ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 6, Special Issue , August 2019

International Conference on Recent Advances in Science, Engineering, Technology and Management at Sree Vahini Institute of Science and Technology-Tiruvuru, Krishna Dist, A.P

Effect of Sizes of Aggregate on the Properties of Self Compacting Concrete

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ABSTRACT: This project leads the civil engineers to a beneficial moment and performs well in the construction works. A large usage of SCC in the future provides a good economical assurance and also makes the cement production to a minimum. Finally, it would be a better option to protect the environment. We have verified many journals in order to have a clear glance of SCC finally we took a simple mix design proposed by "NAN SU" a Taiwan scientist. He has designed based on the bulk density of aggregates and only gave SCC for 25mm aggregate.

In view of his design principle we made SCC for different sizes of aggregates (10mm, 12.5mm, 16mm, and 20mm) separately with good efficiency. In the initial stage, we tried to make out SCC directly from the proposed design. But we have seen a much variation after committing practically.Then we started to modulate according to our views and made SCC mixes for 10mm, 12.5mm, 16mm, and 20mm respectively. It took 47 trail mixes and 40 days for us to conclude SCC by trial and error methods. Finally we succeeded in getting SCC with appropriate proportions for each aggregate. The properties of hardened concrete like compression strength, flexural strength, splitting tensile strength were studied and detailed procedures and results are reported in the pages that follow.

KEY WORDS: Self Compacting Concrete, bulk density, compression strength, flexural strength, splitting tensile strength

I. INTRODUCTION

Concrete is one of the widely used construction material. Ever since concrete has been accepted as material for construction. Researchers have been trying to improve its quality and enhance its performance. Recent changes in the construction industry are demanding an improved durability of the structures. This problem of durability has lead to the development of SCC, which is described as "the most revolutionary development in the concrete industry for several decades". SCC was originally developed at the University of Tokyo in Japan with the help of leading concrete contractors during late 1980's.

Self-compaction of concrete (SCC), a new kind of high performance concrete (HPC) has an excellent deformability and segregation resistance. It is a special kind of concrete that can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process. It emphasizes on high strength and durability of concrete.

Generally a normal concrete can produce a high strength. However it cannot flow freely by itself to pack every corner of moulds and all gaps of reinforcement. Finally it requires well compaction and vibration in the construction process. But SCC has more favorable characteristics such as high fluidity, good segregation resistance and the distinctive self-compacting ability without any need for vibration during the placing process. Therefore it can be compacted in to every corner of formwork purely by means of its own weight. It reduces the risk of honeycombing of concrete.

Benefits from SCC:

1. Less noise from vibrators and reduced danger from hand arm vibration syndrome (HAVS).
2. Speed of placement, resulting in increased production efficiency.
3. Ease of placement, requiring fewer workers for a particular pour.
4. Better assurances of adequate consolidation.
5. Reduced wear and tear on forms from vibration.
6. Reduced wear on mixers due to reduced shearing action.
7. Improved surface quality and fewer bug holes

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8. Consistent water-cement (w/c) ratios of less than 0.35
9. Reduced energy consumption from vibration equipment
10.

Materials used in SCC:

The materials used for SCC are selected from those used by the conventional concrete industry. Typical materials used for SCC are coarse aggregate, fine aggregate, cement, mineral admixtures (fly ash, ground-granulated blast furnace slag), and chemical admixtures (super-plasticizer, viscosity-modifying agents). SCC can be designed and constructed using a broad range of normal concreting materials, and that this is essential for SCC to gain popularity.

II. LITERATURE REVIEW

Kuroiwa: Kuroiwa (1993) developed a type of concrete, which contained materials normally found in conventional concrete such as Portland cement, aggregate, water, mineral and chemical admixtures. The chemical admixtures were added in order to improve the deformability and the viscosity of the concrete. The newly developed type of concrete was called super-workable concrete and showed excellent deformability and resistance to segregation. It could also fill completely heavily reinforced formworks without any use of vibrators. After the laboratory tests it was found out that the super-workable concrete had superior properties in the fresh state and excellent durability after hardening. Because of its properties, it was considered that it would be suitable for projects involving heavily reinforced areas and was employed in the construction of a 20-story building. The concrete was placed in the center-core from basement to the third floor. The building had a design of a hybrid structure, in which the reinforced concrete core was surrounded by a steel mantle. The greatest diameter used for the reinforcing bars was 2” and the forms were very congested. Ready mixed concrete plants situated near the construction site produced approximately 2000 m^3 of super-workable concrete, which was placed successfully.

Subramanian and Chattopadhyay: Subramanian and Chattopadhyay (2002) are research and development engineers at the ECC Division of Larsen & Toubro Ltd (L&T), Chennai, India. They have over 10 years of experience on development of self-compacting concrete, underwater concrete with antiwashout admixtures and proportioning of special concrete mixtures. Their research was concentrated on several trials carried out to arrive at an approximate mix proportion of self-compacting concrete, which would give the procedure for the selection of a viscosity modifying agent, a compatible super plasticizer and the determination of their dosages. The Portland cement was partially replaced with fly ash and blast furnace slag, in the same percentages as Ozawa (1989) has done before and the maximum coarse aggregate size did not exceed 1.

Hajime Okamura: A new type of concrete, which can be compacted into every corner of a formwork purely by means of its own weight, was proposed by Okamura (1997). In 1986, he started a research project on the flowing ability and workability of this special type of concrete, later called self-compacting concrete. The self-compactability of this concrete can be largely affected by the characteristics of materials and the mix proportions. In his study, Okamura (1997) has fixed the coarse aggregate content to 50% of the solid volume and the fine aggregate content to 40% of the mortar volume, so that self-compactability could be achieved easily by adjusting the water to cement ratio and super plasticizer dosage only.

III. TESTS ON MATERIALS

Table 1. Physical properties of cement

S.No	Type of Test	Result
1	Fineness	2.59%
2	Normal consistency	26%
3	Specific Gravity	3.09
4	initial setting time (min)	49 mins
5	Final setting time (min)	295 mins
6	Compressive strength – 7 days	43Mpa
7	Compressive strength – 28 days	53 Mpa

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Table 2. Physical properties of Fine Aggregates

S.No	Type of Test	Result
1	Fineness modulus	3.06
2	Specific Gravity	2.69
3	Bulk density - loose	1567 kg/m^3
4	Bulk density - compacted	1713 kg/m^3

Table 3: Physical properties of Course Aggregate

S.No	Type of Test	Result
1	Fineness modulus	7.165
2	Specific Gravity	2.71
3	Bulk density – loose- 20mm	1442 kg/m^3
4	Bulk density –16 mm	1462 kg/m^3
5	Bulk density – 12.5 mm	1560 kg/m^3
6	Bulk density – 10 mm	1560 kg/m^3

IV. MIX DESIGN

Nan-su mixdesign

The principle consideration of the proposed method is to fill the paste of binders in to voids of the aggregate formwork piled loosely. The contents of coarse and fine aggregates, binders, mixing water and SP will be the main factors influencing the properties of SCC.

The procedure of the proposed mix design method can be summarized in the following steps:

Step 1:Calculation of coarse and fine aggregates

When surface-dry coarse and fine aggregates are loosely stacked together, friction and voids exist between them. Lubrication occurs when water and binders are added to the aggregates, thus, making the pile of aggregates becomes more compact. Usually, the volume ratio of aggregate after lubrication and compaction in SCC is about 59–68%. The packing factor (PF) of aggregate is defined as the ratio of mass of aggregate of tightly packed state in SCC to that of loosely packed state. Clearly, PF affects the content of aggregates in SCC. A higher PF value would imply a greater amount of coarse and fine aggregates used, thus, decreasing the content of binders in SCC. Consequently, its flowability, self-compacting ability and compressive strength will be reduced.

The content of fine and coarse aggregates can be calculated as follows (Eqs. (1) and (2)):

$$Wg = PF \times Wg_L(1-s/a) \quad \text{---------} (1)$$

$$Ws = PF \times W_{sL} \times s/a \quad \text{---------} (2)$$

Where Wg: Content of coarse aggregates in SCC (kg/m3);

Ws: Content of fine aggregates in SCC (kg/m3);

WgL: Unit volume mass of loosely piled saturated surface- dry coarse aggregates in air (kg/m3);

Ws_L: Unit volume mass of loosely piled saturated surface-dry fine aggregates in air (kg/m3);

PF: Packing factor, the ratio of mass of aggregates of tightlypacked state in SCC to that of loosely packed state in air;

s/a: Volume ratio of fine aggregates to total aggregates, which ranges from 50% to 57%.

Step 2:Calculation of cement content:

To secure good flowability and segregation resistance, the content of binders (powder) should not be too low. According to the ‘‘Guide to Construction of High Flowing concrete’’, the minimum amount of cement to be used for producing normal concrete and the high durability concrete are 270 and 290 kg/m3, respectively. However, too much cement used will increase the drying shrinkage of SCC. Generally, HPC or SCC used in Taiwan provides a compressive strength of 20 psi (0.14 MPa)/kg cement. Therefore, the cement content to be used is (Eq. (3)):

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$$C = f'c/20 \quad \text{------------ (3)}$$

Where C : cement content (kg/m3);
f ′c : designed compressive strength (psi).

Step 3: Calculation of mixing water content required by cement

The relationship between compressive strength and water/cement ratio of SCC is similar to that of normal concrete. The water/cement ratio can be determined according to BIS or other methods in previous studies. The Content of mixing water required by cement can then be obtained using (Eq. 4):

$$Wwc = (w/c) \times C \quad \text{--------- (4)}$$

Where Wwc: content of mixing water content required by cement (kg/m3);

W/c: the water/cement ratio by weight, which can be determined by compressive strength.

Step 4: Calculation of fly ash (FA) and ground granulated blast-furnace slag (GGBS) contents

Large amounts of powder materials are added to SCC to increase flowability and to facilitate self-compacting. However, an excess amount of cement added will greatly increase the cost of materials and dry shrinkage. More over, its slump loss would become greater, and its compressive strength will be higher than that required in the design. In view of this, the proposed mix design method utilizes the appropriate cement content and W/C to meet the required strength. To obtain the required properties such as segregation resistance, FA and GGBS are used to increase the content of binders. When the flow values of the FA and GGBS pastes are equal to that of the cement paste and let W/F and W/S be the ratios of water/FA and water/GGBS by weight.

Then the volume of FA paste (V_{Pf}) and GGBS paste (V_{PB}) can be calculated as follows:

$$V_{Pf} + V_{PB} = 1-(Wg/1000 \times Gg) - (Ws/1000 \times Gs) - (C/1000 \times Gc) - (Wwc/1000 \times Gw) - Va \quad \text{----------------- (5)}$$

Where Gg: specific gravity of coarse aggregates;
Gs: specific gravity of fine aggregates;
Gc: specific gravity of cement;
Gw: specific gravity of water;
Va : air content in SCC (%).

If the total amount of Pozzolonic materials (GGBS and FA) in SCC is Wpm (kg/m3), where the percentage of FA is A% and the percentage of GGBS is B% by weight, the adequate ratio of these two materials can be set according to the properties of local materials and previous engineering experience.

$$Vp_f + Vp_b = (1 + W/F) \times A\,\% \times Wpm/ (1000 \times G_f) + (1+ W/S) \times B\,\% \times Wpm / (1000 \times G_b) \quad \text{-------------- (6)}$$

Where G_f: Specific gravity of fly ash,
G_b: Specific gravity of GGBS,
G_f, G_b, Gc, W/F and W/S can be obtained from tests,
A% and B% are given, and
V_{Pf}+ V_{PB} can be obtained from Eq. (5). Hence,
Wpm can be calculated using Eq. (6). Also,
W_f (FA content in SCC, Kg/m3) and W_B (GGBS content in SCC, Kg/m3) can be calculated (Eqs. (7) and (8)),

$$W_f = A\% \times Wpm \quad \text{---------------- (7)}$$

$$W_B = B\% \times Wpm \quad \text{---------------- (8)}$$

Mixing water content required by FA paste is (Eq. (9)):

$$W_{wf} = (W/F) \times W_f \quad \text{-------------------- (9)}$$

Mixing water content required by for GGBS paste is (Eq. (10)):

$$W_{wB} = (W/S) \times W_B \quad \text{-------------------(10)}$$

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Step 5:Calculation of mixing water content needed in SCC

The mixing water content required by SCC is that, the total amount of water needed for cement, FA and GGBS in mixing. Therefore, it can be calculated as follows (Eq. (11)):

$W_w = W_{wc} + W_{wf} + W_{wB}$--------------------(11)

According to the Japanese Architecture Society:

Ww = 160–185 kg/m3.

Step 6: Calculation of SP dosage

Adding an adequate dosage of SP can improve the flowability, self-compacting ability and segregation resistance of fresh SCC for meeting the design requirements. Water content of the SP can be regarded as part of the mixing water. If dosage of SP used is equal to n% of the amount of binders and its solid content of SP is m%, then the dosage can be obtained as follows (Eq. (12) and (13)):

Dosage of SP used $W_{SP} = n\% \times (C + W_f + W_B)$ ----------- (12)

Water content in SP $W_{wSP} = (1\text{-}m\ \%) \times WSP$ ------------ (13)

Step 7:Adjustment of mixing water content needed in SCC

According to the moisture content of aggregates at the ready-mixed concrete plant or construction site, the actual amount of water used for mixing should be adjusted.

Step 8: Trial mixes and tests on SCC properties

Trial mixes can be carried out using the contents of materials calculated as above. Then, quality control tests for SCC should be performed to ensure that the following requirements are met.

1. Results of slump flow, U-Box, L-flow and V-funnel tests should comply with the specifications of the JAS.
2. The segregation phenomenon of materials should be satisfactory.
3. Water–binder's ratio should satisfy the requirements of durability and strength.
4. Air content should meet the requirement of the mix design.

Step 9:Adjustment of mix proportion

If results of the quality control tests mentioned above fail to meet the performance required of the fresh concrete, adjustments should be made until all properties of SCC satisfy the requirements specified in the design. For example, when the fresh SCC shows poor flowability, the PF value is reduced to increase the binder volume and to improve the workability.

Mix Design of SCC:

Mix Design for 20mm size aggregates:

Characteristic Strength	= 30 Mpa
Maximum size of aggregates	= 20 mm
Specific gravity of coarse aggregates, Gg	= 2.71
Specific gravity of fine aggregates, Gs	= 2.65
Bulk density of loose coarse aggregates	= 1442 kg/m^3
Bulk density of loose fine aggregates	= 1567 kg/m^3
Specific gravity of cement, Gc	= 3.1025
Specific gravity of fly-ash	= 2.18
Volume of fine/course aggregate ratio	= 58/42
Specific gravity of super plasticizer	= 1.222

Determination of Coarse aggregate:

Assume P.F	= 1.15
Amount of course aggregate	= 1.15 x 1442 (1-0.58)
Wg	= 696.48 kg/m^3

Determination Fine aggregate:

Amount of fine aggregate, Ws	= P.F x Wg (1-s/a)
	= 1.15 x 1567 x 0.58
	= 1045.2 kg/m^3

Determination of cement:

C = F ′c/20
Given 0.14 Mpa = 20PSI
∴ C = 4285/20 = 214 kg/ m^3

Determination of water:

For BIS water cement ratio for 30 Mpa is = 0.46
∴ W/C = 0.46
W = 0.46 x 214 = 98.44 kg/ m^3

Determination of Fly Ash:

Volume of fly ash V_f = (1-Wg/1000 x Gg – Ws/1000 x Gs – C/1000 x Gc – Wwc/1000 x Gw – 0.015)
= 1-0.257-0.394-.069-.0984-0.015
= 0.1666 kg/ m^3

Total weight of pozzalonic material 0.1666 = (Wfa x 1 /1000 x 2.18) + (Wfa x 0.45 x 1)
Wfa = 183.33 kg/ m^3

Water content for fly ash = 0.45 x 183.33 = 82.5 kg/ m^3

Determination of SP dosage:

SP dosage = 1.8 % of (214 + 183.33)
= 7.152 kg/ m^3

Water content in SP = (1 – 0.4) x 7.152
= 4.291 kg/ m^3

Total water content = 98.44 + 82.5 – 4.291
= 176.649 kg/ m^3

Water binder ratio = 0.445

Cement	Fly ash	Fine aggregate	Coarse aggregate	SP
214	183.33	1045.2	696.486	7.152
1	0.856	4.884	3.254	0.0334

ADJUSTMENTS:-

After conducting no of trails we conclude that, the following SCC mix ratios are satisfying the required workability and flowability conditions.

Water binder ratio = 0.435

Cement	Fly ash	Fine aggregate	Coarse aggregate	SP
214	231.76	1045.2	696.486	4.494
1	1.083	4.884	3.254	0.021

Mix Design for 16mm size aggregates:

Cement	Fly ash	Fine aggregate	Coarse aggregate	SP
214	231.76	1009.15	739.77	4.494
1	1.083	4.715	3.457	0.021

Mix Design for 12.5 mm size aggregates:

Cement	Fly ash	Fine aggregate	Coarse aggregate	SP
214	214	991.28	867.3	4.708
1	1	4.631	3.772	0.022

Mix Design for 10mm size aggregates:

Cement	Fly ash	Fine aggregate	Coarse aggregate	SP
214	214	991.128	867.3	4.494
1	1	4.631	3.772	0.021

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V. TESTS ON SCC

S.No	Method	Property
1	Slump Flow Test	Filling Ability
2	T_{50cm} Slump Flow	Filling Ability
3	V-Funnel Test	Filling Ability
4	V-Funnel at $T_{5minuts}$	Segregation resistance
5	L-Box Test	Passing Ability

Slump Flow & T_{50} test:

Slump Flow is definitely one of the most commonly used SCC tests at the current time. This test involves the use of the slump cone used with conventional concretes as described in ASTM C143 (2002). The main difference between the Slump Flow test and ASTM C143 is that the Slump Flow test measures the "spread" or "flow" of the concrete sample once the cone is lifted rather than the traditional "slump" (drop in height) of the concrete sample. The T_{50} test is determined during the Slump Flow test; it is simply the amount of time that the concrete takes to flow to a diameter of 50 centimeters. Typically, Slump Flow values of approximately 24 to 30 inches are within the acceptable range; acceptable T_{50} times range from 2 to 5 sec.

L-box test:

The L-box attempts to model the actual placement of concrete; this is desirable concept for a quality acceptance test.

The L-box value is a ratio of the levels of concrete at each end of the box after the test is complete. The L-box consists of a "chimney" section and a "trough" section after the test is complete, the level of concrete in the chimney is recorded as H1; the level of concrete in the trough is recorded as H2. The L-box value (also referred to as the "L-box ratio", "blocking value", or "blocking ratio") is simply H2/H1. Typical acceptable values for the L-box value are in the range of 0.8 to 1.0. If the concrete was perfectly level after the test is complete, the L-box value would be equal to 1.0; conversely, if the concrete was too stiff to flow to the end of the trough the L-box value would be equal to zero.

V-funnel test and V-funnel test at $T_{5minutes}$:

V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20mm. The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

VI. RESULTS AND DISCUSSION

Tests on SCC:

1. Workability tests
2. Compressive strength
3. Split tensile strength
4. Flexural strength

Table 6: List of workability Values

S.No	Size of Aggregate	Slump value	T_{50}	V-Funnel	V-Funnel at $T_{5\ Minutes}$	L-Box H2/H1
1.	20 mm	650 mm	3 Sec	4 Sec	5 Sec	0.79
2.	16 mm	640 mm	4 Sec	4 Sec	5 Sec	0.805
3.	12.5 mm	660 mm	3 Sec	4 Sec	4 Sec	0.82
4.	10 mm	660 mm	4 Sec	3 Sec	4 Sec	0.81

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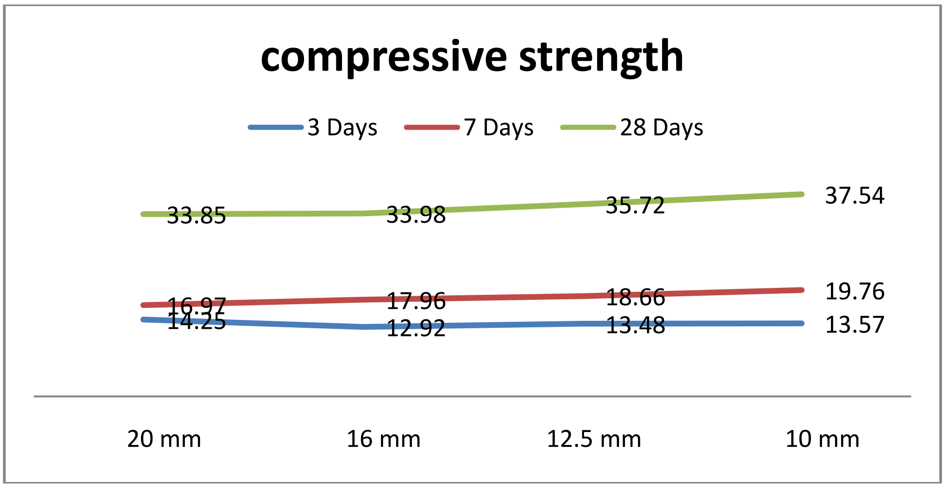
Table 7: Test results on compressive strength

S.No	Max Size of Graded Aggregate	Compressive Strength (N/mm^2)		
		3 Days	7 Days	28 Days
1.	20 mm	14.25	16.97	33.85
2.	16 mm	12.92	17.96	33.98
3.	12.5 mm	13.48	18.66	35.72
4.	10 mm	13.57	19.76	37.54



Graph 1: Test results on compressive strength

Table 8: Test results on flexural strength

S.no	Max Size of of Graded Aggregate	Flexural Strength (N/mm^2)		
		3 Days	7Days	28Days
1.	20 mm	2.39	2.92	6.52
2.	16 mm	2.75	3.22	6.54
3.	12.5 mm	2.92	4.32	6.67
4.	10 mm	3.29	4.22	7.2

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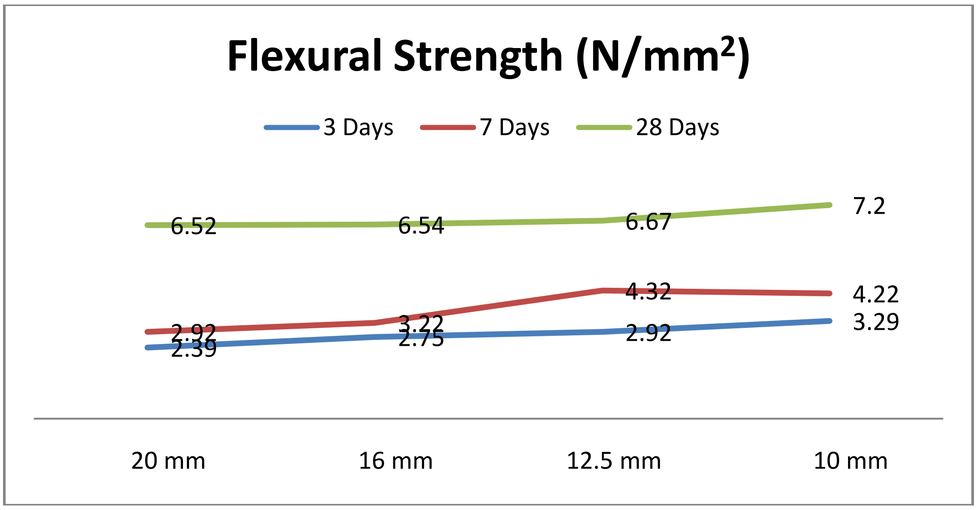
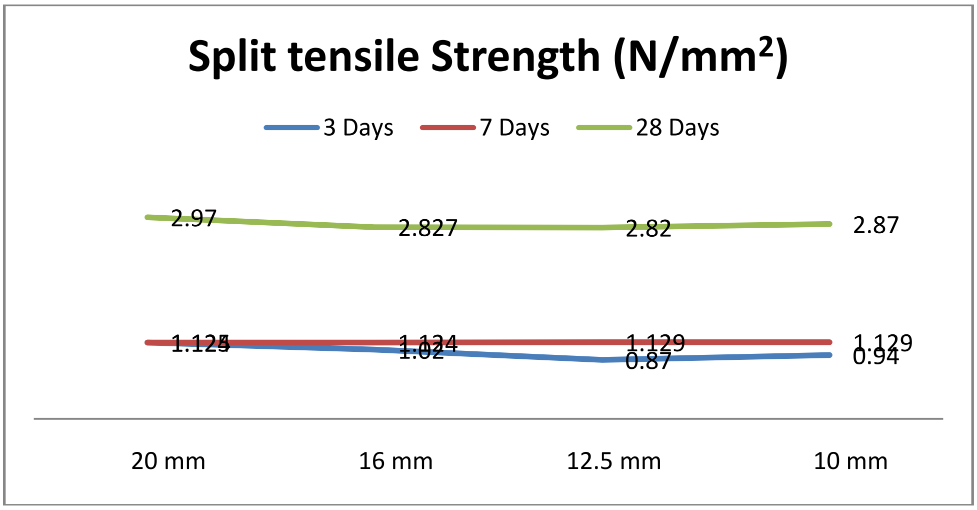


Table 9: Test results on split tensile strength

S.no	Max Size of Graded Aggregate	Split Tensile Strength (N/mm2)		
		3 Days	7Days	28Days
1.	20 mm	1.125	1.124	2.97
2.	16 mm	1.02	1.124	2.827
3.	12.5 mm	0.87	1.129	2.82
4.	10 mm	0.94	1.129	2.87



Graph 3: Test results on split tensile strength

VII. CONCLUSIONS

1. After committing various trail tests, we have finally achieved M_{30} grade self compacting concrete for different sizes of aggregates which could satisfy all the SCC characteristics (flowability, passing ability and segregation resistance) given by European standards. As there are no Indian standards, comparison could not be made.

ISSN: 2350-0328

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2. Owing to the cube density and aggregate ratio it was observed that much compressive strength is gained to 10mm aggregate than that of the other sizes of aggregates.
3. From the observations it was found that nearly half of the compressive strength is gained in 3 days and 2/3 rd of the strength in 7 days and crossed the target mean strength in 28 days duration which could satisfies IS: 456-2000.
4. It was also observed that flexural strength is more for 10mm size aggregate due its high density and more aggregate bonding. It also attained the permissible values for 3 days, 7 days and 28 days as per IS: 456-2000.
5. Split tensile test exhibited almost equal values for every size of aggregate. Split tensile strength has given nearly equal value in 3 days, 7days and 28 days' time for all sizes of coarse aggregates. So it is said that size of aggregates make no effect in split tensile strength especially in short term durations.
6. A good economical assurance is provided by the mix design proposed by "NAN-SU" due to the consumption of less quantity of cement compared to the nominal mix.
7. Wholly we have maintained good workability for every mix design for easy placing and passing ability and finally satisfied all the conditions of SCC to make it eligible as good construction material.

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