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INFLUENCE OF MIX DESIGN METHODS ON THE COMPRESSIVE SRENGTH OF CONCRETE

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ABSTRACT

Concrete mixes are designed to achieve a defined workability, strength and durability. The design is geared towards the selection and proportioning of constituents to produce a concrete with pre-defined characteristics both in fresh and hardened states. This study investigates the variation of concrete compressive strength with mix designed methods. Four common mix design methods were used namely: American Concrete Institute (ACI), Department of Environment (DOR), Road Note 4 (RN4) and CPIIO. The Ibeto brand of Portland cement was used in the research and a characteristic strength of 20N/mm^2 was designed for using the first four mix design methods. The concrete components used were tested for specific gravity; moisture content and grading were found suitable. Four sets of concrete cubes (150 x 150 x 150 mm) each were casted using four mix designs. Compressive strengths were evaluated at 7, 14, 21, and 28 days of curing. The 28th day strengths of the four sets of concrete were found to be 30.7 N/mm^{2,} 33.7 N/mm^{2,} 33.0 N/mm^{2,} and 35.1 N/mm^2 for ACI, DOE, RN4, and CP110 mix design methods, respectively.

Keywords: compressive strength, mix design, concrete, curing, mix proportion.

INTRODUCTION

Concrete mix design is the science of deciding relative proportions of concrete ingredients to achieve the desired properties in the most economical way. As a matter of fact, concrete is the most frequently mentioned material in the construction industry. It is very versatile in building because it can be designed for strength from 10 N/mm^2 up to 100 N/mm^2 which is regarded as its grade. A good number of building failures are traceable to concrete incompetence among several other factors. The works involved, from the design to construction stages in buildings are largely those of selecting materials, components and structures that will meet the expected building standards and aesthetics on economy basis (Anyinuola and Olalusi, 2004) [1].

The basic ingredients of concrete are the same, but it is their relative proportioning that makes the difference. There are some essential concrete properties that make it fit for building construction. A fresh concrete should be workable, cohesive, and have a retarded initial setting. At hardened state, concrete should be strong, impervious, and durable. The relative proportions of the concrete ingredients are determined in order to achieve a desired strength and workability in a most economical way. This proportioning is guided by different methods of design adopted in concrete making. Good quality materials, thorough mixing, proper transporting and placing, adequate compaction and lots more carefulness may not still yield good concrete quality if the proportioning of materials have not been properly done. Adherence to concrete mix designs in concrete making is the crux of quality control in construction. Dubravka and Irina [2] proposed two approaches in quality control namely; prescriptive approach and performance approach. The prescriptive approach is at the design stage when the necessary materials are specified, their proportioning stated, and the construction method recommended. At the performance stage, the interest is on the proper way of construction in order to achieve the design strength and the expected life without volume change. To achieve these objectives, all the materials involved in the concrete making must be investigated to ensure their compliance with the standards owing to the fact that the physical and geotechnical properties of materials vary from one location to another. The values of the physical and geotechnical parameters of component materials form the basis of the concrete mix design considerations. Salihu (2011) [3] gave a breakdown of the concrete grades and their recommended usage in line with BS812 (1975, 1989, 1995) as shown in the table below.

Table-1. Concrete grades, mix proportions, and usage.

Concrete grade (N/mm^2)	Mix proportion (Cement : Sand : Gravel)	Recommended usage
10	1:4:8	Blinding concrete
15	1:3:6	Mass concrete
20	1:2.5:5	Light reinforced concrete
25	1:2:4	Reinforced concrete
30	1:1.5:3	Heavy reinforced concrete/precast
35	1:1.5:2	Pre-stress concrete/precast
40	1:1:1	Very heavy reinforced concrete

The above ratio were rated by weight but were concreted to equivalent proportions by volume. Mere using of the ratios indicated in the Table-1 above may not always yield the stated concrete grade owing to the fact that materials from different locations may not have the same properties. This buttresses the need for a specific mix design method to be adopted for a particular project, having in mind the expected grade. Durability of all finished projects is of immense importance. According to Kong and Evans (1987) [4], durability of concrete is its ability to withstand the environmental conditions to which it is exposed. ACII211 (1974) [5] also opined that concrete must be able to withstand those exposures which may deprive it from its serviceability state such as freezing and thawing, wetting and drying, heating and cooling, concrete opposing chemicals among others.

There is a serious need for thorough vibration during the placing of concrete. This will go a long way expelling entrapped air, and packing the aggregate particles together so as to increase the density of the concrete and ensure discontinuous pores within the concrete BS8110; Part1 (1985) [6]. Curing is also very important in ensuring that concrete achieves its design strength. According to Samir *et al*., [7] as reported by James *et al*., [8] an improperly cured concrete can be subjected to plastic shrinkage cracking (loss of moisture from fresh concrete) and drying shrinkage (loss of moisture from concrete that has set) among other side effects.

Kong and Evans [4] defines the characteristic strength of concrete as the value of compressive strength below which not more than a prescribed percentage of the test result should fall. The target mean strength or design strength exceed the characteristic strength by a margin. Different mix design methods arrive at the target mean strength in different ways and also estimated the mix proportions in different ways. The interest of this study is on four mix design methods namely, American Concrete Institute, Department of Environment, Road Note 4, and British Code of Practice (110). The procedures involved in the designs are outlined below.

American concrete institute (ACI) mix design method

This method of mix design involves nine steps vis-à-vis:

a) Selection of slump value relative to the purpose of the concrete usage.
b) Selection of the largest or maximum size of aggregates to be used with the criteria that it should not be greater than $^1/_5$ of the narrowest width of formwork, $^1/_3$ of depth of slabs, and $^3/_4$ of the minimum clear spacing between individual reinforcing bars.
c) Estimation of the water and air content as it relates to the chosen slump and maximum aggregate size.
d) Selection of water/cement ratio as it relates to the 28th day compressive strength.
e) Calculation of cement content by the ratio of the mixing water content to the water/cement ratio.
f) Estimation of coarse aggregate content as it relates to the maximum aggregate sizes and the fines modulus.
g) Subtracting the outcomes of step 1 to step 6 from the volume of fresh concrete to give the volume of fine aggregates.
h) Adjustment for aggregate moisture.
i) Trial batch adjustment after testing.

Department of environment mix design method

The work published under the title ‘’Design of Normal Concrete Mixes’’ originated from the works of the Building Research Establishment, Transport and Road Research Laboratory in the United Kingdom. The design involves; selection of the water/cement ratio appropriate for the required target mean strength from the code after which the free water content is selected relative to specified slump value. The ratio of the free water content to the water/cement ratio gives the cement content. Subtracting the sum of free water content and cement content all in kg/cm^3 from the concrete density gives the aggregate content. The code provides the proportion of fine aggregate for different water/cement ratios. With this proportion the quantity of fine aggregates is estimated from the total aggregate content and the coarse aggregate content is also gotten from the difference between the aggregate content and fine aggregate content.

Road note 4 mix design method

This method of mix design provides a compilation of tables and charts that could help a designer to extract information regarding the design being embarked upon. Water/cement ratio is selected for a given range of compressive strengths and slumps. The cement content is in turn selected for the type of aggregate and grading available. The charts give clue on the ratio of coarse to fine aggregates.

CP110 mix design method

This is a very simple design method to use. It presents in one table, the cement content by weight, the total aggregate content by weight, and the percentage of the fine aggregate for a chosen concrete grade, maximum aggregate size and the slump range.

Many more mix design methods exist but the study of the output variation of the compressive strength tests from these common mix designs would reveal the quintessence of mix design and the relevance of using a more adaptable code for a particular project.

MATERIALS AND METHODS

Materials used for this investigation include; Portland cement, coarse aggregates, fine aggregates and water. The Ibeto brand of Portland cement was bought from Eke Awka market and was protected to avoid lumps before the experiment. The coarse aggregates used were granitic materials collected from quarries at Benin. River bed sand sourced manually from the River Niger in Anambra State was used for the experiment. Portable water at the Nnamdi Azikiwe University was used and the tests were conducted at the Civil Engineering Laboratory of the same university. The different mix proportions got from the respective mix designs were batched by weight and the casting, curing and crushing were done in accordance with the guidelines specified by BS1881; Part108 (1983) [9], BS8110; Part1, (1985) [6], and BS1881; Part3 (1992) [10] respectively. 150x150x150mm cubes were casted and the compressive strengths were investigated at 7, 14, 21, and 28 days of curing.

DESIGN CALCULATIONS

With the maximum aggregate size of 20mm, the designs were carried out for a characteristic strength of 20N/mm^2. Different mix proportions were arrived at following the steps earlier outlined in this paper.

ACI method

Choice of Slump = 20mm - 80mm
Maximum size of aggregates = 20mm
Mixing water content (Non air entrained concrete) = 200kg/m^3

$$Ta\,\mathrm{rg}\,et\ mean\ design\ strenght,\ f_t = f_c + k\delta$$
$$where\ \ f_c =$$
$$k = Himsworth\ coefficient\,(1.64)$$
$$\delta = s\tan dard\ deviation\ taken\ as\ 0.4\ of\ \ f_c$$

Hence; $f_t =$ 20 + (1.64 x 0.4 x 20) = 33N/mm^2

Water/ cement ratio = 0.5
Cement content = 200/0.5 = 400kg/m^3
Bulk density of coarse aggregate = 1600kg/m^3

For a maximum aggregate size of 20mm and fines modulus of fine aggregate as 2.80, the dry bulk volume of coarse aggregate is 0.62 per unit volume of concrete.

Therefore, the quantity of coarse aggregate = 0.62 x 1600 = 992kg/m^3
Density of non air entrained concrete = 2355 kg/m^3

The mass of aggregates per unit volume of concrete is 2355 - (200+400+992) = 763 kg/m^3. Hence the design proportion in kilogram per cubic meters is 400:200:763:992 for cement, water, sand, and granite respectively. Hence a mix of 1:0.5:2:2.5 was provided.

DOE method

The target mean strength is calculated with the formula, $f_t = f_{cu} + ks$

Where = $ks = 0.67\,f_{cu}\ \ for\ f_{cu} \le 22.5N / mm^2$
$$f_t = 20 + 0.67x20 = 33.4N / mm^2$$

Water/cement ratio = 0.5
Maximum aggregate size = 20mm
Slump range = 30 - 60mm
Free water content = 210 kg/m^3
Cement content = 210/ 0.5 = 420 kg/m^3
Fine aggregate proportion = 35%
Total aggregate content = 2420 - (420+210) = 1790 kg/m^3
Fine aggregate content = 1790 x 35% = 626.5 kg/m^3
Coarse aggregate content = 1790 - 626.5 = 1163.5 kg/m^3
Therefore, cement: water: sand: granite is 420:210:266.5:1163.5 for a unit weight of cement, the proportion 1:0.5:1.5:3 was used.

RN4 method

Required Characteristic strength = 20N/mm^2 which should be 60% of target mean strength. Therefore the target mean strength f_t = 20/0.6 = 33.3N/mm^2
Water/ cement ratio = 0.5
Aggregate cement ratio = 5.4
Fine / coarse aggregate ratio = 25%
For a unit weight of cement, fine aggregate proportion = 25% of 5.4 = 1.35
Coarse aggregate proportion is then 5.4 - 1.35 = 4.05.
The mix proportion of 1:0.5:1.4:4 was then used.

CP110 method

For a characteristic strength of 20N/mm^2 and strength margin of 10N/mm^2 the target mean strength for the design was 30N/mm^2.
Slump range = 25 - 75mm
Maximum aggregate size = 20mm.

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For a cubic meter of concrete, the table gives cement content as 400 kg/m^3, total aggregate of1700kg/m^3, and fine aggregate percentage of 40%.
Therefore fine aggregate proportion = 40% of 1700 = 680 kg/m^3
Coarse aggregate = 1700 - 680 = 1020 kg/m^3. For a unit weight of cement, the mix proportion used is 1:0.5:1.7:2.55.

Based on these calculations, the concrete proportions were batched by weight in the laboratory.

RESULTS AND DISCUSSIONS

Particle size distribution

Figure-1 is a plot of sieve analysis carried on the aggregate samples in accordance with the guidelines specified by BS1377; Part2 (1990) [11]. The figure displays the maximum and minimum sizes of granite as 20mm and 5mm respectively while those of sand were 3mm and 0.75mm, respectively. This corresponds to ranges for coarse and fine aggregates.

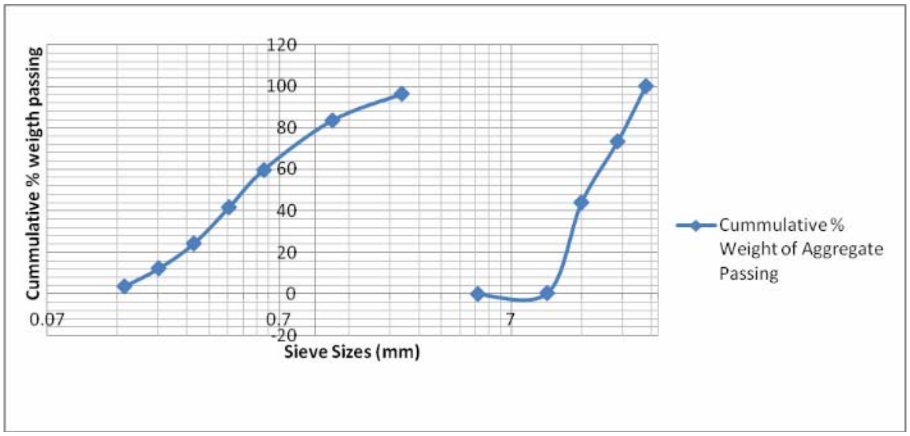

Figure-1. Particle size distribution of fine and coarse aggregates.

Moisture content

Table-2 shows the calculation of the moisture content of the river bed sand used. The average percentage moisture content of 1.25% is so low that the moisture content of the sand is negligible in the batching and will not have any significant effect on the water content of the plastic concrete.

Table-2. Moisture content test result for fine aggregate.

Pan No.	W_1	W_2	W_3	W_2-W_3	W_1-W_2	% Moisture content	Average % moisture content
1	108.4	107.3	18.3	89.0	1.15	1.29	1.25
2	110.0	109.0	18.7	90.3	1.00	1.12	
3	94.0	93.0	18.7	74.3	1.00	1.35	

Where W_1 = weight of pan + wet soil; W_2 = weight of pan + dry soil; W_3 = weight of pan; W_1- W_2 = weight of moisture; W_2 – W_3 = weight of dry soil.

Compressive strength

Tables 3 to 6 succinctly display the compressive test results for cubes cured and crushed. It could be observed that for all the mix design methods, there is a significant increase in the strength of concrete with age at curing which is demonstrated in Figure-2 for the four different mix design methods. This is in agreement with works of James *et al*., (2011) [8], Joseph *et al*., (2012) [12], and Udoeyo *et al*., (2006) [13]. Table-7 as well as Figure-2 explains the effectiveness of the mix design methods in achieving the target mean strength as well as the variation of these strengths with the design methods. CP110 gave the highest compressive strength, despite the fact that it demanded the least target mean strength by calculation. This is obviously due to the fact that it has the highest percentage composition of cement and least percentage of aggregates in the mix. The result also suggests that the higher the aggregate sizes in the mix, the higher the compressive strengths achieved. This could be seen by considering why ACI and DOE demanded the same aggregate proportion of 4.5 but DOE, with higher coarse aggregate content gave a significantly higher compressive strength than ACI. RN4 with the highest aggregate proportion of 5.4 still yielded a better concrete than ACI. The reason is still pointing to the presence of larger quantity of coarse aggregates in the mix than fines. All the mix designs exceeded the characteristic strength by an amount above 10N/mm^2 which confirms that they are

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both adequate for concrete making but it is important to note that ACI and RN4 yielded a lesser compressive strength than their target mean strength. This therefore, suggests that for more critical construction works, CP110 could be adopted. Some other mix design methods exist, and this study has revealed the relative integrity of the four methods under consideration with a submission that the engineer adopts the most conversant and confident for any project. With proper design, close monitoring and supervision of projects, and insistence on proper quality control, structural component failures would no longer be attributed to poor concrete.

Table-3. Compressive strength test result for ACI mix design.

Cube mark	**Age for testing** (Days)	**Size of cube** (Mm)	**Wt. of cube** (Kg)	**Concrete density** (Kg/M^3)	**Test load** (Kn)	**Crushing strength** (N/Mm^2)	**Average crushing strength** (N/Mm^2)
A1	7	150	8.0	2370	338	15.0	16.1
A2	7	150	8.5	2519	358	15.9	
A3	7	150	8.5	2519	392	17.4	
A1	14	150	8.4	2489	466	20.7	19.7
A2	14	150	8.3	2459	438	19.5	
A3	14	150	8.0	2370	428	19.0	
A1	21	150	8.1	2400	482	21.4	21.3
A2	21	150	8.2	2430	506	22.5	
A3	21	150	8.0	2370	452	20.1	
A1	28	150	8.5	2519	729	32.4	30.7
A2	28	150	8.0	2370	6355	28.2	
A3	28	150	8.4	2489	708	31.5	

Table-4. Compressive strength test result for DOE mix design.

Cube mark	**Age for testing** (Days)	**Size of cube** (Mm)	**Wt. of cube** (Kg)	**Concrete density** (Kg/M^3)	**Test load** (Kn)	**Crushing strength** (N/Mm^2)	**Average crushing strength** (N/Mm^2)
D1	7	150	8.0	2370	434	19.3	19.7
D2	7	150	8.5	2519	439	19.5	
D3	7	150	8.6	2578	459	20.4	
D1	14	150	8.7	2578	558	24.8	23.9
D2	14	150	8.2	2430	545	24.2	
D3	14	150	7.8	2311	513	22.8	
D1	21	150	8.3	2459	603	26.8	26.6
D2	21	150	8.4	2489	608	27.0	
D3	21	150	8.1	2400	567	26.1	
D1	28	150	8.5	2519	745	33.1	33.7
D2	28	150	8.5	2519	797	35.4	
D3	28	150	8.4	2489	734	32.6	

Table-5. Compressive strength test result for RN4 mix design.

Cube mark	**Age for testing** (Days)	**Size of cube** (Mm)	**Wt of cube** (Kg)	**Concrete density** (Kg/M^3)	**Test load** (Kn)	**Crushing strength** (N/Mm^2)	**Average crushing strength** (N/Mm^2)
R1	7	150	8.5	2519	387	17.2	17.1
R2	7	150	9.0	2667	392	17.4	
R3	7	150	8.5	2519	378	16.8	
R1	14	150	8.4	2489	491	21.8	21.8
R2	14	150	9.0	2667	504	22.4	
R3	14	150	8.0	2370	477	21.2	
R1	21	150	8.0	2370	540	24.0	24.8
R2	21	150	8.2	2430	563	25.0	
R3	21	150	8.1	2400	572	25.4	
R1	28	150	8.6	2548	707	31.4	32.0
R2	28	150	8.7	2578	716	31.8	
R3	28	150	9.0	2667	740	32.9	

Table-6. Compressive strength test result for CP110 mix design.

Cube mark	**Age for testing** (Days)	**Size of cube** (Mm)	**Wt of cube** (Kg)	**Concrete density** (Kg/M^3)	**Test load** (Kn)	**Crushing strength** (N/ Mm^2)	**Average crushing strength** (N/ Mm^2)
C1	7	150	8.5	2519	423	18.8	18.4
C2	7	150	8.0	2370	416	18.5	
C3	7	150	8.0	2370	400	17.8	
C1	14	150	8.5	2519	558	24.8	24.3
C2	14	150	8.4	2489	245	24.2	
C3	14	150	8.0	2370	536	23.8	
C1	21	150	7.5	2222	580	25.8	26.2
C2	21	150	8.5	2519	600	26.6	
C3	21	150	7.8	2311	590	26.2	
C1	28	150	8.5	2519	788	35.0	35.1
C2	28	150	8.0	2370	783	34.8	
C3	28	150	8.4	2489	801	35.6	

Table-7. Summary of the compressive strengths and mix proportions.

Mix design method	**Target mean strength**	**28^{th} day strength**	**Mix proportion**	**Aggregate proportion**
ACI	33.00	30.70	1: 0.5: 2: 2.5	4.50
DOE	33.40	33.70	1: 0.5: 1.5: 3	4.50
RN4	33.30	32.00	1: 0.5: 1.4: 4	5.40
CP110	30.00	35.10	1: 0.5: 1.7: 2.5	4.25

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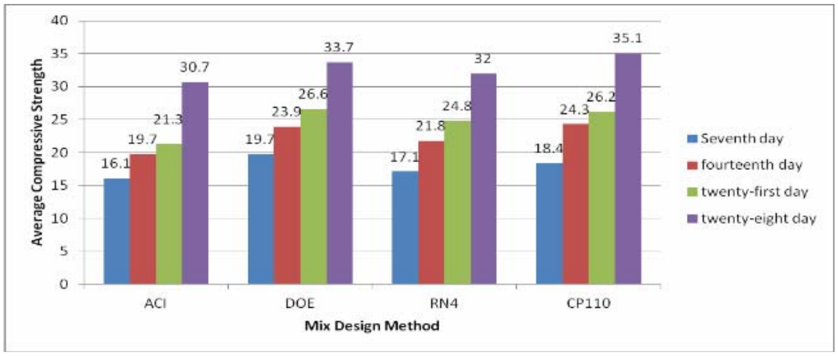

Figure-2. Variation in compressive strength with mix design methods and age at curing.

CONCLUSIONS AND RECOMMENDATION

Based on the observations from this study, it could be concluded that;

a) The particle sizes of fine and coarse aggregates ranged from 0.075mm to 3mm and 5mm to 20mm respectively, which is within the range specified by BS882. Confirming the River Niger sand as a good construction material.
b) The moisture content of sand exposed to air has a negligible or no effect on the mixing water quantity of a concrete if the river bed sand is allowed some after collection before usage.
c) The 28th day compressive strengths of concrete cubes differ for the four mix design methods used, though they all exceeded the characteristic strength by above 50%. CP110 gave the least mean strength by calculation, yet the highest by investigation.
d) There is a relationship between the aggregate size and quantity to the final strength of concrete. The study revealed a decrease in strength with increase in aggregate quantity and a decrease in strength with decrease in aggregate sizes.

It is, therefore, recommended that contractors of civil works appreciate and also take advantage of the integrity and quintessence of concrete mix designs. Further work is also required in order to investigate the integrity of the other existing mix design methods and to recommend a particular mix design for a particular project category.

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