Effect of Exposure of Cement on the Compressive Strength of Concrete

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ABSTRACT

Concrete quality is of paramount importance to engineers and this is dependent on the quality of cement. One of the reasons for poor quality of cement is exposure condition of cement which is considered in this research. The behavior of the compressive strength of concrete with respect to the duration of exposure of cement was investigated and the limiting duration of exposure of cement beyond which it is not fit for structural concrete was established. Two basic exposure conditions were considered (Warehouse and Open-Air) for different durations (ranging from 6 to 42 hours). The target strength of concrete for this research was 30MPa; Slump and crushing tests were carried out for 99 samples and it was observed that the strength of concrete significantly reduced from 29.13MPa for the control sample (No exposure) to 17.28MPa and 13.90MPa for 42 hours cement exposure under Warehouse and Open-Air exposure respectively. A regression model was calibrated to predict the strength of concrete and % Loss of strength with increase in exposure duration for both conditions, this model possessed high correlation. Furthermore, the limiting exposure duration was established to be 16.7 hours and 10.5 hours under Warehouse and Open-Air exposure respectively. Finally, it was observed that the Strength of concrete is hugely dependent on the quality of cement which is significantly affected by the exposure duration; also, the workability of the concrete is not affected by the exposure of cement.

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1. INTRODUCTION

In recent times, concrete has become the bedrock of infrastructural civilization in Nigeria, statistics have it that over 75% of the infrastructures in Nigeria are made with concrete [1].

Concrete is a very sensitive composite material made up of cement, fine and coarse aggregates, water and sometimes admixtures. This study focuses on what is arguably the most important constituent of concrete which is Cement. On most construction sites in Nigeria, Cement is stored in bags, bulk in silos, storage drums, etc [2]. Inspiration for this study was born when the researcher observed in a certain construction site that cement was stored properly and it was observed that cement was being exposed without care.

Cement is a very sensitive material which has high affinity for moisture including atmospheric moisture, [3] thus this research work. It has been observed that cement can react with carbon dioxide when exposed to air or other atmospheres containing this gas [4]. Charles and others [5] discovered that this reaction is a function of the concentration of the water vapor in the atmosphere and the exposure duration. Kashef and others [6] investigated this chemical reaction and came up with a chemical equation for the carbonization of cement. After this carbonization process, cement may not be able to achieve its designed strength and this could negatively impact concrete made with it.

2. MATERIAL AND METHODS

Concrete is the main object of study in this experiment; consequently, the materials used are those revolving around the production and use of concrete. Concrete is a composite material comprising of Cement, fine aggregates, coarse aggregates, water and sometimes admixtures. The constituents of concrete used for the experiments will be detailed in the section below:

2.1 Cement

The cement used for the experiment is a local brand of cement known as Dangote 3X Cement. The cement is available in retail shops around Nigeria. The cement is of grade 42.5 Ordinary Portland cement and conforms to BS EN 197-1:2000 [7] standards for cement production. The chemical properties of this cement in comparison with standard specifications have been accessed by Olanade and others [8].

2.2 Aggregates

The fine aggregate used in the course of the experiment was river sand obtained from a nearby river sand dump in Rumuiche community of Ikwerre Local Government in Rivers State. The properties of this sand have been accessed by the Quality Assurance and Control (QA/QC) department of Salvation Ministries Cathedral Project, Igwuruta, Port Harcourt. This information is contained in its technical report by Leton Precious [9]; Sieve analysis was carried out on the sand specimen and the Particle Size Distribution curve was obtained. Coarse aggregate used for this research was medium gravel generally between 8mm – 16mm.

2.3 Experimental Procedure

First and foremost, after ascertaining the quality and properties of the materials used, Concrete mix design was carried out for the concrete samples. Following that, the sampling strategy for the experiment was determined in order to achieve the aim of the research. Furthermore, the concrete was mixed and the several tests were carried out on it; both in the fresh and hardened states.

2.3.1 Concrete mix design procedure

For the purpose of this research, the ACI method of concrete mix design was employed as specified by Shetty M.S. [10] with reference to ACI 211.1-1977 [11]. The target concrete grade for this experiment is M30 concrete i.e concrete with a strength of 30 MPa. A measure of variation was applied conforming to the formula:

\[ f_{ck} = f_m + ks \]

The value of \( k \) is equal to 1.65 (according to IS 456-2000 [9] where not more than 5% of the test results are expected to fall below the characteristic strength.

Therefore:

\[ f_{ck} = 30 + 1.64(5) = 38.2 \text{ MPa} \]
The water-cement ratio was then obtained for the required compressive strength of concrete using appropriate table specified by Shetty [10].

\[
\text{W/C ratio} = 0.45
\]

The water content in order to achieve the required slump with the maximum size of aggregate was then obtained using appropriate table specified by Shetty [10].

\[
\text{Water content} = 200 \text{ Kg/m}^2
\]

(N/B: Maximum size of aggregate = 20 mm; Desired slump = 80-100mm)

The first estimate of the density of fresh concrete was made from appropriate table [11] referencing the maximum size of aggregate and type of concrete (air entrained or non-air entrained).

Estimated Density = 2355 Kg/m$^3$

The cement content was then calculated from the values of the water content and the value of the W/C ratio already obtained.

Cement content = \(\frac{200}{0.45} = 444.4 \text{ Kg/m}^3\)

The weight of Coarse aggregate (C.A) was then obtained from appropriate chart [11] using the dry rodded bulk volume of C.A and Unit mass of C.A

\[
\text{Weight of C.A} = 0.62 \times 1600 = 992 \text{ Kg/m}^3
\]

The weight of the fine aggregate (F.A) was then obtained from calculations thus:

\[
\text{Weight of F.A} = 2355 - (444.4 + 992 + 200) = 718 \text{ Kg/m}^3
\]

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**Table 1. Sampling strategy**

| Sample ID | Description                                      |
|-----------|--------------------------------------------------|
| ENE-0     | No exposure to cement (9 cube samples)           |
| ENE-1     | 6 hours Warehouse exposure (9 cube samples)      |
| ENE-2     | 12 hours Warehouse exposure (9 cube samples)     |
| ENE-3     | 18 hours Warehouse exposure (9 cube samples)     |
| ENE-4     | 24 hours Warehouse exposure (9 cube samples)     |
| ENE-5     | 42 hours Warehouse exposure (9 cube samples)     |
| ENE-6     | 6 hours open-air exposure (9 cube samples)       |
| ENE-7     | 12 hours open-air exposure (9 cube samples)      |
| ENE-8     | 18 hours open-air exposure (9 cube samples)      |
| ENE-9     | 24 hours open-air exposure (9 cube samples)      |
| ENE-10    | 42 hours open-air exposure (9 cube samples)      |

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Fig. 1. Particle size distribution curve for fine aggregate used [Source: Leton P, 2014]
2.3.2 Sampling strategy

Here the concept of exposure of cement which is the aim of the experiment becomes relevant. Eleven (11) samples were considered as follows:

Two types of exposures were considered: In the Warehouse exposure condition, cement was poured into several head pans and kept at the center of the warehouse for different durations. While in the open-air exposure, the cement was poured into several head pans and in an open environment not vulnerable to rain water. In this case, an open ‘devotion ground’ was used.

2.4 Test Carried Out on Concrete

Basically two (2) tests were carried out on concrete in the fresh and hardened states. The slump test was carried on concrete in the fresh state while the compressive strength (crushing) test was carried out on concrete in the hardened state.

2.4.1 Slump test

The slump test is carried out on freshly mixed concrete. The concrete was batched by mass where the individual constituents were weighed before mixing. The slump test was carried out for the eleven (11) different sample categories and the results collected.

2.4.2 Compressive strength test

After the slump tests have been carried out, the concrete was then placed in cube moulds for about 24 hours and the de-moulded and allowed to cure for 7, 14 and 28 days as the case may be. Thereafter, it was taken to the materials laboratory where the compressive strength test was set up. The apparatus required to carry out the compressive strength test includes: The Compressive Strength machine (1112KN to 2224 KN capacity), 150mm x 150mm x 150mm steel cube moulds, Curing tank, scoop, vibrating machine and head pans. All test procedures were in conformance with British Standards [12,13].

3. RESULTS AND DISCUSSION

In this section, the result of the experimental works from the previous section are presented and analyzed and consequently, findings are discussed.

3.1 Slump Test

result from the slump test carried out for each sample is arrayed in the table.

3.2 Compressive Strength Test Results

The summary of the Compressive test results is given in Table 3 for the purpose of further analysis.

3.3 Analysis of Compressive Strength Results

First, attempt was made to relate exposure time of cement, compressive strength of concrete and consequent loss in strength with respect to the control sample which has no exposure to cement. This analysis is tabulated and illustrated graphically in Fig. 4.

For ease of analysis and clarity, two (2) cases are considered;

CASE 1 – Warehouse Exposure Condition
CASE 2 – Open-air Exposure Condition

![Fig. 2. Researcher carrying out slump test](image-url)
Fig 3. Compressive strength test samples

Table 2. Slump test results for various samples

| Sample   | Slump (mm) |
|----------|------------|
| ENE-0    | 100        |
| ENE-1    | 120        |
| ENE-2    | 80         |
| ENE-3    | 120        |
| ENE-4    | 100        |
| ENE-5    | 100        |
| ENE-6    | 80         |
| ENE-7    | 120        |
| ENE-8    | 100        |
| ENE-9    | 100        |
| ENE-10   | 120        |

Table 3. Summary of compressive strength results

| S/No | Sample ID | Average Compressive Strength at 7 days (MPa) | at 14 days (MPa) | at 28 days (MPa) |
|------|-----------|---------------------------------------------|------------------|------------------|
| 1    | ENE-0     | 21.28                                       | 26.5             | 29.13            |
| 2    | ENE-1     | 18.99                                       | 23.81            | 25.23            |
| 3    | ENE-2     | 18.48                                       | 22.79            | 24.49            |
| 4    | ENE-3     | 16.8                                        | 21.06            | 22.67            |
| 5    | ENE-4     | 15.37                                       | 19.08            | 20.59            |
| 6    | ENE-5     | 13.15                                       | 16.21            | 17.28            |
| 7    | ENE-6     | 17.34                                       | 21.48            | 23.38            |
| 8    | ENE-7     | 16.54                                       | 21.14            | 22.29            |
| 9    | ENE-8     | 14.99                                       | 18.67            | 20.33            |
| 10   | ENE-9     | 12.09                                       | 16.23            | 17.59            |
| 11   | ENE-10    | 10.35                                       | 12.39            | 13.90            |

From the summary table, it can be noticed that the strength value of concrete constantly reduces from ENE-0 to ENE-5 and from ENE-6 to ENE-10; this is due to the increase in the exposure duration of cement. Analysis were carried out to investigate this loss in strength with respect to exposure of cement.
The loss of strength was computed by subtracting the strength values for the particular sample from the strength value of the control sample. The graph of strength against exposure duration and %Loss in strength against exposure duration are illustrated as shown in Fig. 5.

Regression and Correlation analysis were performed on the data and a Regression model developed to predict the Strength and % Loss in strength. For the Strength and Exposure Relationship, an exponential regression model was developed which is given by:

\[ A = 28.09e^{-0.01B} \]  \hspace{1cm} (3.1)

Where: \( A \) – Compressive Strength of Concrete in MPa

B – Exposure time in Hours

This exponential model gave a correlation value of 97.8%. Similarly, for the %Loss and Exposure Relationship, a linear model is used to predict the behavior and is given by:

\[ C = 4.67 + 0.92B \]  \hspace{1cm} (3.2)

Where: \( C \) - %Loss in Strength of Concrete in MPa

This linear model gave a correlation value of 95.2%. Furthermore, it is desired to establish a limiting exposure value for the use of cement for Structural purpose. This is simply the exposure time beyond which cement should not be used for the production of structural concrete.

\[ A = 28.09e^{-0.01B} \]

\[ C = 4.67 + 0.92B \]
The BS 8110:1985 provided a partial factor of safety for compressive strength of concrete in the design of reinforced concrete structures which is:

$$F_{cc} = \frac{0.67 f_{cu}}{\gamma_c}$$

0.67 is the factor provided for the compressive strength of concrete which implies that at least 67% of the strength must be achieved. However, for the purpose of this research, at least 80% of the strength of concrete should be achieved; in other words, %Loss of strength of concrete should not exceed 20%. The %Loss - Exposure model (Equation 3.2) is used to predict the Exposure time corresponding to 20% Loss in strength:

\[ i.e \quad C= 20; \quad B=? \]

\[ B = \frac{C - 4.67}{0.92} = \frac{20 - 4.67}{0.92} = 16.66 \text{ Hours} \]

Thus, it can be stated that the limiting value of exposure time under Warehouse condition for the use of cement for structural concrete is 16 Hours, 40 Minutes.

Considering the CASE-2, similar relationships were also established. Loss of strength was computed subtracting the strength values for the particular sample from the strength value of the control sample. The graph of strength against exposure duration and %Loss in strength against exposure duration are illustrated as shown.

Regression and Correlation analysis were also performed on the data and a Regression model developed to predict the Strength and % Loss in strength. For the Strength and Exposure Relationship, an exponential regression model was developed which is given by:

$$A = 27.34e^{-0.01B}$$

(3.3)

Where: A – Compressive Strength of Concrete in MPa
B – Exposure time in Hours

This exponential model gave a correlation value of 97.0%. Similarly, for the %Loss – Exposure Relationship, a linear model is used to predict the behavior and is given by:

$$C = 7.95 + 1.15B$$

(3.4)

Where: C - % Loss in Strength of Concrete in MPa

This linear model gave a correlation value of 92.2%. The limiting duration of cement was computed thus:

Exposure time corresponding to 20% Loss in strength:

\[ i.e \quad C= 20; \quad B=? \]

\[ B = \frac{C - 7.95}{1.15} = \frac{20 - 7.95}{1.15} = 10.45 \text{ Hours} \]

Fig. 6. Relationship between warehouse and open air exposure
Thus, it can be stated that the limiting value of exposure time under Open-air condition for the use of cement for structural concrete is 10 Hours, 27 Minutes.

It is discovered that the limiting exposure duration for Open-air exposure is less than that of Warehouse exposure condition due to the fact that in the open air condition, there is more available moisture for cement to react with than in the Warehouse condition. In other words, cement deteriorates faster in open air condition than in warehouse condition. Fig. 6. gives a graphical illustration of the Strength – exposure relationship for Warehouse and Open-air conditions.

4. CONCLUSION

Based on the study conducted, following the methodology and results obtained in the previous sections, the following conclusion can be made regarding the behavior of concrete produced with cement with various duration of exposure:

1. There is considerable reduction in the compressive strength of concrete with increase in exposure duration of cement. Cement with no Exposure (Control Sample) gave a Compressive Strength of 29.13MPa while a significantly lower Strength value of 17.28MPa and 13.90MPa was recorded for 42 Hours Exposure duration for Warehouse and Open-Air Exposure respectively. Thus an inverse relationship between compressive strength and exposure time was established.

2. It was also observed that the rate of loss of strength of concrete with exposure time varied for the different exposure condition; from 0% for the control sample to 40.68% and 52.28% for 42 Hours exposure duration for Warehouse and Open-Air exposure respectively. Thus an inverse relationship between compressive strength and exposure time was established.

3. A statistical model was also developed to predict the compressive strength and % loss in strength with different exposure values.

4. The limiting exposure time beyond which cement should not be used for the production of structural concrete was established for both warehouse and open-air exposure conditions. For warehouse exposure the limiting exposure time is 16 hours, 40 minutes; while for open-air exposure, it is 10 hours, 27 minutes.

5. Finally, it was observed the workability of concrete was not affected by the exposure of cement. Hence, exposure of cement has no effect on the workability of concrete, rather other factors such as water-cement ratio, maximum size of aggregate, etc are the main factors that influence the workability of concrete.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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