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A New Mix Design Method for Self-Compacting Concrete Based on Close Aggregate Packing Method

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Abstract

The close aggregate packing method is a new type of mix design used to design for self – compacting concrete. To improve the particle packing density of concrete, the particles should be selected to fill up the voids between large particles with smaller particles and obtain a dense and stiff particle structure. A higher degree of particle packing leads to minimum voids, maximum density, and cement and water requirement will be less. The optimum bulk density was obtained at a proportion of 42% coarse aggregates (20mm downsize), 18% coarse aggregates (12.5mm downsize), and 40% fine aggregates. The peak value of the compressive strength of cubes is 81 MPa, while that of the cylinders' split tensile strength is 2.82 MPa. The mix ratio of 1:0.80:1.20:0.25:0.013 (cement: fine aggregate: coarse aggregate: water ratio: supper plasticizer dosage) should be used for the consistent production of a Grade 80 MPa self-compacting concrete as it will meet the European Standard for Self-Compacting Concrete acceptability criteria for a self-compacting concrete and also give 28 days compressive strength of 81 MPa.

Keywords - *Concrete, Self-compacting Concrete, Bulk density, voids ratio, packing density, mix design, plotting.*

I. INTRODUCTION

Concrete is one of the most versatile and widely used construction materials. Due to the increasing demand for reinforced concrete structures in modern society to meet new developments, increasing population, and new ambitious structural design ideas, the reinforcement in concrete structures became denser and clustered. The heavy and dense reinforcement can raise problems of pouring and compacting the concrete. The concrete must be able to pass the dense rebar arrangement without blocking or segregating. The design of such concrete is very challenging because of poor placement and the lack of good Vibratory compaction can lead to the inclusion of voids and loss of long-term durability of concrete structures. This has been a concern for engineers for many years. Hemanth et al., 2017. [1]

Self-compacting concrete (SCC) is a special type of concrete that can be placed and consolidated under its own weight without any vibration effort due to its excellent deformability. At the same time, it is cohesive enough to be handled without segregation or bleeding. Cajun *et al.* 2015. [2]

Depending on its composition, self-compacting concrete (SCC) can have a wide range of properties, from a normal to an ultra-high compressive strength, from a poor to extremely high durability. The mixture of self-compacting concrete (SCC) is strongly dependent on its constituents' composition and characteristics in its fresh state. The properties of self-compacting concrete (SCC) in its fresh state greatly influence its properties in the hardened state. Therefore, it is critical to understand its flow behavior in the fresh state. Since the self-compacting concrete (SCC) mix is essentially defined in terms of its flow-ability, its rheology's characterization and control are crucial for its successful production. Hemanth et al., 2017. [1]

Furthermore, the need for very fluid concrete has existed for a long time. In earlier times, this always had to be done with a high increase in the water content. The results were poor stability of the concrete because of insufficient cohesion. Segregation and bleeding caused very low concrete quality. Other very negative effects were the reduced strength and durability and the increased porosity of the concrete, resulting from high-water content. Beissel *et al.* 2001. [3]

II. LITERATURE REVIEW

Caijun *et al.*; 2015: The concept of self-compacting concrete (SCC) was first proposed by Okamura in 1986, and the prototype was first developed by Ozawa at the University of Tokyo in 1988. [2]

Corinaldesi & Moriconi; 2011: The development of self-compacting concrete is considered as a milestone achievement in concrete technology due to several advantages: high performance of both fresh and hardened concrete (high flowability and segregation resistance, low porosity, high strength, and durability, etc.); wider applications (components and structures with complicated shape and highly congested by steel reinforcements); money-saving (increased works' speed and reduced costs for energy, equipment, and workmanship); enhancement towards modernization of construction process; environment protection due to high consumption of industrial by-products and improved working environment by reduced noise and health hazards. [4]

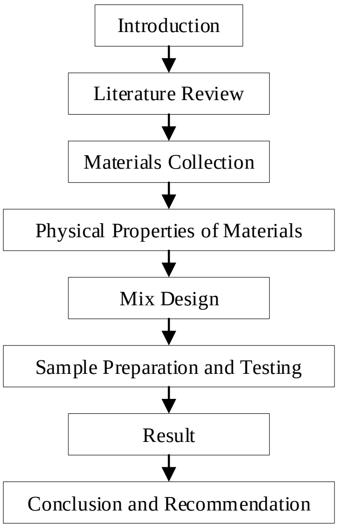
Godfrey *et al.*; 2018: Carried out research work on New Absolute Volume Mix Design Method for Self-Compacting Concrete, and their work established a mix design for SCC. The self-compacting concrete produced by their new mix design had high deformability with moderate viscosity, which ensured uniform dispersion of concrete constituents during transportation, casting, and after that until set. With varying water-cement ratios of 0.15, 0.15, 0.2, 0.25, and 0.3, a variation of the compressive strength of 69,67,65,64 and 40 MPa at 28 Days Wet curing and crushing, respectively. [5]

Bapat *et al.*; 2004: Carried out a number of extensive mix design trials to arrive at a suitable mix-proportion for N-30 grade using 20mm maximum size aggregates. It was observed from Bapat *et al.* (2004) that the compressive strength of the concrete increases with aging. On average, the compressive strength ranges from 9, 17, and 38 MPa at age 7, 14, and 28 days respectively, while that of Split Tensile and Flexural Strength ranges from 2.5, 3.8, and 4.5 MPa for sample 1 to 7, respectively at average. [6]

Khaleel & Abdul; 2013: Carried out research work on a mixed design method for self-compacting metakaolin concrete with different properties of coarse aggregate. Metakaolin mixtures, namely MK5, MK10, and MK15, showed good strength attainment compared with the control mixture due to metakaolin's pozzolanic activity. It was also observed that the concrete's compressive strength increases when the volumn of metakoalin present in the concrete is less and decreases when the volume of metakoalin is more with respect to concrete age at 7 14 and 28, 56, and 90 days. At age 28, 5%, 10%, and 15% of metakaolin present in the hardened concrete give 94, 90, and 88 MPa. While concrete with 0% metakaolin, i.e., without metakaolin, gives 70 MPa. [7]

Ubojiekere *et al.*; 2018: Carried out research work on Workability and Mechanical Properties of High-Strength Self-Compacting Concrete Blended with Metakaolin, and their work established that metakaolin increases strength significantly. The compressive strength for the 0.40 water/binder ratio, SCC group, ranged from 24 MPa to 56 MPa. For 0.35 water/binder ratio, the compressive strength for the SCC group ranged from 29 MPa to 64.3 MPa. Their research work also concluded that metakaolin should be adopted in the production of High strength self-compacting concrete.[8]

III. METHODOLOGY



IV. MATERIALS COLLECTION

A. Materials

Five basic ingredients were used in this experimental work:

1) Ordinary Portland Cement branded Dangote Cement CR 42 (Grade 42.5) conforming to EN 197-1 was used in producing samples.
2) Continuously graded granite aggregate of 20mm maximum size coarse aggregate and 12.5mm coarse aggregate conforming to EN 12620 was used.
3) Fine aggregate is manufactured sand, and river sand (conforming to EN 12620) has been used.
4) Water that conformed to EN 1008 was used in this experiment.
5) Fosroc Auracast 200, a low viscosity, high-performance water reducer, and advanced high early-age strength, superplasticizer conforming to EN 934-2 was used in this experiment.

V. PHYSICAL PROPERTIES OF MATERIALS

The physical properties of the materials were carried out by sieve analysis of the fine and coarse aggregate. The bulk density and specific gravity of fine and coarse aggregate were determined, and the specific gravity of cement and superplasticizers are also known.

A. Cement

Grade 42.5 Ordinary Portland Cement (OPC), a product of Dangote Cement, was used. The cement is of uniform color (grey color) and free from any hard lump. The specific gravity of cement determined in the laboratory is 3.10.

B. Aggregates

The aggregates used in this research work were fine and coarse aggregates (normal weight aggregate). The use of aggregate in the concrete mix improves both the volume stability and the durability of the resulting concrete.

C. Fine Aggregate (FA)

The fine aggregates used were collected from the river (Bathowate Sand fill in Ogbogoro Community, Obio / Okpor Local Government Area, Rivers State). The sand was collected to ensure it those not contained any deleterious materials. Sieve analysis was carried out on the fine aggregate according to BS 812: Part 103: 1995. The bulk density test and specific gravity test were carried out according to BS 812: Part 2: 1995. The fine aggregate used had a bulk density value of 1936 Kg/m^3 and a specific gravity of 2.50 (2500 Kg/m^3).

D. Coarse Aggregate

Crushed rock was used as coarse aggregate, having a maximum size of 20mm obtained from Akpanka in Calabar, Cross River State. Inspections were carried out to ensure the aggregate is free from harmful materials and dried to surface condition before use. The coarse aggregate used had a bulk density value of 1607 Kg/m^3 and a specific gravity of 2.54 (2540 Kg/m^3).

E. Water (W)

Water helps in the hydration of the concrete mix. Water aids in the production of concrete (it starts a reaction between the cement and aggregates). Water suitable for concrete work is water suitable for drinking. The water used for this research work is pipe borne water free from contaminations made available in Rivers State University in Structure Laboratory. The specific gravity of water is 1.0 (1000 Kg/m^3).

F. Superplasticizer (SP)

The superplasticizer (SP) used in this research work Fosroc Auracast 200A. The use of a superplasticizer is practiced to produce flowing, self-leveling, self-compacting tremie concreting and the production of high strength and high-performance concrete. The use of superplasticizers is more powerful as dispensing agents, and they are high range water reducers. The specific gravity of the Fosroc Auracast superplasticizer is 1.06.

As discussed in this section, the physical properties of materials determined in the laboratory are presented in table 1.

TABLE I
Physical Properties of Materials

S/No.	Materials	Physical Properties Bulk Density (Kg/m3)	Specific Gravity (S.G)	Specific Gravity (S.G) (Kg/m3)
1	Fine Aggregate (FA)	1936	2.50	2500
2	Coarse Aggregate (CA) - (20mm to 12.5mm)	1607	2.54	2540
3	Coarse Aggregate (CA) - (12.5mm to 6.70mm)	1733	2.56	2560
4	Blended Aggregate 18 42 40	2130	2.38	2380
5	Cement	-	3.10	-
6	Superplasticizer (SP)	-	1.06	-
7	Water (w)	-	1.00	-

VI. MIX DESIGN

A. Mix Design for M80 Grade Concrete (Using the Close Aggregate Packing Method, i.e., Packing Density Method)

The packing density method of mix design is the only mix design method used for proportioning normal concrete, high strength concrete, and self-compacting concrete. Narasimha *et al.*, 2014. [9]

Batch Volume:

1. Number of 100 × 100 × 100 cubes per batch = 9;
   Volume $= (0.1x0.1x0.1)x9 = 0.009m^3$
2. Number of 500 × 100 × 100 beams per batch = 3;
   Volume $= (0.5x0.1x0.1)x3 = 0.015m^3$
3. Number of 300mm long × 150mm diameter cylinders per batch = 6;

Volume $= \left(\left(\frac{3.142x0.15^2}{4}\right)x(0.3)\right)x6 = 0.0318m^3$

$$Therefore, Batch\,Volume$$
$$= (0.009 + 0.0318 + 0.015)$$
$$= 0.0558$$

Considering the ratio of 40% of fine aggregate (sand) and 60% of coarse aggregate.

For Fine Aggregate (sand) = 40%

For Coarse Aggregate:

20mm aggregate (CA) and 12.5mm aggregate are in the ratio of 30% and 70% respectively of 60% overall coarse aggregate (CA).

Hence, for 20mm coarse aggregate (CA) = $\frac{30}{100}x60 = 18\%$

For 12.5mm coarse aggregate (CA) $\frac{70}{100}x60 = 42\%$

Therefore, the three aggregate ratio CA 20mm: CA 12.5mm: FA is 18:42:40

(1) The bulk density of combined coarse aggregate 20mm to 12.5mm, 12.5mm to 6.70mm, and fine aggregate (sand) blended = 2130 Kg/m^3.
(2) The specific gravity of blended coarse aggregate (CA) and fine aggregate (FA)= 2380 Kg/m^3.
(3) Void Content:

Voids content in percentage volume = $\frac{Specific\ Gravity\ (S.G) - Bulk\ Density\ (B.D)}{Specific\ Gravity\ (S.G)} x \frac{100}{1}$

$$= \frac{2380 - 2130}{2380} x \frac{100}{1}$$

$$= \frac{250}{2380} x \frac{100}{1}$$

$$= 0.10504x100$$

$$\underline{= 10.50\%}$$

(4) Packing Density (P.D):

(a) The packing density of 20mm aggregate (20mm to 12.5mm):

$$= \frac{1607x0.18}{2540} = \frac{289.26}{2540} = 0.1139$$

(b) The packing density of 12.5mm aggregate (12.5mm to 6.70mm):

$$= \frac{1733x0.42}{2560} = \frac{727.86}{2560} = 0.2843$$

(c) The packing density of fine aggregate (FA):

$$= \frac{1936x0.40}{2500} = \frac{774.4}{2500} = 0.3098$$

(d) Total packing density = Packing Density of CA (20mm) + Packing Density of CA (12.5mm) + Packing Density of FA (fine aggregate).

Packing Density (P.D) $= 0.1139 + 0.2843 + 0.3098 = 0.7080 kg/m3$

(5) Determination of Paste Content for M80 Grade Concrete:

(a) Void Content $= 1 - P.D$

$$= 1 - 0.7080$$

$$= 0.2920$$

(b) Assuming paste content as 10% in excess of void content, detailed calculations to obtain all the ingredients of concrete such as coarse aggregate 20mm, 12.5mm, fine aggregate, cement, and water content is given below:

Paste Content $= 0.2920 + 0.1x0.2920 = 0.3210$

The primary paste volume required for filling ability:

$V_P = V_{Exp} + V_{Void}$

$$V_{exp} = excess\ paste\ volume$$

$$V_p = 0.3210 + \frac{10.50}{100}$$

$$V_p = 0.3210 + 0.105$$

$$V_p = 0.4260$$

The volume of aggregate $= 1 - V_p = 1 - 0.4260 = 0.5740$

(c) Total Solid Volume of Aggregates:

$$= \frac{weight\ fraction\ of\ 20mm}{Specific\ Gravity\ (S.G)} + \frac{weight\ fraction\ of\ 12.5mm}{Specific\ Gravity\ (S.G)} + \frac{weight\ fraction\ of\ fine\ aggregate}{Specific\ Gravity\ (S.G)}$$

$$= \frac{0.18}{2.54} + \frac{0.42}{2.56} + \frac{0.40}{2.50}$$

$$= 0.0709 + 0.1641 + 0.160$$

$$\underline{= 0.395m^3}$$

Weight of aggregate:

$$= \frac{Volume\ of\ Aggregate}{Total\ Solid\ Volume\ of\ Aggregate} x\ weight\ fraction\ x\ 1000\ (Kg/m^3)$$

Weight of 20mm aggregate $= \frac{0.5740}{0.395} x0.18x1000$

$$= 1.4532x0.18x1000$$

$$\underline{= 261.58Kg/m^3}$$

Weight of 12.5mm aggregate $= \frac{0.5740}{0.395} x0.42x1000$

$$= 1.4532x0.42x1000$$

$$\underline{= 610.33Kg/m^3}$$

Weight of fine aggregate $= \frac{0.5740}{0.395} x0.40x1000$

$$= 1.4532x0.40x1000$$

$$\underline{= 581.27Kg/m^3}$$

(dA1) Water Cement Ratio of 0.25:

$\frac{w}{c} = 0.25; w = 0.25c$

Total Paste $= c + w + S.P$

S.P = 1.3% of cementitious weight

$Therefore, Total\ paste$

$$= \frac{c}{S.G_{cement}} + \frac{0.25c}{S.G_{water}} + \frac{0.013}{S.G_{S.P}}$$

$$= \frac{c}{3.10} + \frac{0.25}{1.00} + \frac{0.013}{1.06}$$

$$= 0.3226c + 0.25c + 0.0123$$

$$\underline{= 0.5849c}$$

$$Cement\ Content = \frac{V_p}{Total\ Paste} x1000\ in\ Kg/m^3$$

$$= \frac{0.4260}{0.5849} x1000$$

$$= 0.7283x1000$$

$$\underline{= 728.30Kg/m^3}$$

$Water\ Content\ (w) = 0.25x728.30$

$$= 182.08Kg/m^3$$

Batch Weight:

Batch Volume = 0.0558m^3

- Weight of 20mm CA $= 261.58x0.0558 = 14.60Kg$
- Weight of 12.5mm CA $= 610.33x0.0558 = 34.06Kg$
- Weight of FA (Sand) $= 581.27x0.0558 = 32.43Kg$
- Weight of Cement (c) $= 728.33x0.0558 = 40.64Kg$
- Weight of Superplasticizer (S.P) $= 0.013x40.64 = 0.53Kg$
- Weight of Water (w) $\underline{= 182.08x0.0558 = 10.16Kg}$

TOTAL WEIGHT = $\mathbf{132.42Kg}$

$$\frac{Cement}{1} : \frac{Sand}{0.80} : \frac{20mm\ \&\ 12.5mm\ combined\ CA}{1.20} : \frac{Water}{0.25} : \frac{S.P}{0.013}$$

The mix proportion for SCC Close Aggregate Packing Method using water/cement ratio of 0.25,0.30 and 0.35 is presented in Table 2

TABLE 2
Concrete Mixture Proportion

W/C	20mm Coarse Aggregate (Kg/m^3)	12.5mm Coarse Aggregate (Kg/m^3)	Fine Aggregate (Kg/m^3)	Cement (Kg/m^3)	Super-plasticizer (Kg/m^3)	Water (Kg/m^3)	Total (Kg/m^3)
0.25	261.49	610.14	581.08	728.88	9.48	182.22	2,373.29
0.30	261.49	610.14	581.08	671.48	8.73	201.44	2,334.36
0.35	261.49	610.14	581.08	622.45	8.09	217.86	2,301.11

VII. SPECIMEN PREPARATION AND TESTING

A. *Material Handling*

1) The materials (coarse aggregate and fine aggregate) were air-dried and oven-dried in the laboratory at 115°C.
2) All tests carried out were done according to the European Guidelines for Self-Compacting Concrete (EFNARC) and according to the British Standard (BS 1881), BS 882, BS 5328, and BS 8110.

The sample mixes prepared went through various laboratory tests for self-compacting concrete-like slump flow test, J-ring test, V funnel test, and L Box test.

B. *Experimental Process*

1) Air drying of aggregates in the oven
2) Sieve analysis, bulk density, and specific gravity determination
3) Batching of aggregate and cement by weight
4) Mixing of Aggregate using an electric concrete mixing machine
5) Workability determination using slump flow test, J-ring test, V-funnel test, and L-Box test in accordance with the European Guidelines for SCC (EFNARC)
6) Curing of concrete in accordance with BS 8110
7) Compressive strength determination
8) Flexural Tensile strength determination
9) Split tensile strength determination.

C. *Workability*

Table 3 shows the acceptable limits/criteria for self-compacting concrete proposed by EFNARC 2002 [10]

TABLE 3
Acceptable Criteria for SCC. EFNARC (2002)

	Method	Unit	Minimum	Maximun
1	Slump flow by Abrams cone	mm	650	800
2	T_{50} Slump flow	sec	2	5
3	J-ring	mm	0	10
4	V-funnel	sec	6	12
5	Time increase, V-funnel at $T_{5minutes}$	sec	0	3
6	L-box	(h_2/h_1)	0.8	1
7	U-box	$(h_2 - h_1)mm$	0	30

6.1 Slump Flow Test and T_{500mm} Slump-Flow Test

Introduction: The slump flow test is done to access the horizontal flow of concrete in the absence of obstructions. It is the most commonly used test and gives a good assessment of filling ability. The test also indicates the resistance to segregation. Shetty & Chand, 2013. [11].

Equipment: the equipment is shown in Fig. 1.

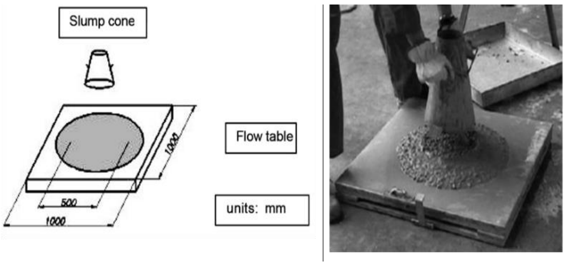


Fig. 1. Slump Flow Test Method

Interpretation of Result: The higher the flow value, the greater its ability to fill formwork under its weight. A value of at least 650mm is required for SCC. In case of severe segregation, most coarse aggregate will remain in the center of the concrete and mortar pool and paste at the periphery of concrete.

6.2 J – Ring Test

Introduction: The J-ring test denotes the passing ability of the concrete. The diameter of the ring formed by vertical sections is 300mm and height 100mm.

Equipment: the equipment is shown in Fig. 2.

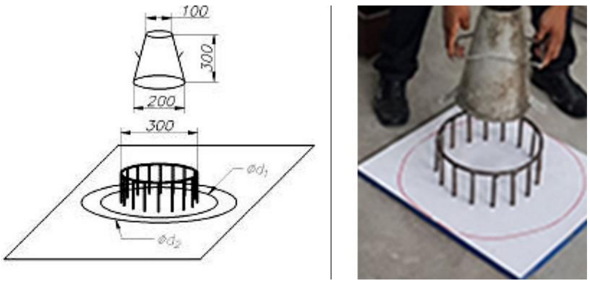


Fig. 2. J – Ring Test Method

Interpretation of Result: The measured flow is certainly influenced by how the concrete movement is hindered by the reinforcing bars.

6.3 V–Funnel Test and V–Funnel Test at T_5 min

Introduction: The V-Funnel test is used to determine the concrete's filling ability (flowability) with a maximum size of aggregate 20mm size.

Equipment: the equipment is shown in Fig. 3.

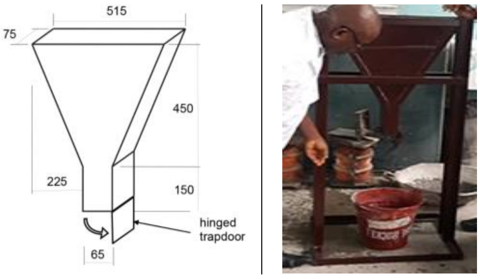


Fig. 3. V–Funnel Test Apparatus

Interpretation of Result: This test is used in determining the ease of flow of the concrete; the shorter the flow times, the greater flowability. For self-compacting concrete, a flow time of 10 seconds is considered appropriate.

6.4 L – Box Test Method

The test assesses the flow of concrete and also the extent to which the concrete is subjected to blocking by reinforcement.

Equipment: the equipment is shown in Fig. 4.

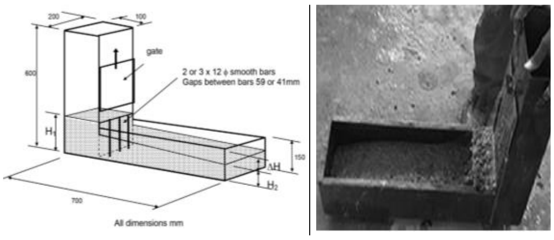


Fig. 4. L – Box Test Apparatus

Interpretation of Result: If the concrete flows as freely as water, at rest, it will be horizontal. Therefore, $\frac{H_2}{H_1}$ It will be equal to 1. Therefore, the nearer the test values, the blocking ratio, is to unity, the better the concrete.

D. *Hardened Concrete Tests*

6.5 Compressive Strength Test

Empty molds are filled with fresh concrete using a standard procedure. After 24 hours, the specimens are taken out of the molds and moist cured for 28 days. At the end of the curing period, they are tested, as shown in fig. 5. The compressive strength is calculated from the equation below: $f_c = \frac{failure\ load}{cross\ sectional\ area}$

Fig. 5. Experimental Setup for Compression Test

VIII. RESULT

A. *Workability*

Table 4 shows the results of the laboratory tests on the fresh Self-Compacting Concrete. It can be observed from Table 4 that a water/cement ratio of 0.25 achieved a high slump flow of 794mm, water/cement ratio of 0.35 achieved a high T50 cm flow of 5.0secs, water/cement ratio of 0.25 achieved a high J-ring flow of 600mm, water/cement ratio of 0.35 achieved a high V-funnel of 12secs and water/cement ratio of 0.25 achieved a high L-box of 0.84 (h2/h1).

TABLE 4
Self-Compacting Concrete Workability Results from Fresh Concrete

Mix ID	W/C Ratio	Slump Flow (mm)	T_{50} cm Slump Flow (sec)	J-Ring Flow (mm)	J-Ring (sec)	V-Funnel (sec)	L-Box (h_2/h_1)
SCC1	0.25	794	4.0	600	7	9	0.84
SCC2	0.30	751	4.5	594	8	10	0.83
SCC3	0.35	680	5.0	550	9	12	0.80
EFNARC (2002)	**650 – 800**	**2.0 – 5.0**	**0 – 10.0**		**-**	**6.0 – 12.0**	**0.8 – 1.0**

7.1 Flow Test: Fig. 6 shows a plot of the slump flow (mm) against the W/Cement ratio. It shows the change in slump flow as the water/cement ratio is increased. It can be observed from Fig. 6 that the slump flow value decreases as the water/cement increases. It can also be observed that the slump flow is within the acceptable criteria for self-compacting concrete (EFNARC, 2002); EFNARC (2002) criteria: 650mm to 800mm.

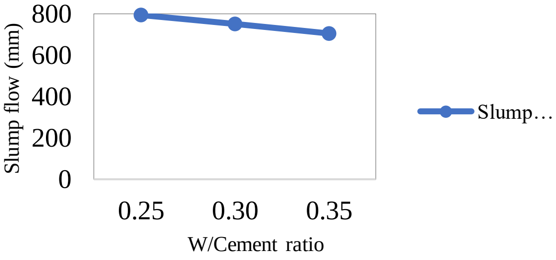


Fig. 6. Slump Flow (mm) against W/Cement Ratio

Fig. 7 shows a plot of the slump flow (mm) against W(C+FA) ratio, and W/Cement ratio, comparing this research work to works are done by Godfrey *et al. (2018)*, Dhiyaneshwaran *et al.* (2013) [12], and Shankar & Khadiranaikar (2015) [13]. It was observed that a much higher high slump flow could be achieved at a low water/cement ratio using the Close Aggregate Packing Method of mix design for self-compacting concrete.

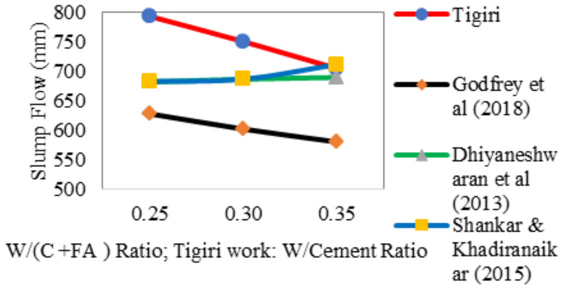


Fig. 7. The plot of Slump Flow (mm) against W(C+FA); W/Cement Ratio, Validating with other Research Works

7.2 T$_{50}$ cm Slump Flow Test: Fig. 8 shows a plot of the T$_{50}$ cm slump flow (sec) against the W/Cement ratio. It shows the change in T$_{50}$ cm slump flow as the water/cement ratio is increased. It can be observed from Fig. 8 that T$_{50}$ cm slump flow increased as the cement/cement ration increased. It can also be observed that the T$_{50}$ cm slump flow is within the acceptable criteria for self-compacting concrete (EFNARC, 2000); EFNARC (2002) criteria: 2.0sec to 6.5sec.

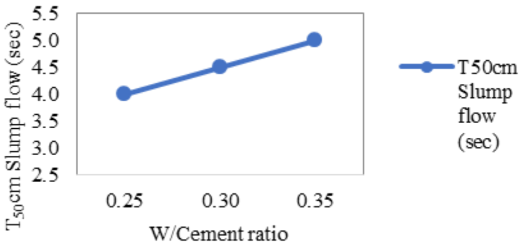


Fig. 8. The plot of T$_{50}$ cm Slump Flow (sec) against W/Cement Ratio

7.3 J – Ring Flow Test: Fig. 9 shows a plot of the J–ring flow (mm) against W(C+FA) ratio and W/Cement ratio, comparing this research work to works are done by Godfrey *et al. (2018).* It was observed that a much higher high J–ring flow could be achieved at a low water/cement ratio using the Close Aggregate Packing Method of mix design for self-compacting concrete.

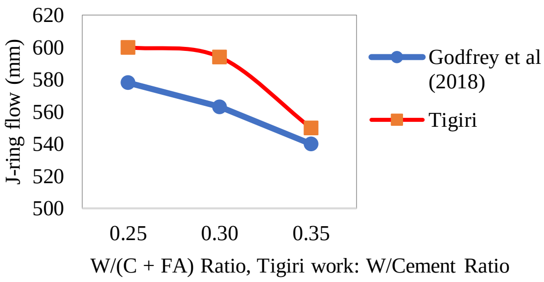


Fig. 9. The plot of J – Ring Flow (mm) against W(C+FA); W/Cement Ratio, Validating with other Research Works

7.4 V Funnel Test: Fig. 10 shows a plot of the V-Funnel time (sec) against water/cement ratio, comparing this research work to works done by Dhiyaneshwaran *et al.* (2013) and Shankar & Khadiranaikar (2015). As the water/cement ratio reduced, the difference in V-Funnel time was increased/decreases.

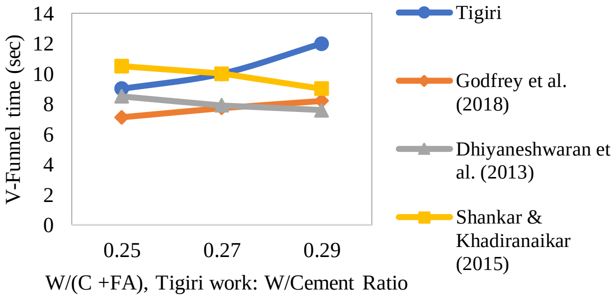


Fig. 10. The plot of V Funnel (sec) against W/Cement Ratio, Validating with other Research Works

7.4 L Box Test: Fig. 11 shows a plot of the L-Box (h_2/h_1) ratio against water/cement ratio, comparing this research work to works are done by Godfrey *et al.* (2018), Dhiyaneshwaran *et al.* (2013), and Shankar & Khadiranaikar (2015). It was observed that works by Godfrey *et al. (*2018*) and* Dhiyaneshwaran *et al.* (2013) gave results that were within the EFNARC (2002) acceptable criteria for self-compacting concrete, while the research work by Shankar & Khadiranaikar (2015) gave results that were unrealistic as no L Box (h_2/h_1) ratio value can exceed 1.0.

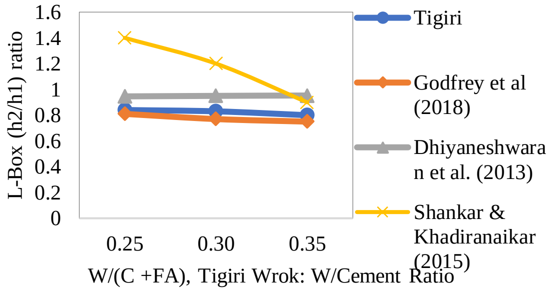


Fig. 11. L Box (h_2/h_1) against W/Cement Ratio, Validating with other Research Works

B. *Hardened Concrete Tests*

7.5 Compressive Strength: The compressive strength of the self-compacting concrete mix consisting of 12.5mm coarse aggregate, 20mm coarse aggregate, fine aggregate, cement, and supper plasticizer was measured in the laboratory and found to increase with age. The increase in the water/cement ratio resulted in a reduction in the concrete's compressive strength.

Table 5 and Table 6 show the laboratory test results on hardened concrete (Compressive Strength and Split Tensile Strength) on the Self-Compacting Concrete. It can be observed from Table 5 that a water/cement ratio of 0.25 achieved a Grade 80 Self-Compacting Concrete.

TABLE 5
Compressive Strength of Self-Compacting Concrete from Hardened Concrete

Mix ID	W/C	Compressive Strength									Average Compressive Strength		
		7 Days Compressive Strength (MPa)			14 Days Compressive Strength (MPa)			28 Days Compressive Strength (MPa)			7 Days Strength (MPa)	14 Days Strength (MPa)	28 Days Strength (MPa)
SCC1	0.25	59	70	63	70	75	72	81	79	84	64	72	81
SCC2	0.30	50	62	60	65	63	60	70	74	78	57	63	74
SCC3	0.35	42	58	48	52	60	58	68	65	71	49	57	68

TABLE 6
Split Tensile Strength of Self-Compacting Concrete from Hardened Concrete

Mix ID	W/C	Split Tensile Strength									Average Split Tensile Strength		
		7 Day Split Tensile Strength (MPa)			14 Days Split Tensile Strength(MPa)			28 Days Split Tensile Strength (MPa)			7 Days Strength (MPa)	14 Days Strength (Mpa)	28 Days Strength (MPa)
SCC1	0.25	2.40	2.62	2.48	2.62	2.71	2.66	2.82	2.78	2.87	2.50	2.66	2.82
SCC2	0.30	2.21	2.46	2.42	2.52	2.48	2.42	2.62	2.69	2.76	2.36	2.47	2.69
SCC3	0.35	2.03	2.38	2.17	2.26	2.42	2.38	2.58	2.52	2.64	2.19	2.35	2.58

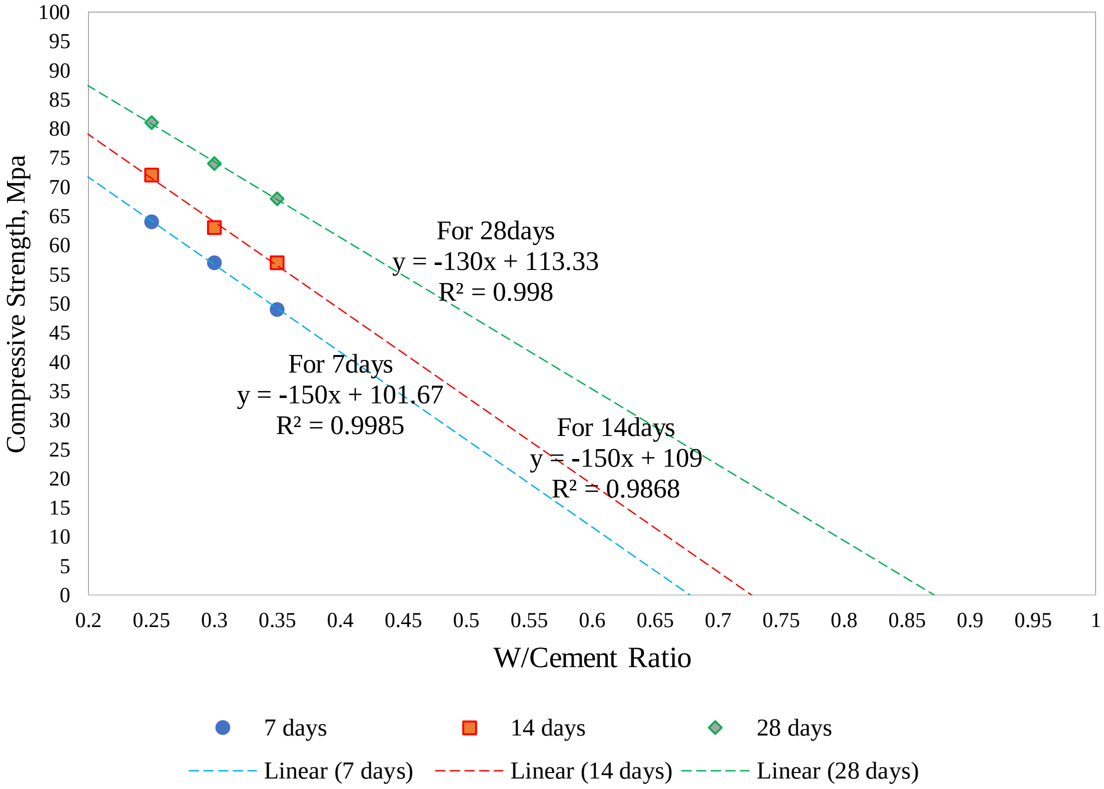


Fig. 16 Prediction of Compressive Strength for Self-Compacting Concrete Using MS Excel – Linear Forecast Trimline at 7 days, 14 days, and 28 days

Fig. 12 shows the 28 days compressive strength (MPa) plot against the water/cement ratio. It can be seen that the 28 days compressive strength of the SCC with a water/cement ratio of 0.25 gives higher strength.

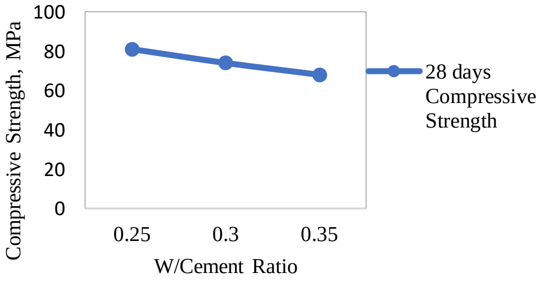


Fig. 12. The plot of the 28 days Compressive Strength (MPa) against W/Cement Ratio for Self-Compacting Concrete

Fig. 13 shows the variation of compressive strength with the age of concrete at 7 days, 14 days, and 28 days.

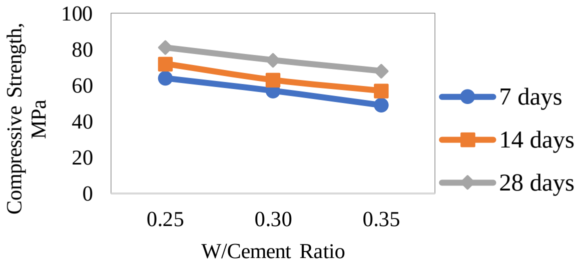


Fig. 13. The plot of Compressive Strength (MPa) against W/Cement Ration for Self-Compacting Concrete at 7 Days, 14 Days, and 28 Days

Fig. 14 shows the variation of 28 days compressive strength against water/cement ratio, comparing this research work to works are done by Godfrey *et al. (2018)*, Dhiyaneshwaran *et al.* (2013), and Shankar & Khadiranaikar (2015). It was observed that the mix design used in this research work produced a much higher compressive strength than other research works.

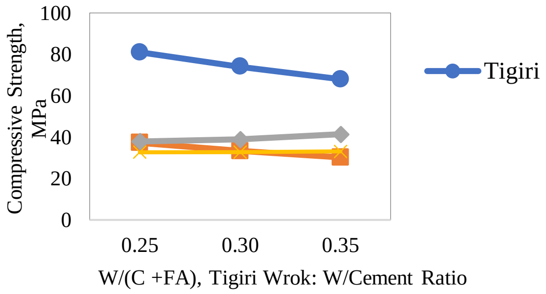


Fig. 14 Plot of 28 Days Compressive Strength (MPa) against W/Cement Ratio for Self-Compacting Concrete, Validating with other Researches

7.6 Split Tensile Strength: Fig. 15 shows the variation of split tensile strength with the age of concrete at 7 days, 14 days, and 28 days. It was observed that split tensile strength reduced with an increase in the water/cement ratio.

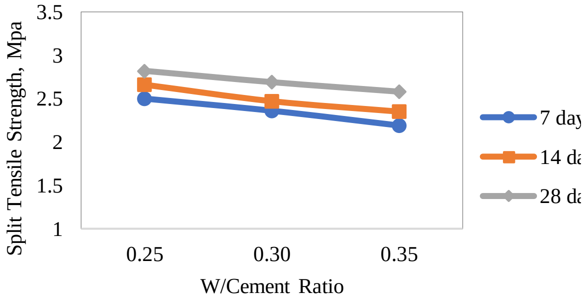


Fig. 15. The plot of Split Tensile Strength (MPa) against W/Cement Ration for Self-Compacting Concrete at 7 Days, 14 Days, and 28 Days

C. *Prediction of Compressive Strength for Self-Compacting Concrete Using MS Excel – Linear Forecast Trimline at 7 days, 14 days, and 28 days.*

Fig. 16 shows the prediction of compressive strength for self-compacting concrete at 7days, 14 days, and 28 days.

From fig. 16, the following model was formulated in MS Excel:

For 7 days compressive strength:

$$y = -150x + 101.67 \qquad (1)$$

$R^2 = 0.9985$

For 14 days compressive strength:

$$y = -150x + 109 \qquad (2)$$

$R^2 = 0.9868$

For 28 days compressive strength:

$$y = -130x + 113.33 \qquad (3)$$

$R^2 = 0.998$

From the above model, y represents the compressive strength of SCC (dependent variable), and x represents the W/Cement ratio (independent variable), meaning the compressive strength "y" depends on the value/amount of water-cement ratio "x" used.

Equations 1, 2, and 3 above give a predictive model for designing a self-compacting concrete for a 7days early strength, 14 days, and 28 days respectively, using the close aggregate packing method of mix design.

IX. CONCLUSION AND RECOMMENDATION

A. *Conclusion*

Based on the results of the study, the following conclusions were drawn:

(1) The method of aggregate blending produces a workable and less void Self-Compacting Concrete. In the aggregate blending, a ratio of 40% fine aggregate (sand) and 60% of coarse aggregate was adopted. For 20mm coarse aggregate (CA), 30% of the 60% was considered $\left(\frac{30}{100}x60 = 18\%\right)$ and for 12.5mm coarse aggregate (CA), 70% of the 60% was considered $\left(\frac{70}{100}x60 = 42\%\right)$. The three aggregates ratio CA 20mm: 12.5mm: FA is 18:42:40. The blended aggregate's bulk density had a value of 2130 Kg/m^3 and a specific gravity of 2.38 (2380 Kg/m^3).

(2) Concrete with Fosroc Auracast 200 superplasticizer had high workability and produced a slump flow range of 794mm – 800mm within the EFNARC (2002) acceptability criteria Self-Compacting Concrete.

(3) The Self-Compacting Concrete produced in this research work had 28 days of compressive strength ranging from 68Mpa – 81 MPa.

(4) An increase in water/cement ratio resulted in a reduction in workability and strength of self-compacting concrete. The SCC mix design with a water/cement ratio of 0.25 gave 28 days compressive strength of 81 MPa, which is higher than that of water/cement ratio of 0.30 and 0.35, which gave a 28 days strength of 74MPa and 68MPa, respectively.

(5) The mix ratio of 1:0.80:1.20:0.25:0.013 gave 28 days compressive strength of 81 MPa, a Grade 80 MPa concrete.

(6) A model for the design of self-compacting concrete using the close aggregate packing method was formulated in this research work for 7 days, 14 days, and 28 days and it is given as:

$y = -150x + 101.67$ for 7 days compressive strength.

$y = -150x + 109$ for 14 days compressive strength.

$y = -130x + 113.33$ for 28 days compressive strength.

B. *Recommendation*

Based on the results of this study, the following are recommended:

(1) The mix ratio of 1:0.80:1.20:0.25:0.013 should be used for consistent production of a Grade 80 MPa Self-Compacting Concrete as it will meet the EFNARC (2002) acceptability criteria for a Self-Compacting Concrete and also give 28 days compressive strength of 81 MPa.

(2) The Close Aggregate Packing Method developed in this research work should be used as the standard for Self-Compacting Concrete design. While the software and model developed in this research work can be used to design Self-Compacting Concrete.

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