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Enhancement of Compressive Strength of Self Compacting Concrete Using Waste Marble Dust and Ground Granulated Blast Furnace Slag

Pratik Gajjar[1], Virendra Singh[1], Parth Thaker[2]

[1]*M.Tech. Scholar, Department of Structural Engineering Design, CEPT University, Ahmedabad, Gujarat, India*
[2]*Assistant Professor, Faculty of Technology, CEPT University, Ahmedabad, Gujarat, India*

Abstract —*In the past few years use of Self Compacting Concrete (SCC) is growing tremendous and much research and modification has been done to produce self compacting concrete which has the desired characteristics. Utilization of treated and untreated industrial and domestic waste as raw materials in concrete is a latest trend in the world. The present study focuses on utilization of Ground granulated blast-furnace (GGBFS) and waste marble dust in SCC as a partial replacement of cement. This research work represents the process of the development of the concrete for strength and durability aspects in various proportions varying from 0%, 10%, 15%, 20% and 25% marble dust as a replacement of cement along with ground granulated blast-furnace slag. The main aim of the study was to identify the best proportion of marble dust with ground granulated blast-furnace slag, which can be replaced with cement to get the desired strength and durability. The proportion of ground granulated blast-furnace slag was taken as 40% by weight of cement decided from previous studies published in various journals. The effect of marble dust is evaluated by performing the different tests on the cubes and cylinders to know its compressive strength at different intervals of days, splitting tensile strength tests. Tests of these specimens were conducted at 7, 28 and 56 days after casting.*

Keywords*-Ground Granulated Blast Furnace; Marble Dust; Self-Compacting Concrete; Strength Test; Workability Test*

I. INTRODUCTION

Concrete is one of the most used construction materials in the construction industry and it has become an excellent and important construction material in the infrastructure and industrial development due to its various advantages like good mechanical properties, highly durable, economical and under proper conditions, it is very permanent.
Since its demonstration in the later years of 1980's Self Compacting Concrete (SCC) has acquired a progressive change in the construction industry. Since the manufacturing procedure is substantially easy compared to the ordinary concrete, it is broadly utilized as a part of mass concreting works, construction of bridges, metro rail development projects and so on. The nature of concrete quality is vastly improved with SCC than the ordinary concrete. Another preferred standpoint is that less skilled workers are required in order to place, and finish concrete. Many countries have the deficiency of skilled workers on construction sites; therefore SCC has an additional advantage compared to ordinary concrete. SCC becomes extremely important material on construction sites. Superplasticizers and powder or viscosity modifying agents are extremely important ingredients of SCC. Superplasticizer in mix increases the flowability of material with low yield value while powder or viscosity modifying agents help to maintain the viscosity of the mix. Therefore, use of these two reduces the segregation and bleeding. Limestone powder, pulverized fuel ash (PFA), and granulated ground blast furnace slag are used as powder materials for SCC. To reduce the risk of blocking of concrete flow by congested reinforcement and narrow opening in the formwork, coarse aggregate content in SCC mix is much lower than the nominal mix.

The use of SCC had steadily increased in the recent years on construction site, looking to advantages of the SCC on over the normal vibrated mix concrete composition.
Following are the advantages of SCC over the conventional concrete.

- Easy placement of concrete in congested reinforcement
- Saved the construction times for large construction sites
- Reduced the noise pollution
- More homogeneous mix and good quality concrete across the entire concrete cross section
- Improve the surface finishes
- Conventionally high early strength of the concrete
- Reduced the labour requirements on construction site

SCC usage is on the rise worldwide for cast-in-situ and precast concrete construction. Many contracting agencies have shown interest and working to develop methodology and specification for SCC. Japan and Europe have done a lot of initial work and investigation to develop understanding and knowledge about SCC.
Blast furnace slag is a by-product obtained in the manufacture of pig-iron. It is a product formed by the combination of the earthy constituents of iron-ore with the limestone flux at high temperature in the blast furnace (about 15000 c). The molten slag is rapidly quenched by a hose of water to yield a glassy granular product called granulated blast furnace slag. Hydrated slag's, granulated or palletized, give the same hydrates as Portland cement i.e., C-S-H and AF1 phases. As they

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react more slowly with water than Portland cement, they can be activated by different ways: chemically in presence of lime and sulphate activators, physically by grinding or thermally. Slag, which is obtained by grinding the granulated blast furnace slag, is highly pozzolanic in nature. Cement replacement levels of slag can be much higher than that of other pozzolanic materials, such as, Fly ash and silica fume. Generally, GGBS has higher 'CaO' content than other pozzolanas.
Use of these kinds of admixtures decreases the cost of SCC as well as increases its long-term performance. To assess the effectiveness of GGBS in SCC some of the parameters like chemical composition, hydraulic reactivity, and fineness have been carefully examined earlier It was seen that among these, the reactive glass content and fineness of GGBS alone will influence the cementitious/pozzolanic efficiency or its reactivity in concrete composites significantly.

II. LITERATURE REVIEW

P, Jeeva. S, Dhinesh.A, Manoj Kumar. R, Subramanian. M (2013). They studied a review on the development of self-compacting concrete with mineral admixture silica fume. Silica fume is added at 10%, 12.5%, and 15% of cement weight. They have performed slump test, v funnel test, J-ring test, L-box test and U-box test on the fresh properties of SCC, and some NDT tests on thehardened properties of SCC ultrasonic pulse velocity test and compressive strength test by rebound hammer test. They suggested not to use more than 6% silica fume in the concrete mix, and SCC gives resistance against corrosion, freeze-thaw actions, and sulfate attack due to reduced porosity.

Kennouche .S, Zelizer .A, Benmounah .A, Hami .B, Mahdad .M, Bernoulli .H and Bijou .S (2013). They studied the various properties of SCC mixing silica fume in 15% weight of the cement, Portland cement of two different type, polycarboxylates and plynaphtalen two types of admixtures, 3/8 mm and 8/15 mm aggregates are used coarse and fine sand of fineness modulus 3.2 and 1 are used and French association of civil engineering's recommendations are used for the mix design. After performing the tests for both the fresh and hardened concrete they concluded that fixing the dosage of silica fume at 15% the fresh properties of SCC has given a good result, but the mechanical properties show that the compressive strength is higher 25 Mpa which shows very low porosity, which is because of silica fume as filler material, they studied that the viscosity of the cement paste is inversely proportional to the percentage of superplasticizer.

Huseyin Yilmaz Aruntas et al. (2010) studied the Utilization of waste marble dust as an additive in cement production. In this experimental study, the waste marble dust (WMD) as an admixture in blended cement has been investigated. For this purpose, waste marble dust added cements (WMDCs) have been obtained by inter grinding WMD with Portland cement clinker at different blend ratios: 2.5 %, 5.0 %, 7.5 % and 10 % by weight. Strength tests have been carried out on mortar specimen at 7, 28, and 90 days. WMDCs have been compared to each other as well as to control cements of CEM I and CEM II with respect to their physical, chemical and mechanical properties. Obtained results showed that WMDCs conform to EN 197-1 standard and thus 10 % WMD can be used as an additive material in cement manufacturing.

Er.Ranjodh Singh, Er.Rohin Kaushik, Er.Gurniwaz Singh (2013). they had tried to achieve SCC with high fluidity and cohesiveness by replacing the fine aggregates with brick dust and marble powder, both are waste materials in industry and harmful to the environment so they tried to use these byproducts to replace the fine aggregates in SCC. They used OPC 43 grade cement, with 37% standard consistency and 3.15 specific gravity, fine and coarse aggregates both with specific gravity 2.65 and fineness modulus 2.2 and 7.87 respectively. After conducting the tests they concluded that SCC can be obtained using both brick dust and marble powder, concrete with 25% marble dust possessed well-hardened properties, under certain conditions both marble dust and brick dust increase the strength of SCC.

Aravinth S. N. (2014) he tried to develop high strength self-compacting concrete of M60 with ordinary Portland cement 53 grade, silica fume, and superplasticizer GLENIUM B233 and tried to achieve SCC by trial mixes. He worked on EFNARC -2005 guidelines. After conducting the test for both fresh and hardened properties of SCC he concluded that reduction of w/p ratio (water powder ratio) increases the compressive strength, optimum dosage of chemical admixture is 1.5%-2%, below 1.5% of SP would affect the workability and over dosage would affect setting time, dosage of SP would vary linearly with the weight of cementitious materials, water content should be selected carefully before adding VMA because rheological behavior is more sensitive to water, results shows that concrete with 15-17.5% silica fume gives compressive strength 60.75 Mpa to 70.92 Mpa for w/p ratio 0.368 to 0.334.

Prince Arulraj et al. (2013) carried out an experimental investigation on use of granite powder as an alternative material for fine aggregate in concrete production. The percentages of granite powder added by weight to sand by weight were 0, 5, 10, 15, 20 and 25. To improve the workability of concrete 0.5 % Superplasticiser was added. This attempt has been done due to the exorbitant hike in the price of fine aggregate and its limited availability due to the restriction imposed by the government of Tamil Nadu. Fifty four cubes and 36 cylinders were cast. Compressive strength and split tensile strength were found. The test results indicate that granite as replacement sand with granite powder has a beneficial effect on the mechanical properties such as compressive strength and split tensile strength of concrete.

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III. MATERIAL USED IN PRESENT STUDY

The ingredients such as cement, aggregates and admixtures, used for the production of Self Compacting Concrete shall generally satisfy the requirements of IS 456: 2000.

3.1 Cement

General suitability is established for cement conforming to IS 12269: 1987. The cement used for experiment was Ordinary Portland Cement of grade 53. The properties of cement are found out by lab testing such as chemical constituents and physical properties such as fineness specific surface and specific gravity etc. The tests were carried out as per the Indian Standards. (Courtesy: Hathi Cements PVT LTD)

Table 1 Properties of Cement

Particulars	Test Results
Magnesia (% by mass)	3.79
Sulphuric Anhydride (% by mass)	2.49
Total loss on ignition (% by mass)	1.49
Total Chloride (% by mass)	0.037
Al_2O_3/Fe_2O_3	1.16
Insoluble Residue (% by mass)	0.54

Table 2 Physical Analysis Data

Test	Test Result
Fineness Specific Surface	315
Initial Setting Time (min)	175
Final Setting Time (min)	280

3.2 Ground Granulated Blast-Furnace Slag

Ground granulated blast-furnace slag provides reactive fines with a low heat of hydration. GGBFS is already present in some cement but is also available as an addition in some countries and may be added at the mixer. A high proportion of GGBFS may affect stability of SCC resulting in reduced robustness with problems of consistence control while slower setting can also increase the risk of segregation. Ground blast furnace slag is also available in some countries as a type I addition. (Courtesy: GURU Metachem)

Table 3 Properties of GGBFS

Characteristic	Test Results
Magnesia content (%)	8.25
Sulphide Sulphur (%)	0.68
Sulfate content (%) as SO_3	0.15
Manganese content (%)	0.32
Chloride content (%)	0.001
Glass content (%)	91.73
Moisture content (%)	0.02
Loss on Ignition (%)	0.36
Insoluble Residue (%)	0.25

Table 4 Physical Analysis Data

Test	Test Result
Fineness Specific Surface	362
Initial Setting Time (min)	205

3.3 Aggregates

Aggregates are used for mix shall conform to IS 383: 1970. The maximum size of the aggregates majorly depends on the application and is limited to 20 mm in maximum cases. Particles smaller than 125 micron contributes to the powder content. The moisture content should be properly monitored and must be kept into account in order to produce same consistent SCC mix.

Aggregates are one of the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Earlier, aggregates were considered as chemically inert materials but now it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that the aggregates occupy 70–80 per cent of the volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.

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Aggregates were used in our experimental work were same as they were used in normal construction work and purchased from a local dealer.
Both coarse and fine aggregates were in Saturated-Surface-Dry (SSD) condition. The maximum size of coarse aggregate was 20mm, and fine aggregates are in the form of Sand.

3.4 Marble Dust

Marble dust used for experimental work was acquired from a quarry of marble dust at Palanpur. The properties of marble dust are found out by lab testing such as chemical constituents and physical properties such as fineness specific surface and specific gravity etc. The tests were carried out as per the Indian Standards.

Table 5 Properties of Marble Dust

Oxides	%weight
CaO	50.87
SiO_2	7.27
Al_2O_3	0.11
MgO	0.84
SO_3	0.37
Na_2O, K_2O	-
Loss by Ignition	39.76
Total Chloride	-
Fe_2O_3	0.45

Table 6 Physical Analysis Data

Test	Test Result
Fineness Specific Surface	128
Specific Gravity	2.69

3.5 Mixing Water

Suitability is established for mixing water and for recycled water from concrete production conforming to IS 456: 2000.

3.6 Admixtures (Superplasticiser)

Admixtures used shall be complying with IS 9103: 1999, when appropriate. Superplasticizers are an essential component of SCC to provide the necessary workability. Other types may be incorporated as necessary, such as Viscosity Modifying Agents (VMA) for stability, air entraining admixtures to improve freeze-thaw resistance, retarders for control of the settings, etc.
The admixture should bring about the required water reduction and fluidity but should also maintain its dispersing effect during the time required for transport and application. The required consistence retention will depend on the application. Precast concrete is likely to require a shorter retention time than for concrete that has to be transported to and placed on site. Superplasticiser used in experiment was based on second generation polycarboxylic ether polymers. (Provided in Product Manual: BASF)

Table 7 Performance Test Data for Superplasticiser

Aspect	Light Brown Liquid
Relative Density	1.10 ± 0.01 at 25°C
pH	≥ 6
Chloride ion content	<0.2%

3.7 Viscosity Modifying Agent

Admixtures which are used to modify the cohesion of the SCC without significantly alter the fluidity of mix are called as a viscosity modifying agents (VMA). These admixtures are reduce the effect of moisture content variations, fine aggregate fineness or its grading and also help to make SCC more robust and less sensitive to small variations in proportions and other side conditions. Although, a good mix design process and selection of other SCC ingredients should not be avoided by adding the VMA.

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Table 8 Performance Test Data for VMA

Aspect	Colourless free flowing liquid
Relative Density	1.10 ± 0.01 at 25˚C
pH	≥6 at 25˚C
Chloride ion content	<0.2%

3.8 Additions (including mineral fillers and pigments)

SCC requires special rheological characteristics, both inert and reactive additions are commonly used to enhance and maintain the fresh properties such as workability, as well as to regulate the cement content and so reduce the heat of hydration.

Typical additions are: Stone powder, Fly ash, Silica Fume, Ground Granulate Blast-Furnace Slag, Ground Glass Filler, Pigments and Fibers can also be effectively use.

IV. TEST PROGRAM AND METHODS

This investigation represents the process of the development of the concrete for strength aspects in various proportions varying from 0%, 10%, 15%, 20% and 25% marble dust as a replacement of cement along with ground granulated blast-furnace slag. The main aim of the study was to identify the best proportion of marble dust with ground granulated blast-furnace slag, which can be replaced with cement to get the desired strength and durability. The proportion of ground granulated blast-furnace slag was taken as 40% by weight of cement decided from previous studies published in various journals. The effect of marble dust is evaluated by performing the different tests on the cubes and cylinders to know its compressive strength at different intervals of days, splitting tensile strength tests (compressive strength of cubes after cured in sodium chloride and sulphuric acid for 56 days). Tests of these specimens were conducted at 7, 28 and 56 days after casting.

4.1. Methodology

Methodology followed for the experimental work is as follows.

- Test of various materials to be used.
- Concrete mix design for M30 grade of concrete.
- Tests for fresh properties of concrete.
- Casting of concrete specimens and curing.
- Testing of specimens and acquisition of data.
- Analysis, result and discussion.
- Conclusion.

4.2. Workability Test

4.2.1 V-Funnel Test

A V-funnel made to the dimensions (tolerance ± 1 mm) as shown in the Figure 1, fitted with a quick release watertight gate at its base and supported in such a way that the top of the funnel is horizontal. The V-funnel apparatus shall be made of metal and the surfaces of the metal be smooth, and not be such that it is not readily attacked by cement paste or be susceptible to rusting.

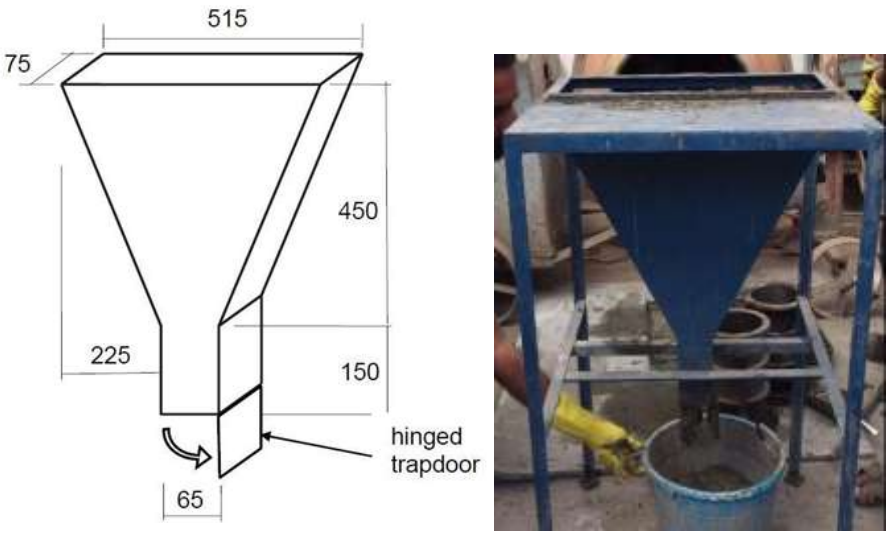

Figure 1 V-Funnel test Apparatus

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4.2.2 L-Box Test

L box, general dimensions are shown in the Figure 2. L box device is made by such material so it gives smooth and flat surface. L box device should be made by rust free. For ease of cleaning, vertical hopper may be required to remove; therefore its assembly should be easily removable. The required volume should be poured inside the L-box by closing the vertical hopper.

There are two arrangements which represent the reinforcement bars of elements. First arrangement has two 12 mm diameter bars having 59mm of spacing between them and second arrangement has three 12 mm diameter bars having 41mm spacing. These two arrangements are interchangeable.

L box test is used to measure the different properties of the concrete such as flowability, segregation, and blocking. Concrete is poured into the vertical shaft of L box and one minute time is given to rest the concrete in vertical shaft. Afterwards, concrete has allowed to flow by opening the vertical hopper. Concrete will pass from the reinforcement arrangement and it reaches to the other end. The time is recorded for concrete to reach to the other end. Once concrete is settled down, the distances H1 and H2 are measured.

The ratio of H2/H1 should be in between 0.8 to 1.0. Concrete stability and blocking ability can be measured by visual observation. If aggregates are placed in all the parts of horizontal shaft then concrete is stable.

Figure 2 L-Box test Apparatus

4.2.3 Slump-Flow Test

To determine the flowability and the stability of self-compacting concrete slump-flow tests are performed. The equipment is constructed of one flow table and one slump cone. The table is circular in shape on which a concentric diameter of 50cm is marked. The slump cone is kept in the center of the table and pressed against it while pouring concrete in the cone. Next, the cone is lifted vertically and the stop watch is started to note the time. Time foe the concrete to reach the 50cm diameter is recorded. After the concrete has stopped flowing, the final diameter to which the concrete has flowed and if necessary any segregation border at the concrete periphery is measured.

Figure 3 Slump Flow Test

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4.3 Strength Test

4.3.1 Compressive Strength Test

Compression tests were conducted to investigate the ultimate strength of concrete with ground granulated blast-furnace slag and Marble Dust as replacement of cement in various proportions. Compression tests were conducted on three 150mm x150mm x 150mm concrete cubes after 7, 28 and 56 days of casting. The tests were done on Compressive Testing Machine (CTM).

The compressive strength of a sample was calculated using,

$$C= P/A$$

Where,
C = Compressive Strength (N/mm^2)
P = Total load on specimen at point of failure (N) A =Area of the specimen (mm^2)

4.3.2 Splitting Tensile Test

Tensile strength is measured by this particular test by using Compressive Testing Machine. The concrete cylinder specimens are being tested at 28th and 56th days. A concrete cylinder of size 300mm height and 150mm diameter is subjected to the action of compressive force along two opposite edges. For the uniform distribution of loads two steel plates were placed at those two particular edges only to transfer the compressive force, it doesn't take part into load carrying capacity of cylinder. The cylinder is placed with its axis horizontal between the plates of the testing machine, and the load is increased until the failure takes place along the length of cylinder and splits the cylinder in two.
The tensile strength is found out by using equation,
$T=2P/\pi LD$
Where,
T= Tensile strength of concrete (N/mm2)
P= Compressive load on the specimen at the time of failure (N)
L= Length of the specimen (mm)
D= Diameter of the specimen (mm)

Figure 4 Compressive Strength test Machine with Specimen

V. LABORATORY TEST RESULTS AND DISCUSSION

5.1 Workability Test Results

The results of V-Funnel test for different percentage of ground granulated blast-furnace slag and marble dust as a replacement of cement are shown in table below. Based on the results from V Funnel test it can be observed that, filling ability of the self compacting concrete with replacements by fly ash and marble dust are consistence with the result for control mix.

Table 9 Workability Test Result

Sr. No	Mix ID	V-Funnel (S)	L-Box	Slump Flow (mm)
1	G0Md0	7	0.8	650
2	G40Md0	8	0.9	655
3	G40Md10	8	0.91	655
4	G40Md15	7.5	0.98	670
5	G40Md20	8	0.9	665
6	G40Md25	10	0.8	650

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Based on the results from V Funnel test it can be observed that, filling ability of the self compacting concrete with replacements by GGBFS and marble dust are consistence with the result for control mix, except in case of G40Md25 it can be seen that V Funnel time increases by 2 seconds which shows that for that SCC mix filling ability is slightly decreases. Here it can be noticed that increase in content of GGBFS and marble dust slightly reduces filling ability of SCC.
Above test results for L Box test represent that passing ability of the self compacting concrete for different mixes depends on the GGBFS and marble dust contents. Results shows that passing ability of the SCC increases upto replacement of cement by 40% GGBFS and 15 % marble dust, further increase in marble dust content passing ability of SCC starts to reduce mainly because of the lumps formed in the SCC mix.
Based on the above test results, it can be observed that Slump flow in case of self compacting concrete increases effectively from 650 mm to 670 mm for control mix and G40Md15 respectively, further increase in marble dust content reduces the slump flow of the SCC, it was observed during testing that reduction in slump flow mainly happen due to formation of lumps and segregation of aggregates.

5.2 Compressive Strength Test Results

The results of compressive strengths for different percentage of ground granulated blast-furnace slag and marble dust as a replacement of cement at the age of 7, 28 and 56 days are shown in table below.

Table 10 Compressive Strength Test Result

S. No.	Mix ID	Compressive Strength (N/mm²)		
		7th Day	28th Day	56th Day
1	G0Md0	27.76	38.01	43.57
2	G40Md0	27.92	38.32	44.36
3	G40Md10	27.95	39.68	44.66
4	G40Md15	21.97	33.29	37.83
5	G40Md20	20.60	26.42	31.48
6	G40Md25	18.94	24.90	28.77

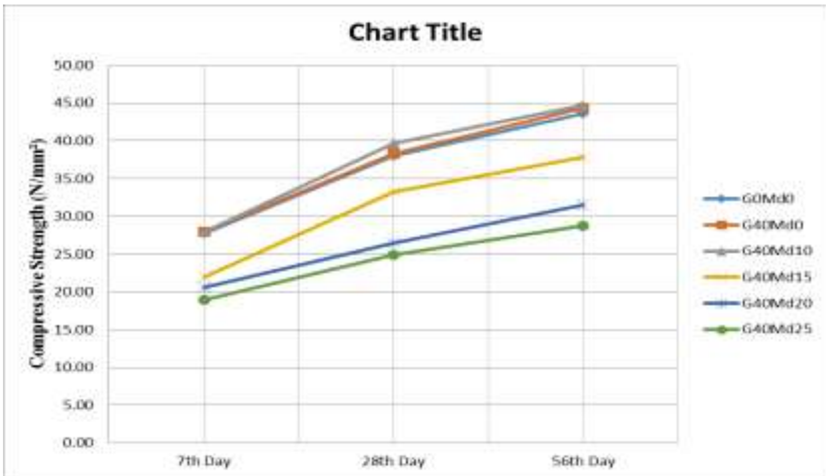

Figure 5 Compressive Strength test results for different mixes of SCC

Results from the compressive test represent that for replacement of cement by marble dust upto 10%, compressive strength of the SCC gives comparatively higher results than Control mix.
Compressive strength for the replacement of cement by 40 % GGBFS and 10 % marble dust gives higher results than control mix and almost same result as when cement is replaced by only 40% GGBFS. Further increase in marble content starts to decrease the compressive strength of the SCC.
Also rate of gaining of strength is also higher for upto replacement of cement by 40% GGBFS and 10% marble dust. Results for 28th day of testing shows that first four mixer were able to gain the required strength for M30 grade of concrete. While results for the 56th day of testing shows that first five mixes were able to obtain the required compressive strength for M30 grade of concrete.

5.2 Splitting Tensile Strength Test Results

The results of splitting tensile strengths for different percentage of ground granulated blast-furnace slag and marble dust as a replacement of cement at the age of 28 and 56 days are shown in table below.

Table 11 Splitting Tensile Strength Test Result

Sr No.	Mix ID	Splitting Tensile Strength (N/mm^2)	
		28th Day	56th Day
1	G0Md0	3.78	3.80
2	G40Md0	3.74	3.75
3	G40Md10	3.79	3.80
4	G40Md15	2.96	3.03
5	G40Md20	2.27	2.46
6	G40Md25	2.10	2.28

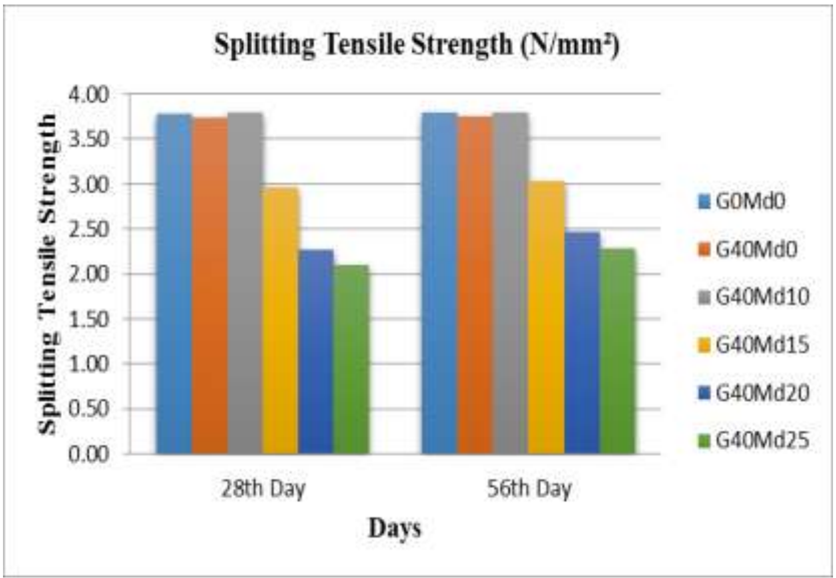

Figure 6 Splitting Tensile test results for different mixes of SCC

Results for the splitting tensile strength shows that tensile strength of the SCC for the replacement of cement by 40% GGBFS and 10% marble dust gives almost same results as control mix at both 28th day and 56th day. Further increase in the marble dust content reduces the splitting tensile strength of the concrete.

V. CONCLUSION

A few generalized conclusions are summarized below:

- The present study was carried out for M30 grade of self compacting concrete mix with replacement of cement with different proportions of marble dust (10%, 15%, 20% and 25%) and 40% of ground granulated blast-furnace slag.
- It is recommended that, at minimum, Slump test, L-Box test and V-Funnel should be performed for the laboratory verification tests.
- Test performed on fresh concrete (i.e. Slump test, L-Box and V-Funnel) resulted in almost similar result for all different mix proportions. SCC with marble dust and fly ash for replacement upto 20% by marble dust show slightly better performance of fresh SCC than control mix.
- The study reveals that cement replacement by 10% and 15% of marble dust and 40% of GGBFS achieves required compressive strength at 7 and 28 days.
- The test results shows that cement replacement by 10% of marble dust and 40% of GGBFS gain required splitting tensile strength at 28 and 56 days.
- From compressive strength test and splitting tensile strength test it can be concluded that the best proportion of marble dust and GGBFS are 10% and 40% respectively with 28 days of curing.

One can extend the work in this area by taking concrete grade other than M30 and by taking marble dust from the different region. The properties studied in this experimental work were compressive strength, tensile strength and Durability test of self compacting concrete. Other properties such as flexural strength, modulus of elasticity and abrasion resistance etc. can also be studied in detail.

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