Comparative Study on the Design Methods to Achieve Self-Compacting Concrete

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***Abstract*- Self-compacting concrete (SCC) has the property to flow and densify on its own. The mix of SCC will be generally cohesive which will prevent the bleeding and segregation issues in concrete. In general, the SCC mix demands the usage of mineral admixtures and the High Range Water Reducing admixtures to maintain its fluidity. These mineral admixtures are generally the by-products from various industries. The utilization of these mineral admixtures not only makes the SCC mix economical by reducing the but also gives an eco-friendly edge for concrete preparation as it reduces the disposal issues. M40 grade of SCC concrete is attempted to achieve through Nan Su and Modified Nan Su method in which the cement is supplemented with the incorporation of the mineral admixtures like Fly Ash, Sugarcane Ash, Kaolin Clay, and Wood As. The outcome of the work concludes that the SCC mixes produced with the modified Nan Su method provide better mechanical strength.**

Keywords- Self Compacting Concrete; Compressive strength

I. INTRODUCTION

The Self Compacting Concrete (SCC) is being used widely mainly due to its advantages like reduction in time and vibration. It also provides better durability and finish. The main constituents in an SCC mix are similar to the conventional vibrated concrete which consists of cement as a binder, aggregates as filler and water for mixing. In addition to the regular constituent SCC demands the usage of additives which generally has chemical and mineral components.

The primary need of adopting SCC in construction is due to its flow ability and capabilities to fill the foam work with congested reinforcement. Henceforth, in order to prevent the blockage of concrete during passing complex reinforcement the usage of coarse aggregate content is to be reduced. The reduction in the coarse aggregate content boosts the cement requirement making the mix uneconomical and also increasing the hydration temperature. Hence to check the excess cement content in the mix the usage of other mineral admixtures as a replacement for cement helps in reducing the ill effects of increased cement content in the mix. In general, the mineral admixtures which has pozzolanic property is used in SCC mix. But, parallelly the works related to understanding the feasibility of utilizing other kinds of mineral admixtures are also being carried out.

The major drawback in adopting the SCC lies in the designing the mix of SCC as there is no such proven methodology to design SCC, whereas the SCC is generally designed by trial and error to meet the requirements of the mix specified by the European Federation of National Association for Representing Concrete (EFNARC) [1]. The EFNARC specifies the guidelines and recommends the tests to be carried out on a concrete mix to categorize it as SCC based on the ability to fill, pass, maintain fluidity and reduce segregation. Hence this present work aims in assessing the feasibility of developing the SCC mix by using two different methods of mix design and by incorporating Fly Ash, Sugarcane Ash, Kaolin Clay and Wood Ash in the mix as a replacement for the Cement.

A. Cement

The Ordinary Portland Cement (OPC) of 53 Grade Cement conforming to IS 12269:1987 [2] was used throughout this work. Its physical properties are tested as per IS 4031:1988 [3] [4][5] and are given in Table I.

B. Aggregates

River sand of specific gravity 2.63, fineness modulus 2.9 of Zone II gradation is used as fine aggregate. The crushed granite of 12 mm and down-size with specific gravity of 2.5 is used as coarse aggregate. The tests on the fine aggregate and coarse aggregate were performed as per IS: 383-1970 [6].

TABLE I. PHYSICAL PROPERTIES OF CEMENT

Physical properties	Results	Range
Specific gravity	3.03	3.12-3.19
Normal consistency (%)	32	30-35%
Initial Setting time (mins)	35	30
Final Setting time (mins)	580	600

C. Fly Ash

Fly ash is a by-product of thermal power plants. The particle size in Fly Ash is smooth and spherical and has a size ranging from 10 – 25 µm. The finer particles in fly ash generally help in improving the fluidity of a concrete mix. The properties of Fly Ash are shown in Table II.

D. Sugarcane Ash

Sugarcane industry produces stalks of sugarcane after extraction of the juice to prepare sugar and molasses. These sugarcane stalks are burnt in the process which has pozzolanic nature. Table II shows the properties of Sugarcane Ash.

E. Kaolin Clay

Kaolin clay is also called Lithomarge clay which generally consists of Aluminum Silicates. It is an important raw material in the industries which manufacture porcelain items. Table II shows the properties of Kaolin Clay.

F. Wood Ash

The Wood Ash used in this study is obtained from the local tobacco industry of Hunsur, Karnataka, India. The Wood Ash (WA) is obtained by burning the Tamrind wood to process and dry the wood. The chemical constituents of the wood ash is tabulated in Table III and the properties of the wood ash is tabulated in Table II.

TABLE II. PHYSICAL PROPERTIES OF MINERAL ADMIXTURES

Materials	Properties		
	Colour	Consistency	Sp. Gravity
Fly Ash	Greyish Black	140	2.27
Sugarcane Ash	Dull white	38	2.70
Kaolin Clay	Cream White	72	2.40
Wood Ash	White Grey	59	2.20

G. Super Plasticizer

The superplasticizer named Fosroc Conplast SP430 DIS is used and its properties are shown in Table IV as mentioned by the manufacturer.

TABLE III. CHEMICAL COMPOSITION OF WOOD ASH

Particular	Value
SiO_2 (%)	66.3
Al_2O_3 (%)	4.70
Fe_2O_3 (%)	2.20
CaO (%)	10.23
MgO (%)	5.32
Na_2O (%)	2.7
K_2O (%)	1.9
Loss of Ignition	4.78

TABLE IV. PROPERTIES OF SUPER PLASTICIZER

Physical properties	Result
Specific gravity	1.2
Colour	Brown liquid
Brand	Fosroc Conplast SP430 DIS

II. MIX PROPORTIONING METHODS

A. Nan Su Method

This method was introduced by Nan Su, et al [7]. This method gives the mix design and proportioning of various concrete ingredients.

B. Modified Nan Su Method

Vilas V. Karjinni et.al [8] proposed a Mixture Proportion Procedure for SCC. This method of mixed design highlighted the limitations of the Nan Su et.al method. Vilas V et.al introduced the correction factor for the cement content to make the Nan Su et.al method suitable for SCC design for grades less than M50.

Table V and Table VI show the mix proportion that was adopted from two different methods. A design target strength adopted was M40.

TABLE V. MIX PROPORTION ARRIVED THROUGH NAN SU METHOD

Materials (Kg/m^3)	Mix Containing			
	Fly Ash	Sugarcane Ash	Kaolin Clay	Wood Ash
Cement	290	290	290	290
Powder	63	155	102	111
Fine Aggregate	961	961	961	961
Coarse Aggregate	743	743	743	743
Water	209	179	194	186
Plasticizer	6.36	8.00	7.06	7.22

TABLE VI. MIX PROPORTION ARRIVED THROUGH MODIFIED NAN SU

Materials (Kg/m^3)	Mix Containing			
	Fly Ash	Sugarcane Ash	Kaolin Clay	Wood Ash
Cement	400	400	400	400
Powder	18	43	28	31
Fine Aggregate	961	961	961	961
Coarse Aggregate	743	743	743	743
Water	192	184	188	186
Plasticizer	7.52	7.98	7.72	7.76

III. ACCEPTANCE TESTS ON SCC MIXES BASED ON EFNARC GUIDELINES

The laboratory tests are conducted to gauge the requirements of the SCC mix as per the EFNARC [1]. The accepted range of results is represented in Table VII and the test results are tabulated in Table VIII and Table IX for both mixes.

TABLE VII. SCC – ACCEPTANCE CRITERIA AS PER EFNARC

Test	Accepted Range
Slump Flow	650 – 800 mm
V- funnel	6-12 sec
L- box	0.8-1.0
U- box	0-30 mm

TABLE
VIII. FRESH TEST ON MIXES PREPARED THROUGH NAN SU METHOD

Mix with	Mix Containing			
	Slump Flow	V- funnel	L- box	U- box
Fly Ash	700 mm	9 sec	0.9	20 mm
Sugar Cane Ash	725 mm	7 sec	1.0	10 mm
Kaolin Clay	675 mm	11 sec	0.8	24 mm
Wood Ash	690 mm	10 sec	0.9	26 mm

TABLE IX. FRESH TEST ON MIXES PREPARED THROUGH MODIFIED NAN SU

Mix with	Mix Containing			
	Slump Flow	V- funnel	L- box	U- box
Fly Ash	740 mm	8 sec	0.8	25 mm
Sugar Cane Ash	760 mm	7 sec	1.0	15 mm
Kaolin Clay	710 mm	10 sec	0.9	28 mm
Wood Ash	720 mm	9 sec	0.8	mm

IV. TEST ON HARDEND PROPERTIES

The concrete specimens were cured for a period of 7,14 and 28 days and were tested for compressive strength and flexural strength and split tensile strength in accordance with IS: 516-1959 [9] and IS: 5816-1999 [10]. The compressive strength results are tabulated in Table X and Table XI. The flexural strength results are tabulated in Table XII and Table

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XIII. The Split tensile strength results are tabulated in Table XIV and Table XV.

TABLE X. COMPRESSIVE STRENGTH OF SCC PREPARED THROUGH NAN SU METHOD

Mix with	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Fly Ash	24.50	30.50	33.00
Sugar Cane Ash	26.00	31.50	35.50
Kaolin Clay	23.50	29.50	32.00
Wood Ash	19.50	25.00	28.50

TABLE XI. COMPRESSIVE STRENGTH OF SCC PREPARED THROUGH MODIFIED NAN SU METHOD

Mix with	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Fly Ash	30.50	36.50	40.50
Sugar Cane Ash	33.50	39.50	41.50
Kaolin Clay	31.00	34.00	40.00
Wood Ash	26.00	32.50	36.00

TABLE XII. FLEXURAL STRENGTH OF SCC PREPARED THROUGH NAN SU METHOD

Mix with	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Fly Ash	3.15	3.50	3.60
Sugar Cane Ash	3.20	3.60	3.75
Kaolin Clay	3.00	3.50	3.50
Wood Ash	2.75	3.20	3.30

TABLE XIII. FLEXURAL STRENGTH OF SCC PREPARED THROUGH MODIFIED NAN SU METHOD

Mix with	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Fly Ash	3.60	3.95	4.10
Sugar Cane Ash	3.75	4.00	4.20
Kaolin Clay	3.55	3.70	3.95
Wood Ash	3.20	3.40	3.80

TABLE XIV. SPLIT TENSILE STRENGTH OF SCC PREPARED THROUGH NAN SU METHOD

Mix with	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Fly Ash	1.80	2.15	2.20
Sugar Cane Ash	1.90	2.25	2.30
Kaolin Clay	1.70	2.20	2.15
Wood Ash	1.20	1.50	1.90

TABLE XV. SPLIT TENSILE STRENGTH OF SCC PREPARED THROUGH MODIFIED NAN SU METHOD

Mix with	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Fly Ash	2.25	2.50	2.70
Sugar Cane Ash	2.35	2.65	2.80
Kaolin Clay	2.10	2.35	2.50
Wood Ash	1.85	2.15	2.30

V. DISCUSSIONS ON THE RESULTS

A. Mix Proportion

In both methods of mix design, the consistency of the finer materials is the main factor that determines the quantity of powder in the mix. Adopting Nan-Su et al and the Modified Nan Su method of mix design, will reduce the number of trails to achieve the perfect SCC mix to meet the EFNRAC guidelines.

The cement content in the Modified Nan Su method is more than that of the Nan Su method as the modification factor is adopted.

B. Compressive Strength

The compressive strength test results show that all the mixes which were prepared by adopting the Nan Su method failed to attain the target design strength of 40 MPa. The compressive strength of the SCC mixes prepared with the Modified Nan Su method with admixtures like Fly Ash, Sugarcane Ash, Kaolin Clay and Wood Ash is 18.51%, 14.45%, 20% and 20.83% more than the mixes prepared with the Nan Su method with the same admixtures respectively.

The SCC prepared with the Nan Su method containing Sugarcane Ash had better compressive strength gain than all other mixes with about 35.50 MPa. The compressive strength achieved by the SCC mix containing Sugarcane Ash reported compressive strength that is 7.5%, 10.9% and 24.5% more than the SCC mix containing Fly Ash, Kaolin clay and Wood Ash respectively.

Unlike the SCC mix prepared by adopting the Nan Su method, the SCC mixes were designed by adopting the Modified Nan Su method that achieved the target designed strength of 40 MPa except with the mix containing Wood Ash.

The SCC prepared with the Modified Nan Su method containing Sugarcane Ash had better compressive strength gain than all other mixes with about 41.00 MPa for 28 days of curing. The compressive strength achieved by the SCC mix containing Sugarcane Ash reported a compressive strength that is 2.5%, 3.75% and 15.27% more than the SCC mix containing Fly Ash, Kaolin clay and Wood Ash respectively.

C. Flexural Strength

The flexural strength of the SCC mixes prepared by the Modified Nan Su method is higher than the mixes prepared by the Nan Su method. The flexural strength gain is alike to that of Compressive strength in which the mixes containing Sugarcane Ash showed better flexural strength than the other mixes. In the case of mixes produced with the Nan Su method, the flexural strength of the mix with Sugarcane ash is 4.16%, 7.14% and 13.63% higher than that SCC mix containing Fly Ash, Kaolin clay and Wood Ash respectively. Whereas in the case of the mixes produced with the Modified Nan Su method the flexural strength of the mix with Sugarcane ash is 1.2%, 8.10% and 17.64% higher than that SCC mix containing Fly Ash, Kaolin clay and Wood Ash respectively.

The flexural strength of the SCC mixes prepared with the Modified Nan Su method with admixtures Fly Ash, Sugarcane Ash, Kaolin Clay and Wood Ash is 8.86%, 6.25%, 5.40% and 2.94% higher than the mixes prepared with the Nan Su method with the same admixtures respectively.

D. Split Tensile Strength

The Split Tensile Strength of the SCC mixes prepared by the Modified Nan Su method is higher than the mixes prepared by the Nan Su method. The split tensile strength gain has a similar pattern as that of Compressive strength and flexural strength in which the mixes containing Sugarcane Ash showed better split tensile strength than the other mixes. In the case of mixes produced with the Nan Su method, the flexural strength of the mix with Sugarcane ash is 4.34%, 6.52% and 17.39% more than that of SCC mix containing Fly Ash, Kaolin clay and Wood Ash respectively. Whereas in the case of the mixes produced with the Modified Nan Su method the flexural strength of the mix with Sugarcane ash is 3.57%, 10.71% and 17.85% more than that of SCC mix containing Fly Ash, Kaolin clay and Wood Ash respectively.

The flexural strength of the SCC mixes prepared with the Modified Nan Su method with admixtures like Fly Ash, Sugarcane Ash, Kaolin Clay and Wood Ash is 18.51%, 17.85%, 14.00% and 17.39% more than the mixes prepared with the Nan Su method with the same admixtures respectively.

VI. CONCLUSIONS

1. The Nan Su method and Modified Nan Su method can be adopted to achieve the desirable fresh properties to meet the EFNARC standards to ensure viscosity, the ability to fill and the passing of the Self Compacting Concrete mixes.
2. The quantity of mixing water and the superplasticizer is dependent on the quantity of cement and admixtures in the mix.
3. The Strength gain in the mixes prepared with the Modified Nan Su method is better than the mixes prepared with the Nan Su method. This may be due to the higher cement and lesser admixture content in the Modified Nan Su method.
4. The Sugarcane Ash can be considered an effective partial replacement for cement as it provided better strength than the other admixtures.
5. Fly Ash and Kaolin clay can also be used as a partial replacement for cement as there is not much reduction in the strength.

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