STUDY OF DESIGN AND PERFORMANCE OF SELF-COMPACTING CONCRETE USING ADVA-960 SUPER PLASTICIZER

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***Abstract:** Self compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is one of the special concrete .It is able to flow under its own weight In general SCC has higher results in reducing the time of construction and reducing the noise pollution. In order to obtain the fresh properties for SCC, proportion of mineral and chemical admixtures to be added. In our study the fresh properties of self-compacting concrete can be improved considerably by introducing the mineral admixture FLY ASH, and chemical admixture ADVA-960(super plasticizer). In our project we do the mix design according to NAN SU mix design procedure according to EFNARC specifications and study the fresh and hardened properties of concrete. Tests conducted for finding the fresh properties like passing and filling ability are J-RING TEST, L-BOX TEST, SLUMP CONE TEST. Finally we check the Compressive strength at the ages of 7, 14, and 28 days.*

***Keywords:** Self compacting concrete, fly ash, adva-960, filling ability, passing ability, compressive strength*

1.INTRODUCTION

Self-compacting concrete (SCC) has been described as "the most revolutionary development in concrete construction for several decades". Originally developed to offset a growing shortage of skilled labor, it has proved beneficial economically because of a number of factors, including: Faster construction, reduction in site manpower, better surface finishes, Easier placing, improved durability, greater freedom in design, thinner concrete sections, reduced noise levels, absence of vibration, Safe working environment.

For several year beginning in 1983, the problem of the durability of concrete structures was a major topic of interest in Japan. To make the durable structures, sufficient compaction by skilled workers was required. However gradual reduction in the number of skilled workers led to a similar reduction in the quality of construction work. At this time Prof. Hajime Okamura at the University of Tokyo in Japan wanted to solve the problem of degrading quality of construction and he had come out with a new concrete called Self Compacting Concrete that would consolidate under its own weight. This type of concrete would directly bypass the need for external vibration, eliminating the problem of unskilled labor. So, Self Compacting Concrete is defined as highly workable concrete that can flow through densely reinforced or geometrically complex structural elements under its own weight to adequately fill the voids without segregation or excessive bleeding and without vibration. The main advantage of the Self compacting concrete is to shorten construction period and to assure compacting in the structures especially in the confined zones where vibration and compaction is difficult.

1.1 Need for the present work:

- The main property that defines SCC is highly workability in attaining consolidation and specified hardened properties. Before it satisfies the hardened properties it should also satisfy the fresh properties in terms of filling ability, passing ability and segregation resistance. The self-compatibility is largely affected by the characteristics of the materials and mix proportions. As on today there is no established methodology to arrive at the mix proportions.
- The strength of SCC is provided by the aggregate binding by the paste at hardened state, while the workability of SCC is provided by the binding paste at fresh state. Therefore, the contents of coarse and fine aggregates, binders, mixing water and SP will be the main factors influencing the properties of SCC.
- In Nansu's method of mix design the volume ratio of fine aggregate to total aggregates ranges from 50 % to 58 % to achieve the fresh properties of SCC. And as per "EFNARC" specifications the coarse aggregate content normally ranges from 28% to 35 % by volume of mix to achieve the fresh properties of SCC.
- The need of the present work is to find the optimum content of fine aggregate to total aggregate ratio (i.e., 55, 56, 57, 58 percentages) that satisfies the fresh properties and also the hardened properties of SCC keep in the water/powder ratio is constant.

1.2 Scope of the present work

In this present study, the experimental studies have been carried out as following:

- Developing SCC for two grades of concrete i.e., M40 and M60 grades using Nan-Su method of mix design, which satisfies fresh properties of SCC as per "EFNARC" specifications.
- To study the influence of different fine aggregate to total aggregate ratios (i.e., 55, 56, 57, 58 percentages) on both the grades of concrete on mechanical properties such as compressive strength, splitting tensile strength, and flexural strength for M40 and M60 grades of concrete.
- A total of 144 specimens were casted. (i.e., 48 cubes, 48 cylinders and 48 prisms)

2. MATERIALS

2.1 Super Plasticizer ADVA-960:

The different materials used in this work are: 53 Grade ordinary Portland Cement, Fine Aggregate, Coarse Aggregate, Super Plasticizer(**ADVA-960**), Viscosity modifying agent VMA(Stream-2), Fly ash, Water

This program consists of casting and testing of total 144 specimens. The specimens of standard cubes (150mm x 150mm x 150mm), standard cylinders of (150mm dia x 300mm height) and standard prisms of (100mm x 100mm x 500mm) were casted for 7 and 28 days for compressive strength, splitting tensile strength and flexural strength of concrete.

2.2 Cement

Ordinary port land cement (Ultra-tech cement) of 53 grades conforming to IS: 12269 were Used. The test results of cement given in table 1

Table 1. Physical properties of ordinary Portland cement:

S.No.	Property	Test method	Test result
1.	Normal consistency	Vicat apparatus	33%
2.	Specific gravity	Specific gravity bottle	3.07
3.	Initial setting time Final setting time	Vicat apparatus	50 min 180 min
4.	Fineness	Sieve test on sieve no.9	9%

2.3 Fine aggregate

Locally available natural sand was used. Specific gravity and fineness modules were found to be 2.56 and 2.73respectively. The details of sieve analysis are given in table 3. It could be seen that sand confirms to zone II, as per IS 383-1970.

2.4 Coarse aggregate

Crushed granite stone chips (angular) of12mm and maximum size 20mm were used. Specific gravity and fineness modulus were found to be 2.62 and 7.61 respectively.

Table 2. Properties of fine aggregate and coarse aggregate

S.No.	Property	Test method	Test results for fine aggregate	Test results for coarse aggregate
1.	Specific gravity	Pycnometer (IS 2386-1986 Part-3)	2.56	2.62
2.	Bulk density i) Loose ii) Compacted	(IS 2386-1986 Part 3)	1643 kg/m^3 1742 kg/m^3	1470 kg/m^3 1560 kg/m^3
3.	Fineness modulus	Sieve analysis (IS 2386-1963 Part 2)	2.73	7.61

Table 3. Fineness modulus of fine aggregate

S.No.	IS sieve size	Weight retained, gms	Cumulative weight retained, gms	Cumulative% weight retained	Cumulative % passing
1	10mm	0.00	0.00	0.00	100.00
2	4.75mm	10.00	10.00	1.00	99.00
3	2.36mm	46.50	56.50	4.65	94.35
4	1.18mm	188.00	244.50	24.45	75.55
5	600µ	288.00	532.50	53.25	46.75
6	300µ	358.00	890.50	89.05	10.95
7	150µ	109.50	1000.00	100.00	0.00

Fineness modulus of fine aggregate = 272.85/100
= 2.72

2.5 Super plasticizer

High range water reducing admixture called as super plasticizers are used for improving the flow or workability for decreased water cement ratio without sacrifice in the compressive strength. These admixtures when they disperse in cement significantly decrease a viscosity of the paste by forming a thin film around the cement particles. In the present work water-reducing admixture ADVA-960 conforming to ASTM C494 types F. EN934-2 T3.1/3.2, IS 9103: 1999 is used. ADVA-960 is an admixture of a new generation based on modified poly-carboxylic ether. The product has been primarily developed for application in high performance concrete where the highest durability and performance is required.

2.6 Viscosity modifying agent (VMA)

The use of viscosity modifying admixture (VMA) gives more possibility of controlling segregation when the amount of powder is limited, this admixture helps to provide very good homogeneity and reduces the tendency to segregation. In the present work **Stream2**VMA is used.

2.7 Fly ash

The fly ash used in the investigation was procured from Vijayawada Thermal power station (VTPS). This is collected from electrostatic precipitator. The silica content of the fly ash was estimated to about 96%. The fly ash passing from 90p sieve was used throughout the experiment. The specific gravity of fly ash was found to be 1.95. The fly ash used in this study was basically to improve workability and cohesiveness of concrete.

2.8 Water

Portable water was used for mixing and curing.

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3. RESEARCH METHODOLOGY

The methods for mixture proportioning of SCC differ from the traditional methods, though they are equally empirical. Moreover, in SCC, the design is governed by the properties of the fresh concrete. The ingredients for self- compacting concrete are similar to the plasticized concrete. It consists of cement, coarse aggregate, fine aggregate, and water, mineral and chemical admixtures. Similar to conventional concrete, SCC can be also affected by the physical characteristics of minerals and mixture proportion. The mixture proportioning is based on creating a high degree of flow ability while maintaining a low water to cementitious materials ratio, w/cm (<0.40). This is achieved using high range of water reducing admixture combined with stabilizing agents to ensure homogeneity of the mixture. A number of methods exist to optimize the concrete mix proportions for self-compacting concrete

4. MIX DESIGN PROCEDURE BY NAN-SU METHOD:

The principal consideration of the proposed method is to fill the paste of binders into voids of the aggregate framework piled loosely. The loose unit weight of the aggregate is according to the shoveling procedure of ASTM C29, except discharging the aggregate at a height of 30 cm above to the top of the measure. Usually, the volume ratio of aggregate is about 52–58%, in other words, the void in the loose aggregate is about 42–48% according to ASTM C29. The strength of SCC is provided by the aggregate binding by the paste at hardened state, while the workability of SCC is provided by the binding paste at fresh state. Therefore, the contents of coarse and fine aggregates, binders, mixing water and SP will be the main factors influencing the properties of SCC. With the proposed method, all we need to do is to select the qualified materials, do the calculations, conduct mixing tests and make some adjustments, and SCC with good flow ability and segregation resistance can be obtained with self-compacting ability as specified by the JSCE. The procedures of the proposed mix design method can be summarized in the following steps.

4.1 Calculation of coarse and fine aggregate contents:

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%. In this study, 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 flow ability, self-compacting ability and compressive strength will be reduced. On the other hand, a low PF value would mean increased dry shrinkage of concrete. As a result, more binders are required, thus, raising the cost of materials. In addition, excess binders used would also affect the workability and durability of SCC. Therefore, it is important to select the optimal PF value in the mix design method so as to meet the requirements for SCC properties, and at the same time taking economic feasibility into consideration.PF value is taken from graph as shown in Fig .1

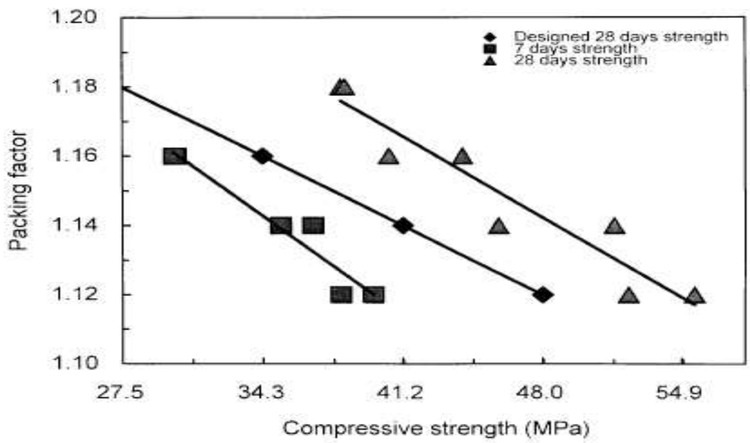

Fig .1 Effect of aggregate packing factor on compressive strength of SCC

The content of fine and coarse aggregates can be calculated as follows 1 and 2:

$$Wg = PF \times WgL(1\text{-}S/a) \quad \ldots\ldots\ldots.. \quad (1)$$

$$Ws = PF \times WsL \times S/a \quad \ldots\ldots\ldots.. \quad (2)$$

where W_g: content of coarse aggregates in SCC (kg/m^3); W_s: content of fine aggregates in SCC (kg/m^3); W_{gL}: unit volume mass of loosely piled saturated surface-dry coarse aggregates in air (kg/m^3); W_{sL}: unit volume mass of loosely piled saturated surface-dry fine aggregates in air (kg/m^3); PF: packing factor, the ratio of mass of aggregates of tightly packed 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 58%.

The Japanese Architecture Society specifies three categories of maximum size of aggregate: 15, 20 and 25 mm. The most commonly used size is 20 mm. It is also suggested that the content of coarse aggregates should be about 50% of the dry packed unit weight (JIS A1104, ASTM C29). Since the winter temperature in Japan is below 0°C, the amount of air required in the concrete is about 4.5%. In contrast, Taiwan is in the subtropical region and has no freezing and thawing problems; so the air content in SCC is about 1.5%, depending on the construction method as well as the type and dosage of SP.

4.2 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/m^3, 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:

$$C = f'c/20 \qquad \ldots\ldots(3)$$

Where C: cement content (kg/m^3);$f'c$: designed compressive strength (psi).

4.3 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 ACI 318 or other methods in previous studies. The content of mixing water required by cement can then be obtained using (Eq. 4):

$$W = (W/C)C \qquad \ldots\ldots \quad (4)$$

Where W_{wc}: content of mixing water content required by cement (kg/m^3); W/C: the water/cement ratio by weight, which can be determined by compressive strength.

4.4 Calculation of fly ash (FA) and adva-960 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. Moreover, 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 (ASTM C230) of the FA and GGBS pastes are equal to that of the cement paste and let W/F and W/Sbe 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:

$$V_{Pf} + V_{PB} = 1 - \frac{W_g}{1000 \times G_g} - \frac{W_s}{1000 \times G_s} - \frac{C}{1000 \times G_C} - \frac{W_{wc}}{1000 \times G_w} - V_a \quad (5)$$

Where G_g: specific gravity of coarse aggregates; G_s: specific gravity of fine aggregates; G_c: specific gravity of cement; G_w: specific gravity of water; V_a: air content in SCC (%).

If the total amount of Pozzolanic materials (GGBS and FA) in SCC is W_{pm} (kg/m^3), 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

$$V_{Pf} + V_{PB} = \left(1 + \frac{W}{F}\right) \times A\% \times \frac{W_{pm}}{1000 \times G_f} + \left(1 + \frac{W}{S}\right) \times B\% \times \frac{W_{pm}}{1000 \times G_B} \quad (6)$$

Where G_f, G_B, G_c, 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, W_{pm} can be calculated using Eq. (6). Also, W_f (FA content in SCC, Kg/m^3) and W_B (GGBS content in SCC, Kg/m^3) can be calculated ((7) and (8)),

$$Wf = A\% \times Wpm \qquad \ldots\ldots \qquad (7)$$

$$WB = G\% \times Wpm \qquad \ldots\ldots \qquad (8)$$

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

$$Wwf = (W/F)Wf \qquad \ldots\ldots \qquad (9)$$

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

$$WwB = (W/S)\,WB \qquad \ldots\ldots \qquad (10)$$

4.5 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:

$$Ww = Wwc + Wwf + WwB \qquad \ldots\ldots \qquad (11)$$

According to the Japanese Architecture Society Ww: =160–185 kg/m^3.

4.6 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 (12)and (13):

Dosage of SP used

$$WSP = n\% \,(C + Wf + WB) \qquad \ldots\ldots \qquad (12)$$

Water content in SP

$$WwSP = (1 - m\%)\,WSP \qquad \ldots\ldots \qquad (13)$$

4.7 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.

4.8 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–binders ratio should satisfy the requirements of durability and strength.
4. Air content should meet the requirement of the mix design.

4.9 Adjustment of mix proportions:

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 flow ability, the PF value is reduced to increase the binder volume and to improve the workability.

5. TEST METHODS

Properties of fresh Self Compacting Concrete (SCC) mixes must meet three key properties:

1. Ability to flow into and completely fill intricate and complex forms under its own weight
2. Ability to pass through and bond to congested reinforcement under its own weight.
3. High resistance to aggregate segregation.

Due to the high content of powder, SCC may show more plastic shrinkage or creep than ordinary concrete mixes. These aspects should therefore be considered during designing and specifying SCC. Current knowledge of these aspects is limited and this is an area requiring further research. Special care should also be taken to begin curing the concrete as early as possible.

The workability of SCC is higher than the highest class of consistence described within EN 206 and can be characterized by the properties like filling ability, passing ability and segregation resistance

Filling ability:

a) Slump flow test , b) T_{50}cm slump,c) V-funnel test, d)Orimet.

Passing ability:

a) L – Box, b) U – Box,c) J – ring, d)Fill-box

Segregation resistance:

a) GTM test , b) V-funnel @ T_5 min

Table 4. Test methods of workability properties of SCC

S.NO	METHOD	PROPERTY
1	Slump flow test	Filling ability
2	T_{50} cm Slump flow	Filling ability
3	V-funnel test	Filling ability
4	V-funnel at T_5 minutes	Segregation Resistance
5	L-Box test	Passing ability
6	U-Box test	Passing ability
7	Fill box apparatus test	Passing ability
8	J-ring test	Passing ability
9	Orimet test	Filling ability

Table 5. Acceptance criteria of fresh properties for Self-compacting concrete as per "EFNARC" specifications:

S.NO.	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump flow test	mm	650	800
2	T_{50} cm Slump flow	sec	2	5
3	V-funnel test	sec	6	12
4	V-funnel at T_5 minutes	sec	0	+3
5	L-Box test	H2/H1	0.8	1.0
6	U-Box test	(H2-H1) mm	0	30

Table 6. Trial mixes of M50-GRADE (FA/TA=56%)

Trial mix	Grade	Cement	Fly ash	FA	CA	Water	SP	Water/powder	Results of fresh concrete
T1	M50	414.00	7.95	912.23	525.49	216.59	3.51	0.56	Not satisfied
T2	M50	415.00	8.23	923.55	535.86	222.45	3.65	0.56	Not satisfied
T3	M50	416.07	9.80	946.79	589.99	228.83	4.17	0.56	Satisfied

6. RESULTS AND DISCUSSION

Table 7. Test results for M50- Grade of concrete (7 and 28 days)

M50 GRADE	Compressive Strength (N/mm^2)		Splitting Tensile Strength (N/mm^2)	
	7 days	**28 days**	**7 days**	**28 days**
Trail-1	50.64	70.62	3.00	4.19
Trail-2	52.23	71.48	3.12	4.21
Average	**51.44**	**71.05**	**3.06**	**4.2**

7. RESULTS AND DISCUSSIONS

- Mix proportions for M50 Grade of SCC were developed using Nan Su method of mix design, which satisfied the fresh properties of SCC as per "EFNARC" specifications.
- The filling ability has determined from the slump flow test according to the specifications the value should be ranging from 650 to 800 for M50 grade the obtained filling ability value is 737 so hence the filling ability has been satisfied.
- The passing ability has determined from the L-Box test according to the specifications the H2/H1=1 or nearer to this and the minimum acceptable value is 0.8 for M50 grade the we obtained 0.86 so hence the passing ability has been satisfied.
- The passing ability has determined from the J-ring test according to the specifications value should be ranging from 0.8 to 1 for M50 grade the obtained filling ability value is 7.4 and hence the passing ability has been satisfied.
- The hardened properties are tested for compressive and split tensile strength and the results were found. The strengths of the cubes and cylinders were more compared to that of conventional concrete to this self-compacting concrete.
- The cost per cubic meter of concrete was found for conventional concrete and also self-compacting concrete and it was found that cost for self-compacting concrete is higher.

8. CONCLUSIONS

After the analysis of the results of the experimental program the following conclusions arrived

- Mix proportions for M50 grade of self compacting concrete were developed using Nan Su method of mix design, which satisfied the fresh properties of SCC as per "EFNARC" specifications.
- As the fine aggregate to total aggregate ratio 56%, the fresh properties (i.e, filling ability, passing ability and segregation resistance) have been satisfied as per "EFNARC" specifications.
- The hardened properties were also tested for compressive strength and split tensile strength. They were found to be satisfactory.

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