A Comparative Analysis of Batching by Weight and Volume towards Improved Concrete Production

Opeyemi Joshua[1]; Olabosipo I. Fagbenle[2]; Kolapo O. Olusola[3]; Shunanum J. Shamaki[4]; Joyce A. Abuka-Joshua[5]; Ayodeji O. Ogunde[6]; Lekan M. Amusan[7]; and Ignatius O. Omuh[8]

[1]Dept. of Building Technology, College of Science and Technology, Covenant Univ., Ota, Ogun State, Nigeria. E-mail: ope.joshua@covenantuniversity.edu.ng
[2]Dept. of Building Technology, College of Science and Technology, Covenant Univ., Ota, Ogun State, Nigeria. E-mail: olabosipo.fagbenle@covenantuniversity.edu.ng
[3]Dept. of Building, Faculty of Environmental Design and Management, Obafemi Awolowo Univ., Ile-Ife, Nigeria. E-mail: kolaolusola@yahoo.co.uk
[4]Dept. of Building Technology, College of Science and Technology, Covenant Univ., Ota, Ogun State, Nigeria. E-mail: shunanum.shamaki@stu.cu.edu.ng
[5]Dept. of Geo-Sciences, Univ. of Lagos, Lagos State, Nigeria. E-mail: joyceabuka@gmail.com
[6]Dept. of Building Technology, College of Science and Technology, Covenant Univ., Ota, Ogun State, Nigeria. E-mail: ayodeji.ogunde@covenantuniversity.edu.ng
[7]Dept. of Building Technology, College of Science and Technology, Covenant Univ., Ota, Ogun State, Nigeria. E-mail: lekan.amusan@covenantuniversity.edu.ng
[8]Dept. of Building Technology, College of Science and Technology, Covenant Univ., Ota, Ogun State, Nigeria. E-mail: ignatius.omuh@covenantuniversity.edu.ng

Abstract

Batching of concrete is generally the proportioning of the different constituents of concrete before mixing which could be by weight or volume. Mix-design justified by trial test is the best method to achieve a concrete of desired properties. Standardized prescribed concrete (SPC) mix-design is mostly adopted in mass concreting to high strength concreting applications in most developing nations. British standards accept volume batching for SPC only in mass concrete (<15 MPa) but batching by weight for normal and higher strength concrete. Structural concrete like in storey buildings requires at least a normal strength concrete (>20 MPa) recommended to be batched by weight. Designs batched by volume have been identified as the most commonly used method in concrete production in Nigeria and most developing nations, especially by medium to small scale construction firms due to the very high cost of employing batching plants. This research work developed a modified volumetric batch mix-design that will be equivalent to SPC design mix batched by weight in normal and higher strength concrete. The physical properties of the constituent concrete materials, fine aggregate, 12 and 19 mm sized coarse aggregates were determined. The strength of SPC mix of ST2, ST4, and ST5 to British standard were determined when batched by weight and their volume equivalents mix-design batch determined. The strengths of these SPC mixes were batched by volume and their weight equivalent batch-design determined. A relationship was determined between both batching mix-design methods for all the prescribed mixes and strengths using the binder-aggregate and coarse-fine aggregate ratios, such that the preferred weight batching design mix could be achieved by a modified mix-design batched by volume. This study concludes that concrete mix-design batched by weight is superior to when batched by volume and the desired design batching by weight could be achieved by generating a modified mix-design-batch by volume. This will improve the quality of concrete storey buildings in most developing nations.

Keywords: Weight batching; Volume batching; Concrete mix-design; Standardized prescribed concrete.

1.0 INTRODUCTION

In concrete production, after materials are organized to construction site, batching is usually the first on-site activity in concrete production which could also imply that batching is the first activity in the control of the quality of concrete. Therefore, batching of concrete is generally the proportioning of the different ingredients of concrete (i.e. cement, sand, coarse aggregate and water) before mixing which could be either by weight or volume. Only standardized cement that is specified in British, European, American and other equivalent standards should be used and not the unstandardized developing binders as contained in Joshua et. al., (2015); Joshua et. al., (2016); Joshua, et. al., (2017) and other related studies. Though, a comprehensive mix-design that is justified by trial tests is most preferable to achieve a concrete of desired fresh and hardened property but in the construction of simple storey buildings (up to four storey), Standardized Prescribed Concrete (SPC) mix-designed to standards is mostly adopted in mass concreting to normal concreting applications in Nigeria and most developing nations. Mix 1:2:4 is most commonly used as a normal concrete strength classification (Adewole et. al., 2015). In most Nigerian construction practice, mix-design 1:2:4 is always used as normal strength concreting, 1:1.5:3 for higher strength concreting and 1:3:6 for blinding and mass concreting. Concrete mix of 1:2:4 conform to the standardized prescribed mix of ST4 with slum class S2 (BS8500-2:2002) with expected characteristic cube strength of 20MPa (BS8500-1:2002) when batched by weight as prescribed in these standards.

A pilot survey in Lagos shows that over ninety percent (90%) of storey buildings in Nigeria are structures whose structural frame/elements are made of reinforced concrete (Joshua *et al.*, 2013), the place of reinforced concrete in the Nigerian building industry is germane to the quality of its building's structural strength and stability, therefore, batching in concrete could be a point from which the quality of buildings in Nigeria could be controlled. But the vast majority of this prescribed concrete mix in Nigerian construction is batched by volume instead of weight as a result of the higher capital investments needed in securing batching plants by small and medium scale construction firms that are mostly responsible for construction of storey buildings in Nigeria (Adewole et al., 2015). Also, batching by volume have been identified by Olusola et. al., (2012); Adewole et al., (2015); and Hedidor and Bondinuba, (2017) as the most commonly used batching method for medium to small scale construction firms in Nigeria, Ghana and other neighboring West African countries.

Neville and Brooks (2010) in their study on concrete concludes that the use of volumetric batching method in concrete production is a bad construction practice and this assertion was justified by Hedidor and Bondinuba (2017). Despite these, volumetric batching method is still the most widely used method in the majority of construction sites in Nigeria, Ghana and other neighboring West African countries, especially by small to medium sized construction firms (Adewole et al., 2015; and Hedidor and Bondinuba, 2017).

This batching by volume instead of batching by weight as prescribed in the standard results to even lower concrete durability in terms of strength by over 14% strength variation and lower quality of fresh concrete property (Olusola et. al., 2012), and hence, the production of less durable structural concrete in buildings. This could also be adduced to the higher rate of occurrence of incessant building collapse in Nigeria in which was predicted by Oni (2010) and Ede (2010) that Nigeria alone would experience over ninety-one (91) storey building collapse with great casualties and fatalities between the years 2010 and 2017. This study therefore looks at ways of improving structural concrete production by still batching by volume but would be the equivalent of batching by weight of same standardized prescribed design-mix ratio. This is with a view to deriving a new modified mix proportion by volume from the standardized prescribed mix ratio by weight as generally indicated standards. This study seeks to develop a mix-design by volume batch, as though it was batched by weight for improved concrete strength and durability characteristics than the current concrete practice even though volume batching methods is still employed in the concrete production.

2.0 MATERIALS AND METHODS

The materials used in this study are Dangote Portland cement grade 42.5N CEM II A-L that conforms to BS EN 197-1:2011 which was obtained from the local market; river dredged fine aggregate sharp sand that was air-dried and sieved with the #4 sieve (4.76mm) that conform to BS EN 12620:2002 +A1 (2008); 12mm and 19mm sized quarry crushed coarse aggregate obtained from Odeda quarry in Abeokuta, Ogun State; and bore hole drinkable water that is locally sourced.

The data in this study are experimental. Sieve analysis was performed on all the aggregates (both fine and the coarse samples) to determine their gradation which will be the main physical property of the aggregate that was tested. Standardized Prescribed Concrete (SPC) conforming to ST2, ST4 and ST5 (1:3:6, 1:2:4 and 1:1.5:3 respectively) as specified in BS 8500-2:2002 were batched by weight with the 12mm and 19mm aggregate size and the volumetric equivalent of the batches were determined before they were mixed with water and cast into 150mm cube molds. The expected strengths were not to be less than 15MPa, 20MPa and 25MPa respectively. This was repeated with the 19mm aggregates.

This whole process was repeated, but in this case batched by volume and the weight equivalent mix-design of the volumetric design batch was determined before there were mixed with water and cast into 150mm molds. Three (3) of every set was cast with a total of thirty-six (36) cubes cast. The cubes were cured by immersion in a water tank for twenty-eight days and their 28-day strengths were determined.

3.0 RESULTS AND DISCUSSIONS

This section discusses the physical and mechanical properties of concrete's primary materials which include cement, fine aggregates (river sand) and coarse aggregates of varying sizes from quarry sites. The quality of concrete produced using these primary materials was investigated and the test results were appropriately discussed.

3.1 Gradation of the Fine and Coarse Aggregates Used

Figure 1 is the gradation curve (sieve analysis) of the fine aggregate used in this study

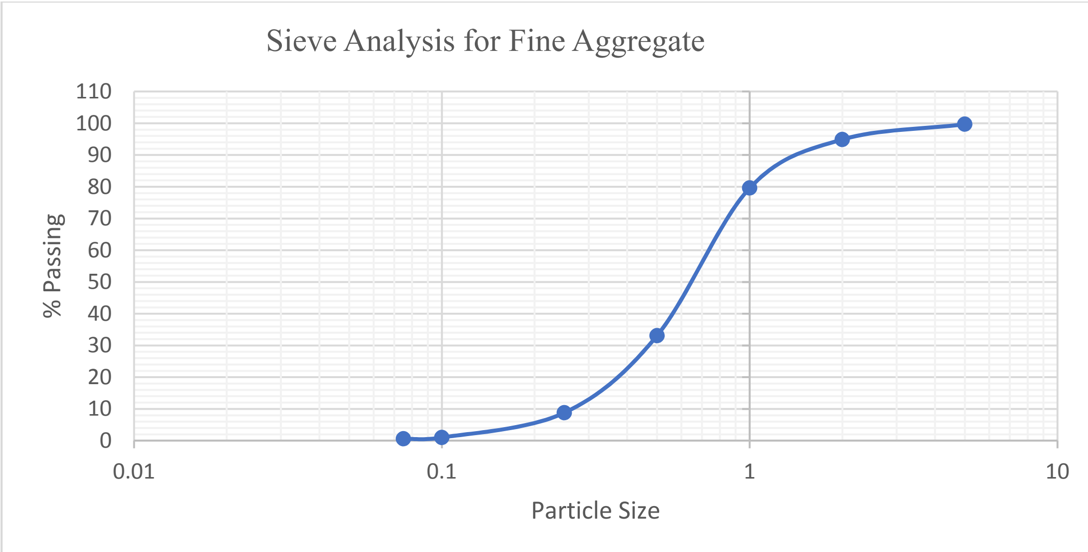

Figure. 1: Grain Size Distribution for the Fine Aggregates.

The fine aggregate used in this study satisfies the provisions of BS EN 206-1:2013 for grain size distribution to be used in concrete work as the grain size distribution curve is within its stipulated curve limits specified by this standard.

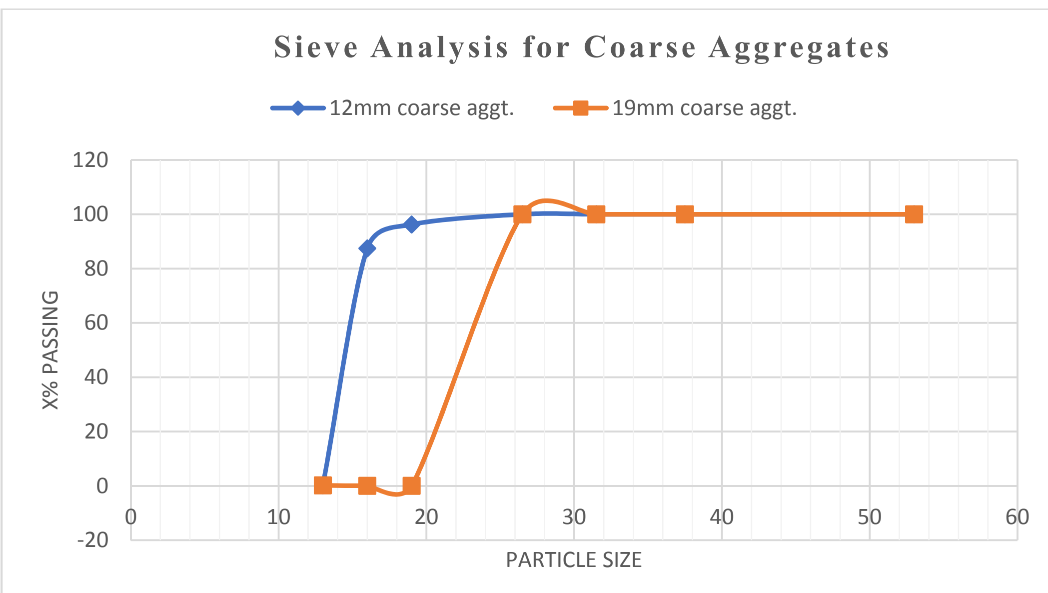

Figure 2: Grain Size Distribution for the Coarse Aggregate.

Both coarse aggregate sizes used in this study satisfies the provisions of BS EN 206-1:2013 for grain size distribution to be used in concrete work as both grain size distribution curves are within its stipulated limits, though, they are classed as poorly graded by the Unified Classification System (USCS), they are simply uniformly graded (Holtz and Kovacs, (1981).

3.2 Batching Methods and their Equivalents.

This section shows the results of batching the concrete constituents using SPC mix-design by weight and determining the volumetric batch equivalent design-mix of the weight batch. Similarly, batching the constituents mix-design by volume and determining the weight batch equivalent design-mix of the volume batch. Their binder-aggregate ratios were then determined and represented in Table 1.

Table 1: Mix-design Batch and their Equivalent Mix-designs in other Batching Method

Aggt Size	Batch Type	Mix-design/ Binder Aggt ratio	Coarse/Fine aggt. ratio	Mix ratio/ Binder Aggt ratio	Coarse/Fine aggt. ratio	Mix ratio/ Binder Aggt ratio	Coarse/Fine aggt. ratio
12mm	Volume	**1:1.5:3** 0.222	2.0	**1:2:4** 0.167	2.0	**1:3:6** 0.111	2.0
	Weight Eq	**1:1.94:3.38** 0.188	1.742	**1:2.62:4.18** 0.147	1.595	**1:3.05:6.36** 0.106	2.085
19m	Volume	**1:1.5:3** 0.222	2.0	**1:2:4** 0.167	2.0	**1:3:6** 0.111	2.0
	Weight Eq	**1:1.99:3.31** 0.189	1.663	**1:2.83:4.56** 0.135	1.611	**1:2.87:6.34** 0.109	2.209
12mm	Weight	**1:1.5:3** 0.222	2.0	**1:2:4** 0.167	2.0	**1:3:6** 0.111	2.0
	Volume Eq	**1:1.48:2.6** 0.245	1.757	**1:1.6:2.88** 0.223	1.8	**1:2.25:4.07** 0.158	1.808
19mm	Weight	**1:1.5:3** 0.222	2.0	**1:2:4** 0.167	2.0	**1:3:6** 0.111	2.0
	Volume Eq	**1:1.6:2.8** 0.227	1.75	**1:1.21:2.30** 0.172	1.9	**1:2.71:4.47** 0.139	1.649

The lower the binder-aggregate ratio, the greater the aggregate and fewer the binder contents in the concrete mix, hence, lower strength would be expected. Vice-versa for higher binder-aggregate ratio.

As observed in Table 1, the weight equivalents of all binder-aggregate ratio batched by volume are all less than the actual weight batched binder-aggregate ratio. This implies that all batches by volume contain more aggregate content by weight than when they are all batched by weight, hence, weaker concrete is expected in the batches by volume compared to when the same batching is done by weight. For instance, in Table 1, when fresh concrete with standardized prescribed mix-design of 1:2:4 with 12mm aggregate size was batched by volume, the aggregate-binder ratio is 0.167 by volume batch. When the weight equivalent mix-design of the same volume batch is determined, the same 1:2:4 batched by volume becomes 1:2.62:4.18 and 0.147 (binder-aggregate ratio) when viewed as a weight batch, and the concrete strength was 20.65 MPa, see Figure 4. This implies that when the two mix-designs (same mix-design batched by volume and by weight) are compared from the weight perspective, the weight equivalent of the volume batch becomes 1:2.62:4.18 with binder aggregate ratio of 0.147 as against when the mix-design was batched by weight, 1:2:4 with binder aggregate ratio of 0.167 with a concrete strength of 22.47Mpa, see Figure 5. This indicates that the volume-batch design mix in weight will contain more aggregate content than when it is originally batched by weight and this is evident in the strength variation. The more aggregate content in the volume batch will then imply a weaker concrete mix by virtue of the reduced binder content.

3.3 Compressive Strength Test Results

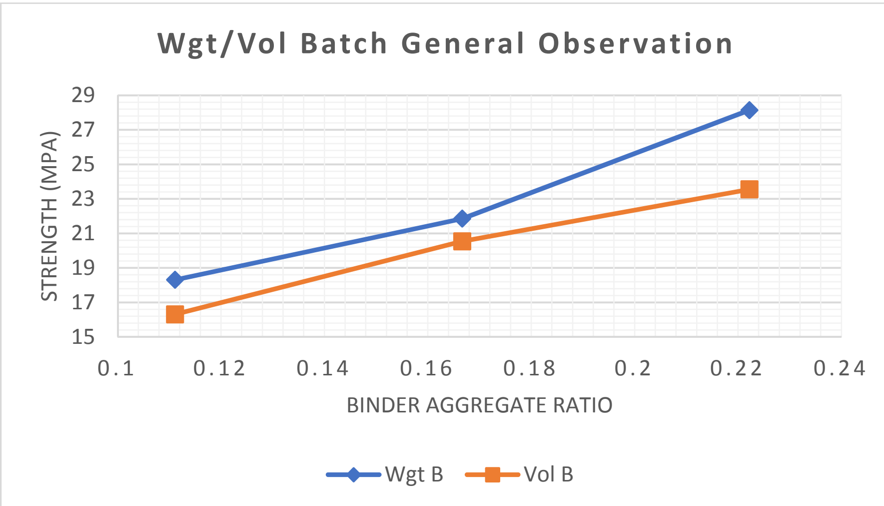

Figure 3: General Compressive Strengths of all Weight and Volume Batches

The strength is related to the SPC mix-design by the binder aggregate ratio. According to Mehta and Monteiro (2014), the more the binder content in a concrete mix, the better the strength property of the hardened concrete. The concrete cube strength will be discussed in relation to the binder aggregate ratio.

Figure 3 is a result of the average compressive strength of all the concrete batched by volume and by weight. It shows that the strength of all concrete batched by weight produced superior strength to those batched by volume and this is confirmed in Olusola et.al. (2012).

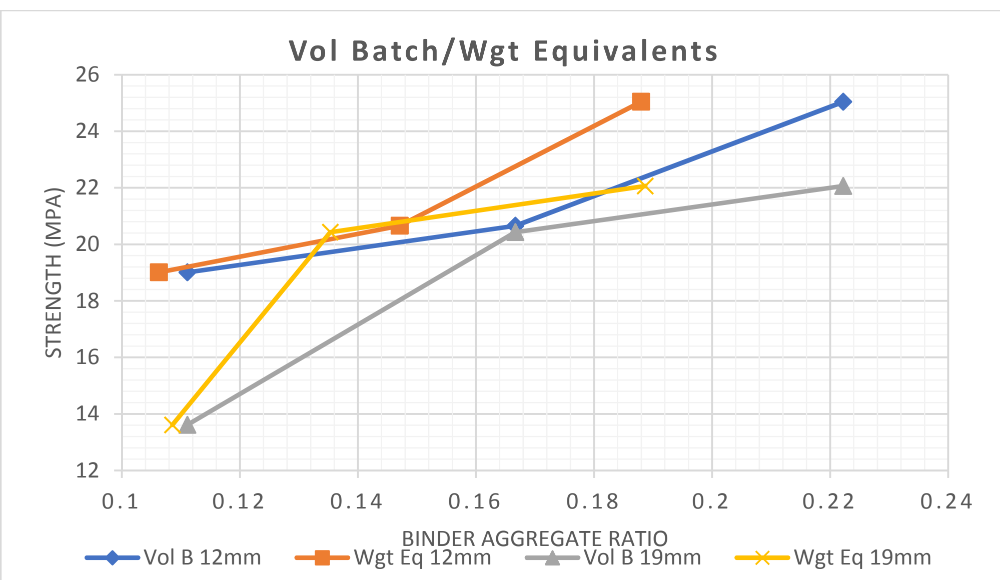

Figure 4: Shows Volume Batching and its Weight Equivalent

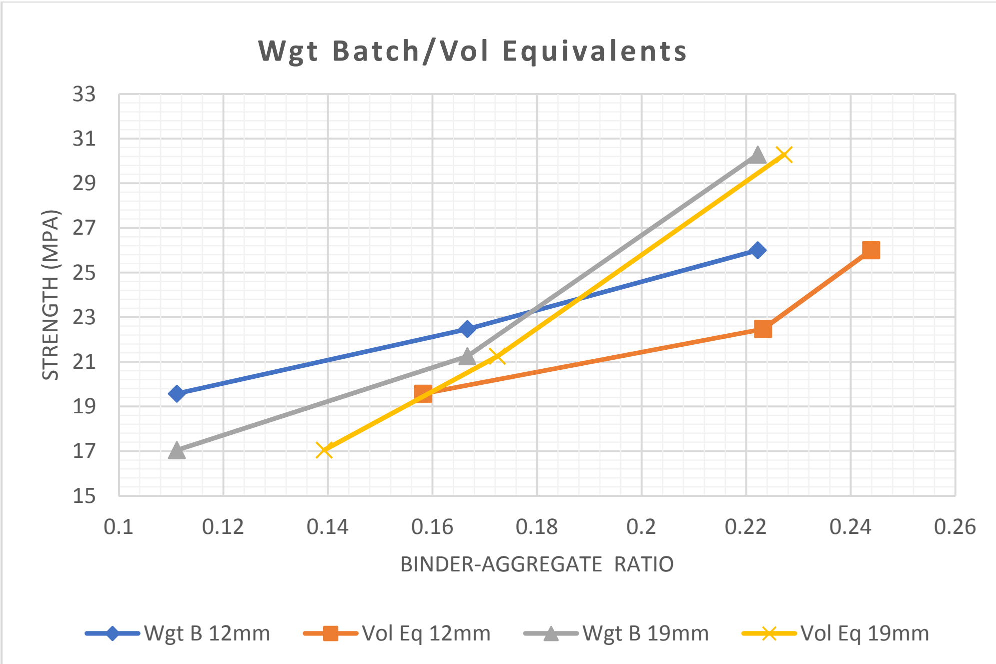

Figure 5: Shows Weight batch and its volume equivalent

Where:

Wgt B	-	Weight Batch
Vol B	-	Volume Batch
Vol B 12mm	-	Volume batched with 12mm aggregate size
Wgt Eq 12mm	-	Weight equivalent of volume batched with 12mm aggregate size
Vol B 19mm	-	Volume batched with 19mm aggregate size
Wgt Eq 19mm	-	Weight equivalent of volume batched with 19mm aggregate size
Wgt B 12mm	-	Weight batched with 12mm aggregate size
Vol Eq 12mm	-	Volume equivalent of weight batched with 12mm aggregate size
Wgt B 19mm	-	Weight batched with 19mm aggregate size
Vol Eq 19mm	-	Volume equivalent of weight batched with 19mm aggregate size

Figure 4 and Figure 5 shows a relationship that exist between the strength of concrete batched by volume and by weight. This can be used as a rough guide to relate a weight batch to a volume batch mix-designs that will be equivalent to the design mix batched by weight.

From Table 1, the average coarse to fine aggregate ratio is 1.776 when batched by weight and the volume equivalent of the weight batch determined.

For instance, if we want to prepare a mix-design to produce a concrete strength of 23 MPa with a 19mm aggregate size. Since the goal is to obtain a mix-design to be batched by volume in a way as though it was designed to be batched by weight. The first step would be to identify the aggregate size to be used. Secondly would be to used Figure 5 to determine a point on the Volume quivalent curve of the weight-batch that corresponds with the target strength of 23 MPa. That point is 0.184 and this imply that the binder aggregate ratio is 0.184. The inverse of 0.184 would be 5.435 which would be equivalent to the sum of the fine and coarse aggregate ratios. Since the coarse to fine aggregate ratio would be 1.776, then the mix-design by volume batch that would produce a concrete with 23 MPa target strength would be 1:1.95:3.49.

Another instance is that if a specified SPC mix-design of 1:2:4 is prescribed to be batched by weight with 12mm coarse aggregate size. The binder-aggregate ratio would be 0.167, this point will be located on the weight batch 12mm aggregate curve and the expected strength determined on Table 5. Another point on same Table 5 would be located on the "Vol Eq 12mm" curve that corresponds to the noted strength on the earlier curve and the binder aggregate ratio determined, which is 0.223. The inverse of 0.223 would be 4.484 which would be equivalent to the sum of the fine and coarse aggregate ratios. Since the coarse to fine aggregate ratio would be 1.776, then the mix-design by volumetric batch that would produce a concrete sharacteristic, as though the original mix-design of 1:2:4 was batched by weight, would be 1:1.62:2.87. Therefore, the volumetric batch of SPC mix-design 1:2:4 prescribed to be batched by weight, would be 1:1.62:2.87. This coincides with the volume equivalent of the weight-batched design-mix of 1:2:4 (1:1.6:2.88) as shown in Table 1.

4.0 CONCLUSION, RECCOMENDATION AND LIMITATIONS

From the results and discussions, the following were the conclusions made:

- Batching the same mix-design by weight will produce better quality concrete than when batched by volume.
- There exist a possibility of designing a volume batch that would be quivalent to any specified standardised prescribed mix-design by weight as long as the design strength is not greater than 25 MPa .
- This study would go a long way in addressing the reduced quality of concrete employed in most Nigerian structural concrete due to volume batching short comings by still batching by volume that will be equivalent to batching the original SPC mix-design by weight. This will translate to better structural intergrity of buildings within the study area.

This study hereby recommend the following:

- Figure 4 and Figure 5 could be used as a chart for deriving a standardised prescribed concrete mix-design by volume that would be equivalent to a specified mix-design by weight as long as the target strength is not beyond 25 MPa.
- This same study be repeated on a matrix combination of fine and coarse aggregate that is available within a locality so as to use the strength design charts as Table 1, Figure 4 and Figure 5 of the selected aggregates to determine the volume equivalent mix-design that would be equivalent to the specified mix-design by weight. Though the difference is expected to be minute with the charts generated in this study.
- Further research is recommended to perform this same study utilising other coarse aggregate sizes between 40mm and 22mm (specified SPC sizes in BS8500-1:2002 and BS8500-2:2002) for other concrete applications.

ACKNOWLEDGEMENT

The authors in this study appreciate and acknowledge the role of the Chairman, Board of Regents and the management of Covenant University for supporting and facilitating the presentation of this study on this platform.

REFERENCES

Adewole, K. K., Ajagbe, W.O., Arasi, I. A. (2015). Determination of Appropriate Mix Ratios for Concrete Grades Using Nigerian Portland-Limestone Grades 32.5 And 42.5. *Leonardo Electronic Journal of Practices and Technologies. (26), 79 – 88.*

BS 8500-1 (2015). Method of Specifying and Guidance for the Specifier. British Standard Institute. London.

BS 8500-2 (2015). Specification for Constituent Materials and Concrete. British Standard Institute. London.

BS EN 12620:2002 +A1 (2008). Aggregates for Concrete. British Standard Institute. London.

BS EN 197-1 (2011). Cement Part 1: Composition, Specifications and Conformity Criteria for Common Cements. British Standard Institute. London.

BS EN 206-1 (2000). Cement - Specification, Performance, Production and Conformity. British Standard Institute, London.

Ede, A. N. (2010). Building Collapse in Nigeria: The Trend of Casualties in the Last Decade (2000 - 2010). *International Journal of Civil and Environmental Engineering (IJCEE-IJENS).* 10(6), 32-41.

Hedidor, D. and Bondinuba, F. K. (2017). Exploring Concrete Materials Batching Behaviour of Artisans in Ghana's Informal Construction Sector. *Journal of Civil Engineering and Construction Technology, 8(5), 35-52.*

Holtz R. D. and Kovacs W. D. (1981) An Introduction to Geotechnical Engineering. Prentice Hall Englewood Cliffs, New Jersey 07632.

Joshua O., Ogunde A. O., Omuh I. O., Ayegba C. and Olusola K. O. (2015). Exploring the Pozzolanic Potential of Blend of Palm Kernel Nut Ash (PKNA) With Cement Towards a Sustainable Construction. *Proceedings of the Covenant University International Conference on African Development Issue (CU-ICADI).* (2):135-140

Joshua, O., Olusola, K. O., Ogunde, A. O., Ede, A. N., Olofinnade, R. M., & Nduka, D. O. (2017). Investigating for Pozzolanic Activity in Palm Kernel Nut Waste Ash (PKNWA) with Cement towards a Sustainable Construction. *International Journal of Applied Engineering Research*, *12*(23), 13959-13565.

Joshua, O., Matawal, D.S., Akinwumi, T.D., Ogunro, A.S. & Lawal, R.B. (2016); "Development of Green and Environmentally Friendly Alternative Binder to Cement towards Sustainable Construction", *Proceeding of Internal Summit of Repositioning the Nigerian Construction Industry – Realities and Possibilities, Abuja, Nigeria,* 24th – 26th May, 282-294

Joshua, O., Olusola, K. O., Ayegba, C., & Yusuf, A. I. (2013). Assessment of the Quality Steel Reinforcement Bars Available in Nigerian Market. In *AEI 2013: Building Solutions for Architectural Engineering* (296-305).

Mehta, P. K. and Monteiro, P. J. M. (2014). *Concrete Microstructure Properties and Materials*. 4th ed. McGraw-Hill Companies, Inc. United States of America (USA).

Neville, A. M. and Brook, J. J. (2010). *Concrete Technology*. 2nd ed. Pearson Education Limited. Edinburgh Gate Harlow Essex CM20 2JE England.

Olusola, K. O., Adewumi J. B., Umoh, A. A., and Olawuyi, B. J. (2012). Effect of Batching Methods on the Fresh and Hardened Properties of Concrete. *IJRRAS 13 (3), 773 – 779*

Oni, A. O. (2010): Analysis of Incidences of Collapsed Buildings in Lagos Metropolis, Nigeria. *International Journal of Strategic Property Management,* 14 (4), 332-346