COMPARATIVE STUDY OF COMPRESSIVE STRENGTHS OF CONCRETE PRODUCED BY MANUAL AND MECHANICAL MIXING METHODS

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Abstract
The paper presents the comparison between two methods of concrete production which are machine mixing and hand mixing. Laboratory tests were carried out to determine some important properties of the sand and crushed stones before the concrete mix design. Twenty concrete cubes of size 150mm of a designed concrete mix of 1:2:4 were produced first by mechanical mixing and the production of the same quantity was repeated by manual mixing. Compressive strengths of concrete cubes produced were measured at 7, 14, 21 and 28 days respectively, using five cubes for each day, for each method of production and the average strength was found in each case. All the concrete cubes were cured in a clean water tank. Although, the results showed that the compressive strengths of cubes were satisfactory at 28 days for both methods, the average compressive strengths of cubes produced by manual mixing were slightly higher than those produced by mechanical mixer.

Keywords: Comparative, Compressive Strength, Concrete, Hand Mixing and Machine Mixing

Introduction
Concrete is a structural material widely used in construction industry and it consists essentially of cement, sand and natural gravels or chippings. These constituent materials are mixed together with water to form the concrete [1]. The cement serves as binder to the aggregates while the aggregates serve as the filler materials. Concrete has the unique distinction of being the only construction material manufactured on the site [2], whereas other materials are merely shaped to use at the work site. The aggregates occupy the larger proportion in the volume of concrete.

Of importance in concrete mix are the aggregate grading, aggregate/cement ratios as well as the water/cement ratio because the strength of concrete depends on them. The fresh concrete should be workable to be properly placed and that the hardened concrete needs to be durable and attain a specific compressive strength. The sole aim of mix design is to achieve a mean strength that is greater than the specified strength. The most important variables affecting the strength of concrete at a given age are the water/cement ratio and the degree of compaction. Also [3] reported that the properties of lightweight aggregates and water/binder ratio are the two significant factors affecting the compressive strength and elastic modulus of concrete.

The four most important properties of concrete are workability, durability, resistance to compressive stress and ability to protect steel against rusting [4]. To develop these potential properties fully requires concrete to be proportioned appropriately and an effective production method is needed to produce good quality concrete with the above properties. The effect of various production methods on the compressive strength of concrete has to be examined. It is very important to carry out the investigation so as to save a lot of capital, labour and time that is wasted as a result of structural failures that might be caused by inadequate mixing.

Development of adequate compressive strength is one of the major requirements of good quality concrete and this strength depends on a lot of factors of which this study is one such and inability to achieve the target strength in concrete will seriously affect the structure negatively [5]. The use of manual mixing method in concrete production is so rampant in this country and the effect of this method on the strength was never considered even when there are so many structural failures, of which some are caused by very poor quality concrete production that results in adequate strength.

In Nigeria, two methods of mixing concrete are generally employed namely mechanical mixing and manual mixing. Majority of concrete produced in this country is manually mixed. It is very rare and in most cases, only the big multinational construction companies that use mechanical mixers for concrete production. There is the need to find out the effect (if any) of this common manual production method on the strength of concrete and to confirm that the manual mixing method does not result in lower strength that might cause structural failures encountered in construction industry in Nigeria. Comparison between the two commonly used methods of production of concrete is required in order to establish the basis for the choice of any of them.

Materials and Method

Sand: River sand collected from Bosso village, Minna, Nigeria was used as fine aggregate. It was clean, sharp and free from clay as well as organic matter and well graded, classified as fine aggregate in accordance with [6].

Cement*:* The cement used was Ordinary Portland Cement (OPC) bought from a cement depot Minna, Nigeria and it conformed to [7].

Crushed Stones: Coarse aggregate used in the study was crushed stones with 20mm maximum size supplied from Triacta Quarry in Minna, Nigeria and it conformed to [6] recommendation.

Water*:* Tap water was used for the mixing and it was properly visually examined to ensure that it was clean, free from contaminants either dissolved or in suspension and good for drinking as specified in [8].

Laboratory Tests: Laboratory tests on the sand and crushed stones for the purposes of characterization and classification include determination of particle size distribution, natural moisture content and specific gravity, carried out in accordance with [9]. The determination of bulk densities and water absorption of sand and crushed stones samples was carried out in accordance with [10].

Preparation of Specimens: Mix design is the consideration of the most economical use of available materials to produce concrete of desirable workability, durability and strength [4]. In designing the concrete mix, air entrained concrete under mild exposure conditions was used to improve the workability. A maximum size of 20mm aggregate and a water/cement ratio of 0.53 were adopted, for the desired workability of 30mm-50mm slump. Absolute volume method was used in the determination of the quantity of sand. The mix design resulted in a mix ratio of 1:2:4, which was used in the manual production of 20 concrete cubes of 150 mm size used for the compressive strength test. The mixture of all constituent materials was turned from one end

to another for at least three times of continuous mixing in accordance with [11] report. Water was gradually added so that it could neither escape by itself nor with cement [2]. In the same manner, 20 concrete cubes of the same size were produced using mechanical mixer. Preparation of materials, mixing, curing and sampling were carried out in accordance with [12]. All the cubes were cured in the same clean water tank for better strength development.

Slump Test: Before mixing the concrete for casting the cubes, a trial mix was carried out to determine the slump. Slump test is very useful in detecting variations in the uniformity of a mix of a given nominal proportions [12]. It is a popular method used all over the world on the day-to-day, hour-to- hour variation in the materials being fed into the mixer or mixing platform if by hand.

Compressive Strength Test: An electrically operated Seidner compression machine was used for the crushing test on the concrete cubes in accordance with [13], at the curing ages of 7, 14, 21 and 28 days. Five cubes were crushed in each day for each method of production and the average compressive strength was determined. In the crushing test, care was taken to ensure that the cubes were properly positioned and aligned with the axis of the thrust of the compression machine to ensure uniform loading on the cubes [2].

Design of Concrete Mix

The aim of mix design is to consider the most economical use of available materials to produce concrete of desirable workability, durability and strength. The goal of mix design is achieve a mean strength greater than the specified strength although variations in the actual strength achieved are inevitable. The most important variables affecting the strength of concrete at a given age are the water/cement ratio and the degree of compaction [2]. This agrees with [14] who reported that concrete with water/binder ratio larger than 0.40 increases limit relative compressive strength and initial apparent activation energy.

In this mix design, American Concrete Institute Standard (ACI/211.1-77), which recommends a suitable degree of workability for concrete in the form of slump, was used. This slump depends on the type of construction and the maximum sizes of aggregate varying from 10mm to 150mm. To improve the workability, reduce permeability and bleeding, air entrained was used in the mix design. Specified works cube strength was 150kg/cm^2 at 28 days and the coarse aggregate locally available was well graded having a maximum size of 20mm.

Exposure

Table 7.3 of ACI/211.1-77; mild temperatures rarely below freezing or rainy, in air, Air entrained concrete should be used under mild exposure conditions to improve workability of the mixture. Maximum size of aggregate is 20mm.

Water/Cement Ratio

(a) From strength consideration Table 7.4, ACI/211.1-77 (150kg/cm^2), W/C = 0.71
(b) From durability consideration Table 7.3, ACI/211.1-77, W/C = 0.53

Adopting the smaller ratio = 0.53

Water

The appropriate mixing water Table 7.5, ACI/211.1-77 for the desired workability of slump 30mm – 50mm and maximum size of aggregate =165kg.

Air: Recommended average total air content Table 7.5, ACI/211.1-77 present = 6%.
Cement: The cement content was calculated from the water content and water/cement ratio.

Cement = 165/0.53 = 311kg.

Coarse Aggregate

The coarse aggregate content was estimated using Table 7.6, ACI/211.1-77 from the maximum size of aggregate and fineness modulus of sand. Volume of dry rodded coarse aggregate per unit volume of concrete is 0.62

Dry rodded weight of coarse aggregate as determined = 1865kg/m^3

Weight of Coarse Aggregate required $= 0.62 \times 1855 = 1150kg$

Table 1: The quantity of sand by Absolute volume method

Item no	Ingredients	Weight (Kg)	Solid volume (cm^3)
1.	Cement	311	$\frac{311}{3.15} \times 10^3 = 98.73 \times 10^3$
2.	Water	165	$165 \times 10^3 = 165 \times 10^3$
3.	Coarse aggregate	1150	$\frac{1150}{2.68} \times 10^3 = 429 \times 10^3$
4.	Entrapped air (6%)		$\frac{6}{100} \times 1000 \times 10^3 = 60 \times 10^3$

Total volume of ingredients except sand $= 752.83 \times 10^3 cm^3$

Solid volume of sand $= (1000 \times 10^3 - 752.83 \times 10^3) = 247.17 \times 10^3 cm^3$

Weight of dry sand required $= 247.17 \times 10^3 \times 2.64 = 652528.8 = 653kg$

Estimated batch quantities per m^3 of concrete

Cement	= 311kg
Water	= 165kg
Coarse aggregate	= 1150kg
Sand	= 653kg
Density of fresh concrete	= 2279kg/m^3

Mix ratio by weight

Cement		Sand		Coarse aggregate		Water
1	:	2.1	:	3.70	:	0.53
1	:	2	:	4	:	0.53

Mix Proportion

A mix of 1:2:4 as designed was used with a water/Cement ratio of 0.53 in calculating the quantities of constituent materials to be mixed, absolute volume method was used. This method assumes that the volume of compacted concrete is equal to the sum of the absolute volumes of all ingredients [15].

Mathematically, $\frac{W}{1000} + \frac{C}{1000G_c} + \frac{A_1}{1000G_1} + \frac{A_2}{1000G_2} = 1m^3$ of concrete

Where W, C, A_1 and A_2 are the weights of water, cement, fine aggregate and coarse aggregate per m^3 of concrete respectively, G_c, G_1 and G_2 are the specific gravities of cement, fine aggregate and coarse aggregate respectively.

Cement = 1 part, Sand = 2 parts and Crushed stones = 4 parts, water/cement ratio (W/C) = 0.53

$$w = 0.53C \quad (1)$$

$$\frac{W}{1000} + \frac{C}{1000G_c} + \frac{A_1}{1000G_1} + \frac{A_2}{1000G_2} = 1m^3 \quad (2)$$

Cement/Aggregate ratio:

Sand $= \frac{1}{2} = \frac{C}{A_1}, A_1 = 2c$ (3)

Crushed stone $= \frac{1}{4} = \frac{C}{A_2}, A_2 = 4C$ (4)

Substituting (1), (3), (4) into (2),
C = 320.9 kg
Volume of mould used = 0.003375 m^3
1 m^3 of concrete = 320.9 kg of cement
0.003375 m^3 of concrete $= 0.003375 \times 320.9 = 1.083kg$ in 1 cube of concrete

For 40 cubes of concrete,
Weight of cement$= 1.083 \times 40 = 43.32kg$
Weight of sand $= 2 \times 43.32 = 86.64kg$
Weight of crushed stones $= 4 \times 43.32 = 173.28kg$
Weight of water $= 0.5 \times 43.32 = 21.66kg$

Results and Discussion

Identification of the Aggregates

The properties of sand and crushed stones used for the study are summarized in Table 2 while Figures 1 and 2 show their particle size distribution. The sand is well graded and classified in zone 1 in accordance with [6] classification for aggregates. The properties of the aggregates are in good agreement with the recommendation of [6] for clean quartz and flint sands. Also Shirley [16] reported that normal-density aggregates generally have specific gravities between 2.5 and 3.0. The bulk density of the crushed stones is 1855kg/m^3 and it conforms to [6] recommendation for aggregates from natural sources for concrete.

Table 2.0: Properties of Cement, Sand and Crushed Stones

Property	Cement	Sand	Crushed Stones
Natural moisture content (%)	21.15	0.54	-
Water absorption (%)	1.5	0.25	-
Finenesss modulus	-	2.81	3.36
Specific Gravity	3.15	2.64	2.68
Bulk density (kg/m^3)	1472	1660	1855

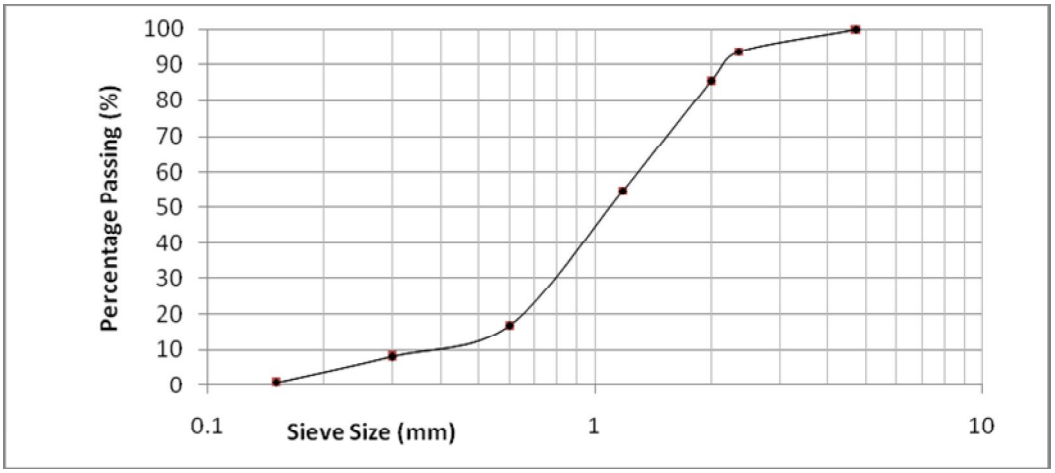

Figure 1.0: Particle size distribution of sand used

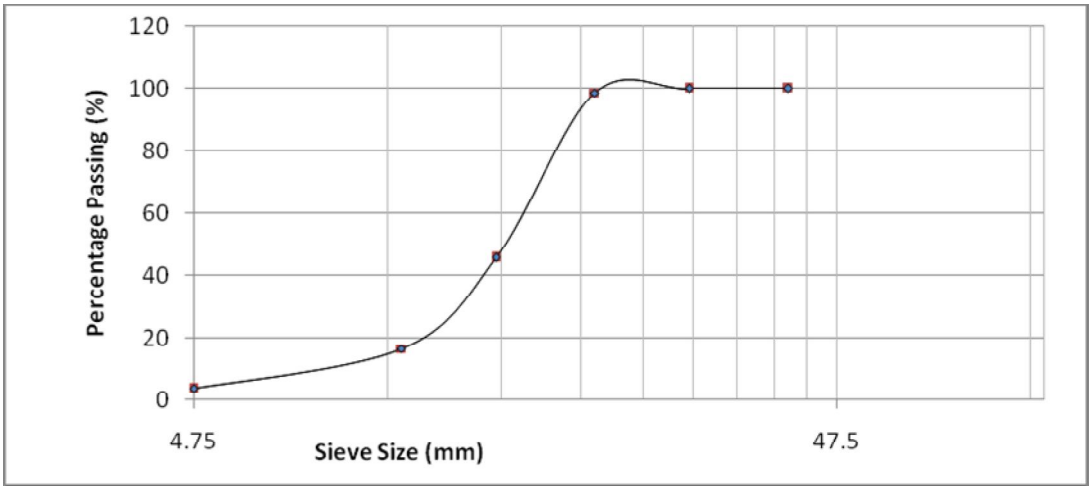

Figure 2.0: Particle size distribution of crushed stones samples

Slump: In this study, a slump of 40mm was measured for both methods of production in accordance with [13] and it satisfied the value adopted in the design.

Compressive Strength

The relationship between compressive strength and age of curing for concrete produced by both hand and machine mixing is presented in Figure 3.0. Contrary to the general expectation that the mechanical mixer would produce concrete of higher strength, it was found that hand mixed concrete developed adequate strengths which were slightly higher than those produced by mechanical mixer. The percentage differences in compressive strengths of concrete produced by hand and mixer are 4.5, 6.3, 6.4 and 4.3% for 7, 14, 21 and 28 days respectively. This trend could be attributed to the fact that uniformity and consistency of concrete that give rise to higher strength can be achieved by longer mixing time as noticed in the manual mxing method. Both hand and machine mixed concrete followed the usual trend of increase in compressive strength with age and adequate strengths of 18.06N/mm^2 and 17.32N/mm^2 respectively were measured at 28 days for the two production methods. The characteristic and

the target compressive strengths are 13.54N/mm^2 and 15.86N/mm^2 for both hand and machine mixing methods. It was also noted that the greatest increase in strength was recorded at the curing age of 14 days for both production methods. This indicates that concrete gains greater percentage of its strength at the age between 7 and 14 days no matter whichever method of production is used.

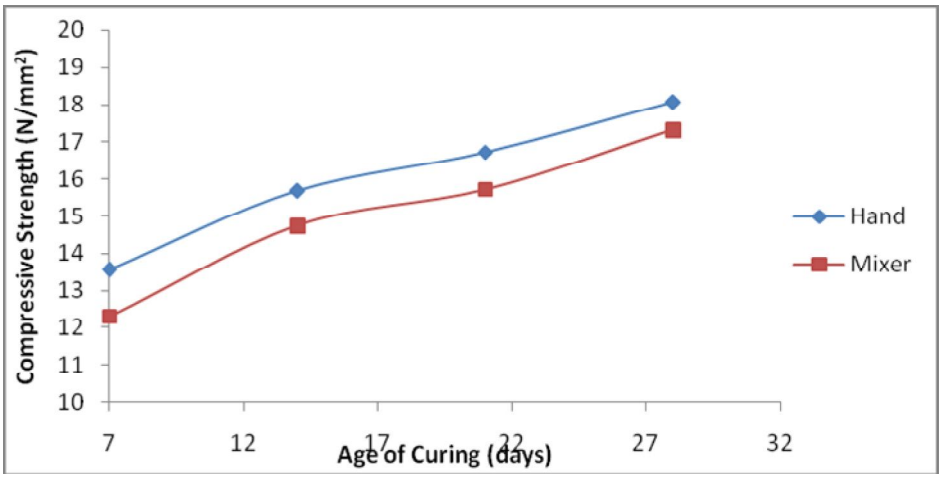

Figure 3.0: Compressive strength-age of curing relationship for hand and machine mixed concrete

Conclusion

The over all conclusions emerging from this study are that:

1. Contrary to the general expectation that the mechanical mixer would produce concrete of higher strength, it was found that hand mixed concrete developed adequate strength at 28 days. This study shows that the compressive strengths of concrete produced by manual mixing were slightly higher than their machine counterparts at 7, 14, 21 and 28 days of curing respectively.
2. The two commonly used production methods for concrete (hand and machine) are good and the choice of any method will therefore depend on the convenience, speed required in the work, scope of work involved as well as cost implication.
3. The properties of the two aggregates defined in this experiment are of paramount importance in the realization of the satisfactory results as stated in this result.
4. Uniformity of mixing is of paramount importance in developing adequate compressive strength in concrete irrespective of the method of production.

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