with ACI 237R (2007), ASTM C 1621 and EFNARC (2002). In this test, the horizontal spread of concrete is measured. This measured spread is compared with the unconfined slump flow.

Fig. 6 J Ring Test

ACI 237R (2007) suggests that the difference between the unconfined slump flow and J ring slump flow should not exceed 50 mm. For mixes where the difference between unconfined slump flow and J-Ring slump flow exceeds 50 mm, blockage may occur. Marble powder replacement up to 15 % by weight of cement showed satisfactory performance in terms of passing-ability (Figure 7).

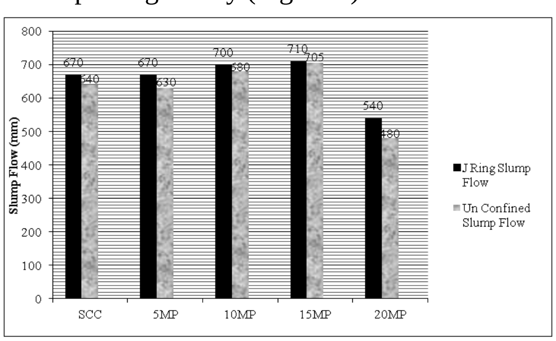

Fig. 7 J Ring Test Results ASTM C 1621

Additionally, following FENARC (2002), the height of concrete just inside and outside of the J ring was measured. As per EFNARC (2002), the concrete shows good passing-ability if this difference is less than 1cm. This was satisfactory for mixes up to 15% WMP (Fig. 8).

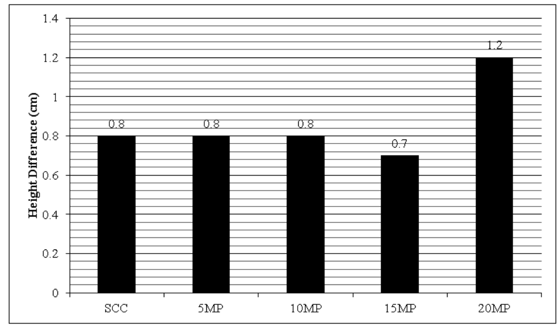

Fig. 8 J Ring Test Result EFNARC

4.3 L-Box Test

This test is also used to determine the passing-ability of concrete. Concrete is allowed to pass through 800 mm long and 200 mm wide channel after passing through three equally spaced (35 mm) 12 mm steel bars in the beginning of channel (Figure 9). The height of concrete was checked at the end of the channel and just before the obstacle (i.e. the equally spaced bars) was checked. The ratio of heights of concrete at the end of channel and at its beginning (where the steel bars are installed) gives the blocking ratio. This test is proposed in both ACI 237R (2007) and EFNARC (2002) with similar procedures and limitations. A blocking ratio ranging from 0.8 to 1.0 is satisfactory in terms of passing-ability. Blocking ratio less than 0.8 may prone to passing-ability problems i.e. the mix which have very high viscosity (need some vibration) or a mix having segregation (unstable mix).

Fig. 9 L-Box Test

It can be seen in Figure 10 that all mixes up to 15 MP shows satisfactory results for passing-ability using L-Box test. However, the blocking ratio of 20MP mix was less than 0.8, which is the limiting value in both ACI 237 and EFNARC (2002). The 20MP of WMP gave unsatisfactory results mainly due to high cohesiveness of the mix.

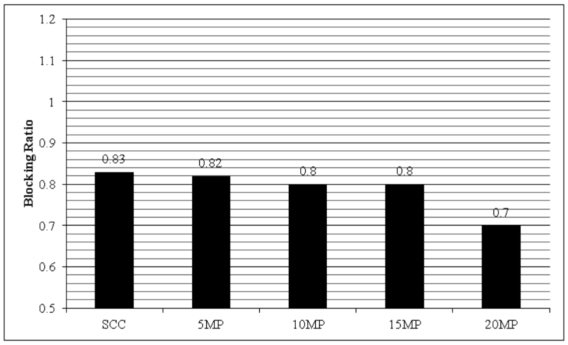

Fig. 10 L Box Test Results

4.4 Column Segregation Test

This test determines the static stability of concrete. In this test, freshly prepared concrete mix was filled in a 660 mm long and 200 mm diameter column and was allowed to stay for 15 minutes. This column can be separated in to three parts (Figure 11). Hence, after leaving the concrete in the standard prescribed column, the weights of aggregates in the concrete mix in upper and lower parts of the three parts column were determined. This was done by removing and collecting concrete in upper part of the column first, this concrete was washed on a standard #4 sieve, which washed away all the constituents except the coarser part of the aggregates. This left over part of aggregates was weighed in saturated surface dry condition. Similar procedure was used for the concrete in lower portion of the column. These amounts of aggregates gave percentage static segregation. ACI 237R (2007) suggests that the percentage static segregation should be less than 10% in SCC. As per ACI 237R (2007), a mix having less than 5% static segregation may require some vibration for filling completely. All mixes had shown percentage static segregation less than 10% (Figure 12). It was observed that the segregation resistance was increased with the increase in marble powder contents. However, for 20MP mix, percentage segregation is 3.7%; therefore, it may require some vibration for filling completely as per ACI 237 (i.e. percentage static segregation should be more than 5% for flowable concrete).

Fig. 11 Column Segregation Test

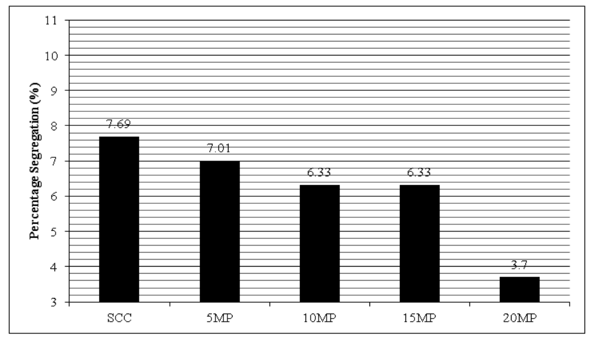

Fig. 12 Column Segregation Test Results

4.5 V-funnel test

This test gives an idea about filling or flowability of a concrete mix. In this test, the SCC was filled in a gated V-shaped funnel of standard dimensions (Figure 13). The filled concrete was allowed to flow through the funnel when the gate was opened. The time taken by the concrete mix to flow completely through this V shaped funnel was recorded as V-funnel time. V-funnel was again filled with the concrete mix. This refilled concrete mix was allowed to stay for 5 minutes, after which the gate was opened and again the time taken by concrete to flow completely through this V-funnel was recorded as V- funnel time at 5 minutes ($T_{5minutes}$) which gives an idea of the segregation resistance of concrete.

This test was done following EFNARC (2002).V-funnel time values are ranged from 8 to 12 seconds for adequate flowability. V-funnel flow time less than 8 seconds is for concrete having too low viscosity whereas, V-funnel flow time greater than 12 seconds represent high viscosity (the mix is having segregation issues).

V-funnel time $T_{5minutes}$ as suggested by EFNARC (2002) should not exceed 3 seconds from the V-funnel flow time. A segregating mix ($T_{5minutes}$ > 3 seconds) may take longer time due to blockage caused by aggregates accumulating in the lower portion of the funnel and may hinder the flow. Also longer V-funnel time $T_{5minutes}$ may be due to rapid loss in workability. Figure 14 shows that the V-funnel time of all mixes was in EFNARC (2002) satisfactory range i.e. 8 seconds to 12 seconds. Also, V-funnel time $T_{5minutes}$ was in the required satisfactory limit (i.e. increase in flow time was less than 3 seconds).

Fig. 13 V Funnel Test

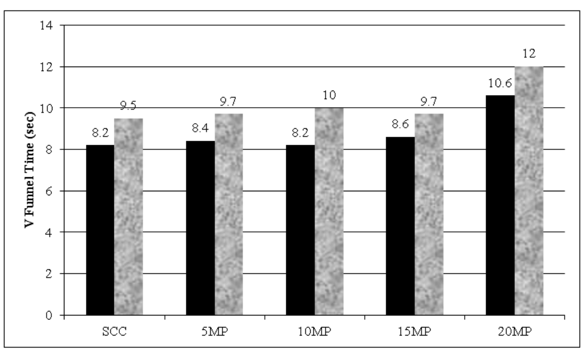

Fig. 14 V Funnel Test Results

No adverse effect of WMP addition upto 15% on fresh properties of SCC was observed; however, there was a decrease in flowing and passing abilities and an increase in segregation resistance with 20% replacement of cement with WMP. Similar findings were reported by Topcu *et al.* (2009). This could be due to the reason that filling the voids in a packed system may improve the arrangement of particles, ensuring a better contribution of the mixing water to achieve adequate fluidity of the mixture upto a certain critical dosage above which considerable increase in viscosity is expected (Topcu et al., 2009).

5. Tests on hardened concrete

Hardened concrete was tested for compressive and flexural strengths. Compressive strength tests were performed at the age of 7, 14 and 28 days to investigate the effect of marble powder addition on strength development of SCC. Compressive strength was determined following procedure in ASTM C 39. Three cylinders of 150 mm diameter and 300 mm height were casted for each testing age. The results of compressive strength tests are shown in Figure 15. The control mix had a 28 days compressive strength of 57.54 MPa. A decrease in compressive strength was observed by replacement of WMP with cement. The filler effect of WMP can be the reason of early age strength development. The similar results were reported in Topcu *et al.* (2009). Moreover, flexural strengths of four prisms (510×100×100 mm) were determined at the age of 28 days for all the mixes as per ASTM C 293. The flexural strength has also shown similar trend as in case of compressive strength. The results are in Figure 16.

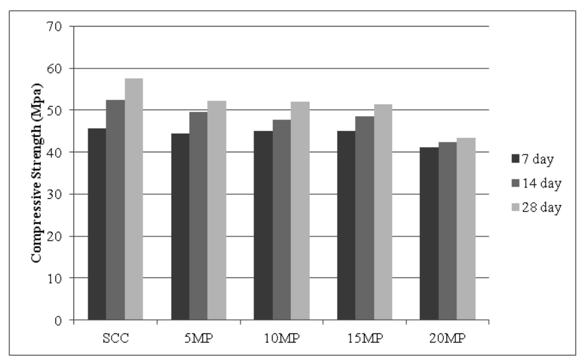

Fig. 15 Compressive Strength Test Results

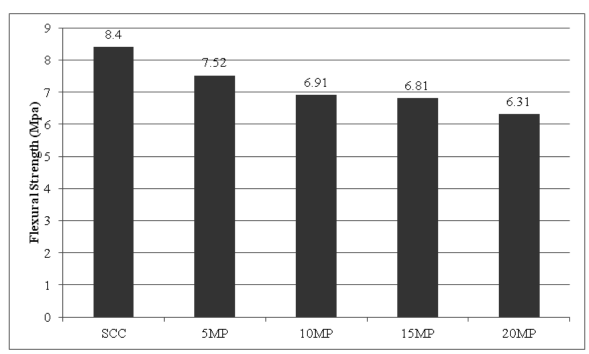

Fig. 16 Flexural Strength Test Result

6. Conclusion

Following conclusions are drawn from the experimental work:

1. Waste Marble Powder (WMP) can be effective filler for SCC concrete. It can be directly added to concrete without much processing.
2. When the fresh properties such as flowability, passing-ability and segregation resistance are considered, 15% of marble powder replacement has given good results.
3. Marble powder can be used up to 15% without much affecting compressive and flexural strengths.
4. It can be concluded that WMP replacement up to 15% by weight of cement can be considered as most favorable amount having particle size less than 150μm as a filler material in producing good quality SCC.

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