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EFFECT OF EXPOSURE OF CEMENT ON THE COMPRESSIVE STENGTH OF CONCRETE

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Abstract: **In this study, the effect of exposure of cement on the compressive strength of concrete was investigated. The compressive strength of concrete with different cement exposure time and conditions and the limiting exposure time of cement beyond which cement should not be used in structural concrete production were determined. The fresh cement as well as cement exposed to two conditions (warehouse and open-air exposure) for different durations (6, 12, 18, 24 and 42 Hours) was used in the production of concrete with target strength of 30 N/mm^2. Slump and compressive strength tests were carried out on the various samples produced using the two types of cement and it was observed that the compressive strength value of concrete constantly reduced from 29.13N/mm^2 for the control sample (No cement exposure) to 17.28N/mm^2 and 13.90N/mm^2 for 42 hours cement exposure in Warehouse and open-air exposure conditions respectively. A regression model was also developed to predict the compressive strength of concrete and the percentage loss in compressive strength with increase in exposure time for the both conditions. The limiting exposure value was found to be 16.66 Hours and 10.45 Hours for warehouse and open-air exposure respectively. It was also observed that there was a considerable reduction in the compressive strength of concrete with increase in exposure time of cement and the rate of loss of strength of concrete with exposure duration varied for the different exposure conditions. It was also observed that the workability of concrete was not affected by the exposure condition of cement.**

Keywords: **Compressive strength, exposure time, warehouse exposure, open-air exposure, regression model, target strength.**

1. INTRODUCTION

In recent times, concrete has become the bedrock of infrastructural civilization in Nigeria. Statistics has shown that over 75% of the infrastructures in Nigeria have to do with concrete. Thus, it is important to study and understand every aspect of concrete from the production, transportation, placing and eventually maintenance of concrete.

Concrete today has a very wide range of applications. Virtually every civil engineering work in Nigeria today is directly or indirectly involving the use of concrete. The use of concrete in civil engineering works includes: construction of residential houses, industrial warehouses, roads pavement construction, Jetty, Shore Protection works, piles, domes, bridges, culverts, drainages, canals, dams, off-shore structures, etc (Shetty, 2005; Neville, 2011; Edward and David, 2009; Duggal, 2009; Gambhir, 2005; Mindness et al., 2003). In Nigeria, the cases of failure of structures and roads (concrete related failure) occur on a daily basis. This is traceable to lack of adequate designs, poor construction, poor workmanship, substandard materials, lack of experience, etc (Chendo and Obi, 2015; Oloyede et al., 2010).

This study highlights the effect of exposure conditions of cement on the compressive strength concrete. The two exposure conditions studied were open air and warehouse exposure conditions.

2. MATERIALS AND METHODS

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 standards for cement production. The chemical and physical properties are shown in table 1 and 2 respectively.

Table 1: Chemical Composition of Dangote 3x Cement

Chemical Parameters	Dangote 3x Cement	BS EN 197-1:2000
SiO_2	20.48	18.0-24.0
Al_2O_3	5.02	2.6-8.0
Fe_2O_3	3.15	1.5-7.0
CaO	62.45	61.0-69.0
MgO	1.92	0.5-4.0
Na_2O	0.61	-
K_2O	0.72	0.2-1.0
SO_3	0.18	0.2-4.0
LOI	4.76	-

According to Nwankwojike et al. (2014), the physical properties of Dangote cement are given in table 2.

Table 2: Physical Properties of Dangote 3x Cement

Parameters	Dangote 3x Cement	BS EN 197-1:2000
Fineness	2%	10% maximum
Specific Gravity	3.15	3.10-3.15
Initial setting time	126 mins	30 mins minimum
Final setting time	200 mins	600 mins maximum
Soundness	2.5	10 maximum
Bulk density	1250 Kg/m^3	1000-1400 Kg/m^3

The fine aggregates used in this study was sharp river sand obtained from a nearby river sand dump in Rumuiche community of Ikwerre Local Government Area of Rivers State. Sieve analysis was carried out on the sand specimen and the particle size distribution curve was obtained (Fig 1). The sand was found to be in Zone I and conforming to classifications provided by BS EN 1199-1200:2000.

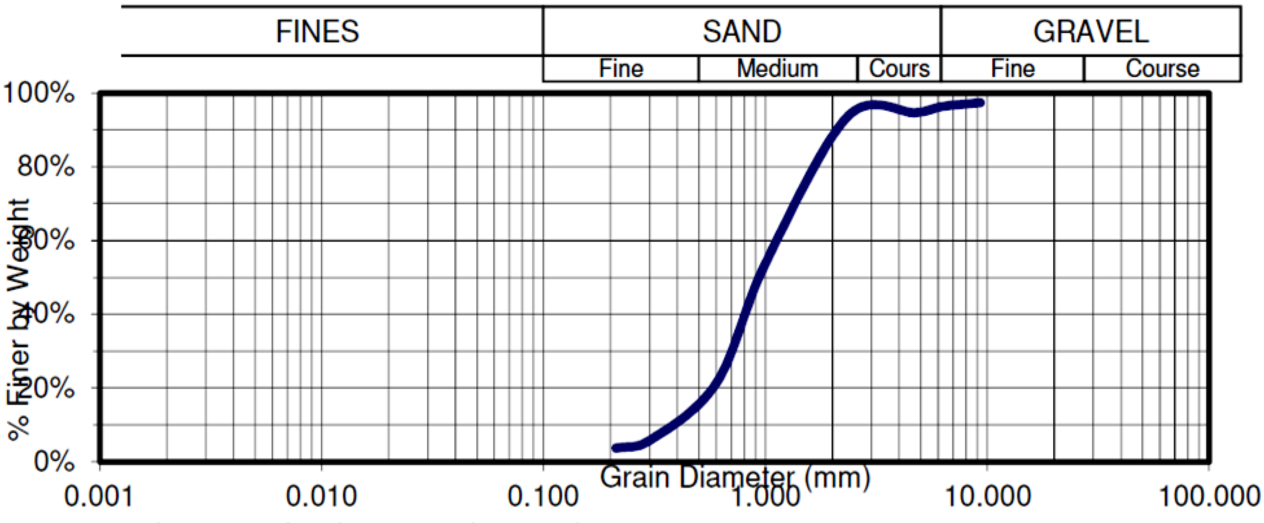

Fig 1: Particle size distribution curve for fine aggregate used

The coarse aggregate used for the experiment were mechanically crushed gravel obtained from a quarrying site in Calabar, Cross River, in Nigeria. The maximum size of the coarse aggregate used was 20 mm**.** The water used for the mixing of concrete and consequently curing of concrete was borehole water gotten from the premises of Salvation Ministries Cathedral Project site. The water was free from any observable color and smell and generally fit for drinking. Consequently, the water is fit for the mixing and curing of concrete as specified by BS 3148:1970.

Concrete mix design procedure

In this study, the ACI method of concrete mix design was employed as specified in ACI 211.1-1977.

The target concrete grade for this study is 30 N/mm^2.

3. RESULTS

3.1 Slump test results

The slump test was 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 samples and the results collected (table 3).

Table 3: 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

From table 3, it can be observed that there is no consistent correlation between the slump value of the fresh concrete and the degree of exposure of cement. The variability in the slump values can be traced to inconsistency in the mixing of the concrete amongst other factors. The target slump for the sample concrete was 80-100mm; thus about 73 % of the slump values fall within the target slump, hence within the acceptance criterion.

3.2 Compressive strength test results

The compressive test results are presented in Table 4.

Table 4: Compressive strength results at different ages

S/No	Sample ID	Average Compressive Strength		
		at 7 days (N/mm^2)	at 14 days (N/mm^2)	at 28 days (N/mm^2)
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 table 4, it can be seen 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 time of cement. The results of the loss in strength with respect to exposure time of cement are presented in table 5.

Table 5: Relationship between exposure time, strength and loss in strength for warehouse exposure condition

Sample	Exposure time (Hrs)	Strength (N/mm^2)	Strength Loss (N/mm^2)	Percentage Loss in strength
ENE-0	0	29.13	0	0
ENE-1	6	25.23	3.9	13.39
ENE-2	12	24.49	4.64	15.91
ENE-3	18	22.67	6.46	22.18
ENE-4	24	20.59	8.54	29.32
ENE-5	42	17.28	11.85	40.68

For warehouse exposure condition, the loss of strength was computed by subtracting the strength value for the particular sample from the strength value of the control sample. The graphs of strength against exposure duration and percentage loss in strength against exposure time for warehouse exposure condition are shown in Fig 2 and Fig 3 respectively.

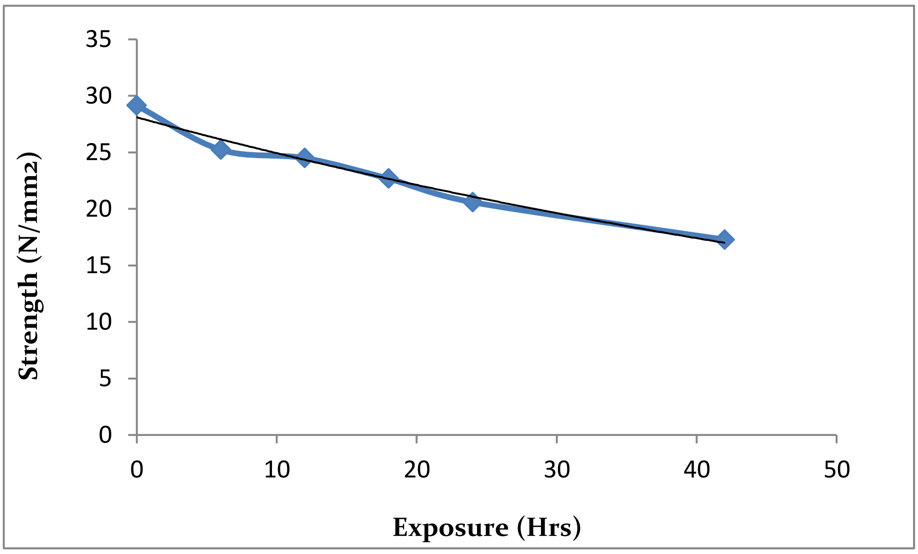

Fig 2: Relationship between exposure and strength for warehouse exposure condition

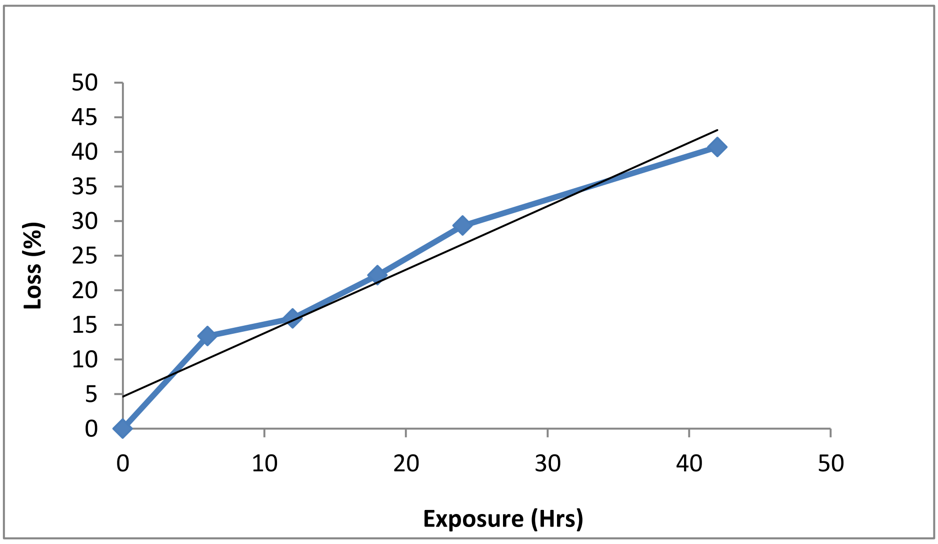

Fig 3: Relationship between exposure and loss for warehouse exposure condition

3.3 Mathematical model development

The strength-exposure empirical relationship is given by:

$$A = 28.09e^{-0.01B} \quad (1)$$

Where: A = compressive strength of concrete in N/mm^2, B = Exposure time in Hours

Equation (1) gave a correlation coefficient value of 97.8 %.

The percentage loss in strength-exposure time empirical relationship is given by:

$$C = 4.67 + 0.92B \quad (2)$$

Where: C = percentage loss in strength of concrete in N/mm^2

This linear model gave a correlation value of 95.2 %.

The BS 8110:1985 provided a partial factor of safety for compressive strength of concrete in the design of reinforced concrete structures which is:

$$F_{cc} = \frac{0.67\, f_{cu}}{\gamma_c} \quad (3)$$

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, this study aimed at achieving at least 80% of the strength of concrete. This implies that the percentage loss of strength of concrete should not exceed 20%. Equation (2) is used to predict the exposure time corresponding to 20% loss in strength:

Using equation (2), for C = 20,

$$B = \frac{C - 4.67}{0.92} = \frac{20 - 4.67}{0.92} = 16.66\ Hours$$

This implies that the limiting value of exposure time under warehouse condition for the use of cement for structural concrete is 16 Hours, 40 Minutes. The exposure time, strength and loss in strength for open-air exposure condition shown for different samples are presented in table 6.

The graphs of strength against exposure duration and percentage loss in strength against exposure duration for open-air exposure and warehouse condition are shown in Fig 4 and Fig 5 respectively.

Table 6: Relationship between exposure time, strength and loss in strength for open-air exposure condition

Sample	Exposure time(hrs)	Strength (N/mm^2)	Loss (N/mm^2)	% Loss
ENE-0	0	29.13	0	0
ENE-6	6	23.38	5.75	19.74
ENE-7	12	22.29	6.84	23.48
ENE-8	18	20.33	8.8	30.21
ENE-9	24	17.59	11.54	39.62
ENE-10	42	13.9	15.23	52.28

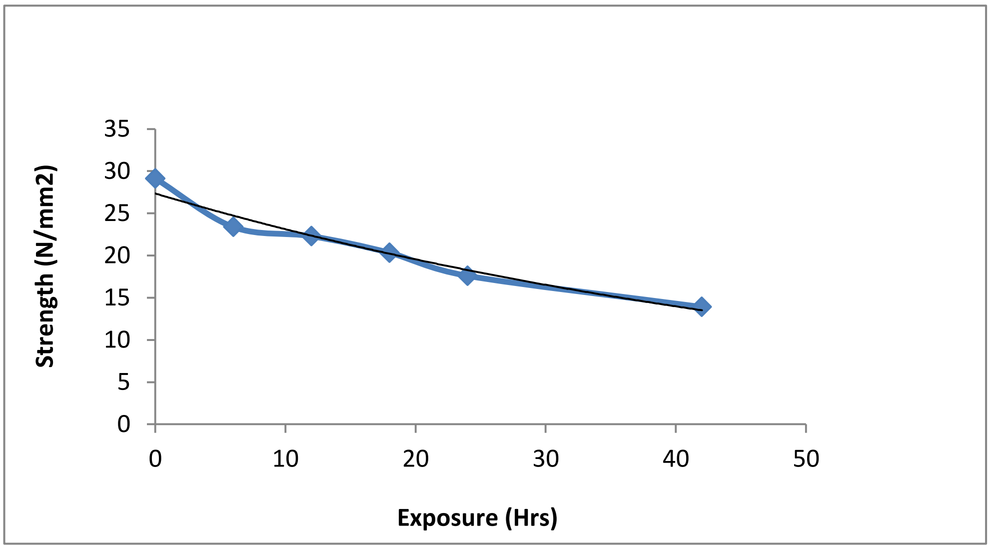

Fig 4: Relationship between exposure and strength for open-air exposure condition

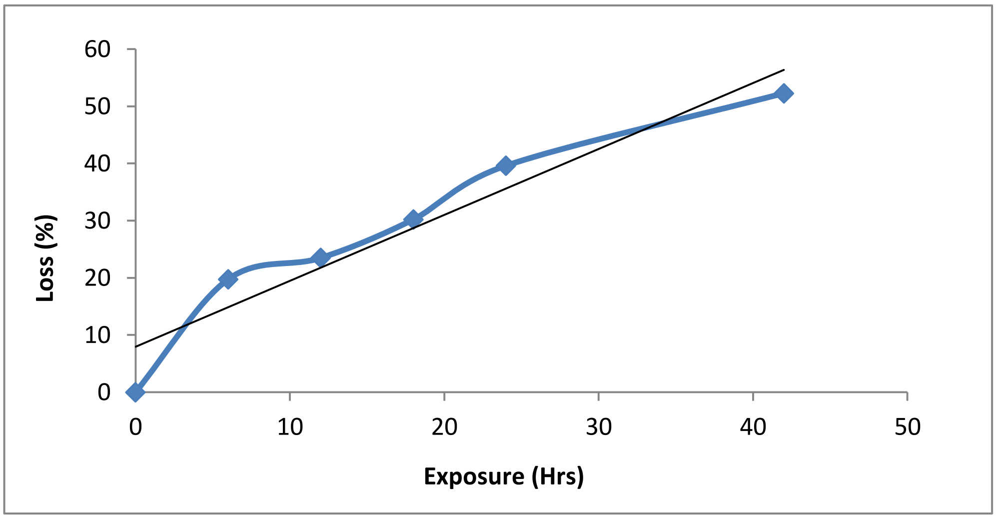

Fig 5: Relationship between exposure and loss for warehouse exposure condition

3.4 Remedial condition model development

The strength-exposure empirical relationship is given by:

$$A = 27.34e^{-0.01B} \quad (4)$$

Where: A = compressive strength of concrete in N/mm^2, B = exposure time in Hours

Equation (4) gave a correlation value of 97.0%.

The percentage loss in strength-exposure time empirical relationship is given by:

$$C = 7.95 + 1.15B \quad (5)$$

Where: C = percentage loss in strength of concrete in N/mm^2

Equation (5) gave a correlation coefficient value of 92.2%.

Again, using equations (4) and (5), the limiting exposure time corresponding to 20 percent loss in strength is obtained as:

$$B = \frac{C - 7.95}{1.15} = \frac{20 - 7.95}{1.15} = 10.45\ Hours$$

This implies 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 can be observed that the limiting exposure time for open-air exposure is less than that of warehouse exposure condition arising from 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 is the graph of strength as a function of exposure for warehouse and open-air conditions.

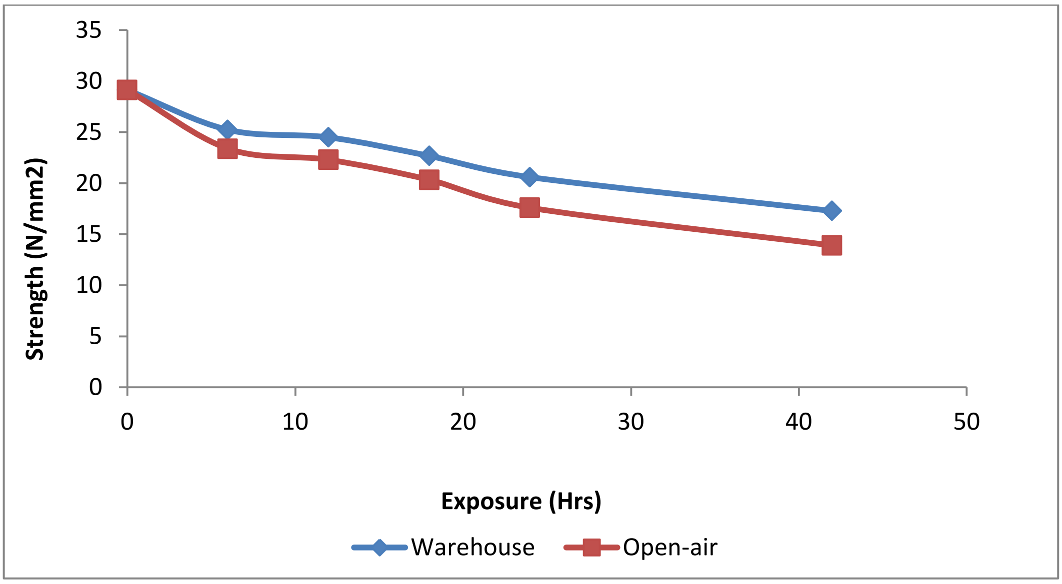

Fig 6: Relationship between warehouse and open air exposure

3.5 Remedial analysis

$A = 28.09e^{-0.01(17)} = 23.69\ N/mm^2$

Thus the percentage loss in strength with the given exposure is given by:

$C = 4.67 + 0.92(17) = 20.31\%\ Loss$

Also, determining the strength to target in order to obtain 30N/mm^2 even after 20.31% loss.

$20.31\% = \frac{x-30}{30} \quad \rightarrow x = (0.2031 \times 30) + 30 = 36.1$ N/mm^2

A model was developed by Felekoglu et al. (2007) following Abrams' law to predict the behavior of W/C ratio and it is given by:

$$y = 0.847e^{-0.02x} \qquad (6)$$

Where: y = W/C ratio, x = target compressive strength

Thus, targeting 36.1 N/mm^2,

$y = 0.847e^{-0.02(36.1)} \cong 0.41$

4. CONCLUSIONS

Based on the results obtained from the study, the following conclusions can be made:

i. Cement with no exposure (control sample) gave a compressive strength of 29.13N/mm^2 while a rather lower strength value of 17.28N/mm^2 and 13.90N/mm^2 were recorded for 42 hours exposure duration for warehouse and open-air exposure respectively.

ii. 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.

iii. Cement deteriorated faster in open-air exposure condition than in warehouse exposure condition.

iv. The limiting exposure time for warehouse exposure is 16 hours, 40 minutes; while for open-air exposure, it is 10 hours, 27 minutes.

v. The workability of concrete was not affected by the exposure of cement. 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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