

Design of Normal Concrete Mix Based on Both Building Research Establishment and American Concrete Institute Method of Mix Design

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Authors' contributions

This work was carried out in collaboration between both authors. Author ASA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author LHK managed the analyses of the study. Author LHK also managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

To achieve a defined workability, strength and durability in construction works, concrete mixes are designed and this is done towards the selection and proportioning of constituents to produce a concrete with pre-defined characteristics both in fresh and hardened states. This study assesses the design of normal concrete mix based on the American Concrete Institute and Department Of Environment methods of mix. A characteristic strength of 20 N/mm² was designed for using the two mix design methods. The concrete components used were tested for specific gravity; moisture content, particle size distribution, aggregate impact value, aggregate crushing value, slump test and compacting factor test and were found suitable. Two sets of concrete cubes (150 x 150 x 150 mm) each were cast using two mix designs. Compressive strengths were evaluated at 7, 14, 21, and 28 days of curing. The 28th day strengths of the two sets of concrete were found to be 30.5 N/mm² and 29.5 N/mm² for both DOE and ACI mix design methods which did not exceed the calculated targeted strength.

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1. INTRODUCTION

Concrete is the dominant construction material today with an annual worldwide production of over 4.5 billion metric tons [1]. It is a composite material with heterogeneous properties that are vitally dependent on the amount and properties of the constituent phases. Mix design is an essential tool in all aspects of concrete technology and its prime objective is to achieve the required functional properties at the minimum cost, under consideration of environmental parameters and planned production technique. Well-developed mix design methods are thus used in securing sustainable industrial concrete construction techniques. The purpose of concrete mix design is to find the optimum proportion of each ingredient to meet the client's requirements with regard to workability, strength, durability, cost, and ecology [2].

The basic ingredients of concrete are the same, but it is their relative proportioning that makes the difference. The relative proportions of the concrete ingredients are determined in order to achieve a desired strength and workability in a most economical way [3]. 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 [4]. Adherence to concrete mix designs in concrete making is therefore the crux of quality control in construction.

Characteristic strength is also of high importance in concrete mix design. The characteristic strength of concrete is defined by Kong and Evans [5] 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 estimate the mix proportions in different ways. This study therefore focused just on two mix design methods namely the Department of Environment (DOE) and American Concrete Institute (ACI). The procedures involved in their designs are outlined below.

2. DEPARTMENT OF ENVIRONMENT MIX DESIGN METHOD

This method was published by the Building Research Establishment in 1997. The design procedures involves the 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/m^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.

3. AMERICAN CONCRETE INSTITUTE (ACI) MIX DESIGN METHOD

This method of mix design is based on published report given by ACI Standard 211 (1996). It involves selection of slump value relative to the purpose of the concrete usage, followed by that of 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. The estimation of the water and air content as it relates to the chosen slump and maximum aggregate size then follows. The water/cement ratio as it relates to the 28th day compressive strength is selected, calculation of cement content by the ratio of the mixing water content to the water/cement ratio. Estimation of coarse aggregate content as it relates to the maximum aggregate sizes and the fines modulus is carried out. Thereafter, the outcomes of all the mentioned procedures will be subtracted from the volume of fresh concrete to give the volume of fine aggregates.

4. MATERIALS AND METHODS

The materials used include fine aggregate with silt content not more than 10%, coarse aggregate with maximum size not more than 20 mm diameter, Ordinary Portland Cement (OPC) and potable water. All of the materials used were

sourced for locally. Both the silt content and the coarse aggregate were gotten from sand depot and stone quarry in Akure Metropolis, the OPC was purchased in a cement depot while the potable water was fetched from a nearby available borehole.

4.1 Experimental Design

Preliminary test investigations were conducted on the aggregates used to determine their suitability. The tests are particle size distribution, moisture content, specific gravity, aggregate impact value, aggregate crushing value and workability (slump test, compacting factor). The different mix proportions got from the mix designs calculated were batched by weight and the casting, curing and crushing were done in accordance with the guidelines specified by [7], [8] and [9] respectively. The dimension of the cube cast is 150 mm × 150 mm × 150 mm and the compressive strengths were investigated at 7, 14, 21, and 28 days of curing using Equation 1.

$$\text{Compressive strength (MPa)} = \frac{\text{Compression Load (kN)}}{\text{Loading area (mm}^2\text{)}} \quad (1)$$

Design Calculations based on DOE method:

The design of normal concrete mix design based on DOE method is outlined below. As we have variability of concrete, it is necessary to design the mix to have a mean strength greater than the specified characteristic strength by an amount termed 'Margin' and its denoted by ks.

The target mean strength is calculated as;

$$f_t = f_{cu} + ks \quad (2)$$

Where;

f_t is the target mean strength
 f_{cu} is the specified characteristic strength
 s = standard deviation
 k = constant depending on the defective level associated with the specified strength.

$$\text{Target Mean Strength } (f_t) = 20 + (1.64 \times 8) = 33.12 \text{ N/mm}^2$$

Water/cement ratio = 0.47

Maximum aggregate size = 20 mm

Slump range = 60 – 180 mm

Free water content = 225 kg/m³

Cement content = $\frac{225}{0.47} = 479 \text{ kg/m}^3$

Fine aggregate proportion = 40%

Total aggregate content = 2400 - (479+225) = 1696 kg/m³

Fine aggregate content = 1696 × 40% = 678.4 kg/m³

Coarse aggregate content = 1696 - 678.4 = 1017.6 kg/m³

The ratio of cement: sand: granite is 479:678.4:1017.6

Therefore, for a unit weight of cement, the proportion 1:1.5:2.5 was used.

Design Calculations based on ACI method:

The target mean strength is calculated as;

$$f_t = f_{cu} + k\delta \quad (3)$$

Where;

f_t is the target mean strength
 f_{cu} is the specified characteristic strength
 δ = standard deviation taken as 0.4 of f_{cu}
 k = Himsworth coefficient which is 1.64

$$\text{Target Mean Strength } (f_t) = 20 + (1.64 \times 0.4 \times 20) = 33.12 \text{ N/mm}^2$$

Water/ cement ratio = 0.5

Choice of Slump = 20 mm – 80 mm

Maximum size of aggregates = 20 mm

Mixing water content (Non air entrained concrete) = 200 kg/m³

Cement content = $\frac{200}{0.50} = 400 \text{ kg/m}^3$

Bulk density of coarse aggregate = 1600 kg/m³

For a maximum aggregate size of 20 mm 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 × 1600 = 992 kg/m³

Density of non-air entrained concrete = 2355 kg/m³

The mass of aggregates per unit volume of concrete is 2355 – (200 + 400 + 992) = 763 kg/m³.

Therefore, the design proportion in kilogram per cubic meters is 400:763:992 for cement, sand

and granite respectively. Hence, the proportion 1:2:2.5 was provided.

4.2 Characteristics Strength

For a concrete, the characteristic strength is taken as that value below which it is unlikely that more than 5 % of all the compressive strength result will fall. It is calculated using Equation 4.

$$f_{ck} = f_m - 1.64s \quad (4)$$

Where:

f_{ck} = characteristic strength,
 f_m = mean strength and
 s = standard deviation.

The standard deviation s is given by the following formula:

$$\text{Standard deviation (s)} = \sqrt{\sum \frac{(x-m)^2}{n-1}} \quad (5)$$

Where,

n is the number of values in the set of test,
 x is any value in the set of numbers,

m is the average of the set of numbers.

5. RESULTS AND DISCUSSION

The summary result of the preliminary tests performed on the materials which include the fineness of the cement, moisture content of the fine aggregate, particle size distribution of the sand and specific gravity of the fine aggregate is presented in Table 1. The particle size distribution chart of the fine aggregate is shown in Fig. 1.

The summary result of the preliminary tests performed on the aggregates which include the impact value test, moisture content of the fine aggregate, particle size distribution of the sand and specific gravity of the fine aggregate is presented in Table 2.

5.1 Compressive Strength

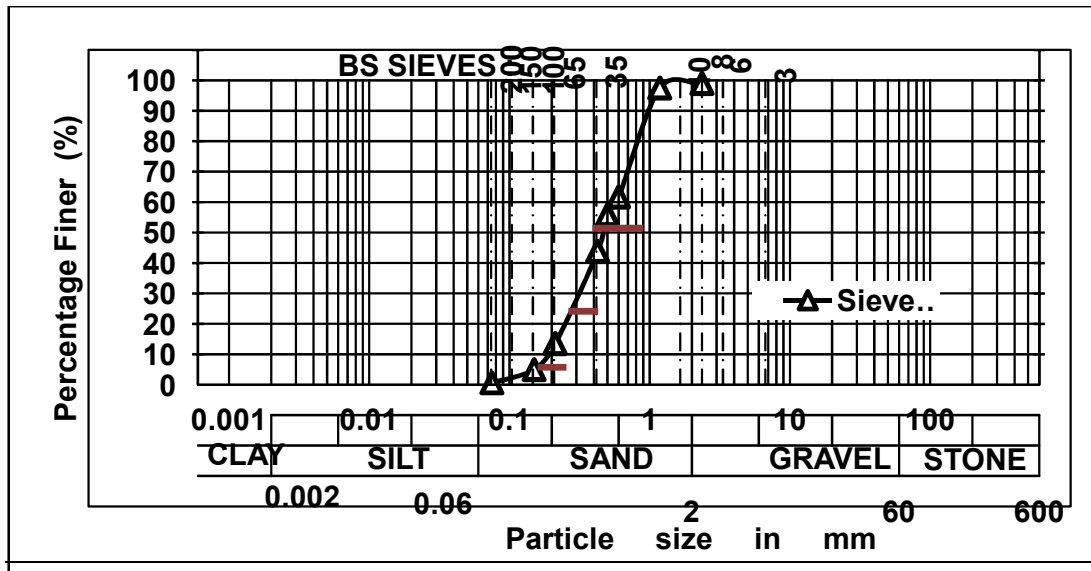
Tables 3 and 4 show the compressive strength test result and their respective average compressive strength for the DOE and ACI mix design.

Table 1. Physical test results of the materials used

Physical test	Results	Remarks
Fineness of the Cement	10%	Falls within the permissible limit
Moisture Content of the Sand	5.14%	
Specific Gravity of the Sand	2.60	Falls within the permissible limit
Specific Gravity of the Coarse Aggregate	2.70	Falls within the permissible limit
Coefficient of curvature (C_c) for sand	1.06	Satisfactory
Coefficient of uniformity (C_u)	2.90	The sand is well graded, since it is within the satisfactory range of 2 and 3 for coefficient of uniformity

Table 2. Test result on coarse aggregate and workability of concrete

Physical test	Results	Remarks
Aggregate impact value	20.3%	Falls within the standard limit of 18-21 for construction work.
Aggregate crushing value	28.44%	Falls within the standard limit of 27-30 for construction work
Slump test	120 mm	Falls within the recommended values of Concrete used for Normal RCC work. It ranges from 80 to 150 mm
Compaction factor	0.95	Degree of workability is high



Mean Characteristics Strength

Table 5. Mean characteristic strength at 28th Day

S/N	Crushing load (kN)	Compressive strength MPa (N/mm ²) (x)	(x – m) ²
1	400.5	17.8	0.86
2	450.6	20.0	1.61
3	386.2	17.2	2.34
4	409.9	18.2	0.28
5	460.0	20.4	2.79
6	423.9	18.8	0.00
Sum	2531.1	112.4	7.88
Average	421.85	18.73	1.31

$$\text{Standard deviation (s)} = \sqrt{\sum \frac{(x-m)^2}{n-1}} = \sqrt{\sum \frac{7.88}{5}} = 1.58$$

Applying Equation 4, the characteristic strength will give 16.14 N/mm²

Table 6. Summary of the compressive strengths and mix proportions

Mix design method	Target mean strength (N/mm ²)	28 th Day strength (N/mm ²)	Mix proportion
DOE	33.12	30.5	1:1.5:2.5
ACI	33.12	29.5	1:2:2.5

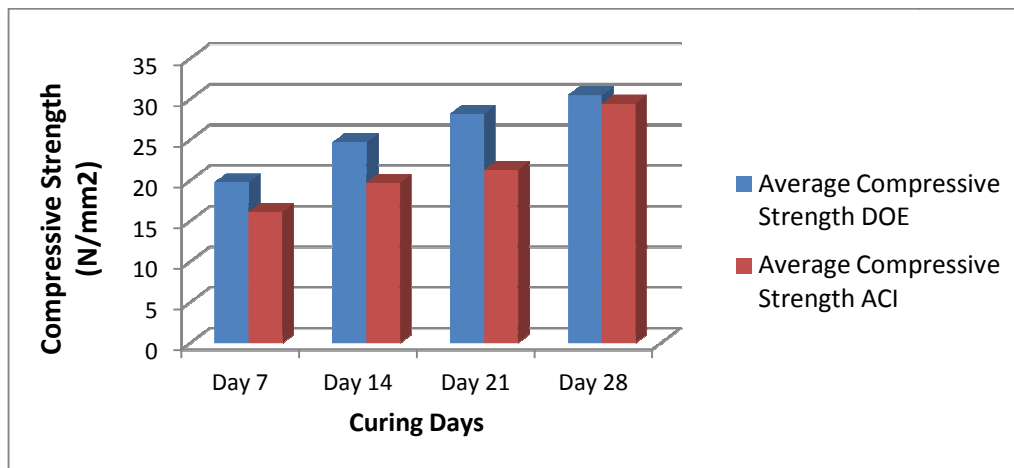


Fig. 2. Variation in compressive strength with mix design methods and age at curing

Tables 3 and 4 gives the compressive test results for cubes using both DOE and ACI design methods. It could be observed that for the two mix design methods, there is a significant increase in the strength of concrete with age at curing which is also seen in Fig. 2. This nature of result is in agreement with [4] and [10]. Tables 5, 6 and Fig. 2 give the summary of 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. DOE gave the highest compressive strength, despite the fact that it has the same target mean strength by calculation with ACI. This occurrence is clearly 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 but

DOE with higher coarse aggregate content gave a significantly higher compressive strength than ACI. The two mix designs exceeded the characteristic strength by about 3 to 4 N/mm² which confirms that they are both adequate for concrete making.

6. CONCLUSIONS AND RECOMMENDATION

From the study, all the preliminary tests performed show satisfactory results. It could be observed that the 28th day compressive strengths of concrete cubes differ for the two mix design methods used, though they all exceeded the characteristic strength by close to 50%. A relationship between the aggregate size and quantity to the final strength of concrete was observed. There is a decrease in strength with increase in aggregate quantity and a decrease in strength with decrease in aggregate sizes. It is therefore recommended that users of concrete should appreciate and also take advantage of the integrity and quintessence of concrete mix designs.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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