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Introduction into Mix Ratio Matrix Analysis of Concrete for the Determination of Cement Grade

Orumu S.T.[1] and Nelson T.A.[2]

Department of Civil Engineering

Niger Delta University

Wilberforce Island, Bayelsa State

Nigeria

ABSTRACT

This paper presents a novel method to determine the grade of cement from concrete instead of mortar by a simple 2X2 Mix Ratio Matrix Analysis of Concrete. Two stages are involved in the model. The first is to determine the actual cement strength and gross aggregate strength while the second stage is to convert this cement strength from 150mm cubes to its equivalent strength if 50mm cubes with the aid of conformity factors of 1.435 which has been established earlier. Three batching methods where considered viz: Batching by weight, volume and the modified volume method (The modification implied here is the complete removal of entrained air in each of the concrete constituents during volume batching before mixing. Here the air volume was removed by increasing the volume of each constituent to make up for the volume of air entrained). Concrete samples produced for the work was from 42.5 grade Dangote brand of cement indicated in the bag. The model was tested with compressive strength for Fifty (54) concrete samples of 1:1.5:3 mix ratio which was batched by the traditional volume method and the modified volume method with Water cement ratio maintained at 0.5 and cured for 7 days, 14 days and 28 days. The results show that Dangote cement has a strength in the range of 34.04mpa and 36.6mpa (48.85mpa and 52.52mpa equivalent of 50mm cubes) and the cement grade is actually 42.5 as claimed by the manufacturer. A range of 43.95mpa and 45.56mpa was computed from the concrete, which is less than the next grade of cement 52.5. This strength of the Dangote cement as obtained was confirmed on compressive strength results of another set of 307 samples batched by weight and prepared for 1:2:4 and 1:1.5:3 by the authors. The Compressive strength result of cubes produced from other literature for 1:3:6 and 1:2:4 when tested in the proposed model revalidates this same result for Dangote cement while giving the strength of different brands of cement i.eIbeto, Elephant, Purechem, and Unichem.

Keywords: *Analysis of concrete, Cement grade, Cement strength, Dangote cement, Mix Ratio Matrix.*

1. INTRODUCTION

Cement and steel are the two most important materials that govern the strength of a structure and should remain under watch by standard organizations and other relevant stakeholders. Although the terms cement and concrete are often used interchangeably, cement is actually an ingredient of concrete. Concrete is a mixture of aggregates and paste. The aggregates are fine and coarse; the paste is water and Portland cement. Cement comprises from 10 to 25 percent (1:3:6 to 1:1:2) of the concrete mixed by volume. Through a process called hydration, the cement and water harden and bind the aggregates into a rocklike mass. This hardening process continues for years meaning that concrete gets stronger as it gets older[1-10]. Each country has its own standard for Portland cement, so there is no single universal international standard. The United States uses the specification prepared by the American Society for Testing and Materials-ASTM C-150 Standard Specification for Portland cement. There are countries that have adopted this as their standard; however, there are countless other specifications. Unfortunately, they do not use the same criteria for measuring properties and defining physical characteristics so they are virtually "non-translatable." The European Cement Association located in Brussels, Belgium, publishes a book titled "Cement Standards of the World".

BS EN 196-1:2016 describes the method for the determination of the compressive and, optionally, the flexural strength of cement mortar. The method applies to common cements and to other cements and materials. It may not apply to other cement types that have, for example, a very short initial setting time. The method is used for assessing whether the compressive strength of cement

is in conformity with its specification and for validation testing of a CEN Standard sand, EN 196-1, or alternative compaction equipment. In America mortar batched by weight in a ratio 1:3 in 50mm cubes are produced, cured and crushed after 2 days, 7 days and 28 days. In Bulgaria 70mm mortar cubes or 100mm concrete cubes are adopted for the strength test of cement. In Nigeria the Ordinary Portland cement OPC that was predominant in the 90's have been almost completely replaced with the Portland Limestone cement PLC of grades 32.5, 42.5 and in very rare cases 52.5. These grades need to be confirmed in every site by every user of these different brand sof cement. These tests ought to be carried out on samples collected from prepared concrete to be used for the construction works. We therefore opine that concrete cubes caste for quality assurance and quality control could produce the strength of cement and by extension the cement grade. It is a fact that if the contributing strength of every ingredient required for concrete production is known, then the sum of the product of the individual mix ratio and the individual contributing strength will produce the expected concrete strength, This paper has addressed this by analyzing the matrix of the mix ratio of cement to the gross fine and coarse aggregate in a 2x2 matrix with the sole purpose of producing the individual contributing strength of cement, using the Dangote brand of cement as the major case study.

2. METHODOLOGY

The ingredients for concrete production are cement, fine aggregate, coarse aggregate and water. Though other additives like admixtures may be added to produce certain desired improved quality of the concrete, the ingredients listed above remain the major ingredients required for the production of concrete. The model proposed in this paper assumes that concrete is made up of cement of ratio 1 to aggregate of ratio (fine ratio + coarse ratio). A minimum of two (2) mix ratio from the same materials are needed to caste the cubes. Two sets of cubes from the different mix ratio to be crushed and used in the model must be cured for the same period i.e2 days, 3days, 7 days, 14 days, 21 days or 28 days. Although the 28 days strength is judged as the actual strength from existing literature, the model shows that the strength of cement used is a constant and does not depend on the period of curing particularly when the modified batching method is used.

2.1 Mathematical model

The model is in the form described below

The column matrix of the compressive strength of two mix ratio is equal to the 2X2 matrix of cement mix ratio and gross aggregate ratio of the two (2) mixes multiplied by the column matrix of cement and aggregate strength.

$$\begin{bmatrix} Fcu1 \\ fcu2 \end{bmatrix} = \begin{bmatrix} cementratio1 & aggregateratio1 \\ cementratio2 & aggregateratio2 \end{bmatrix} \begin{bmatrix} cementstrength \\ aggregatestrength \end{bmatrix} \quad 1$$

From where the desired strength of cement and aggregate is obtained from the product of the inverse 2X2 matrix of cement mix ratio and gross aggregate ratio of the two (2) mixes and column matrix of the compressive strength of two mix ratio. This is given in equation 2 below

$$\begin{bmatrix} cementstrength \\ aggregatestrength \end{bmatrix} = inverse\ of \begin{bmatrix} cementratio1 & aggregateratio1 \\ cementratio2 & aggregateratio2 \end{bmatrix} X \begin{bmatrix} Fcu1 \\ fcu2 \end{bmatrix} \quad 2$$

The second stage to obtain the grade of cement is to multiply the sum of strength of cement and gross strength of aggregate sabove with the conformity factor for converting 150mm cube to 50mm cube which is 1.435[14]. The result is compared to Table 1 of section 7 of BS 12 1996 Specification for Portland cement for the final classification into standard grade.

3. RESULT AND DISCUSSION

The compression results from 150mm concrete cubes batched by the traditional volume batching method and the modified batching method for 1:1.5:3 mix ratio and 1:0.9524:2.4 mix ratio respectively.

This is done for three (3) aggregate types A, B and C using Dangote cement and are now imputed into the model to obtain the result ax shown in table 1

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Table 1: Concrete strength for aggregate types A,B and C

Aggregate type A						
Mix ratio	**Age**	**Concrete strength(Mpa)**	**Cement ratio**	**Aggregate ratio**		**(Mpa)**
1:1.5:3	7days	10	1	4.5	Cement Strength	36.59
1:0.9524:2.		16.78	1	3.35	Aggregates Strength	-5.91
1:1.5:3	7days	10	1	4.5	Cement Strength	33.53
1:0.9524:2.4		16	1	3.35	Aggregates Strength	-5.23
1:1.5:3	7days	10	1	4.5	Cement Strength	35.80
1:0.9524:2.4		16.58	1	3.35	Aggregates Strength	-5.73
1:1.5:3	28 days	19.78	1	4.5	Cement Strength	35.46
1:0.9524:2.4		23.78	1	3.35	Aggregates Strength	-3.49
1:1.5:3	28 days	19.56	1	4.5	Cement Strength	34.34
1:0.9524:2.4		23.33	1	3.35	Aggregates Strength	-3.29
1:1.5:3	28 days	19.78	1	4.5	Cement Strength	35.03
1:0.9524:2.4		23.67	1	3.35	Aggregates Strength	-3.39
Average cement strength (150mm cube)						**35.13**
Average aggregates strength (150mm cube)						**-4.5**
Gross cement strength not raw (150mm cube)						**30.63**
Grade of cement (not raw) (50mm cube using conformity factor of 1.435)						**43.95**
Aggregate type B						
Mix ratio	**Age**	**Concrete strength**	**Cement ratio**	**Aggregate ratio**		
1:1.5:3'	7days	10	1	4.5	Cement Strength	34.39
1:0.9524:2.'		16.22	1	3.35	Aggregates Strength	-5.42
1:1.5:3'	7days	10	1	4.5	Cement Strength	36.15
1:0.9524:2.4		16.67	1	3.35	Aggregates Strength	-5.81
1:1.5:3'	7days	10	1	4.5	Cement Strength	37.02
1:0.9524:2.4		16.89	1	3.35	Aggregates Strength	-6.00
1:1.5:3'	28 days	19.78	1	4.5	Cement Strength	35.46
1:0.9524:2.'		23.78	1	3.35	Aggregates Strength	-3.49
1:1.5:3'	28 days	19.56	1	4.5	Cement Strength	36.97
1:0.9524:2.'		24	1	3.35	Aggregates Strength	-3.87
1:1.5:3'	28 days	19.78	1	4.5	Cement Strength	38.05
1:0.9524:2.'		24.44	1	3.35	Aggregates Strength	-4.06
Average cement strength (150mm cube)						**36.34**
Average aggregates strength (150mm cube)						**-4.78**
Gross cement strength not raw (150mm cube)						**31.56**
Grade of cement (not raw) (50mm cube using conformity factor of 1.435)						**45.29**
Aggregate type C						
Mix ratio	**Age**	**Concrete strength**	**Cement ratio**	**Aggregate ratio**		
1:1.5:3'	7days	10	1	4.5	Cement Strength	35.25
1:0.9524:2.'		16.44	1	3.35	Aggregates Strength	-5.61
1:1.5:3'	7days	10	1	4.5	Cement Strength	36.15
1:0.9524:2.4		16.67	1	3.35	Aggregates Strength	-5.81
1:1.5:3'	7days	10	1	4.5	Cement Strength	35.25
1:0.9524:2.4		16.44	1	3.35	Aggregates Strength	-5.61
1:1.5:3'	28 days	19.78	1	4.5	Cement Strength	38.95
1:0.9524:2.'		24.67	1	3.35	Aggregates Strength	-4.26
1:1.5:3'	28 days	19.56	1	4.5	Cement Strength	36.11
1:0.9524:2.'		23.78	1	3.35	Aggregates Strength	-3.68
1:1.5:3'	28 days	19.56	1	4.5	Cement Strength	37.83
1:0.9524:2.'		24.22	1	3.35	Aggregates Strength	-4.06
Average cement strength (150mm cube)						**36.59**
Average aggregates strength (150mm cube)						**-4.84**
Gross cement strength not raw (150mm cube)						**31.75**
Grade of cement (not raw) (50mm cube using conformity factor of 1.435)						**45.56**

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Table 2.Concrete matrix analysis results of 150mm cubes samples from Dangote cement batched by weight for verification of model

Mix Ratio	Age	Concrete Strength (Mpa)	Cement Ratio	Aggregate Ratio		(Mpa)
1:1.5:3'	7days	20	1	4.5	cement strength	26.67
1:2:4'	7days	17.78	1	6	aggregates strength	-1.48
1:1.5:3'	14days	23.56	1	4.5	cement strength	40.89
1:2:4'	14days	17.78	1	6	aggregates strength	-3.85
1:1.5:3'	28 days	28.89	1	4.5	cement strength	42.22
1:2:4'	28 days	24.44	1	6	aggregates strength	-2.96
Average cement strength (150mm cube)						36.59
Average aggregates strength (150mm cube)						-2.77
Gross cement strength not raw (150mm cube)						33.83
Grade of cement (not raw) (50mm cube using conformity factor of 1.435)						**48.55**

Table 3 Concrete matrix analysis results of 150mm cubes samples from Dangote cement batched by weight from other literature for revalidation of model

Mix Ratio	Age	Concrete Strength (Mpa)	Cement Ratio	Aggregate Ratio		(Mpa)
1:3:6'	3 days	7.11	1	9	Cement Strength	36.45
1:2:4'	3 days	16.89	1	6	Aggregates Strength	-3.26
1:3:6'	7days	12.15	1	9	Cement Strength	30.12
1:2:4'	7days	18.14	1	6	Aggregates Strength	-2.00
1:3:6'	14 days	15.76	1	9	Cement Strength	33.82
1:2:4'	14 days	21.78	1	6	Aggregates Strength	-2.01
1:3:6'	21 days	17.19	1	9	Cement Strength	31.80
1:2:4'	21 days	22.06	1	6	Aggregates Strength	-1.62
1:3:6'	28 days	18.89	1	9	Cement Strength	38.03
1:2:4'	28 days	25.27	1	6	Aggregates Strength	-2.13
Average cement strength (150mm cube)						34.04
Average aggregates strength (150mm cube)						-2.20
Gross cement strength not raw (150mm cube)						**31.84**
Grade of cement (not raw) (50mm cube using conformity factor of 1.435)						**45.69**

Table 4 Summary Classification of cement brand used in [8] to establish their grades using the proposed model

Brand of cement ⇨	**PURECHEM**		**UNICHEM**		**ELEPHANT**		**DANGOTE**		**IBETO**	
Days ⇩	**CEM**	**AG G**	**CEM**	**AG G**	**CEM**	**AG G**	**CEM**	**AG G**	**CEM**	**AG G**
3	27.17	-2.39	23.41	-1.37	20.74	-1.68	36.45	-3.26	44.44	-3.33
7	25.17	-1.89	23.54	-1.06	29.41	-2.35	30.12	-2.00	46.23	-3.27
14	24.45	-1.63	29.31	-1.68	49.07	-4.1	33.82	-2.01	52.77	-3.63
21	46.16	-3.86	32.31	-1.99	47.29	-3.49	31.8	-1.62	52.71	-3.48
28	50.48	-4.32	34.76	-2.1	50.37	-3.74	38.03	-2.13	72.26	-5.58
average	**34.686**	**-2.82**	**28.666**	**-1.64**	**39.376**	**-3.07**	**34.044**	**-2.20**	**53.682**	**-3.86**
Gross cement strength not raw (150mm cube)	**31.87Mpa**		**27.03Mpa**		**36.30Mpa**		**31.84Mpa**		**49.82Mpa**	
Grade of cement (not raw) 50mm cube using conformity factor of 1.435)	**45.73Mpa**		**38.78Mpa**		**52.10Mpa**		**45.69Mpa**		**71.5Mpa**	
Standard Grade of cement	**42.5**		**32.5**		**42.5**		**42.5**		**≥ 52.5**	

The strength of Dangote cement from table 1 are 35.15Mpa, 36.34Mpa and 36.59Mpa while they are 36.59Mpa and 34.04Mpa from table 2 and table 3 respectively. Table 5 below shows how they compare. In the table it could be observed that the aggregate strength contribution is negative and the deviation in percentage from the average is greater than 10% while other parameters compare very favorably with the worst deviation being less than 6%.The sources and grading of the aggregates could be the reason of this discrepancies. The once from the same source compare well see the ones from table 1 in table 5. While table 1 is the main work, results in table 2 is to verify the result while table 3 is to revalidate the model for dangote cement. The conformity

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factor of 1.435 had been established theoretically and experimentally [11] for 150mm cubes to 50mm equivalent. The use of it here converts the strength from 150mm cubes used in the model to its equivalent 50mm cube.The grade of Dangote cement from the three (3) different cases A, B and C and those of table 2 and table 3 is >42.5 Mpa but < 52.5Mpa therefore the standard grade is 42.5.

Table 5 Verification of Dangote grade of cement from three different sources

Source	Cement		Aggregate		Gross Strength		Cement Grade	
	Cement Strength (Mpa)	Deviation (%)	Aggregate Strength (Mpa)	Deviation (%)	Cement Strength (Mpa)	Deviation (%)	Cement Grade (Mpa)	Deviation (%)
Table 1	35.15	-1.65631	-4.5	17.86276	30.63	-4.04737	43.95	-4.05606
Table 1	36.34	1.673102	-4.78	25.19644	31.56	-1.13401	45.29	-1.13081
Table 1	36.59	2.372559	-4.84	26.76794	31.75	-0.53881	45.56	-0.54139
Table 2	36.59	2.372559	-2.77	-27.4489	33.83	5.977069	48.55	5.985854
Table 3	34.04	-4.7619	-2.2	-42.3782	31.84	-0.25688	45.69	-0.2576
average	**35.742**		**-3.818**		**31.922**		**45.808**	

In table 4 an attempt was made at classifying the grade of cement brands used in [8]. The results show that the Ibeto brand is a minimum of grade 52.5 while the for the Elepant are of grade 42.5 which with just a little improvement can hit grade 53.5 see fig 1 below. Purechem and Dangote brands are grade 42.5 while the Unichem cement is of a lower grade of 32.5.

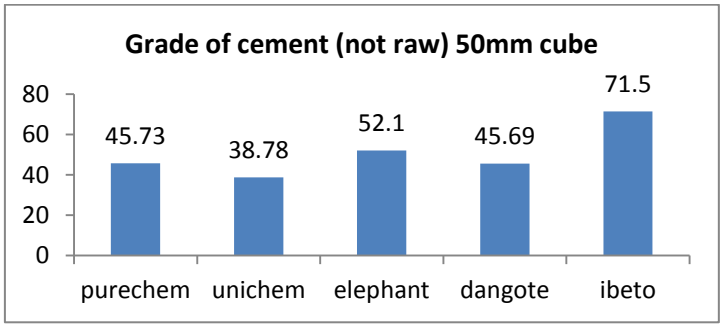

Figure 1 showing the grade of cement of various brand from the proposed matrix analysis method

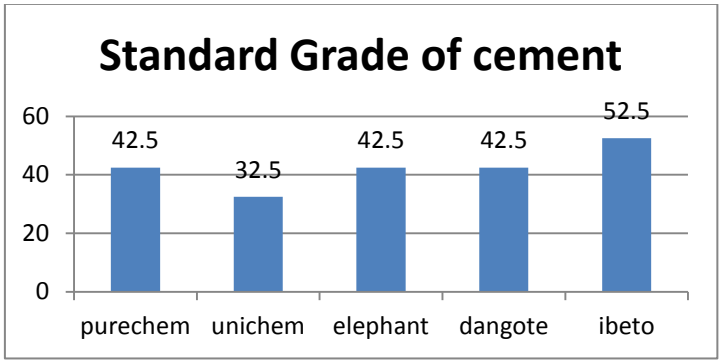

Figure 2 showing the standard grade of cement of various brand from the proposed matrix analysis method

5.0 CONCLUSION AND RECOMMENDATION

A matrix analysis to find the grade of cement from results of test cubes has been presented in this work with striking results. The model assumed that concrete is made up of cement of ratio 1 to aggregate of ratio (fine ratio + coarse ratio). With a minimum of two (2) mix ratio from the same materials, compressive strength of cubes cured for the same period i.e 2 days, 3days, 7 days, 14 days, 21 days or 28 days are imputed into the model. The results show that the strength of cement used is a constant and does not depend on the period of curing when the modified volume and volume batching methods is used.The revelation of individual strengths of cement on one hand and gross aggregate on the other hand indicates an evolution of a new mix design method for concrete.

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It is recommended that work should continue in this area of research with the matrix size increased above two (2) to carter for water cementations material ratio, individual aggregate ratio and admixture ratio.

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