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Comparative Study on the Variability Margin of Concrete Strength between Weight and Volume Batching Methods

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Abstract: *Variability of strength in concrete has significant effect on the structural integrity, safety and performance of every concrete structure. It is a valid concern which defies any mix design method, but depends changes in material, production process and environmental condition. The aim of this study is to determine the effect of the batching method on the margin of variability of concrete strength. Methods of batching by weight and volume were considered for three popular nominal mix proportions including 1:2:4, 1:1.5:3 and 1:1:2. The standard deviation of the 28th day compressive strength was determined and analysed for quantitative and qualitative assessment of concrete quality. The result indicates that lower water/cement ratio recorded higher compressive strength for the same mix proportions under both weight and volume batched method. The three mixes of ratios 1:2:4, 1:1.5:3 and 1:1:2 that were weight batched outperform the volume batch of the same mix ratios in compressive strength by 33.8%, 14.5% and 24.9% respectively. It was concluded that volume batched mixes may only be considered for on – site concrete construction when water/cement ratio can be strictly controlled or stiff mixes are applicable as well as characteristic strength of concrete is below 25N/mm^2. Where these conditions cannot be met, batching by weight with controlled water/cement ratio should be considered for on – site concrete construction. This study recommended the development of mix design template suitable for volume batched mixes considering several factors promoting variability in concrete strength, through the collective efforts of researchers, site engineers and regulatory bodies.*

Keywords: *Variability Margin, Batching Method, Nominal Mix, Standard Deviation, Mix Proportions*

1. INTRODUCTION

Concrete is a major construction material which constitutes 40 – 45% of all the material used in construction industry [1]. The major source of concrete for small and medium scale construction firms is the on – site concrete, prepared from constituent materials such as sand, granite, cement and water which are supplied to construction sites from different sources. The constituent materials of concrete can be batched by weight or volume [2], and the batching process can take place on – site or in batching plant, depending on the scale of construction. However, the common batching method adopted by most small – scale construction firm and for in – situ concrete in Nigeria is the volume batched method. Hattani et al, [3] studied factors influencing quality and performance of concrete mixture by conducting on – site visits to assess challenges associated with batching, mixture design, construction practice among other challenges. It was reported that volume batching and hand mixing of concrete are prevalent in construction sites handled by local contractors, leading to clear deviations from recommended guidelines. Small and medium scale construction firms specialize in general building works and they provide professional services in the area of civil works [4]. The average Nigerian contractor is a small-scale firm, staffed with people with limited knowledge and experience in modern construction and management techniques [5, 6].

The margin of variability of concrete strength is the difference between the specified characteristic strength and the target mean strength of concrete [7]. Variability of concrete strength limits attempts at automating the quality control process of concrete production. Excess variation in strength of concrete within batch and from batch to batch also reduce the accuracy of prediction and reliability of predictive models and algorithms like machine learning which has found application in compressive strength prediction of concrete [8, 9].

The variability of concrete strength for on – site concrete is open to multiple factors such as material properties, batching type, production processes and environmental conditions. It is important to understand and quantify the variability of concrete for reliable and safe structural design [10]. Tutu et al., [11] evaluated concrete production and construction practices at different construction sites in Ghana, and reported such factors as aggregate sourcing, stockpiling, and batching practices as promoter of variability in concrete quality. The common approach to investigating variability of concrete strength is the use of standard deviation or coefficient of variation. The common practice is to assume normal distribution of the compressive strength of concrete and this practice is supported by many standards and codes of practice. The Manual of Concrete Practice ACI [12] stipulates quality control of concrete using standard deviation as represented in Table 1. Standard deviation is a statistical method which determines the dispersion of a set of value about the mean value. According to Boukendakji [13], a lower standard deviation indicates a lower variability and a reduced target mean strength for a given characteristic strength.

Table 1: Standard of concrete control (ACI, 2011)

Class of Operation	**Standard Deviation Range**	
	Field Test	**Lab Test**
Excellent	Below 2.8	Below 1.4
Very Good	2.8 – 3.4	1.4 – 1.7
Good	3.4 – 4.1	1.7 – 2.1
Fair	4.1 – 4.8	2.1 – 2.4
Poor	Above 4.8	Above 2.4

Source: (Adapted Boukendakji, [13])

Variation in strength of concrete has significant effect on the structural integrity, safety and performance of a concrete structure. Although variability margin between batches is commonly considered in most mix design and quality control practice, variability within batch has not been given equal attention. Variations in concrete strength due to batching may arise within batch or between batches, irrespective of whether the batching is by weight or volume. Despite several studies on quality control and mix design of concrete relating to variability margin between batches of concrete mixes [3, 10,11], most of these studies have not thoroughly investigated the impact of the batching method on the variability margin within same batch of concrete. Also, the use of statistical tool like standard deviation in quality control of concrete has been limited to strength variability with focus on several causes other than batching method, since most research on quality control adopt only weight batching method. Leykin et al., [14] assessed the accuracy of concrete quality control system using statistical tools to determine defective results, and recommended improvement in the quality control system and the standard samples of concrete material for testing.

In a nutshell, there is inadequate information relating qualitative assessment of concrete and the quantitative analysis of its strength variability. Therefore, this study is intended to determine the effect of batching method on the variability margin of concrete for improved quality of on – site concrete construction. In this study, weight and volume batched mixes were considered in three different mix proportions of 1:2:4, 1:1.5:3 and 1:1:2, and concrete cube samples were prepared, cured and tested at 28day. The standard deviation of the compressive strength results was calculated and further analysed for quantitative and qualitative assessment of concrete quality.

2. MATERIALS AND METHODS

The materials for this study are Portland limestone cement, river sand, granite and water. The materials were subjected to characterisation tests such as density, particle size distribution and specific gravity. Table 2 shows the summary of the characteristic properties of the materials. The material quantity for each mix is as presented in table 3 and 4.

Table 2: Constituent 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	
	Aggregate Crushing Value	17.32%
		22.21%

Table 3: Concrete specimens batched by weight

Mix No	Cement (kg)	Sand (kg)	Granite (kg)	Water (kg)	W/C Ratio	Mix Ratio	Slump Class
A	25	50	100	15	0.60	1:2:4	S4
B	31.2	47	94	16	0.51	1:1.5:3	S4
C	42	42	84	18	0.43	1:1:2	S4

Table 4: Concrete specimens batched by uncontrolled and controlled volume methods

Mix No	Cement (L)	Sand (L)	Granite (L)	Water (L)	W/C Ratio	Mix Ratio	Slump Class
D	15.6	31.2	62.4	15	0.96	1:2:4	S4
E	24	36	72	16	0.67	1:1.5:3	S4
F	30	30	60	18	0.60	1:1:2	S4
G	16	32	64	10.2	0.64	1:2:4	S1
H	20	30	60	10.4	0.52	1:1.5:3	S1
I	30	30	60	13.6	0.45	1:1:2	S1

2.1 Preparation and Testing of Specimen

Three nominal mix ratios were considered including 1:2:4, 1:1.5:3 and 1:1:2 with expected characteristic strength of 15 N/mm^2, 20 N/mm^2 and 25 N/mm^2 respectively. The mix ratios were batched by weight for control and by two sets of volume batching based on slump classes (S4 and S1) of fresh concrete. The target slump class of S4 truly represents the workability of most on – site concrete in Nigeria, while slump class S1 for stiff mixes was maintained through strict adherence to controlled water/cement ratio. The concrete specimen preparation procedures follow the standard BS EN 12350 – 2 [15], the compressive strength test followed the standard BS EN 12390 – 3 [16]. The procedure produces 20 cubes of 150 mmx150 mm for each of the mixes totalling 180 cubes. The images in Figure 1 represent some of the fresh and hardened concrete handling process for this study.


(a) Concrete mixing process (b) Slump test process


(c) Concrete cube finishes (d) Concrete curing process

Figure 1: Fresh and hardened concrete handling processes

(e) Cured concrete cube ready for test (f) Compressive strength test of concrete cubes
Figure 1: Fresh and hardened concrete handling processes (Cont'd)

3. RESULTS AND DISCUSSIONS

3.1 Characteristic Strength

The characteristic strength of the tested concrete samples was obtained from the average of 20 cubes strength results using relation in Equation 1.

$$f_c = f_m - ks \quad (1)$$

where, f_c is the characteristic or design strength as specified for a given nominal mixes, f_m is the target mean strength obtained as the average strength of the tested concrete specimens, s is the standard deviation obtained from the statistical analysis of the strength results, k is a constant indicating the percentage of defective concretes, derived from the mathematics of the normal distribution of result.

According to Marsh [7], k = 1.28 for a 10% defective strength, it is 1.64 for 5% defective, 1.96 for 2.5% defective and 2.33 for 1% defective. For a typical mix design of concrete 5% defective with corresponding k value of 1.64 is adopted for mix design calculation. Table 5 shows the results of the mean compressive strength as obtained from compression test on concrete cubes, as well as the standard deviation, variability margin and the characteristics strength as obtained from the statistical analysis of the results.

Table 5: Strength, standard deviation, variability margin and batch type

Mix No	Strength Class	Density (kg/m^3)	Mean Strength (f_m) (N/mm^2)	Std Dev. (N/mm^2)	Variability Margin (ks)	Ch. Strength (f_c) (N/mm^2)	Batch Type
A	C12/15	2565	24.7	1.32	2.17	22.5	Weight (S4)
B	C16/20	2530	27.6	1.36	2.23	25.4	
C	C20/25	2540	29.6	2.17	3.56	26.0	
D	C12/15	2600	14.8	1.37	2.25	12.6	Volume (S4)
E	C16/20	2505	17.9	1.90	3.12	14.8	
F	C20/25	2565	20.9	3.03	4.97	15.9	
G	C12/15	2540	19.8	2.11	3.47	16.3	Volume (S1)
H	C16/20	2470	20.5	1.72	2.82	17.7	
I	C20/25	2590	26.1	1.41	2.31	23.8	

From table 5, the characteristic strength for each nominal mix under the weight and volume batch method is presented. The variability constant (k) value of 1.64 was used in calculating the variability margin, so that the characteristic strength obtained would correspond to the mix design values for each of the mixes. None of the volume batched mixes meet the expected characteristic of the three nominal mix proportions. However, the volume batched mixes with low slump range (S1) recorded higher mean strength than volume batched mixes with high slump range (S4) by 33.8%, 14.5% and 24.9%. This indicates that stiffer mix produces higher strength for volume batched than flowable mixes. Despite the high slump range (S4) for weight batched mixes, higher mean strength than the volume batched mixes with low slump range (S1). This difference indicates that weight batch method must be considered for on – site concrete construction. Concrete application for which volume batching may be considered should be limited to compressive strength below C20/25 grade.

From Figure 2, the weight batched mixes recorded higher strength for the mix proportions and also meets the target mean strength of the individual concrete grade, despite high slump class of the mixes. The volume batched mixes with high slump range (S4) recorded the poorest strength value in comparison with weight batched and volume batched with low slump range (S1). This perhaps is due to excess aggregate (resulting from volume batching) and excess water (resulting from high slump range) in the mix. The volume batched mixes with low slump range (S1) recorded significant strength values that can be considered for concrete grade of strength class C12/15, C15/20 and C18/22 for nominal mix proportions of 1:2:4, 1:1.5:3 and 1:1:2 respectively. With a strictly controlled water/cement ratio and a mix with very low slump range, volume batching can be considered for on – site concrete with strength grade below C20/25.

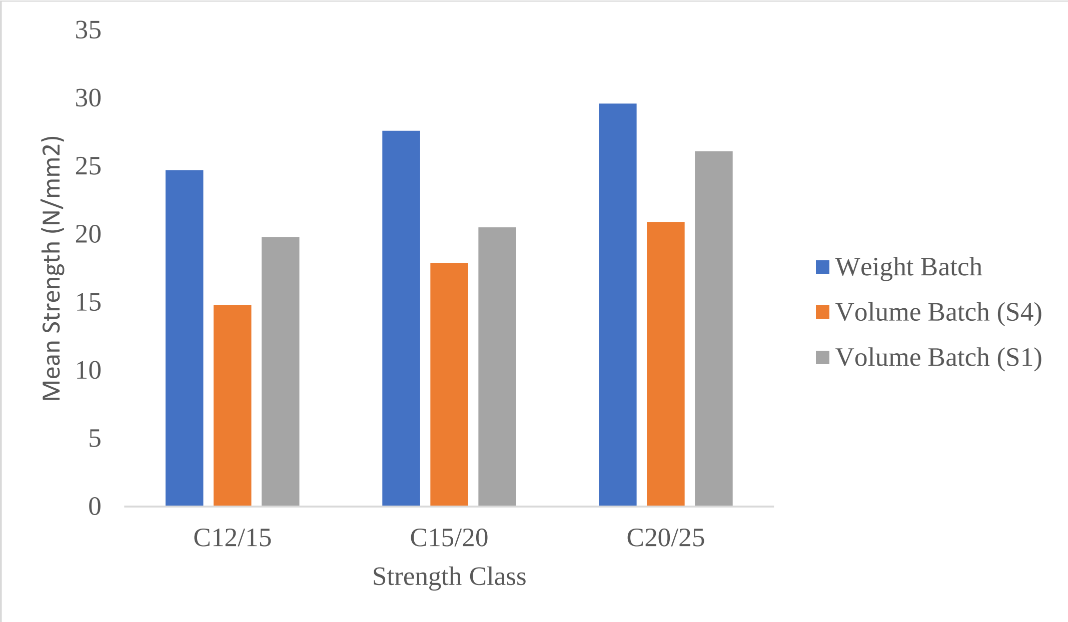

Figure 2: Concrete mean strength for different batching method

3.2 Standard Deviation

The effect of the batching methods on the quality of concrete sample was determined using the ranking scale of the standard concrete control ACI (2011) on the standard deviation results as shown in Table 6.

Table 6: Mean strength, standard deviation of concrete

Mix No	Mean Strength (N/mm^2)	Std Dev. (N/mm^2)	Class of Operation
A	24.7	1.32	Excellent
B	27.6	1.36	Excellent
C	29.6	2.17	Fair
D	14.8	1.37	Excellent
E	17.9	1.90	Good
F	20.9	3.03	Poor
G	19.8	2.11	Fair
H	20.5	1.72	Good
I	26.1	1.41	Very Good

From Table 6 the standard deviation values do not reflect the strength characteristics of concrete and do not indicate a better method between weight batch and volume batch method. The range of standard deviation for both the weight and volume batched mixes for this study fall between 1.32 and 3.03, and the margin fall within the reported range of (1.98 and 3.72) standard deviation for ready mix and weight batched concrete mixes by Boukendakji [13]. Concrete mixes with high slump range (S4) for both weight and volume batches indicate that increase in cement content causes decrease in quality, while the opposite is the case for volume batched mixes with low slump range (S1). This may be attributed to possible segregate in the former mixes and absence of segregation in the latter mixes.

Figure 3 showed that for volume batched mixes with low slump range (S1), the lower the water/cement ratio, the lower the standard deviation. This indicates that the quality of concrete that is volume batched can be easily controlled for stiff mixes. However, stiff mixes may produce honeycombed concrete with openings for ingress of deleterious material into the concrete structure. For high slump mixes, for both weight and volume batching method, lower water/cement ratio translate to higher standard deviation. This behaviour indicates that the presence of excess water in the mix causes considerable variations in the strength of concrete samples from the same batch. It becomes difficult to achieve control over the quality of concrete when there is excess water in the mix.

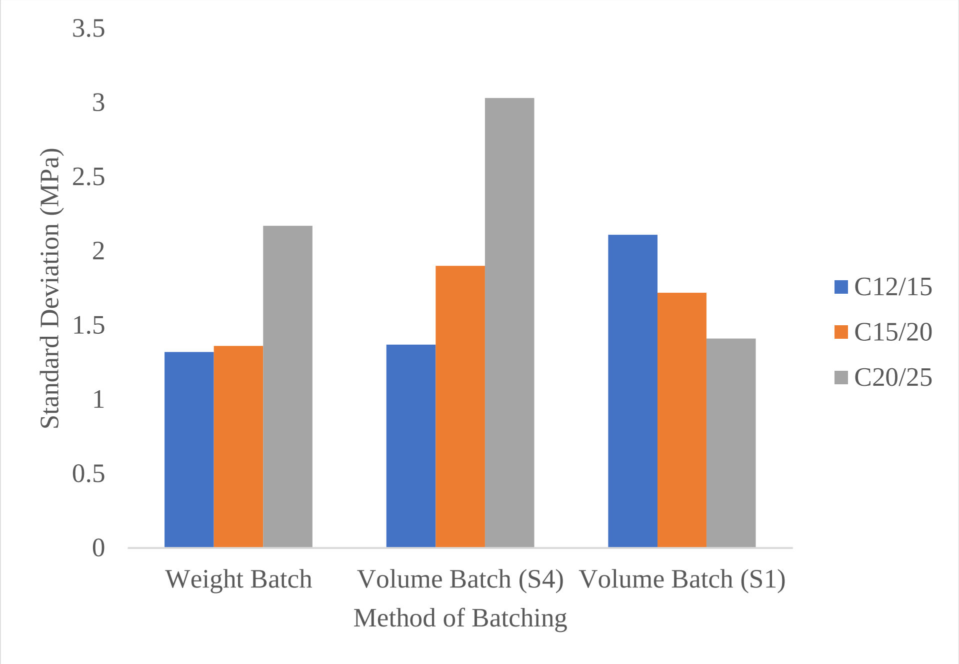

Figure 3: Standard deviation of concrete results from different batching method

4. CONCLUSION

From the findings in this study, it was established that the standard deviation of compressive strength results of concrete can be used to quantify and qualify the quality of the concrete. It was found that improved strength and quality concrete by volume batched method depends on the level of control over water/cement ratio, and the water quantity that produce significant strength may produce stiff concrete. Concrete applications for which volume batching may be considered are limited to small scale construction in which compressive strength of concrete below C20/25 is acceptable and/or construction scenarios where stiff concrete mixes are suitable such as construction sites prone to high water table or wetness. Increase in slump range affect volume batched mixes more than the weight batched mixes, leading to weaker strength and significant variation in concrete strength. It is therefore established that the margin of variability of concrete strength for volume batched mixes depends on the water content in the mix, or the slump range of the mix.

5. RECOMMENDATION

Based on the findings of this study, it is recommended that water/cement ratio should be controlled or slump be kept within 'stiff' range for volume batched mixes in order to minimize variation in concrete strength. Water/cement ratio vs strength table for volume – batched mixes should be developed for on – site construction in Nigeria. Also, a mix design suitable for volume – batched mixes can be developed considering many factors responsible for strength variation of concrete within batch, through the collective efforts of researchers, site engineers and regulatory bodies like COREN.

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