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MIX DESIGN OF SELF COMPACTING CONCRETE USING SUPERPLASTISIZERS (VISCOSITY, MODIFYING AGENT)

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Abstract - Self compacting concrete (SCC) was developed in Japan. SCC technology was originally made possible by the much earlier development of superplasticizers for concrete. It is a highly flowable concrete which gets compacted and fills the formwork completely under its own weight without any application of any external force and vibration. The main objective of this research is to develop a mix design for SCC which will have wide range of strength, workability and durability. For achieving the required objective, the study involves the optimization of 3 phases, which are paste phase, aggregate phase and concrete (casting) phase. The optimization of paste phase can be done by using paste studies. The optimum Super Platicizer (SP) dosage can be done by using marsh cone test and mini slump test and we can know the workability properties of SCC such as filling ability, passing ability, and segregation resistance can be found using workability tests such as slump flow, V-funnel and J-ring tests. A combination of cement and fly ash of 50:50 (by volume) or cement and GGBS (Ground Granulated Blast Furnace Slag) of 60:40 (by volume) has been found to get maximum particle packing density. The purpose of this research is to find the concept of enabling increase in robustness of SCC along with mix design. Micro level studies showed that aggregate moisture is responsible for the variation in rheological response in SCC. The ability of viscosity modifying agents (VMA) to increase robustness is being studied.

***Keywords*:** Self compacting concrete, superplasticizers, workability, filling ability, passing ability, segregation resistance, flyash, GGBS, robustness, rheology

I. Introduction

The development of new technology in material science is processing rapidly. In previous decades, a lot of research was conducted to improve the performance of concrete in terms of the strength and durability qualities. Concrete is no longer the material consisting of water, cement and aggregates only, but has become the engineered material with several new constituents to meet the several specific needs of construction industry. Concrete technology has under gone from macro to micro level study in enhancement of strength and durability properties from 1980 onwards. This type of study resulted in the development of self compacting concrete (SCC).

Self compacting concrete is an engineered material with higher fluidity without segregation and is capable of filling every corner of formwork under its self weight only. Thus, SCC eliminates the need of vibration for compaction of concrete without compromising its engineering properties.

This concrete was first developed in Japan in 1980's to overcome the deterioration of concrete quality due to lack of skilled labours along with the problems at corners regarding homogeneity and compaction. After the development of SCC in Japan 1988, whole Europe started working on this revolution in the field of construction industry. The last half of decade 1991-2000 has remained very active in the field of research in SCC in Europe. Owing to this Europe has gone ahead of USA in publishing the specifications and guidelines for SCC. The first North American conference on design and use of self compacting concrete was organized in November 2002. At present many researchers are working in numerous universities and government R&D organizations due the benefits of the use of this concrete. From India a very limited has been reported, therefore it can be said that SCC is still unknown to many researchers.

There is no standard self compacting concrete, therefore each self compacting concrete has to be designed for the particular structure to be constructed. However, working on the parameters which effect the basic properties of self compacting concrete such as plastic viscosity, deformability, flowability and resistance to segregation may be proportioned.

The primary objective is to create a mix design procedure for SCC based on the concept of rheology and particle packing using the materials present across the country. The scope the SCC is that it can be used in congested structures and it can also be used in the places where time and economy matters the most.

II. Literature Review

Peter Billberg and Mikael Westerholm research on one of the most important factors limiting SCC from becoming a major part of the ready-mixed concrete

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industry is the difficulties involved in steady and variation-free production in terms of fresh properties. The aim of this project is to find a concept enabling increase in robustness of SCC. Micro mortar studies show that misjudged aggregate moisture is the parameter causing the most variation in rheology response. The ability for different viscosity-modifying admixtures (VMAs) to increase robustness to variation in aggregate moisture is studied using concrete-equivalent mortar (CEM). It is shown that depending on VMA type, robustness can indeed be achieved.

Kaustav Das SCC or Self Compacting Concrete is the most innovative type of concrete which is made in recent days. The concept of SCC has been introduced by PR. OKUMARA at OUCHI UNIVERSITY, in early 80's. SCC does not require any external vibration for its compaction, and it can flow on its own weight. There are several research work has been done on the fresh and the hardened properties of SCC, in this research the fresh properties of M35 design mix SCC is going to be observed according to EFNARC guideline. And the mix design is done by Ease of Use NAN SU ET AL method by replacing cement by Silica Fume, and GGBS at various proportions

Payal Painuly, Itika Uniyal Making concrete structure without compaction has been done in the past. Like placement of concrete underwater by the use of termie without compaction. Inaccessible areas were concreted using such techniques. The production of such mixes often used expensive admixtures and very large quantity of cement. But such concrete was generally of lower strength and difficult to obtain. This lead to the development of Self Compacting Concrete (SCC) The workability properties of SCC such as filling ability, passing ability and segregation resistance are evaluated using workability tests such as slump flow, V-funnel and L-Box tests.

III. Methodology

Material characterization	Mix proportionigg	Trial mixes
1.Physical characteristics 2.Mineralogical characteristics 3.Chemical characteristics	1.Optimization of packing density of aggregates 2.Optimization of paste volume	1.As per optimum mix design ± 10 kg/m^3 of design water content

Material Characterization

The materials used for obtaining the SCC of required mix are Aggregates, Binders/Mineral admixtures, Chemical admixtures.

Aggregates:

There are 3 types of aggregates used for the preparation of SCC. They are 20 mm, 10 mm and crusher sand. The desired properties of aggregates for the preparation of SCC are Bulk density, Water absorption capacity, Specific gravity.

Binders/Mineral admixtures:

The substances added to the concrete as a filler, improving the physical structure by occupying the spaces between the cement particles and reacts chemically to impart far greater strength and durability. The commonly used binder for the preparation of concrete is cement and the mineral admixtures used are fly ash and GGBS. The common tests carried out on cement are Specific gravity test, Setting time test, Consistency test, Compressive strength test and Fineness test.

Mix proportion

Mix proportioning is a process which consists of selection of suitable ingredients (cement, aggregates, water and admixtures) of concrete and determining their relative quantities (proportions) to produce an economical concrete.

The aim was to obtain the optimum combination of 10 mm, 20 mm aggregates and crusher (as fine aggregate) so as to have maximum particle packing density.

Ternary Packing Diagram:

The primary tool which is used to evaluate particle packing is the ternary packing diagram. This diagram allows us to create a contour plot which shows where maximum packing occurs.

i e., minimum amount of voids present.

Test Set up for the Determination of Packing Density of Aggregates

Fig.1 Test set up for determining the packing density of aggregates.

It consists of a steel bucket with top diameter of 340m, bottom diameter of 140mm and height of 310mm. A trap door is provided at the bottom of the bucket to release the aggregates and is rests on a stand. A cylindrical container of diameter 270mm with a capacity of 10 litres was used for collecting the falling aggregates. The distance from bottom of the steel bucket to the top of the cylindrical container was 200mm.

Test Procedure:

The mass of coarse aggregates, fine aggregates and river sand were taken based on their mix proportions. The three types of aggregates were mixed manually for obtaining a proper mix. The mixed aggregates were poured into steel bucket without any compaction. The bottom door of the steel bucket was opened to allow the aggregates to fall into the container. Before opening the excess aggregates which were present on the top were removed and mass of each aggregate was calculated based on the mix proportion. This mass is removed from the original mass of similar aggregate taken to determine the exact quantity of individual aggregates filled in the bottom cylinder.

Table:1 Values of packing density of aggregates

Fine Aggregate (% volume)	5-10 mm (% volume)	10-20 mm (% volume)	Packing Density
80	10	10	0.67
60	20	20	0.68
45	45	10	0.65
45	10	45	0.66
40	40	20	0.64
30	40	30	0.62
0	30	70	0.49
0	70	30	0.49
30	70	0	0.59
70	30	0	0.66
70	0	30	0.69
30	0	70	0.60
50	10	40	0.67
50	20	30	0.64
45	10	45	0.66
50	20	30	0.66
50	5	45	0.67
50	30	40	0.66

The above sheet shows the packing density result obtained for crusher, 10mm, 20mm aggregates.

Void content = $(V_C - ((m_1/s_1) + (m_2/s_2) + (m_3/s_3)))/V_C$

Where V_C = volume of the container

m_1, m_2, m_3 = mass of each aggregate type

s_1, s_2, s_3 = specific gravity of each aggregate type

Packing Density = 1 – Void Content

Development of Ternary Packing Diagram:

Experiments were conducted for different proportions of aggregates. 24 combinations of aggregates were selected to cover a wide range of ternary proportions. As 24 data points are inadequate to develop the ternary packing diagram, interpolation was performed to generate additional data points

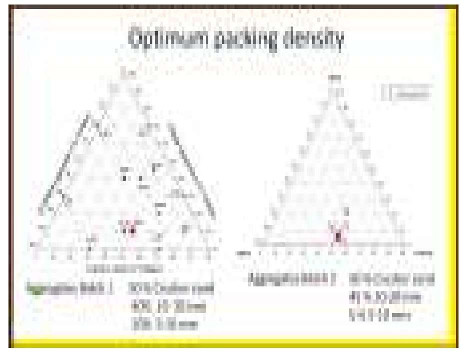

Fig.2 Ternary packing diagram developed for the 24 data points

Optimization of Paste volume:

The concept of packing density is used for optimization of paste volume and can also be done by the following tests.

Marsh Cone Test:

The marsh cone apparatus is used for measuring the viscosity of a liquid and can be used for optimizing the SP dosage. The viscosity of the liquid can be measured indirectly by measuring the flow time for certain amount of material flowing out of the cone.

Fig.3 Marsh cone test

Prepare the dry mix of cement and mineral admixture and Prepare 800 ml cementitious paste using the mixer and pour it into the cone by closing the bottom nozzle. The paste is allowed to settle for 15 seconds. Then the orifice was opened and stop watch was started. The time taken for 500ml paste to fill the cylinder which was kept below the cone was noted.

Mini Slump Test:

This test is used for the optimization of the SP dosage. A paste volume of 40 ml was taken and poured into the cone and it was collected on a wide glass flange. Slight tapping was given to remove the entrapped air and excess paste is removed from the top. The mini slump is lifted up such that it should not disturb the paste. The spread of the paste was measured after 2 minutes. This test is conducted for different w/p ratios with varying SP dosages and the SP dosage corresponding the spread in the range of 170 $\pm$ 10 mm without bleeding is taken as optimum dosage of SP.

Fig.4 Mini Slump Test

Combination used : cement + GGBS

Fig . Determination of optimum dosage of SP using marsh cone test

Fig . Determination of optimum dosage of SP using mini slump test

Mix design of SCC with cement & GGBS:

The chosen paste volume is 450 l/m^3. It is chosen based on the particle packing density of aggregates and voids present in the cylinder filled with aggregates.

Calculation for Cement and GGBS quantities

Paste Volume = 450 l/m^3

Cement (vol)+GGBS (vol)+Water (vol) = 450 l/m^3

Assuming water/powder = 0.35

Cement = 328.7 kg/m^3
GGBS = 328.7 kg/m^3
Water = 230.09 kg/m^3

Calculation of aggregate quantities:

Total aggregate volume = 550 l/m^3

From particle packing densities

50% Crusher : 45% C_{20} : 5% C_{10}

Crusher = 0.5*550*2.82 = 775.5 kg/m^3
C_{20} = 0.45* 550*2.89 = 715.275 kg/m^3
C_{10} = 0.05*550*2.96 = 81.4 kg/m^3

IV. Trial Mixes and Tests

As per the paste studies the w/b ratio was taken as : 0.35

Paste volume (l/ m^3) : 450

Cement (kg/m^3) : 328.7

Fly ash (kg/m^3) : 328.7

Water (kg/m^3) : 230.09

20 mm (kg/m^3) : 715.275

10 mm (kg/m^3) : 81.4

Crusher sand (kg/m^3) : 775.5

FA : 20 mm : 10 mm : 50:45:5

Based on the above values the required mix is prepared and it was subjected to tests shown below.

Slump Cone Test:

The aim of the test is to calculate the spread of the freshly prepared concrete. Here the freshly prepared concrete is poured into slump cone to the top and excess concrete is removed. Later slump cone is lifted up and at the same time stop watch is started. Now the spread of the concrete is noted and is repeated for different mixes. A concrete mix is said to be a good quality mix if its spread will be in the range of 600$\pm$10 mm.

Fig.5 Slump Cone Test

J-Ring test:

This test is also used for calculating the spread and follows the same procedure as slump cone test. The good quality mix in this j – ring test should have the spread < 50 mm corresponding to slump cone value.

Fig.6 J-Ring Test

V-Funnel Test:

This test is used for assessing the viscosity and filling ability of self compacting concrete. These tests consists of a V-funnel which has an opening at the bottom. The bottom is closed and freshly prepared SCC is poured in it to the top and then the bottom is opened and stop watch is started. The concrete is allowed to fall down and time taken for total concrete to fall from the funnel is noted. The concrete is said to have good viscosity and filling ability if the time taken will be in the range of (7 – 12) sec. Now again same procedure is repeated but here concrete is allowed to settle down for 5 min in V – funnel and the time taken for the concrete to fall down is noted and the time should not be more than (7 – 12) + 10 sec.

quantity cast (kg)	: 124
SP** (%)	: 0.175
VMA** (%)	: 0.375
Slump flow (mm)	: 665
Time to 500 mm (s)	: 6.09
J-Ring flow (mm)	: 655
V-funnel flow time (s)	: 7.91
V-funnel after 5 min (s)	: 3.62
Theoretical density (kg/m^3)	: 2462
Fresh concrete density (kg/m^3)	: 2456

Robustness studies – (+10 kg/m^3) of water content:

Paste volume (l/ m^3)	: 450
Concrete quantity cast (kg)	: 124
SP** (%)	: 0.175
VMA** (%)	: 0.375
Slump flow (mm)	: 667.5
Time to 500 mm (s)	: 2.00
J-Ring flow (mm)	: 615
V-funnel flow time (s)	: 4.19
V-funnel after 5 min (s)	: 2.197
Theoretical density (kg/m^3)	: 2462
Fresh concrete density (kg/m^3)	: 2360

Robustness studies – (-10 kg/m^3) of water content:

Paste volume (l/ m^3)	: 450
Concrete quantity cast (kg)	: 124
SP** (%)	: 0.175
VMA** (%)	: 0.375
Slump flow (mm)	: 450
Time to 500 mm (s)	: 6.09
J-Ring flow (mm)	: 352.5
V-funnel flow time (s)	: 20.81
V-funnel after 5 min (s)	: 34.4
Theoretical density (kg/m^3)	: 2462
Fresh concrete density (kg/m^3)	: 2477

D. Casting

After all the above tests were done then this mix is used for casting cubes of size 150mm*150mm*150mm. 12 cubes are casted for determining the 1stday, 3rdday, 7thday and 28thday compressive strength of concrete.

Fig.7 Casting of cubes

E. Compressive Strength Test:

In this test the above shown compression testing machine is used for calculating the compression strength of test specimen. Here the cubes are tested for 1stday, 3rdday, 7thday and 28thday compressive strength. Load is applied gradually at a rate of 140 kg/cm^2 per minute till the specimen fails. Load at the failure divided by area of specimen gives the compressive strength of concrete

Fig.8 Compression strength test set up

Fig.9 Failure of the cube under compression

IV. Results

Table: Compression strength test values for 1- day test

Cubes	Weight (kg)	Stress (MPa)	Load (kN)
1	8.143	9.25	208.2
2	8.216	9.05	203.5
3	8.112	8.52	191.7
AVG	8.157	8.94	201.13

Table: Compression strength test values for 3- day test

Cubes	Weight (kg)	Stress (MPa)	Load (kN)
1	8.296	22.78	512.6
2	8.162	22.58	508
3	8.263	23	517.4
AVG	8.240	22.786	512.66

V. Conclusion

- In this research the paste phase used optimum combination of powder for optimizing superplasticizer dosage for different w/p ratios using mini slump test.
- The dosage corresponding to a spread in the range of 170±10 mm, without bleeding, was identified as the optimum dosage of SP.
- The optimum dosage of SP in cementitious paste was validated in SCC by keeping the paste composition and paste volume constant.
- The optimum dosage of SP for different w/p ratios resulted in a slump flow between 550 and 600 mm, and T_{500} between 1 to 6 seconds in SCC.
- A precise method was developed for the determination of packing density of a combination of aggregates.
- The maximum packing density obtained was 0.68 and minimum packing density was 0.54, for the available aggregates.
- A ternary packing diagram was developed based on the experimental and interpolated data. Using this diagram the packing density of any combination can be determined.
- For the present study, a combination of 50: 5 : 45 (crusher : 10 mm: 20 mm) that gave the maximum packing density of 0.67, was chosen for the trials on SCC in the concrete phase.
- There is no standard self compacting concrete, hence we have to design SCC based on the structure given.

VI. References

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