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Self-Compacting Concrete with Mineral Admixtures: An Experimental Study

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Abstract- Self-Compacting Concrete (SCC) has emerged as an advanced construction material due to its ability to flow under its own weight, completely fill formwork, and achieve full compaction without the need for external vibration. This experimental study investigates the influence of selected mineral admixtures on the fresh and hardened properties of SCC, aiming to enhance its performance and sustainability. Mineral admixtures such as fly ash, ground granulated blast furnace slag (GGBS), and silica fume were used as partial replacements of cement at varying proportions. The fresh properties of SCC were evaluated using standard tests including slump flow, T_{50} time, V-funnel, and L-box tests to assess filling ability, passing ability, and segregation resistance. Hardened properties were examined through compressive strength, split tensile strength, and flexural strength tests at different curing ages. The results indicate that the incorporation of mineral admixtures significantly improves the workability, flow characteristics, and long-term strength of SCC while reducing cement content and heat of hydration. Among the mixtures studied, SCC incorporating an optimum combination of mineral admixtures exhibited superior performance compared to conventional SCC. The study confirms that the effective use of mineral admixtures in SCC not only enhances mechanical and rheological properties but also contributes to sustainable and eco-friendly concrete production.

Keywords: Self-Compacting Concrete, Mineral Admixtures, Fly Ash, GGBS, Silica Fume, Fresh Properties, Mechanical Properties, Sustainable Concrete.

I. INTRODUCTION

General

Development of self-compacting concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in place concrete. Self-compacting concrete (SCC) is an innovative concrete does not require vibration for placing and compaction it is able to flow under its own weight completely filling form work and achieving full compaction even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

Self-compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure and, due to its high-fluidity and resistance to segregation it can be pumped longer distances. The concept of self-compacting concrete was proposed in 1986 by Professor Hajime Okamura (1997), but the prototype was first developed in 1988 in Japan, by Professor Ozawa (1989) at the University of Tokyo. Self-compacting concrete was developed at that time to improve the durability of concrete structures. Since then, various investigations have been carried out and mainly large construction companies have used SCC in practical structures in Japan.

Investigations for establishing a rational mix-design method and self-compatibility testing methods have been carried out from the view point of making it as standard concrete. Self-compacting concrete is cast so that no additional inner or outer vibration is necessary for the compaction. It flows like "honey" and has a very smooth surface level after placing. With regard to its composition, self- compacting concrete consists of the same components as conventionally vibrated concrete, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in different proportions. Usually, the chemical admixtures used are high-range water reducers (super plasticizers) and viscosity-modifying agents, which change the rheological properties of concrete. Mineral admixtures are used as an extra fine material, besides cement, and in some cases, they replace cement. In this study, the cement content was partially replaced with mineral admixture, e.g. flash, slag cement, and silica fume, admixture that improve the flowing and strengthening characteristics of the concrete.

II. TEST METHODS OF S.C.C

General

It is important to appreciate that none of the methods for SCC has yet been standardized, and the test described are not yet perfected or definitive. The methods presented here are descriptions rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised specifically for SCC.

Existing rheological test procedures have not been considered here, though the relationship between the results of these tests and the rheological characteristics of the concrete is likely to figure highly in future work, including standardization work. Many of the comments made come from the experience of the partners in the EU-funded research project on SCC. A further EU project on test methods is about to start. In considering these tests, there are a number of points, which should be taken into account:

- One principal difficulty in such tests is that they have to assess three distinct, though related, properties of fresh SCC – its filling ability (flowability), its passing ability (free from blocking at reinforcement), and its resistance to segregation (stability). No single test so far devised can measure all three properties.
- There is no clear relation between test results and performance on site.
- There is little precise data: therefore, no clear guidance on compliance limits:
- Duplicate tests are advised
- The tests methods and values are stated for maximum aggregate size of up to 20mm different test Values and/or different equipment dimensions may be appropriate for other aggregate sizes.
- different test values may be appropriate for concrete being placed in vertical and horizontal elements;
- similarly, different test values may be appropriate for different reinforcement densities;
- In performing the tests, concrete should be sampled in accordance with EN 12350-1. It is wise to remix the concrete first with a scoop, unless the procedure indicates otherwise.

III. EXPERIMENTAL INVESTIGATION

Objectives

The objectives of experimental study that was conducted are given below:

- Development of SCC mixes with the least amount of cement but with a target compressive strength
- To use the lowest possible water/powder ratio in the development of the SCC mixes.
- To conduct tests on hardened SCC for strengths.

Materials Used

The following materials are employed in the present investigation

Cement 53 grade

Ordinary Portland cement of 53 grade from the local market was used and tested for physical and chemical properties as per IS: 4013-1988 and found to be confirming to various specifications of are 12269-1987.

The Cement used for this study is ordinary Portland cement conforming to the Indian standard IS: 12269(1987), of grade 53.

Table 4.1 Properties of cement

PROPERTY	RESULT
Specific gravity	3.11
Fineness modulus	6.3%
Initial setting time	35 min

Fine aggregate

In the present investigation, fine aggregate, Natural River sand was obtained from local market. The physical properties of fine aggregate like specific gravity, bulk density, gradation and fineness modulus are tested in accordance with IS-2386.

The sand is collected from nearby area; the sand has been sieved in 4.75 mm sieve and Table 4.2 shows the properties of fine aggregate.

Table 4.2 Properties of fine aggregate

PROPERTY	RESULT
Specific gravity	2.62
Fineness modulus	2.72
Zone according to IS383-1970	Zone II

Coarse aggregate

The crushed coarse aggregate of 10mm maximum size was obtained from the local crushing point. The physical properties of coarse aggregate like specific gravity, bulk density, gradation, and fineness modulus are tested in accordance with IS -2386.

The coarse aggregate chosen by shape as per IS: 2386 (part 1) (1963), surface texture characteristics of the aggregate as classified in IS: 383 (1970).Table 4.3 shows the properties of coarse aggregate obtained from tests.

Table 4.3 Properties of coarse aggregate

PROPERTY	RESULT
Specific gravity	2.6
Fineness modulus	6.15
Aggregate impact value	30.23
Crushing value	18.8

Fly ash

In the present investigation work, the TYPE-II fly ash was used as cement replacement material. It is obtained from Vijayawada thermal power station in Andhra Pradesh. The specific surface of fly ash is found to be 4750 cm^2/gm by Blaine's permeability apparatus.

Viscosity Modifying Agent (VMA)

The inclusion of VMA ensured the homogeneity and the reduction of the tendency of the highly fluid mix to segregate. Glenium-2 VMA of M/S BASF INDIA LTD.Is used for this work. Performance fluctuations due to variation in the material quality and the moisture in aggregate are attenuated by the VMA making quality control easy.

Super plasticizer

Super plasticizer (3233 of M/S BASF INDIA LTD) was employed for the preparations of SCC.

Steel fibers

It has been shown that design recommendations for traditional vibrated steel fiber reinforced concrete (SFRC) can also be used for steel fiber reinforced self-compacting concrete (SFRSCC). The mix design of SFRSCC may be carried out based on an existing SCC mix. There is no problem to use the concrete mix for normal SCC when less than 30 kg/m^3 of fibers is used. If 30-60 kg/m^3 is added a test of the mix is required before use, and if the amount of steel fibers exceeds 60 kg/m^3 it is probably necessary to increase the filler content or increase the sand-to-coarse aggregate ratio in the mix composition.

Water

This is least expensive but most important ingredient of concrete. The water which is used for making concrete, should be clean and free harmful impurities such as oil, alkali, acid, etc.., in general the water which is fit for drinking should be used for making concrete.

IV. RESULTS AND DISCUSSION

The results of experimental investigation are discussed as follows

WORKABILITY RESULTS

For the fibre reinforced triple blended SCC, the results of workability tests are shown in Table 4.9. For the various mixes considered, the slump flow times (50cms diameter) results are between 2 to 5 seconds. Similarly the V-Funnel timings are in between 8 to 12 seconds. The measured timings satisfy the EFNARC specifications for SCC mixes. It is generally observed that the timings are on the higher side for higher percentages of steel fibre and higher aspect ratios.

In the experimental investigations M40 concrete mix is designed and used. It can be seen that super plasticizer (Glenium B 233) was used in 1.0% percentage. The Viscosity Modifying Agent (Glenium stream 2) used in the investigation was maintained constant at 0.1%.

The Table 4.9 shows that trial mix 3 as satisfied the SCC criteria when 1.0% SP and 0.1% VMA is added so the trial mix 3 is the final mix proportion which should be adopted for doing the study

This shows that the optimum percentage of super plasticizers is 1.0% and the VMA is 0.1 respectively for both the mix considered. With these percentages, fibre reinforced self-compacting concrete satisfying the requirements can be produced.

Compressive Strength

Compressive strength of concrete is defined as the load, which causes the failure of a standard specimen divided by the area of cross section in uniaxial compression under a given rate of loading. The test of compressive strength should be made on 100mm size cubes and the formula for compression test is equation (5.1).

Compressive strength = P/A (5.1)

Where P= the compressive load on the cube.
A= Area of cube (100x100mm)

The compressive strength results are shown in the Table 5.1. The compressive strength of reference concrete without blending and without fibres is more than 40N/mm2 respectively, which satisfies the design requirements. The concrete mix with triple blending (Fly ash 20% & CSF 10%) is showing higher strength than the reference mix.The mineral admixtures like CSF contribute towards increase in the strength in addition to giving additional beneficial properties. It can be seen from table 5.1 and figs 1 to 3 that the compressive strength of SCC of M40 grades is increasing with increase in fibre percentage. There is increase in the compressive strength with aspect ratio also. In the present investigation the maximum percentage of fibre is kept at 0.4 and the maximum aspect ratio was 30. The strength is higher with an aspect ratio of 20 Hence it is clear that up to certain optimum percentage and optimum aspect ratio, steel fibre contribute towards strength increase.

The strengths are further increased with the presence of steel fibres. The highest compressive strength was obtained with 0.2% fibre and an aspect ratio of 20 with avalue of 69.65 N/mm2. Compared to reference concrete, the strengths have increased by nearly 40 to 45% in M40 MIX, compared to triple blended mixes without fibre the respective increases are nearly 30 to 35% in the case of both the mixes. The admixtures contributed towards increased strength.

Influence Of Fibre Percentage On Strength

As discussed earlier it can be seen that as the fibre percentage is increased, the respective strengths are increasing. The strength increase is more in the case of split tensile strength and the flexural strength. In the case of SCC higher percentages of steel fibre interfere with the flowability of SCC. Hence the percentage of fibre is restricted at 1.0. Up to this optimum percentage, the strengths increase. The optimum percentage of steel is found to be 0.20% and the optimum Aspect Ratio is 20. The highest values are recorded with combination of Fly ash-20.0 and Condensed silica fume -10.0. It can be stated that steel fibre reinforcement has contributed towards increased strength. From this it can be further stated that steel fibre reinforcement results in higher split tensiled flexural strength

Fig. 5.1 Cube before testing

Fig. 5.2 Cube after testing

Fig. 5.3 Compression testing machine

Compressive strength of different batches of self-compacting concrete

Table 5.1

S.No	CODE No.	FIBRE PERCENTAGE	ASPECT RATIO	FLYASH PERCENTAGE	CONDENSED SILICS FUME	AVERAGE CUBE COMPRESSIVE STRENGTH AT 28 DAYS N/mm^2	ULTIMATE LOAD (KN)
1	H0	0.00	0	0	0	43.75	437.5
2	H1	0.10	10	0	0	43.90	439.0
3	H2	0.10	20	0	0	51.60	516.0
4	H3	0.10	30	0	0	42.14	421.4
5	H4	0.10	10	20	0	48.75	487.5
6	H5	0.10	20	20	0	50.81	508.1
7	H6	0.10	30	20	0	44.50	445.0
8	H7	0.10	10	20	10	44.72	447.2
9	H8	0.10	20	20	10	49.28	492.8
10	H9	0.10	30	20	10	42.25	422.5
11	H10	0.20	10	0	0	46.40	464.0
12	H11	0.20	20	0	0	46.55	465.5
13	H12	0.20	30	0	0	39.31	393.1
14	H13	0.20	10	20	0	51.42	514.2
15	H14	0.20	20	20	0	55.45	554.5
16	H15	0.20	30	20	0	44.72	447.2
17	H16	0.20	10	20	10	59.30	593.0
18	H17	0.20	20	20	10	69.65	696.5
19	H18	0.20	30	20	10	54.15	541.5
20	H19	0.30	10	0	0	47.90	479.0

21	H20	0.30	20	0	0	48.20	482.0
22	H21	0.30	30	0	0	42.67	426.7
23	H22	0.30	10	20	0	52.40	524.0
24	H23	0.30	20	20	0	53.30	533.0
25	H24	0.30	30	20	0	51.64	516.4
26	H25	0.30	10	20	10	59.50	595.0
27	H26	0.30	20	20	10	64.30	643.0
28	H27	0.30	30	20	10	56.74	567.4
29	H28	0.40	10	0	0	48.20	482.0
30	H29	0.40	20	0	0	49.50	495.0
31	H30	0.40	30	0	0	48.00	480.0
32	H31	0.40	10	20	0	53.50	535.0
33	H32	0.40	20	20	0	54.75	547.5
34	H33	0.40	30	20	0	52.80	528.0
35	H34	0.40	10	20	10	59.90	599.0
36	H35	0.40	20	20	10	63.72	637.2
37	H36	0.40	30	20	10	58.50	585.0

Influence Of Aspect Ratio Of Steel Fibre

As the aspect ratio of the fibre increase it can be seen that there is increase in the strength. Increase in the aspect ratio particularly contributes towards more flexural strength but there is limit for higher aspect ratios particularly in the case of SCC. When the aspect ratio is high it interfears with the flow of concrete because its weight is more. With higher aspect ratios there may be balling effect also. In the present investigation the optimum Aspect ratio is found to be 20.0.

Cracking Characteristics

In the case of plain SCC specimens, the specimens crack and fail simultaneously. In the case of fibre reinforced SCC, the specimens have undergone gradual and ductile failure. Fibres have helped SCC to possess better cracking beheviour and made it more ductile.

Hence in the case of fibre reinforced SCC, cracking behaviour is gradual and it has become more ductile.

Use Of Triple Blending

Triple blending of cement using mineral admixtures like fly ash and silica fume, helps the concrete mix to flow smoothly and contributes towards strength increase. Besides use of mineral admixtures in certain proportions in concrete matrix, improves the durability property. In the present investigation, M40 concrete mixes were adopted as the reference mixes and triple blending was carried out with 20%fly ash and 10% silica fume. In this case, the benefit received in strength out of triple blending may be marginal but in the case of high strength concrete mixes and high performance concrete, triple blending really helps in strength gaining and durability. Hence for practical modern concrete construction where SCC is employed, triple blending of cement using mineral admixtures in is very much desirable.

V. CONCLUSIONS

Based on the experimental project work conducted, the following conclusions are drawn

1. The optimum percentage of super plasticizer is 1and the VMA is 0.15 respectively. With these percentages, fibre reinforced self-compacting concrete satisfying the requirements can be produced.
2. The concrete mix with triple blending (fly ash 20% and silica fume 10%) shows higher strength than the reference mix.
3. The highest compressive strength was obtained with 0.2% fibre and an aspect ratio of 20. with

triple blending. The comparative strength has increased by nearly 40 to 45%.

4. The values of Young's Modulus are found to be increasing with the addition of fibres. The highest values are recorded at 0.40% fibres with an aspect ratio of 20.
5. Poisson's Ratio is found to be decreasing with increase in the percentage of fibre.
6. In case of fibre reinforced SCC, cracking behaviour is gradual and it is more ductile.
7. For practical modern concrete construction where SCC is employed, triple blending of cement using mineral admixtures is very much desirable.
8. In practical SCC constructions, use of fibres in concrete matrix helps in increasing the impact strength.

Suggestions For Future Work:

Further work may be carried out on triple blended mixes with various other mineral admixtures like GGBS, Metakaoline, Rise husk ash etc. The percentages may be varied. Fibres like glass, poly propylene, polyester etc., may be tried in combination with steel fibres. Other tests for impact permeability acid resistance etc., may be carried out. Extended periods of curing may be adopted.

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