EFFECT OF MIXING TIME ON THE COMPRESSIVE STRENGTH OF CONCRETE

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Abstract

The paper presents the effect of production time on the compressive strength of concrete. Before designing the concrete mix, laboratroy tests were carried out to determine some essential properties of the sand and crushed stones. A designed concrete mix of 1:2:4 was used in the test and the mixing time for the mechanical mixer was varied for 2, 5, 8, 11 and 14 minutes respectively in producing concrete cubes of size 150mm. All the cubes were cured in a clean water tank and their compressive strengths were measured at 7, 14, 21 and 28 days age of curing respectively. One hundred (100) cubes were cast and average of five cubes was determined in each day of crushing, for a particular mixing time. The mixing time was recorded from the time when all the solid materials have been put into the mixer. The results showed that the compressive strengths of cubes increased appreciably with increase in mixing time from 2 to 11 minutes and decreased beyond 11 minutes for all the ages tested. Satisfactory compressive strengths were not measured at mixing times below 5 minutes.

Key Words: Compressive Strength, Concrete, Cubes, Curing, Mixing-Time.

Introduction

Concrete is a structural material widely used in construction industry and it consists essentially of cement, fine aggregate (sand) and coarse aggregate (natural gravels or chippings). These constituent materials properly proportioned are mixed together with water to form the concrete. The cement serves as binder to the aggregate while the aggregate serve as the filler materials that give strength to concrete. Concrete has the unique distinction of being the only construction material manufactured on the construction site, whereas other materials are merely shaped to use at the work site (Neville, 2000). The aggregate occupy the larger proportion in the volume of concrete.

The compressive strength of concrete depends on the aggregate grading, aggregate/cement ratio as well as the water/cement ratio. Also (Chi, Huang, Yang & Chang, 2003) 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. Sang-Hum, Jin-Keun and Yong-Dong reported that concrete with water/binder ratio larger than 0.40 increases limit relative compressive strength and initial apparent activation energy.

The freshly mixed concrete should be workable to be properly placed and the hardened concrete needs to be durable and attain a specific compressive strength. The aim of concrete mix design is to achieve a mean strength that is greater than the strength specified (Raju, 1996). The most important variables affecting the strength of concrete at a given age are the water/cement ratio and the degree of compaction. Workability, durability, resistance to compressive stress and ability to protect steel against rusting are the four most important properties of concrete (Raju, 1996).

To develop these potential properties fully requires concrete to be proportioned appropriately and an efficient production method is required in order to produce good concrete with the above properties.

The relationship between the compressive strength of concrete and the duration of mixing has to be established to ensure production of workable concrete with adequate strength. It is necessary to carry out this research so as to save a lot of capital, labour and time wasted as a result of structural failures due to improper mixing of concrete, which results in low strength. Development of adequate compressive strength when hardened is one of the major requirements for good quality concrete. This strength depends on some factors of which this study is among and inability to achieve the target strength in concrete will seriously affect the structure negatively (Aguwa, 1999). Some of the objectives of this research are; to establish, based on practical experiment, the minimum mixing time required in producing concrete of adequate strength that might not cause failures encountered in construction industry in Nigeria. Secondly, to have good comparison of the compressive strengths achieved for various specified mixing times and to recommend the minimum mixing time required by a mechanical mixer to produce a good workable concrete with adequate compressive strength.

Materials and Method

Sand: The fine aggregate used in the study is sand collected from a river in Bosso village, Minna, Nigeria. It is clean, sharp, and free from clay and organic matter and well graded in accordance with (BS 882, 1992).

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

Crushed Stones: Coarse aggregate used 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 visuallly examined to ensure that it was clean, free from contaminants either dissolved or in suspension and good for drinking as specified in (BS 3148, 1980).

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, were carried out in accordance with (BS 1377, 1990). The determination of bulk densities and water absorption of the sand and crushed stones was carried out in accordance with (BS 812 Part 2, 1975) and (BS 812 Part 101, 1984).

Preparation of Specimens

A batch mix of 1:2:4 by volume of materials as designed was mixed by means of a mechanical mixer. The mixing time was varied for 2 minutes, 5 minutes, 8 minutes, 11 minutes and 14 minutes. A small amount of water was fed into the mixer first and then all the solid materials were fed uniformly and simultaneously into the mixer (Neville, 2000). Greater part of the water was fed during the same time. The remaining small part of water was added after the solids. For a particular mixing time, twenty (20) cubes of 150mm size were cast and cured for 7 days, 14 days, 21 days and 28 days compressive strengths. Five (5) cubes were crushed in each day for a particular mixing time and the average strength was calculated. All the 100 cubes were cured in the same clean water tank in the laboratory in order to gain higher strength. This is in agreement with the report of (Zain, Safiuddin & Mahmud, 2000) that concrete under water curing offers the best results and that data collected also revealed that under controlled curing conditions, it is possible to produce high performance concrete (HPC) at relatively high water/binder ratios.

The mixer was loaded according to the capacity that was found to be 0.07m^3 and the speed was found to be 5 revolutions per minute. This was done by marking chalk on the drum and counting the revolutions (Obande, 1990). About 25 revolutions were required to produce concrete uniform in composition and of satisfactory strength. This speed of 5 revolutions per minute was maintained throughout the mixing period.

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 (BS 1881: Part 116, 1983). 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 (BS 1881 Part 1116, 1983), at the curing ages of 7, 14, 21 and 28 days. Five cubes were crushed in each day for each mixing time and the average compressive strength was determined. In 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 (Neville, 2000).

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 but 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 (Raju, 1996).

In this mix design, American Concrete Institute Standard (ACI/211.1-77) was used. This method recommends a suitable degree of workability for concrete in the form of slump. 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. The specified works cube strength was 150kg/cm^2 which is equivalent to 14.7N/mm^2 at 28 days.

Exposure

From Table 7.3, 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. The maximum size of aggregate allowed 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 from 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 = 1855kg/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 [17].

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

$w = 0.53C$ .... (1)

$\frac{W}{1000} + \frac{C}{1000\,G_c} + \frac{A_1}{1000\,G_1} + \frac{A_2}{1000\,G_2} = 1m^3$ .... (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 was well graded and classified in zone 1 in accordance with (BS 882, 1992) classification for aggregates. The properties of the aggregates are in good agreement with the recommendation of (BS 882, 1992) for clean quartz and flint sands. Also Shirley (BS 1881 Part 116, 1983) 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 (BS 882, 1992) 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
Fineness 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

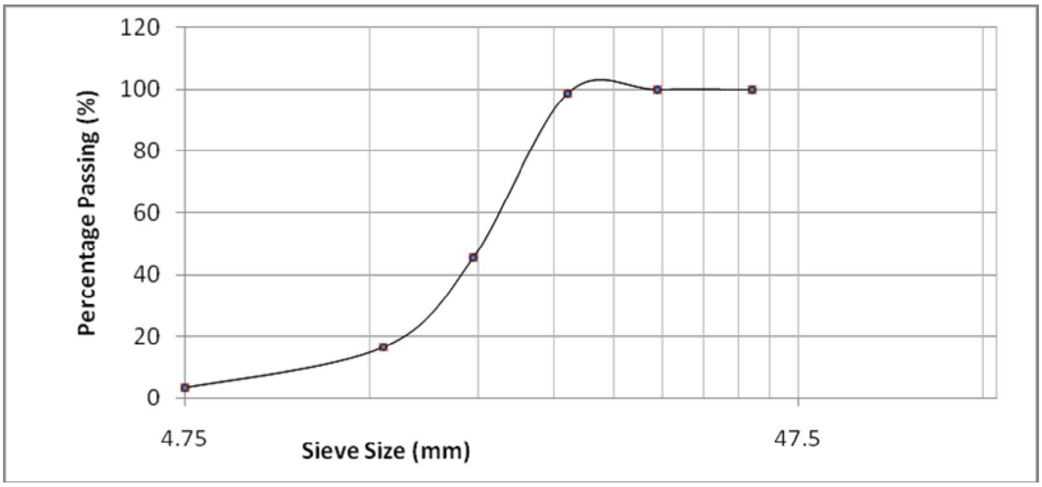

Figure 2.0: Particle size distribution of crushed stones used

Slump: In this study, a slump of 40mm was measured in accordance with (Kraina, 1960) and it satisfied the value adopted in the design.

Compressive Strength

The results of the effects of time on concrete compressive strength are presented in Figure 3.0 and adequate strength of 17.41N/mm^2 was measured at 28 days after five minutes of continuous mixing. The strength continued to increase with the increase in mixing time from five to eleven minutes. This result is in good agreement with (Aguwa, 2010), which reported that compressive strength of concrete cubes appreciably increased with increase in number of turnings from one to foru times. At fourteen minutes, there was a decrease in compressive strength. A low strength of 12.78N/mm^2, which is below the characteristic strength of 13.54N/mm^{2,} was measured at 28 days for mixing time of two minutes. This indicates that at two minutes, concrete uniform in composition and of satisfactory strength cannot be produced.

The greatest increase in strength was recorded at the age of 14 days for all the mixing times and this indicates that concrete gains greater percentage of its strength at the age between 7 and 14 days (Aguwa, 1999). This behaviour is clear for mixing times from two to eleven minutes. The greatest increase in strength was recorded at the mixing time of 5 minutes and this is applicable to all the curing ages of 7, 14, 21, and 28 days. This is a confirmation that adequate strength of at least 13.54N/mm^2 cannot be achieved at a mixing time below 5 minutes. There was a slight decrease in compressive strength at a mixing time of 14 minutes, confirming that mixing beyond 11 minutes is not helpful.

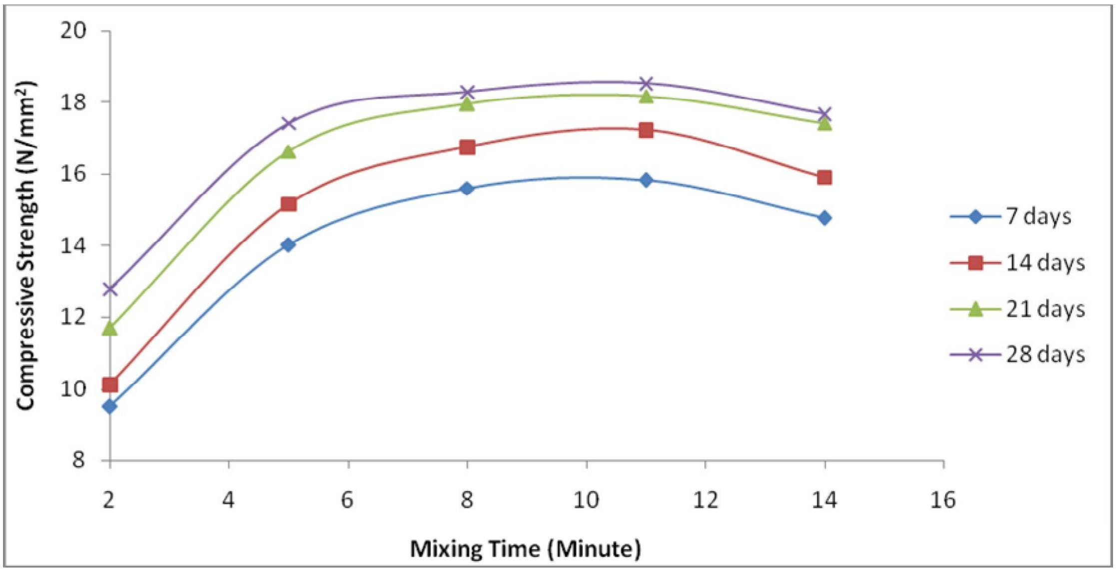

Figure 3.0: Compressive strength-mixing time relation for concrete at 7, 14, 21, 28 days of curing

Figure 4.0 shows the relationship between compressive strength and the age of curing for various mixing times. There was a clear increase in compressive strength with increase in age for all the mixing times studied and this behaviour is in good agreement with reports in other literature.

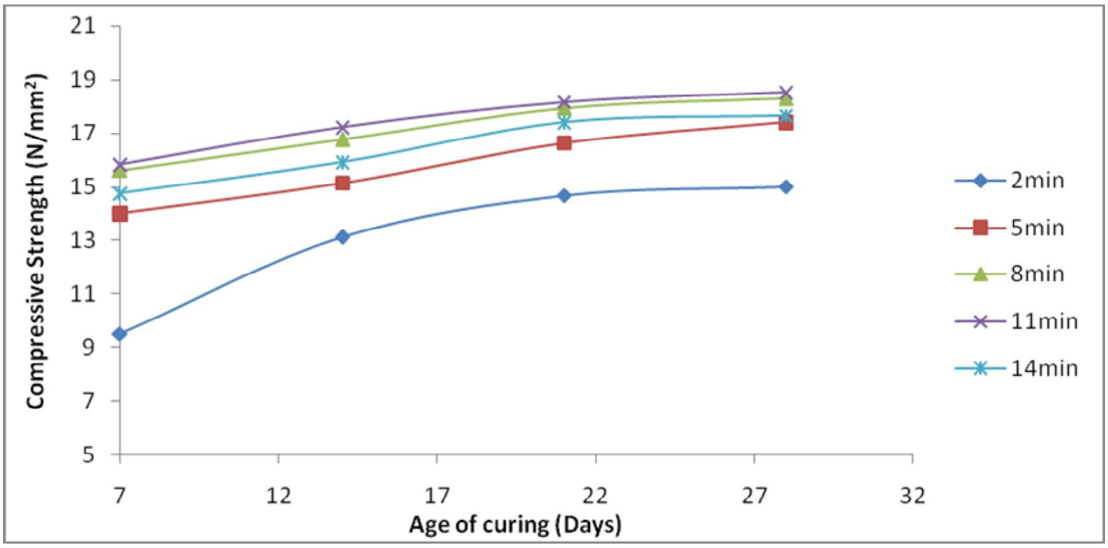

Figure 4.0: Compressive strength-age of curing relation for mixing time of 2, 5, 8, 11 and 14 minutes

Conclusions

The over all conclusions emerging from this study are that:

1. Compressive strength of concrete increases with increase in mixing time from 2 to 11 minutes but not beyond 11 minutes.
2. Satisfactory compressive strengths were developed for mixing times 5, 8, and 11 minutes at the age of 28 days.
3. Low compressive strengths were gained at all the ages for a mixing time of 2 minutes concluding that mixing time below 5 minutes is not advisable.
4. There is a slight decrease in compressive strength of concrete at a mixing time of 14 minutes, confirming that mixing concrete by machine for more than 11 minutes is not necessary.

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