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A Methodology for the Investigation of Cement Retrogression in HP HT Environments

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Abstract

This paper documents a methodology designed and used in the Faculty of Engineering, University of Benin for the determination of the compressive strength of some cement slurries under HP HT (High pressure, high temperature) without the use of a HP HT oven. It illustrates that in the absence of sophisticated laboratories much investigation maybe done by using the basic available equipments.

Keywords:HP HT, cement retrogression, indigenous sands, Ughelli sands

1.0 Introduction

Cement retrogression may be defined as the compromise of cement properties especially the cement strength at high (elevated) pressures and temperatures[1]. This decline is pronounced at temperatures above 230°F [110°C], but it may be controlled by the addition of silica Flour to the cement. Above 230^{o}F most cement compositions exhibit a satisfactory compressive strength when first set but rapidly loses strength on continuous exposure to extreme temperatures. Usually more than half of their original strength is lost within14 hours. X-ray diffraction studies show that calcium hydroxide and dicalcium silicate alpha-hydrate are the culprits.

With the addition of silica flour a two step chemical reaction occur leading to an increase in strength in many cases. This paper documents the methodology used in an investigation carried out at the Faculty of Engineering University of Benin, Edo State Nigeria to evaluate the suitability of indigenous siliceous material for strength stability of cement slurry at elevated temperatures and hence promote the utilization of indigenous Nigerian material(s) [2].Another aim of the experiment is to identify the Pressure -Temperature relationship as it affects the cement integrity under HPHT conditions

1.1 High Temperature Hydration Above 110^{0}c

This process begins with the formation of Alpha Dicalcium Silicate Hydrate (α- C_2SH) which changes the cement components composition with an accompanied loss of compressive cement strength known as strength retrogression.

The C-S-H gel has excellent binding characteristics at temperatures below 230^{0}F (110^{0}C), leading to an increase of compressive strength with time.

At higher temperature, C-S-H bonds breaks down and convert into a phase known as alpha dicalcium silicate hydrate (α-C2SH), which is highly crystalline and much denser than C-S-H , which decreased compressive strength and increase in permeability of the set cement. Thus the onset of cement retrogression may be determined by a reduction of compressive strength.

2.0 Method of Investigation and Instrumentation

Some important characteristics of cement retrogression in HP HT environment are the change in the chemical species of the cement, the loss of compressive strength and an increase in permeability. This paper documents the design of a methodology used to determine the loss of compressive strength of cement under HP HT environment in the absence of a HP HT oven.

The apparatus used in this investigation maybe divided into 2 groups as illustrated in Table 1. This is namely:

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1. **Purchased apparatus:** This includes equipments purchased by the University or the Researcher from a third party. Only recognised suppliers of scientific equipments were used.

2. **Constructed apparatus**:These equipments where fabricated and constructed in the University of Benin Mechanical and Electrical Workshops and Machine Shops.

Table 1: Types of Apparatus Used For the Experiment

S/N	Type of Apparatus
1	Purchased apparatus
2	Constructed apparatus

The respective equipments are listed in Table 2.

Table 2: List of Apparatus Used In the Experiment

1.	Digital weighing machine (BL3002 KERRO ELECTRONIC COMPACT SCALE)	
2.	Universal Compression Tester	
3.	Measuring cylinder	
4.	Stop clock	
5.	Mould	
6.	Regulator	
7.	Heating box	
8.	Mixing bowl	

Figure1:BL3002 KERRO ELECTRONIC COMPACT SCALE

The purchased apparatus / equipments include:

1. The Digital weighing machine used to measure weight of dry additives and cements.
2. the Measuring cylinder used to measure liquids (water) used in the experiments
3. And the Universal Compression Tester used to determine the maximum load each sample can bear before deformation occurs. From the maximum load the compressive strength can be determined by:

$$CS = \frac{ML}{CSA} \quad \text{.......................................} \quad (1)$$

Where:
CS = compressive strength, psi
ML = maximum load, KN
CSA = cross section area, square inches

The constructed apparatus are the second group of equipments used in this investigation. These equipments were constructed in the various laboratories and workshop in the Faculty of Engineering, University of Benin, Edo state.

The mould was constructed in the machine workshop at the University of Benin, Edo state. It was constructed from a metal sheet .Its main purpose is to house the slurry cement (after proper mixing) in order to produce uniformly shapes and sizes cement specimen for testing. The thickness of the metal sheet was approximately 0.08 inches. (Figure 2)

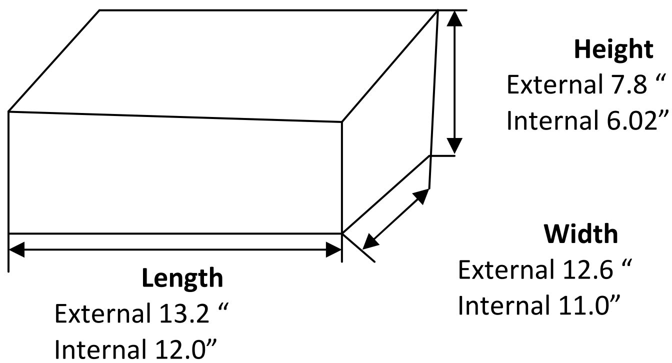

FIGURE 2: THE MOULD

(All measurements in inches)

The cross section area was obtained by the equation: $CSA = LWA$

The compressive strength of each specimen was therefore obtained by the relationship from equation (1).

A regulator was cconstructed in the mechanical workshop. The regulator was fixed with sensors and a control device at the electrical workshop that regulates the amount of heat supplied to the cement specimen. Because of the high temperature involved,temperature measurement was done using a thermocouplewith a capacity (Figure 3).

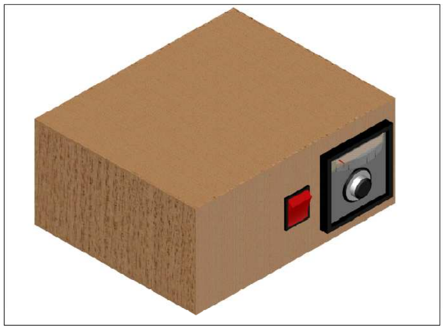

Figure 3: The Regulator

Another device, the "heating box" was also constructed at the mechanical engineering workshop. As the name implies it was used to supply heat to the specimen. Inside the "heating box" are elements capable of supplying heat to the required temperature (Figure 4).

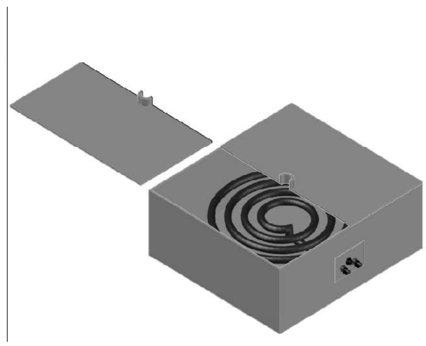

Figure 4: The Heating Box

3.0 Experiments

The experiment involves the use of the Universal Compression Tester (Figure 5)and the heating box to mimic a HP HT environment concurrently. The cement slurry specimen (in the mould) was thus subjected to a high pressure with the Universal Compression Tester and to the effect of a high temperature (with heating via the elements in the heating box) simultaneously

Figure 5: The Universal Compression Tester

The heat was controlled and reading taken at 200,250,300 and 350 degrees Fahrenheit. Pressure was also controlled and values taken at 5,000 psi, 6,000 psi, 7,000 psi, 8,000 psi, 9,000 psi and 10,000 psi.

The maximum loads the slurry can bear before deformation was noted. The compressive strength was obtained from equation (1)

3.1 Variables in The Experiments

Several variables were considered in the investigation. This includes the following. Namely

1. Composition of the slurry
2. Temperature range slurries were subjected to
3. Pressure range slurries were subjected to
4. Curing time (duration) of the slurries
5. Liquid content of the slurry

That composition plays a role in the strength of any material is obvious. Slurries were produced using different percentage of

1. Silica flour
2. Ughelli sands
3. Benin sands
4. API grade G cement
5. And Portland cement

6 different types of slurries (slurry type (A) to (F) were produced depending on the materials present in the slurries (Table 3 and 4).

Table 3: Composition of Each Slurry Type

S/N	SLURRY TYPE	SILICA FLOUR,	UGHELLI SANDS,	BENIN SANDS,	API GRADE G CEMENT,	PORTLAND CEMENT,	VOLUME, WATER , ML
1	A	Yes	Yes	No	Yes	No	1,200
2	B	No	No	Yes	Yes	No	1,000
3	C	No	No	Yes	No	Yes	1,000
4	D	No	No	No	Yes	No	1,000
5	E	No	No	No	No	Yes	1,000
6	F	Yes	No	No	No	Yes	1,000

- “Yes” denote the presence of the material in the slurry

Table 4: Number of Specimen Of Each Slurry Type

S/N	SLURRY TYPE		TOTAL NUMBER OF SLURRIES PREPARED
1	A	Ughelli sand + Silica flour + API G slurry	84
2	B	Benin sands+ API G slurry	84
3	C	Benin sands + Portland slurry	84
4	D	“Neat “ API slurry	48
5	E	“Neat Portland slurry	48
6	F	Portland + Silica flour	84

Temperature **r**eadings were taken at 200, 250, 300, 350 degree Fahrenheit respectively.

Pressure ranges considered in this investigation were from 2,000 psi to 10,000 psi.

The curing timewas controlled as the effect of time on development of compressive strength is well known. Curing time was controlled using a stop clock. Reading were taken after cement slurries were cured for 30, 60, 120 minutes.

The only liquid added to the respective slurries was water. The temperature of the water used was kept constant at 22 degrees centigrade.(71.6 degrees Fahrenheit). Water was collected from a tap in the mechanical laboratory. The water used was ordinary tap without chlorination. Volume of water used was measured with a measuring cylinder and kept constant at 1,200 ml and 1,000 ml.

The Investigation

Detailed investigations of the HP HT environment were undertaken. The investigation involves a substitution and / or total replacement of silica flour with indigenous sands. In some cases (slurry D and E) there were total absences of all siliceous material in the slurries. Findings from these investigations are documented in [1- 5]. Data were obtained from over 400 cement slurries. Data from Ryder [6]was used in the design of the experiments. All constructed equipments were sketched and drawn to scale using specification [7] and subsequently loaded into Autodesk simulation for further investigation [5]. By this approach the experimental data can be used in the prediction of cements in HT HP environments.

4.0 Conclusion

This paper documented an indigenous approach to the determination of the compressive strength of some cement slurries under HP HT. using basic apparatus the effect of cement retrogression in API G cements were studied by a determination of the onset of loss of compressive strength.

It illustrates that in the absence of sophisticated laboratories much investigation maybe done by using available equipments.

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