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*Research Article*

# Investigating mix ratios by volume batching for performance specification of in-situ concrete works

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**Special Issue**

*A Themed Issue in Honour of Professor Onukwuli Okechukwu Dominic (FAS).*

This special issue is dedicated to Professor Onukwuli Okechukwu Dominic (FAS), marking his retirement and celebrating a remarkable career. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

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# Investigating mix ratios by volume batching for performance specification of in-situ concrete works

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**Abstract**

Volume batching of concrete materials is commonly adopted for in - situ concrete works in most construction sites in Nigeria, most especially where small to medium scale concrete works are involved. Prohibitive cost of procurement and maintenance of standard batching plant may be responsible for the adoption of volume – based batching method. The main objective of this study is to validate the characteristic strength of volume batched nominal mix proportions of 1:2:4, 1:1.5:3 and 1:1:2 for purpose of performance specification for in – situ concrete. The validation process adopted involves direct comparison with weight – based batching of similar nominal mix ratios, considering some important properties as density, slump value and compressive strength. The results indicate strength reduction of 16.7%, 30% and 36% for direct volume batching, while the weight batching recorded strength increase of 47%, 25% and 4% over the expected characteristic strength for the strength classes of C12/15, C16/20 and C20/25 respectively. Further analysis indicated that the conventional volume batch (with coarse/fine aggregate ratio of 2) performed better than the non – conventional volume batch method (with coarse/fine aggregate ratio of 1) despite maintaining the same aggregate/binder ratio. It was concluded that the batch method should be specified alongside the target strength for performance specification of nominal mixes for in – situ concrete work.

**Keywords:** in – situ concrete, characteristic strength, volume batching, nominal mix, performance specification

## 1.0 Introduction

The choice of mix proportion is governed by such factors as workability of fresh concrete, compressive strength and durability of hardened concrete. Mix proportion of concrete can be determined on the basis of field experience (i.e. statistical data), or from trial mixtures. The method of proportioning has evolved from the arbitrary volumetric method of the 20$^{th}$ century to the weight and absolute volume methods of the 21$^{st}$ century. Most contract documents carry prescriptive specifications expressed in terms on nominal mix proportion for a given grade of in – situ concrete. These nominal mix proportions are often volume batched in construction sites without clear control over the added water in the mix.

Nominal mix proportion is a simplified prescriptive specification of concrete with no guarantee for achieving specific performance characteristics. Concrete mix ratios obtained either from mix design process or nominal proportions are mostly volume batched in Nigeria, especially by small to medium scale construction firms due to prohibitive cost of procuring batching plant (Joshua et al., 2018). Most standard mix design from which nominal mix proportions are produced are meant to be batched by weight in order to meet the target strength. But when the mix proportions are volume – batched, they tend to fail the target strength of the concrete because batches by volume have been reported (Joshua et al., 2018) to contain more aggregate content by weight than when originally batched by weight.

In Nigeria, mix ratio 1:2:4 is commonly used as a normal concrete strength and mix ratio 1:1.5:3 for higher strength concrete (Adewole et al., 2015). Popular nominal mix proportions which are associated with concrete strength class of C12/15, C15/20 and C20/25 include 1:2:4, 1:1.5:3 and 1:1:2 respectively. The specification of concrete in terms of its nominal mix ratio is prescriptive in nature, as it dictates the portions of each constituent materials in the concrete.

However, performance specification is gaining attention in recent years because of its potentials in addressing some of the identified weaknesses inherent in the prescriptive specification style. Prescriptive specification provides instruction about ingredient and method of concrete production to ensure quality concrete, as well as test for fresh concrete (ASTM C143 – 7, 2015) and hardened concrete test (ASTM C39, 2015) to evaluate the quality of concrete produced. The use of strictly prescriptive specifications has proven insufficient to ensure that structures meet the target performance under service conditions (Gustavo et al, 2022)

In - situ concrete is prepared and placed on site rather than ordered from a batching plant or concrete supplier. The preparation of in – situ concrete involves the selection, batching and mixing of constituent materials including Portland cement, water, fine and coarse aggregates. The fresh concrete is placed in formwork, compacted and allowed to set and harden while undergoing certain type of curing procedure. Considering the multitude of factors that may influence the strength and performance of concrete and the obvious lack of control over most of these factors, it is important that concrete material be specified by the target strength and application rather than methods and materials that may not yield the desired strength.

The use of performance specification of concrete gives clear, measurable and enforceable instructions that cover specific application and functional requirements of concrete. It provides instructions highlighting the functional requirements of hardened concrete based on the expected application. With performance specification, concrete users may be encouraged to seek professionals or certified suppliers who are capable of delivering concrete with required performance properties as it places more responsibilities on the contractor/supplier for ensuring that required strength targets are met. Contractors/supplier of concrete will always consider mix proportions and quality control that will deliver the desired strength properties with no room for compromise, because emphasis is placed on the end and not the means. Performance specification enhances the use of various innovative materials and methods that can improve the quality and durability of concrete. The ACI Strategic Development Council (SDC) recognized the importance of performance – based specifications toward progressing innovation in concrete industry (Obla and Lobo, 2015)

For in – situ concrete, the most significant errors probably arise in batching through variations in water/cement ratio due to changes in moisture content of the aggregate or need for ease of handling of the concrete during mixing and placement. The strength properties of concrete are prone to varying degrees of errors arising from its preparation, production and application. Mixes of the stiffest consistency that can be placed efficiently is usually recommended in most concrete mix design standard, but in practice, mixes that are easy to handle due to their flowable consistency are usually preferred. Thus, the clear disconnection between mix design results and actual in – situ concrete results. The properties of any given concrete material depend on the properties of its material constituents.

There are several mix design methods and they all are intelligent guess about the relative share of the concrete constituents in the mix (Singh and Sharma, 2018). Significant portion of in – situ concrete produced by small scale construction firms in Nigeria do not follow any design process; they are product of nominal mix proportion, which are also volume batched. According to (Adewole et al., 2015); Hedidor and Bondinuba, 2017), volume batching of concrete is prevalent most especially among the small – to – medium scale contractors. Poor quality of concrete has direct link to the substandard batching practices (Ede et al., 2017). Most small-scale construction projects are handled by labour force with inadequate technical competence, and this contribute significantly to premature collapse of building. Most small-scale contractors in Nigeria rely on field experience involving direct volume batching of nominal mix proportions for concrete construction. When professionals are involved in concrete work, trial mixes are used to determine appropriate mix ratios for certain target strength. But, the involvement of local craftsmen like mason and quacks often lead to the use of poor quality of concrete. According to Adewole et al., (2015) the roadside craftsmen neither conduct any trial mix nor any quality assurance tests on concrete. They generally use 1:2:4 mix ratio irrespective of the target strength or grade of concrete.

Several studies have shown that batching methods have significant effects on the strength and workability of concrete. Research investigation by Orumu (2016) on the modified volume batching method for improved strength of in – situ concrete indicated that for a nominal mix ratio of 1:1.5:3, an increase of 20.9% in the volume of cement, a decrease of 24.6% in the volume of fine aggregate and an increase of 1.1% in the volume of coarse aggregate were required to achieve an increase in 28day strength of 22% for the modified volume batching method as compared to the conventional volume batch method. Franklin and Kaboro (2024) carried out a limited study on the influence of the batching methods on properties of concrete and reported higher strength in favor of weight batched method in comparison with volume batched method for different water/cement ratios. The range of strength difference reported was between a minimal 7.8% to a staggering 70.6%. They also observed that the coefficient of variation for mixes batched by volume was significantly higher than those of weight batched mixes. The report concluded that there is likelihood that volume batched concretes on construction sites might not meet their designed target strengths, in spite of the prevalent of this method in several West Africa countries.

It is important to check and ascertain the validity of some of the popular nominal mix proportions in relation to their expected strength performance through verifiable data in order to increase confidence in the structural quality and integrity of in – situ concrete works in Nigeria. This study therefore aimed at determining the comparative level of attainable strength between the weight – based and volume – based batching of three nominal mix proportions including 1:2:4, 1:1.5:3 and 1:1:2 for concrete grade 15, 20 and 25 respectively. The comparison will fill the research gap occasioned by absence of data backed information regarding the percentage difference between the weight batched and volume batched concrete mixes for common nominal mix proportions. With such important information, the percentage loss of strength for a concrete produced by conventional and non – conventional volume batched method with respect to target strength for weight batched method can be readily determined.

## 2.0 Materials and Methods

The materials for this study include Portland limestone cement, river sand, granite and water. The materials are subjected to characterisation tests including water absorption, density, particle size distribution and specific gravity. The summary of the characteristic properties of the constituent materials used for this study is provided table 1.

**Table 1: Material properties**

| Material | Property | Characteristic Value |
|---|---|---|
| Cement | Grade | 42.5N |
| | Density | 1430kg/m$^3$ |
| | Initial setting time | 33min |
| | Final setting time | 346min |
| | Specific Gravity | 3.10 |
| Fine Aggregate | Maximum size | 2.3mm |
| | Density | 1580kg/m$^3$ |
| | Specific Gravity | 2.62 |
| | Water absorption | 2.80 |
| Coarse Aggregate | Maximum size | 20mm |
| | Density | 1430 kg/m$^3$ |
| | Specific Gravity | 2.59 |
| | Water absorption | 2.42 |
| | Aggregate Impact Value | 17.32% |
| | Aggregate Crushing Value | 22.21% |

## 2.1 Specimen preparation and testing

The British standardized prescribed concrete grades of C12/15, C16/20 and C20/25 were adopted for the nominal mix ratios of 1:2:4, 1:1.5:3 and 1:1:2 respectively. The survey we conducted on the concrete strength for nominal mix ratios indicated that these mix ratios were generally accepted for the prescribed concrete grades by majority of our local contractors. The weight batch of these mix ratios was considered as control mix, while the direct volume batch and adjusted volume of the mix proportions were considered. For each mix, 20 cubes of 150mmx150mm were prepared, cured and tested at 28days. The water content for each mix was determined by the target slump class of S4 which truly represent the workability of in – situ concrete in Nigeria. The procedure for preparation of concrete and slump test followed standard BS EN 12350 – 2 (2019). Table 2 and 3 show the mix detail of the constituent material for concrete specimens. The determination of the apparent density of hardened concrete was in accordance with standard BS 12390 – 7 (2019) and the compressive strength was obtained following the standard BS EN 12390 – 3 (2019).

**Table 2: Mix details of concrete specimens batched by weight**

| Mix No | Cement (kg) | Sand (kg) | Granite (kg) | Water (kg) | W/C Ratio | Mix Ratio | C/Agg. Ratio | Slump (mm) | Slump Class |
|---|---|---|---|---|---|---|---|---|---|
| A | 25 | 50 | 100 | 15 | 0.60 | 1:2:4 | 0.167 | 165 | S4 |
| B | 31.2 | 47 | 94 | 16 | 0.51 | 1:1.5:3 | 0.222 | 195 | S4 |
| C | 42 | 42 | 84 | 18 | 0.43 | 1:1:2 | 0.333 | 200 | S4 |

**Table 3: Mix details of concrete specimen batched by conventional and nonconventional volume methods**

| Mix No | Cement (L) | Sand (L) | Granite (L) | Water (L) | W/C Ratio | Mix Ratio | C/Agg. Ratio | Coa/ Fine Ratio | Slump (mm) | Slump Class |
|---|---|---|---|---|---|---|---|---|---|---|
| D | 15.6 | 31.2 | 62.4 | 15 | 0.96 | 1:2:4 | 0.167 | 2 | 185 | S4 |
| E | 24 | 36 | 72 | 16 | 0.67 | 1:1.5:3 | 0.222 | 2 | 195 | S4 |
| F | 30 | 30 | 60 | 18 | 0.60 | 1:1:2 | 0.333 | 2 | 175 | S4 |
| G | 17 | 51 | 51 | 18 | 1.05 | 1:3:3 | 0.167 | 1 | 95 | S3 |
| H | 25 | 56.2 | 56.2 | 18 | 0.72 | 1:2.25:2.25 | 0.222 | 1 | 145 | S3 |
| I | 30 | 45 | 45 | 18 | 0.60 | 1:1.5:1.5 | 0.333 | 1 | 100 | S3 |

## 3.0 Results and Discussion

### 3.1 Characteristic strength

The characteristic strength is the design strength of concrete for structural purpose; hence it is the strength value that is associated with every nominal mix proportion. The average strength obtained from the standard cube test is referred to as target strength and can also be obtained using Equation 1.

$$f_m = f_c + ks \tag{1}$$

where $f_m$ is the target mean strength obtained as the average strength of the tested concrete specimens
$f_c$ is the characteristic strength specified for any given nominal mixes
s is the standard deviation obtained from the statistical analysis of the strength values of the tested specimens.
k is a constant derived from the mathematics of the normal distribution and increases as the proportion of defectives is decreased. Thus, for10% defective, k = 1.28; for 5% defective, k = 1.64; for 2.5% defective k = 1.96 and for 1% defective, k = 2.33. However, BS 8500 – 2 (2015) allows for 5% defective as justification for the use of k = 1.64 in most concrete mix design work.
The characteristic strength for each nominal mix under the weight and volume batching method is as presented in table 4.

**Table 4: Strength details of the concrete specimen**

| Mix No | Strength Class | Density (kg/m³) | Mean Strength ($f_m$) (N/mm²) | Std Dev. | k – value | Ch. Strength ($f_c$) (N/mm²) | Batch Type |
|---|---|---|---|---|---|---|---|
| A | C12/15 | 2565 | 24.7 | 1.32 | 1.64 | 22.5 | Weight |
| B | C16/20 | 2530 | 27.6 | 1.36 | 1.64 | 25.4 | |
| C | C20/25 | 2540 | 29.6 | 2.17 | 1.64 | 26.1 | |
| D | C12/15 | 2600 | 14.8 | 1.37 | 1.64 | 12.5 | Conventional Volume |
| E | C16/20 | 2505 | 17.9 | 1.90 | 1.64 | 14.0 | |
| F | C20/25 | 2565 | 20.9 | 3.03 | 1.64 | 15.9 | |
| G | C12/15 | 2465 | 11.9 | 1.56 | 1.64 | 9.3 | Non – conventional Volume |
| H | C16/20 | 2495 | 13.3 | 2.33 | 1.64 | 9.5 | |
| I | C20/25 | 2520 | 19.6 | 3.44 | 1.64 | 14.0 | |

### 3.2 Effects of batching method on strength of concrete

The results in table 4 indicate that the batching method has direct influence on the compressive strength of concrete.
The batching by weight for nominal mix ratios of 1:2:4, 1:1.5:3 and 1:1:2 is suitable for in – situ production of concrete grade of 22N/mm², 25N/mm² and 26N/mm² respectively, and this is 47%, 25% and 4% strength increase in comparison with the specified strength class for the nominal mixes. The volume batching of the same mix ratios produced concrete strength of 12.5 N/mm², 14 N/mm² and 15.9 N/mm² resulting in 16.7%, 30% and 36% strength

reduction in comparison with the specified strength class of the nominal mix ratios. The non - conventional volume batching with mix ratios 1:3:3, 1:2.25:2.25 and 1:1.5:1.5 produced strength of 9.3N/mm$^2$, 9.5N/mm$^2$ and 14N/mm$^2$ respectively, indicating an abysmal strength reduction of 38%, 52.5% and 44% in comparison with the expected characteristic strength of mixes with similar aggregate contents. These results align with British Standard's restriction of volume batch mixes for standardized prescribed concrete to target strength of less than 15N/mm$^2$ (Joshua et al., 2018).

In order to achieve the specified strength of 15N/mm$^2$ and 20N/mm$^2$, a modified volume batched mixes of 1:1.5:3 and 1:1:2 can be considered on site where adequate quality control measure is guaranteed. This proposition agrees with the conclusion by Joshua et al., (2018) on the use of modified mix design for volume batching of concrete to achieve a target strength. Table 5 shows the equivalent volume for weight batched mixes for specified concrete strength, but these mixes are not practicable for cast in place concrete works.

**Table 5: Equivalent mixes for maximum aggregate size 19mm**

| S/N | Weight Mix Ratio | Volume Equivalent | Specified Strength (N/mm$^2$) |
|---|---|---|---|
| 1 | 1:2:4 | 1:1.4:3.2 | 15 |
| 2 | 1:1.5:3 | 1:1.2:2.3 | 20 |
| 3 | 1:1:2 | 1:0.7:1.6 | 25 |

### 3.3 Effects of batching method on density of concrete

The average density for all the mixes falls within the standard range of normal weight concrete, but there is little information about the quality of mixes from the density values obtained. The average density for the conventional volume batch mixes were higher than their corresponding weight batched mixes, but the former recorded lower strength due perhaps to higher quantity of aggregates in the volume batched mixes. Ironically, in the non – conventional volume batches, lower densities were recorded despite the increase in quantity of fine aggregates in the mixes. However, the range of densities obtained from this research does not align with the use of 2400kg/m$^3$ as the standard density for mix design as stipulated by Nigeria's concrete mix design manual. For the design of normal weight concrete of significant strength, it is evidently clear from this study that the range of density chosen should be between 2500kg/m$^3$ and 2600kg/m$^3$.

### 3.4 Effect of batching method on margin of variability of concrete strength

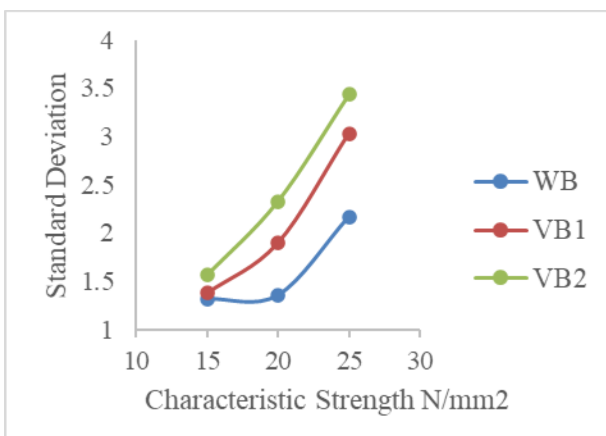


**Figure 1: Standard deviation vs characteristic strength**

Standard deviation is the appropriate statistic for determining strength variation from the average characteristic strength of concrete. The average standard deviation for 20 concrete specimens for all mixes fall below COREN's recommended 6MPa in the concrete mix design manual (2017). This implies that the strength values of the tested specimens were less scattered and reflected a good quality control measures during specimen preparation. However, there is clear indication that the higher the quantity of fine aggregates in concrete mix, the higher the standard deviation, leading to a lower target strength. This observation was in agreement with the findings of Gyurko and Nemes (2020) where it was reported that standard deviation is higher for mixes with high content of fine material.

## 4.0 Conclusion

In this research study, it is shown that the batching method influence target strength of concrete. Conventional and non – conventional mix proportions have been considered for three nominal mixes with strength target of 15N/mm$^2$, 20N/mm$^2$ and 25N/mm$^2$, but the weight batch outperform the volume batch method by 63.7%, 50% and 40% for 15N/mm$^2$, 20N/mm$^2$ and 25N/mm$^2$ strength respectively. However, the conventional mix ratios with coarse/fine aggregate ratio of 2:1 perform better than the non – conventional mix ratio with coarse/fine aggregate ratio of 1:1. The mix ratios of 1:1.5:3 and 1:1:2 produced average strength of 15N/mm$^2$ and 20N/mm$^2$ for conventional volume while the same ratios for weight batch method produced characteristic strength of 20N/mm$^2$ and 25N/mm$^2$. Therefore, the batch method for the constituent materials should be specified alongside the nominal mix ratio for in - situ concrete. It is also important that the constituent material share similar characteristics as the materials reported in this study, to achieve the proposed volume batched concrete strength.

## 5.0 Recommendation

From the findings of this study, it is recommended that a standardized mix table for volume batched concrete mixes with known characteristics properties of the constituent materials be produced, against achievable on – site target strength. This may serve as an important step towards the adoption of performance specification for small scale in – situ concrete works.

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**Nomenclature**
$f_m$ = Target mean strength (N/mm$^2$)
$f_c$ = Characteristic strength (N/mm$^2$)
s = Standard deviation
k = defective strength constant

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