New Absolute Volume Mix Design Method For Self-Compacting Concrete

Godfrey Waribo Tom Jaja, Ngoji Tonye Johnarry, Maurice Efremus Ephraim

Abstract— This research focuses on developing an enhanced rational mix design method for self- compacting concrete and optimizing it with existing specification and modifications of self-compacting concrete generally accepted in the construction industry. Trial mix were prepared and laboratory tests for self-compacting concrete which include slump flow test, J-ring test, V-funnel test and L-Box test were carried out on the fresh concrete. The tests on the trial mix were carried out in accordance with the EFNARC Specification and Guidelines for self-compacting concrete. Compressive strength test, flexural test and split tensile test to BS 1881: 1997 were carried out on a total of 250 cubes, 60 beams and 60 cylinders to investigate the properties of the hardened self-compacting concrete. The proposed new absolute volume method produced a self-compacting concrete with the highest compressive strength of 65 N/mm^2 at 28 days with the same water/cement ratio and best workability in comparison to other existing methods and subsequently should be adopted as the standard for the production of self-compacting concrete.

Index Terms— Self-Compacting Concrete, SCC New Mix Design Method, Self-Consolidating Concrete Mix Design, SCC Absolute Volume Mix Design Method, Civil Engineering Self-Compacting Concrete, High Strength Self-Compacting Concrete Mix Design.

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1 INTRODUCTION

Self-compacting concrete (SCC) has been represented as "the most revolutionary development in concrete construction for many decades". The most advantage of the self-compacting concrete is that it shorten construction period and assure adequate compaction within the structures particularly within the confined zones where vibration and compaction is difficult.

The self-compaction concrete was developed by professor, Hajime Okamura of Japan in 1986, however the prototype was initial developed in 1988 in Japan by Professor Ozawaat in the University of Tokyo. Self-compacting concrete (SCC) increases productivity levels, leading to shortened concrete construction time, makes the construction of heavily congested structural elements (hard to reach areas) easier, improves in-situ concrete quality in difficult casting loading, reduces noise and vibration related injuries and helps in achieving higher surface quality.

A number of mix design methods have been proposed for self-compacting concrete. They can be grouped into Empirical methods, Rheological methods, Particle packing model method, Discrete model method, Continuous model method and Statistical methods.

One of the customary empirical methods is the recommendations proposed by of Okamura and Ozawa [12]. In this method, 50 percent of the solid volume is taken up by coarse aggregate, while 40 percent of the mortar volume is fine aggregate. Paste composition (that is, the water to powder ratio) is then determined using flow tests on mortar. This method was derived from numerous experiments using aggregates specific to the researchers' area. A survey of adjustments in coarse and fine aggregate contents is then made to achieve desired flow properties.

Modifications to the above approach have been proposed by Edamatsu et al. [21]. In the Edamatsu et al.'s method, the limit-

ing coarse aggregate volume ratio is kept at 0.5. The fine aggregate content, in this case, is then fixed using V-funnel test with standardized coarse aggregate (glass beads). Water to powder ratio and super-plasticizer dosage are determined from mortar flow and funnel tests.

The guidelines recommended by EFNARC [6] are also based on Okamura's method. The difference is that instead of fixing the coarse aggregate limit at 0.5, a higher amount is permitted in the case of rounded aggregate (up to 0.6). The proportion of sand in the mortar is varied between 40 and 50 percent, and water to powder ratio and super plasticizer dosage are determined through mortar slump flow and V-funnel Tests. A comparison of the three methods discussed in this section is presented in Table 1.

TABLE 1

EMPIRICAL MIXTURE PROPORTIONING METHODS FOR
SCC

Proposed by	Maximum CA volume ratio	Maximum proportion of sand in mortar, percent	Paste composition (w/p ratio)	Remarks
Okamura and Ozawa (1995)	0.5	40 (empirical)	Mortar flow and V-funnel tests	Originally developed using moderate heat or belite rich cement.
Edamatsu et al. (2003)	0.5	Determined by V-funnel test using standardized coarse aggregate	Mortar flow and V-funnel tests	Enables determination of stress transferability of mortar
EF-NARC (2002)	0.5 – 0.6	40 – 50 percent (empirical)	Mortar flow and V-funnel tests	Allows more freedom in coarse aggregate content

Rheology based methods is based on the principle that conventional methods of measuring concrete workability such as the slump test provide a broad indication of the amount of work required to compact the concrete mixture. With the advent of more fluid concretes (pumpable concrete, self levelling concrete), it was necessary to measure the flow properties of concrete.

Particle packing has been suggested by some researchers as a scientific approach to mixture proportioning of concrete. The concept of particle packing is borrowed from the ceramic industry. Here, the principle is to minimize the void content of a dry granular mixture of all ingredients (including cement, fly ash and microsilica). This is done by the choice of appropriate sizes and gradation of aggregate (Discrete models). While some models adopt a discrete particle size approach, others assume the granular mixture to possess a continuous gradation (Continuous models). Sedran and de Larrard [20] demonstrated the use of a discrete particle model (compressible packing model) to design self-compacting concrete mixtures (without VMA). This model optimized the granular skeleton of concrete, and used the results from rheology measurements on fresh SCC, filling ability (using L-box test), and resistance to segregation.

Khayat et al. [16] proposed a mixture design procedure based on statistical models using a factorial design of experiments. The advantage of such an approach is that one can evaluate the effects of critical factors using minimum number of exper-

iments. Another advantage is that only an approximate idea of the variables that affect the response is required, and not the exact relationships.

The researchers in this work developed a rational method for the design of self-compacting concrete mixtures. Through a series of intensive experimental laboratory work, the absolute volume method for normal conventional concrete was New to be utilized in the design of self-compacting concrete. This new rational state of the art design method was call the New Absolute Volume Method for the design of self-compacting concrete.

Krishna et al. [17] presented an experimental procedure for the design of self-compacting concrete mixes with 29% of coarse aggregate, replacement of cement with Metakaolin and class F fly ash, combinations of both and controlled self-compacting concrete mix with 0.36 water/cementitious ratio (by weight) and 388 litre/m3 of cement paste volume. Crushed granite stones of size 16mm and 12.5mm were used with a blending 60:40 by percentage weight of total coarse aggregate.

Rakesh [15] presented a design mix of self-compacted concrete and carried out a performance – economic comparisons with prevailing conventional grade of M-40 concrete. Indu & Elangovan [5] developed an optimum mix proportioning system for the design of of high strength self-compacting concrete for different grades (30MPa – 80MPa) using numerous trial mixes.

Mohammed [19] developed a simple and rational method for designing self-compacting concrete mixes based on the desired target plastic viscosity and compressive strength of the mix. The expression for the plastic viscosity of a self-compacting concrete mix developed using the so-called micromechanical principles was exploited to develop the rational method. The simplicity and usefulness of the method was enhanced by the provision of design charts for choosing the mix proportions that achieve the mix target plastic viscosity and compressive strength. Experimental work was performed attesting the validity of this mix design procedure via a series of self-compacting concrete mixes in both the fresh and hardened states. The test mixes were found to meet the necessary self-compacting and the compressive strength criteria, thus fully validating the proposed mix proportioning method.

1.1 Research Significance

The main significance of this research was the establishment of a mix design for self-compacting concrete that can be used as standard for self-compacting concrete. The self-compacting concrete produced by this new mix design had high deformability with moderate viscosity which ensured uniform dispersion of concrete constituents during transportation, casting and thereafter until setting. It produced concrete that was capable of retaining fresh concrete properties for longer duration to cater for the time prerequisites of other concreting operations from transportation to final finishing. The self-compacting concrete was able to withstand the possible varia-

tions in the amount of mixing water, moisture content of ingredients and remained cohesive and free flowing.

2 MATERIALS AND METHODS

2.1 Materials

The experimental work was carried out to develop a standard mix design method for self-compacting concrete. Five basic ingredients were used in this experimental work:

- Continuously graded granite aggregate of 10 mm maximum size coarse aggregate conforming to EN 12620 [11] was used.
- Fine aggregate in the form of manufactured sand and river sand (conforming to EN 12620 [11]) have been used.
- Ordinary Portland Cement branded Dangote Cement CR 42 conforming to EN 197-1 [9] was used in producing samples.
- Water which conformed to EN 1008 [10] was used in this experiment.
- Fosroc Auracast 200 a low viscosity, high performance water reducer and advanced high early age strength, super plasticizer conforming to EN 934-2 [8] was used in this experiment.

The sample preparation and test was performed in the Structural Laboratory of Rivers State University of Science and Technology.

2.2 Material Handling

The materials (coarse aggregate, fine aggregate and fly ash) were air dried and oven dried in the laboratory at 115°C. All test carried out were done in accordance to the European Guidelines for self-compacting concrete (SCC) EFNARC [7] and according to the British Standard (BS 1881 [2]), BS 882 [1], BS 5328 [3] and BS 8110 [4]. 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.

2.3 Experimental Process

The Processes used were:

- Air drying of aggregates in the oven.
- Sieve analysis, bulk density and specific gravity determination.
- Batching of aggregate and cement by weight.
- Mixing of Aggregate using electric concrete mixing machine.

- *Author: Godfrey Waribo Tom Jaja (Jnr.), B.Tech, M.Tech Structural Engineering, M.Eng Civil and Environmental Engineering (Geotechnical Engineering). Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria. Email: godfrey.jaja@ust.edu.ng*
- *Co-Author Ngoji Tonye Johnarry, B.Sc Civil Engineering, University Of Lagos Nigeria, M.Sc Highways, City-University London, PhD Structures, University of Strathclyde, Glasgow. Professor of Civil Engineering, Department of Civil Engineering, Rivers State University, Nigeria. Email: tnjohnarry@yahoo.com*

- Workability determination using slump flow test, J-ring test, V-funnel test and L-Box test in accordance to the European Guidelines for self-compacting concrete (SCC) (EFNARC [7]).
- Curing of concrete in accordance with BS 8110 [4].
- Compressive strength determination.
- Flexural Tensile strength determination.

2.4 Workability

The workability of self-compacting concrete is much higher than the highest class of traditional vibrated concrete and can be characterized by the following properties:

- ·Filling ability
- ·Passing ability
- ·Segregation resistance

Each of the characteristic above can be determined by one or more of the following test methods:

TABLE 2

SELF-COMPACTING CONCRETE TEST METHODS

Characteristic	Preferred test method(s)	Range
Flowability	Slump-flow test	550 – 800 mm
Viscosity	T_{50} Slump-flow test or V-funnel test	2 – 5 sec 6 – 12 sec
Passing ability	L-box test J-Ring test	0.8 – 1.0 500 – 700 mm
Segregation	V-funnel at $T_{5minutes}$ or Segregation resistance (sieve) test	

These test methods for self-compacting concrete (SCC) are described below.

2.5 Slump Flow Test and T_{50cm} Test

Introduction

The slump flow is used to determine the horizontal free flow of self-compacting concrete in the absence of obstructions (JSCE, [13]). The diameter of the concrete circle is a measure for the filling ability of the concrete.

Equipment

The equipment is shown in Fig. 1.

Fig. 1.   Slump flow test method

Interpretation of result

The higher the slump flow (SF) value, the greater its capacity to fill formwork under its own weight. A value of no less than 650mm is required for self-compacting concrete.

2.6 J Ring test
Introduction

The J Ring experiment is said to have been started by the Japanese, but there are no historical proof. The test is used to determine the passing ability of the concrete.

Equipment

The apparatus is shown in Fig. 2 below.
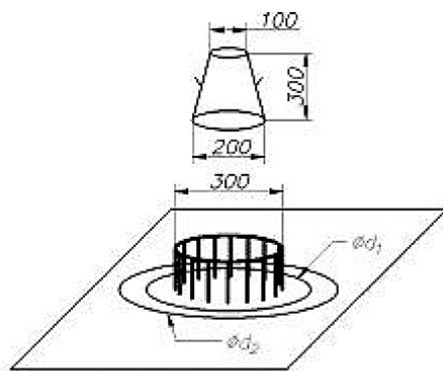
Fig. 2. J Ring Test apparatus

- *Author: Godfrey Waribo Tom Jaja (Jnr.), B.Tech, M.Tech Structural Engineering, M.Eng Civil and Environmental Engineering (Geotechnical Engineering). Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria. Email: godfrey.jaja@ust.edu.ng*
- *Co-Author Ngoji Tonye Johnarry, B.Sc Civil Engineering, University Of Lagos Nigeria, M.Sc Highways, City-University London, PhD Structures, University of Strathclyde, Glasgow. Professor of Civil Engineering, Department of Civil Engineering, Rivers State University, Nigeria. Email: tnjohnarry@yahoo.com*

Interpretation of result

The measured flow is certainly influenced by the extent to which the concrete movement is hindered by the reinforcing bars.

2.7 V funnel test and V funnel test at T 5minutes
Introduction

This test was designed in Japan and utilized by Ozawa et al. (1995). The described V-funnel test is used to know the filling ability (flowability) of the concrete. The V-shaped funnel shown in Fig. 3 is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus measured.

Equipment

The apparatus 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.

2.8 L box test method
Introduction

This test describes the flow of the concrete, and also the extent to which it is subjected to blocking by reinforcement. The apparatus 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, so $H_2/H_1 = 1$. An acceptable value of 0.8 is proposed.

2.9 Mix Design
The mix design method used in this research work proposed is the New Absolute Volume method for self-compacting concrete. This method was derived from the absolute volume mix design method for normal concrete. The modification for this method was arrived at after intensive research and trials.

The New Absolute Volume mix design method for self-compacting concrete is used in the following design of a self-compacting concrete with a water/powder ratio of 0.25. The mix design is shown in details below. (Please note that this mix design method was used in designing for water/binder ratios of 0.15, 0.17, 0.20 and 0.30 and the result is presented in Fig. 11. 0.25 was selected arbitrarily to aid in comparison with other existing mix design methods).

Concrete Mixture Proportioning
New Absolute Volume Method Using Multiple Cementing Materials and Admixtures
STEP 1: Cement
Portland Cement conforming to European Prestandard of strength class 42.5 with a high early strength - Cement ENV 197-1 CEM I 42.5 R.
Relative Density of Cement = 3.1

STEP 2: Fly Ash
Class C, ASTM C 618 (AASHTO M295)

- *Author: Godfrey Waribo Tom Jaja (Jnr.), B.Tech, M.Tech Structural Engineering, M.Eng Civil and Environmental Engineering (Geotechnical Engineering). Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria. Email: godfrey.jaja@ust.edu.ng*
- *Co-Author Ngoji Tonye Johnarry, B.Sc Civil Engineering, University Of Lagos Nigeria, M.Sc Highways, City-University London, PhD Structures, University of Strathclyde, Glasgow. Professor of Civil Engineering, Department of Civil Engineering, Rivers State University, Nigeria. Email: tnjohnarry@yahoo.com*

Relative Density of Fly Ash = 0

Fly Ash dosage % by mass of cementing materials = 0
(Note: Fly Ash is included in this design mix for completeness. This is to immensely assist practitioners that would want to use this design method for self-compacting concrete with multiple cementing materials. Fly ash was not used in this particular trial mix.)

STEP 3: Coarse Aggregate
Well graded 10-mm nominal maximum-size crushed rock (EN 12620)
Oven dry relative density = 2.72
Absorption (%) = 0.5
Moisture content (%)   = 1.015

STEP 4: Fine Aggregate
Natural Sand (EN 12620)
Oven dry relative density = 2.7
Absorption (%) = 0.7
Moisture content (%)   = 5.22
Fineness Modulus = 3.24

STEP 5: Strength
A specified compressive strength f_c', of 60Mpa is required at 28 days.

For a standard deviation (S) of f_{cr}' 3Mpa, (Mpa) will be

$$f_{cr}' = f_c' + 1.65(S) = 64.95 \tag{1}$$

STEP 6: Water to Cement Ratio
A water to cement ratio of 0.25 will be used for this mix design.

STEP 7: Slump
Assume a slump of 50mm without the super plasticizer and a maximum of 600mm to 800mm after the super plasticizer is added.

STEP 8: Water Content
Water: Cement ratio is selected based on requirements in EN 206. Typically water content does not exceed 200 litre/m^3 (200 kg/m^3).
After carrying out 243 experimental trials using the New Absolute Volume Method, it was discovered that a water content of 150 kg/m^3 produced the most stable and consistent self-compacting concrete. It should be noted that the use of 150 kg/m^3 has proved to be the key to the success of this New Absolute Volume Method. Therefore the water content of 150 kg/m^3 was used.

STEP 9: Cementing Materials Content
The amount of cement materials is based on the maximum water-cementing materials ratio and water content. Therefore, 150 kg of water divided by a water-cementing materials ratio of 0.25 requires a cement content of 600 kg.

Fly as dosage of 0% by mass of cementing materials   will   be

used. Therefore, the suggested cementing materials for one cubic meter of concrete are as follows:

Cement (kg):	100%	of	600	=	600	(2)
Fly Ash (kg):	0%	of 600		=	0	(3)

STEP 10: Coarse Aggregate Content

EFNARC Specifications states that the coarse aggregate content should normally be 28 to 35 percent of the volume of the mix.

Assume 40 % coarse aggregate content.

For a 1 cubic meter:

Coarse aggregate (m³) = $(40/100) \times 1$ = 0.4 (4)

If the relative density of coarse aggregate is = 2.72

∴ The mass of coarse aggregate (Mcg) can be calculated as follows:

M_{cg} (kg) = percentage of coarse aggregate x dry relative density of coarse aggregate x 1000 (5)

M_{cg} (kg) = 0.4 x 2.72 x 1000 = 1088 (6)

STEP 11: Fine Aggregate Content

At this point the amounts of all ingredients except the fine aggregates are known. The volume of fine aggregate is determined by subtracting the absolute volumes of all known ingredients from 1 cubic meter. The absolute volumes of the ingredients is calculated by dividing the known mass of each by the product of their relative density and the density of water. Assume a relative density of 1.0 for the chemical admixtures. Assume a density of water of 1000 kg/m³ as all materials in the laboratory are maintained at a room temperature of 22°C.

Volume computations are as follows:

$$\text{Water } (m^3) = \frac{\text{absolute volume of water}}{\text{Relative density of water} \times \text{Density of water}}$$

$$= \frac{150}{1 \times 1000} = 0.150 \qquad (7)$$

$$\text{Cement } (m^3) = \frac{\text{absolute volume of cement}}{\text{Relative density of cement} \times \text{Density of water}}$$

$$= \frac{600}{3.1 \times 1000} = 0.194 \qquad (8)$$

$$\text{Fly Ash } (m^3) = \frac{\text{absolute volume of fly ash}}{\text{Relative density of fly ash} \times \text{Density of water}}$$

$$= \frac{0}{0 \times 1000} = 0 \qquad (9)$$

$$\text{Coarse Agg. } (m^3) =$$

$$\frac{\text{absolute volume of coarse agg.}}{\text{Relative density of coarse agg.} \times \text{Density of water}}$$

$$= \frac{1088}{2.72 \times 1000} = 0.4 \qquad (10)$$

Total Volume (m³) of known ingredients = 0.15 + 0.194 + 0 + 0.4 = 0.744 (11)

The calculated absolute volume of fine aggregate is then = 1000 – 0.744 = 0.256 (12)

∴ The mass (kg) of dry fine aggregate is = 0.256 x relative density of fine aggregate x 1000 (13)

= 0.256 x 2.7 x 1000 = 692 (14)

STEP 12: Admixture Content

The plasticizer dosage rate is 30g per kg of cementing materials. That is 3% of Cementing materials.

∴ The mass (kg) of plasticizer per cubic meter of concrete is = 18 kg

The mixture then has the following proportions before trial mixing for one cubic meter of concrete:

Water (kg)	= 150
Cement (kg)	= 600
Fly Ash (kg)	= 0
Coarse Aggregate (dry) (kg)	= 1088
Fine Aggregate (dry) (kg)	= 692
Super plasticiser (kg)	= 18

TOTAL = 150 + 600 + 0 + 1088 + 692 + 18 = 2548.42 kg (15)

STEP 13: Moisture Corrections

Corrections are needed to compensate for moisture in and on the aggregates. In practice, aggregates will contain some measureable amount of moisture. The dry batch weights of aggregates, therefore, have to be increased to compensate for the moisture that is absorbed in and contained on the surface of each particle and between particles. The mixing water added to the batch must be reduced by the amount of free moisture contributed by the aggregates.

Tests indicate that for this sample, coarse aggregate moisture

content is 1.015 % and fine-aggregate moisture content is 5.22%.

With the aggregate moisture contents (MC) indicated, the trial batch aggregate proportions becomes

Coarse aggregate $(1.015\%$ of MC$)$ $($kg$)$ =

Mass of Coarse Agg. $\times \left(1 + \left(\dfrac{\text{Coarse Agg. Moisture Content}}{100}\right)\right)$

$= 1088 \times \left(1 + \left(\dfrac{1.015}{100}\right)\right) = 1099$ kg $\qquad$ (16)

Fine aggregate $(5.22\%$ of MC$)$ $($kg$)$ =

Mass of Fine Agg. $\times \left(1 + \left(\dfrac{\text{Fine Agg. Moisture Content}}{100}\right)\right)$

$= 692 \times \left(1 + \left(\dfrac{5.22}{100}\right)\right) = 729$ kg $\qquad$ (17)

Water absorbed by the aggregate does not become part of the mixing water and must be excluded from the water adjustment.

Surface moisture (%) contributed by the coarse aggregate amounts to
= Moisture Content (%) of Coarse Agg. - Absorption (%) of Coarse Agg. = 1.015 - 0.5 = 0.515 $\qquad$ (18)

Surface moisture (%) contributed by the fine aggregate amounts to
= Moisture Content (%) of Fine Agg. - Absorption (%) of Fine Agg. = 5.22 -0.7 = 4.52 $\qquad$ (19)

The estimated requirement (kg) for added water becomes =

Water Content$(kg/m^3) -$

$\left(\text{Mass of Coarse Agg.} \times \left(\dfrac{\text{Surface Moisture Content of Coarse Agg.}}{100}\right)\right)$

$-\left(\text{Mass of Fine Agg.} \times \left(\dfrac{\text{Surface Moisture Content of Fine Agg.}}{100}\right)\right)$

$= 150 - \left(1088 \times \left(\dfrac{0.515}{100}\right)\right) - \left(692 \times \left(\dfrac{4.52}{100}\right)\right) = 113.1 \; kg$ $\qquad$ (20)

STEP 14: Trial Batch

For a laboratory trial batch it is convenient, in this case to scale down the weights to produce 0.1m³ of concrete as follows:

Water (kg) = Estimated Water Content x 0.1
$\qquad$ = 113.1 x 0.1 = 11.31 $\qquad$ (21)

Cement (kg) = Mass of Cement x 0.1
$\qquad$ = 600 x 0.1 = 60 $\qquad$ (22)

Fly Ash (kg) = Mass of Fly Ash x 0.1 = 0 $\qquad$ (23)

Coarse Aggregate (kg): (1.015% of MC) = Mass of Coarse Agg. x 0.1 = 1099 x 0.1 = 109.9 $\qquad$ (24)

Fine Aggregate (kg): (5.22% of MC) = Mass of Fine Agg. x 0.1 = 729 x 0.1 = 72.9 $\qquad$ (25)

Super plasticizer (kg): = Mass of Super plasticizer x 0.1
$\qquad$ = 18 x 0.1 = 1.8 $\qquad$ (26)

TOTAL MASS = 11.31 + 60 + 109.9 + 72.9 + 1.8
$\qquad$ = 255.87 kg $\qquad$ (27)

STEP 15: Final SCC Mix Ratio
The Final Mix ratio for a 0.25 Water/powder ratio SCC is given as
(Cement : Fine : Coarse : W/C Ratio) = **1 : 1.21 : 1.83 : 0.25.**
The Mix ratio above was used to calculate the Mix Specification given in Table 3.0 for the New Absolute Volume Method (NAVM) for self-compacting concrete.

Validation
The New Absolute Volume method (NAVM) for self-compacting concrete proposed in this research work will validated by customary methods and specifications generally accepted in the construction industry. They include methods proposed by Okamura and Ozawa [12], Edamatsu et al. [21] and EFNARC [6]

The various mixture proportioning and specifications for Okamura and Ozawa [12], Edamatsu et al. [21], EFNARC [6], New Absolute Volume method (NAVM) is shown in Table 3 below

TABLE 3(A)

SPECIFICATIONS FOR THE VARIOUS MIX DESIGN METHODS

Existing Specifications	Water (litres)	Cement (kg)	Fine Agg. (kg)
EFNARC [6]	3.366	15.863	17.910
New Absolute Volume Method (NAVM)	2.26	12.0	14.57
Okamura & Ozawa [12]	2.8	10.822	9.62
Edamatsu et al. [21]	2.406	9.019	12.025

TABLE 3(B)

SPECIFICATIONS FOR THE VARIOUS MIX DESIGN METHODS

Existing Specifications	Coarse Agg. (kg)	Super plasticizer (litres)	Mix Ratio (Cement : Fine : Coarse : W/C Ratio)
EFNARC [6]	17.910	0.65	**1:1.13:1.13:0.25**
New Absolute Volume Method (NAVM)	21.98	0.65	**1:1.21:1.83:0.25**
Okamura & Ozawa [12]	25.585	0.65	**1:0.89:2.36:0.25**
Edamatsu et al. [21]	25.585	0.65	**1:1.33:2.84:0.25**

- *Author: Godfrey Waribo Tom Jaja (Jnr.), B.Tech, M.Tech Structural Engineering, M.Eng Civil and Environmental Engineering (Geotechnical Engineering). Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria. Email: godfrey.jaja@ust.edu.ng*
- *Co-Author Ngoji Tonye Johnarry, B.Sc Civil Engineering, University Of Lagos Nigeria, M.Sc Highways, City-University London, PhD Structures, University of Strathclyde, Glasgow. Professor of Civil Engineering, Department of Civil Engineering, Rivers State University, Nigeria. Email: tnjohnarry@yahoo.com*

3   RESULTS AND DISCUSSION

Results and discussions of laboratory experiments on the existing specifications and modifications for self-compacting concrete generally accepted in the construction industry for the production of self-compacting concrete which include the methods proposed by Okamura and Ozawa [12], Edamatsu et al. [21], EFNARC [6] and the New Absolute Volume method (NAVM) for self-compacting concrete proposed in this research work. A constant water/powder ratio of 0.25 was maintained in all the mixes. The test conducted were on particle size distribution of the 10mm coarse aggregate and fine aggregate, workability of fresh concrete, compressive strength test on hardened concrete from standard cubes. The analysis was carried out in tables and graphs and presented below.

A total of 60 cylinders, 60 rectangular samples and 250 cubes were casted and tested at ages of 7, 14 and 28 days of wet curing. All test were carried out in accordance to BS 882 [1], BS 1881 [2] and EFNARC [7].

Workability

Trial mixes for self-compacting concrete were prepared using methods proposed by Okamura and Ozawa [12], Edamatsu et al. [21], EFNARC [6] and the New Absolute Volume method (NAVM). The percentages of both fine and coarse aggregate varied in relation to the various design methods as shown in Table 3(a), 3(b). The results from the various workability tests are given below.

3.1   Slump Flow Test

This test measured the free horizontal flow (under the influence of gravity alone) of self-compacting concrete mix on a plain surface without any obstruction. The time needed for the concrete to cover a 50 cm diameter spread circle (T_{50} cm time) from the time the slump cone is lifted is recorded. Fig. 5 shows the variation of slump flow (mm) for the various existing specifications for the design of self-compacting concrete. It can be observed that the proposed New Absolute volume method (NAVM) had the highest flow slump flow value of 680mm while the method proposed by Edamatsu et al. [21] had the least slump flow value of 600mm. This result is due to the fact that the New Absolute Volume method (NAVM) specification accommodates the use of a high cement volume which is necessary for a self-compacting concrete with high workability.
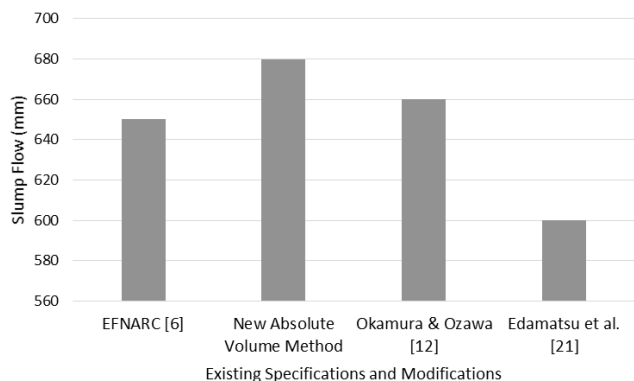
Fig. 5. Variation of Slump Flow (mm) for the various existing specifications

3.2 J-Ring Flow Test

The J-ring flow test was carried out in other to determine the passing ability of the trial mixes. Fig. 6 shows the variation of J-ring flow (mm) for the various existing specifications for the design of self-compacting concrete. It can be observed that Okamura and Ozawa [12] and New Absolute volume method (NAVM) both had high J-Ring flow values.
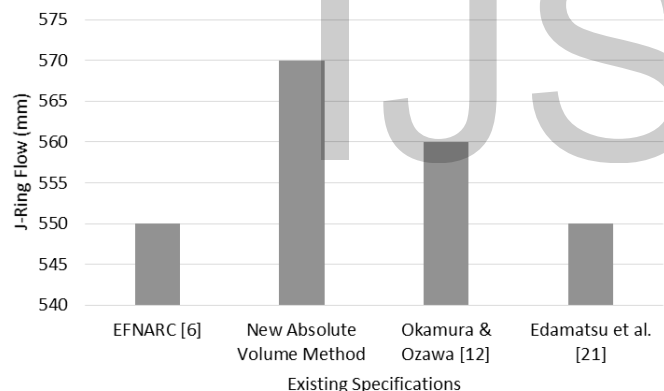

Fig. 6. Variation of J-Ring Flow (mm) for the various existing specifications

3.3 V-Funnel Test

For The V-funnel test was used to determine the viscosity and filling ability of self-compacting concrete. Fig. 7 shows the variation of V-Funnel (sec) for the various existing specifications for the design of self-compacting concrete. It can be observed that the New Absolute Volume method (NAVM) specifications had the lowest V-Funnel time of 5 sec due to its high workability. It can also be noted that the values of V-Funnel time of all the various specifications where well within the acceptable criteria for self-compacting concrete.
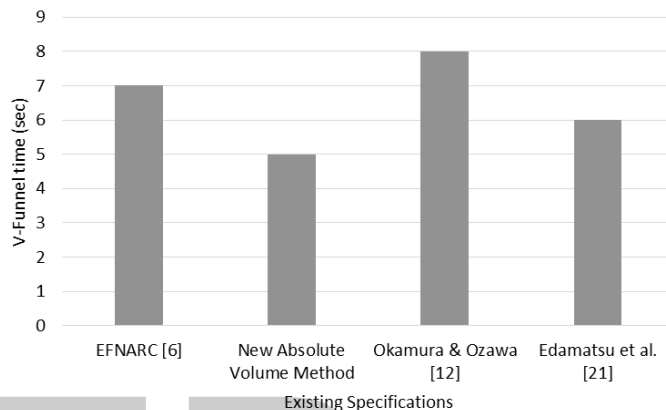

Fig. 7. V-Funnel time (sec) for the various existing specifications.

3.4 L-Box Test

The L-box test was used to determine the passing ability of self-compacting concrete to flow through tight openings. Fig. 8 shows the variation of L-Box h_1/h_2 ratio for the various existing specifications for the design of self-compacting concrete. It can be observed that the EFNARC [6] and the New Absolute Volume method (NAVM) gave values of L-Box h_1/h_2 ratio which are close to the acceptable value.
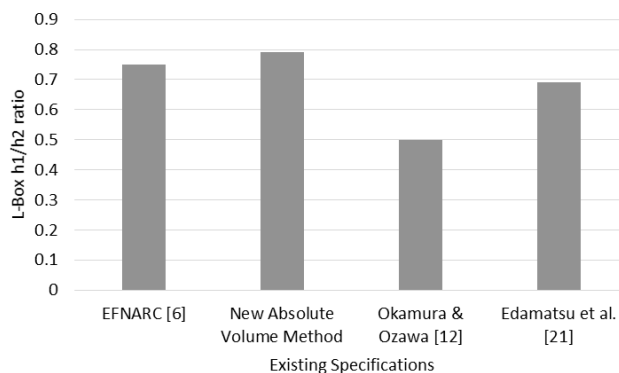

Fig. 8. L-Box h_1/h_2 ratio for the various existing specifications

3.5 Compressive Strength Test

- *Author: Godfrey Waribo Tom Jaja (Jnr.), B.Tech, M.Tech Structural Engineering, M.Eng Civil and Environmental Engineering (Geotechnical Engineering). Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria. Email: godfrey.jaja@ust.edu.ng*
- *Co-Author Ngoji Tonye Johnarry, B.Sc Civil Engineering, University Of Lagos Nigeria, M.Sc Highways, City-University London, PhD Structures, University of Strathclyde, Glasgow. Professor of Civil Engineering, Department of Civil Engineering, Rivers State University, Nigeria. Email: tnjohnarry@yahoo.com*

The compressive strength of the trial mix consisting of 10mm coarse aggregate, fine aggregate, cement and super plasticizer was measured in the laboratory and found to increase with age for the various mix design specifications. Fig.. 9 shows the variation of compressive strength (MPa) for the various existing specifications at 7 days, 14 days and 28 days. It can be observed that the specification proposed by New Absolute Volume method (NAVM) gave the highest 28 days compressive strength of 65 MPa followed by the specification proposed by EFNARC [6] which had a compressive strength of 64 MPa. The specification proposed by Edamatsu et al. [21] had the lowest compressive strength of 51.6 MPa.

Fig. 10 shows the variation of 28 Days Compressive Strength (MPa) against Duration of Wet Curing (Days) with Varying W/C Ratio using the New Absolute Volume Method.
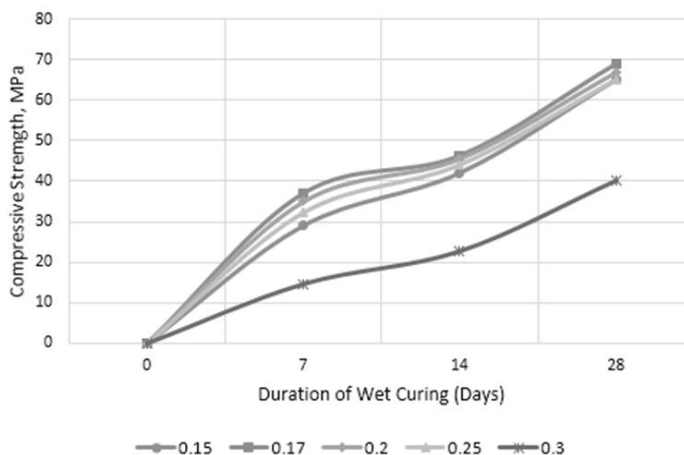

Fig. 10. Variation of 28 Days Compressive Strength (MPa) against Duration of Wet Curing (Days) with Varying W/C Ratio using the New Absolute Volume Method.

3.6   Split Tensile Strength Test

Fig. 11 shows variation of split tensile strength (MPa) for the various existing specifications at 7 days, 14 days and 28 days. It can be observed that the New Absolute Volume method (NAVM) specification proposed gave the highest 28 days split tensile strength of 15.20 MPa followed by the specification proposed by EFNARC [6] which had a compressive strength of 12.16 MPa. The specification proposed by Edamatsu et al. (2003) had the lowest compressive strength of 9.80 MPa.
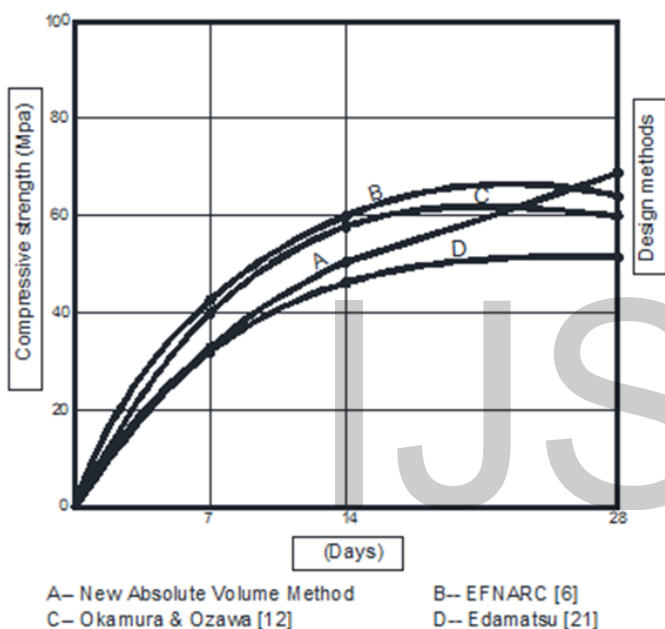

Fig. 9. Variation of Compressive strength (MPa) for the various existing specifications at 7 days, 14 days and 28 days
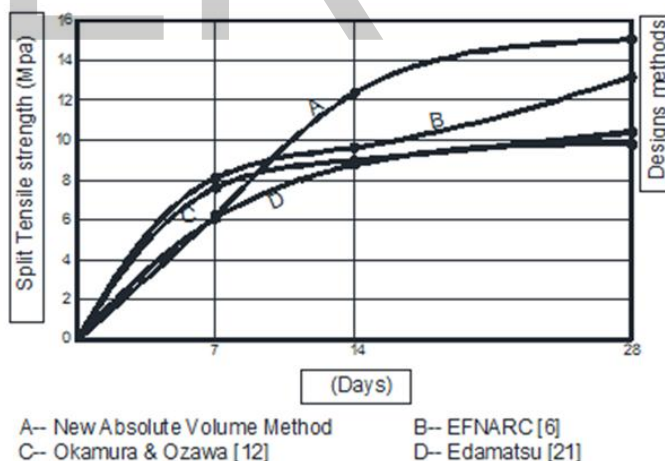

Fig. 11. Variation of Split tensile strength (MPa) for the various existing specifications at 7 days, 14 days and 28 days.

• *Author: Godfrey Waribo Tom Jaja (Jnr.), B.Tech, M.Tech Structural Engineering, M.Eng Civil and Environmental Engineering (Geotechnical Engineering). Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria. Email: godfrey.jaja@ust.edu.ng*
• *Co-Author Ngoji Tonye Johnarry, B.Sc Civil Engineering, University Of Lagos Nigeria, M.Sc Highways, City-University London, PhD Structures, University of Strathclyde, Glasgow. Professor of Civil Engineering, Department of Civil Engineering, Rivers State University, Nigeria. Email: tnjohnarry@yahoo.com*

3.7 Flexural Strength Test

Fig. 12 shows variation of flexural strength (MPa) for the various existing specifications at 7 days, 14 days and 28 days. It can be observed that the New Absolute Volume method (NAVM) specification gave the highest 28 days split tensile strength of 8.80 MPa followed by the specification proposed by EFNARC [6] which had a compressive strength of 7.04 MPa. The specification proposed by Edamatsu et al. [21] had the lowest compressive strength of 5.67 MPa.
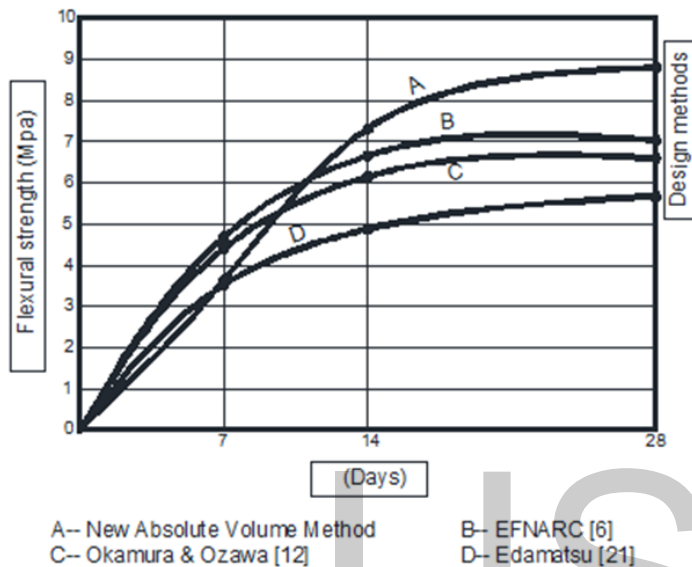

Fig. 12. Variation of Flexural strength (MPa) for the various existing specifications at 7 days, 14 days and 28 days.

4 CONCLUSION

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

1. The existing specifications proposed by Okamura and Ozawa [12], Edamatsu et al. [21], EFNARC [6] and New Absolute Volume method (NAVM) produced self-compacting concrete with good workability with workability values well within the acceptable range of self-compacting concrete.
2. The specification proposed by the New Absolute Volume method (NAVM) allows the use of a high volume of cement and while that of Edatmatsu et al. [21] allows for the use of a low volume of cement.
3. The specification proposed by the New Absolute Vol-

ume method (NAVM) gave the most workable self-compacting concrete followed by that of Okamura and Ozawa [12], before the specification proposed by EFNARC [6]. The specification proposed by Edatmatsu et al. [21] gave the least workable concrete at the same water/cement ratio.

4. The specification proposed by the New Absolute Volume method (NAVM) produced a self-compacting concrete with the highest compressive strength of 65 MPa, followed by that of EFNARC [6] which gave 64 MPa compressive strength, before the specification proposed by Okamura and Ozawa [12] which gave 60 MPa. The specification proposed by Edamatsu et al. [21] produced a self-compacting concrete with the least compressive strength of 51.6 MPa at the same water/cement ratio.
5. Specifications and modifications that allow for high volumes of cement produce self-compacting concrete with high compressive and flexural strength and a very good workability.

4.1 Recommendations

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

1. The existing specifications and modifications of self-compacting concrete should be New further to allow for higher volumes of cement in order to produce self-compacting concrete with high compressive and flexural strength and very good workability.
2. Specifications proposed by the New Absolute Volume method (NAVM)and EFNARC [6] should be adopted in the various construction industries as the standard for the production of self-compacting concrete due to their ability to produce self-compacting concrete with high compressive and flexural strength and a very good workability.

5 ACKNOWLEDGMENTS

- *Author: Godfrey Waribo Tom Jaja (Jnr.), B.Tech, M.Tech Structural Engineering, M.Eng Civil and Environmental Engineering (Geotechnical Engineering). Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria. Email: godfrey.jaja@ust.edu.ng*
- *Co-Author Ngoji Tonye Johnarry, B.Sc Civil Engineering, University Of Lagos Nigeria, M.Sc Highways, City-University London, PhD Structures, University of Strathclyde, Glasgow. Professor of Civil Engineering, Department of Civil Engineering, Rivers State University, Nigeria. Email: tnjohnarry@yahoo.com*

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