THE IMPACT OF AIR-AND WATER-COOLING METHODS ON THE COMPRESSIVE STRENGTH OF FIRE EXPOSED CONCRETES

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PLAGIARISM

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DEDICATION

This work is dedicated to the Almighty God for His infinite mercies and grace.

ACKNOWLEDGEMENT

My deepest gratitude goes to God Almighty, the Creator of heaven and earth in whose strength and wisdom I have been able to start and finish this project.

Special thanks to my supervisor, Engr. Orobosa, who gave me the understanding. encouragement and assistance to carry out this work. I also express sincere thanks to the lecturers and staff of the Department of Civil Engineering, University of Benin, for their guidance, mentorship and assistance.

Finally, my gratitude goes to my family for all the love. May God continue to bless you all.

ABSTRACT

Fire exposure destroys concrete structures, and the cooling methods significantly impacts residual strength Rapid cooling, especially with water, may cause additional damage due to thermal shock, yet limited studies compare air- and water- cooling effects. In order to determine which cooling technique best maintains structural integrity, this study will examine how various techniques affect the breaking strength of Grade 30 concrete exposed to temperatures of 200°C, 400°C, and 600°C.

This study involves the preparation of Grade 10 concrete specimens, which were cured for 28 days before being subjected to elevated temperatures of 2000C 400C and 600°C in a controlled furnace. After exposure, the specimens were cooled using air and water to compare the effects of each method on compressive strength. The compressive strength of all samples was tested using a compression testing machine, and the results were analyzed through tabular and graphical comparisons to evaluate strength reduction trends.

The study revealed that compressive strength decreased with increasing temperature, with watercooled samples experiencing greater strength loss than air-cooled due to rapid thermal shock. At 600°C, Average water-cooled samples record 26.561 N/mm², while air-cooled samples record 28.014 N/mm², confirming that gradual cooling helps to retain more structural integrity. Based on these findings, air cooling is recommended as a safer and more effective method for post- fire concrete recovery. Further research should explore advanced cooling techniques to enhance fire resistance and durability.

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ACRONYMS

C-Degrees Celsius

OPC Ordinary Portland Cement

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Concrete is a fundamental material in modern constriction, known for its strength, durability, and versatility. It is used in a variety of structures, from residential buildings to bridges, dams, and tunnels. One of the key properties that makes concrete a preferred building material is its high compressive strength, which enables it to bear significant loads However, despite its durability, concrete is not immune to damage, especially when exposed to high temperatures, such as those experienced during a fire.

Fire poses a serious threat to concrete structures. When exposed to intense heat. concrete undergoes several physical and chemical changes that can compromise its structural integrity These changes include the evaporation of water within the concrete, the decomposition of key binding agents such as calcium hydroxide ($Ca(OH)_2$), and the weakening of the cement paste matrix. As the temperature rises, the compressive strength of the concrete begins to deteriorate, leading to cracking, spalling, and in severe cases, structural failure.

The impact of fire on the compressive strength of concrete is a critical area of study for several reasons. First, in the event of a fire, the safety of building occupants depends on the ability of the concrete structure to maintain its integrity long enough for evacuation. Second, understanding the extent of fire damage to concrete is essential for post-fire assessments, allowing engineers to determine whether a building can be repaired or if it poses a danger and mast be demolished. Finally, this knowledge can help inform the design of fire-resistant concrete mixes and influence building codes und fire safety regulations.

Previous studies have shown that concrete's performance in a fire is influenced by several factors, including the type of aggregate used, the moisture content, and the duration and intensity of the fire. While concrete has inherent fire-resistant properties due to its non-combustibility and ability to insulate, extended exposure to high temperatures can lead to significant loss of compressive strength. Research has demonstrated that at temperatures above 300°C, concrete starts to lose strength, with more severe losses occurring at higher temperatures.

This study aims to further investigate the effects of fire on concrete, focusing particularly on the reduction in compressive strength. By examining how various factors such as exposure time, temperature, and concrete composition influence strength degradation, this research will contribute to a better understanding of fire's impact on concrete structures. This knowledge is vital for improving the fire resistance of concrete, enhancing building codes, and ensuring safer construction practices

The cooling method applied after fire exposure plays a crucial role in determining the extent of damage and recovery of strength. This study aims to investigate the effect of air and water-cooling methods on the compressive strength of fire-exposed concrete, contributing to improved post-fire safety and rehabilitation practices in construction.

1.2 STATEMENT OF THE PROBLEM

Concrete is a construction material that is mostly used due to its high compressive strength and durability: However, concrete undergoes various physical and chemical changes that can reduce its compressive strength when it is exposed to extreme best.

Although, concrete is considered fire-resistant, bid the degree to which fire affects t structural integrity, especially is compressive strength is not yet fully understood Over the years, Engineers had significant challenge trying to accurately assess fire-damaged concrete. As concrete is exposed to fire for longer duration its structure is severely weakened, and short-term exposure may only affect the surface layers, so the compressive strength differs depending on the duration of the fire After exposure to fire and extreme heat, different cooling methods such as water and air are applied on the concrete with little attention paid to the fact that air and water could also influence the compressive strength of the concrete. There is great need to study the compressive strength of concrete after using water and air with different temperatures, and ascertain which positively affects the compressive strength of the concrete

1.3 AIMS AND OBJECTIVES

This project aims to assess the impact of air-cooling and water-cooling methods on the compressive strength of concretes exposed to fire.

Thus, the specific objectives are to:

1. Design the concrete mix of the experiment samples.
2. Determine the compressive strengths of concrete before exposure.
3. After concrete is exposed to 200 degrees Celsius, 400 degrees Celsius, and 600°C, assess its compressive strength.
4. Once the concrete has cooled, find its torsional strengths using water and air.
5. Carryout a comparative analysis of the various cooling method

1.4 SCOPE OF STUDY

The scope of this research is focused on evaluating the impact of air- and water- cooling methods on the compressive strength of concretes exposed to fire. Key areas of the study include:

1. Temperature Range: Higher temperatures of 200 degrees Celsius, 400 degrees Celsius, and 600 degrees Celsius will be applied to the concrete specimens in order to simulate typical fire exposure circumstances. These temperature ranges are significant because research has shown that concrete undergoes notable physical

   and chemical changes, such as microcracking and loss of compressive strength, at these temperature thresholds (Khoury, 2000, Kodur and Phan, 2007).

2. Cooling Methods: Two distinct cooling methods will be evaluated:

I. Air-cooling: Specimens will be cooled naturally in ambient air after fire exposure. This method represents a gradual cooling process that has been shown to reduce thermal shock and minimize microcracking in concrete (Poon et al., 20011).

II. Water-cooling Spots will be cooled rapidly to praying water, mimicking fire scenario However, rapid cooling can introduce thermal stress, which may lead to increased cracking and spalling, negatively affecting the concrete's compressive strength (Sahmaran and Yaman, 2008).

3. Compressive Strength Testing: Following fire exposure and cooling, compressive strength tests was performed to assess the residual strength of the concrete Compressive strength is a key indicator of the concrete's structural integrity, and past studies have demonstrated that it decreases significantly after exposure to high temperatures, particularly when rapid coping methods are applied (Khour 2000).

4. Concrete Mix Design: All concrete specimens was produced swing a consistent concrete mix design (e.g., 1:2:4 mix ratio), and Ordinary Portland Cement (OPC) will be used to ensure uniformity and comparability. This standardized approach aligns with the procedures used in similar studies, allowing for a controlled evaluation of the impact of coning methods (Poon et al., 2001).

5. Sample Size: A sufficient number of specimens was prepared and tested at each. temperature level for both cooling methods. This ensures statistically significant results, allowing for reliable conclusions to be drawn on the cooling methods effects (Sahmaran & Yaman, 2005).

6. Analysis: The data collected was statistically analyzed to determine the significance of differences in the compressive strength of concrete cooled by air and water. This approach follows standard experimental protocols in concrete fire resistance research (Kodur & Phan 2007).

1.5 JUSTIFICATION OF STUDY

The rationale for studying the effect of fire on concrete's compressive strength putting umo consideration the cooling methods lies in enhancing structural safety informing post-fire assessments and improving building codes. By understanding how tire weakens concrete, engineers and architects can design buildings and infrastructure that are more resilient to fire damage, also the fire services can employ the best cooling method which could contribute to the compressive strength of concrete. This leads to safer structures, reducing the risk of collapse during or after a fire event

Furthermore, this research can influence updates to building codes and fire safety standards, leading to stricter requirements for fire resistance in concrete structures, ultimately improving the safety and durability of buildings. The data gotten from the research can also he used by insurance and fire companies in developing better fire protection policies and practices and utilize the possible best cooling method respectively.

CHAPTER TWO

LITERATURE REVIEW

2.1 CONCRETE

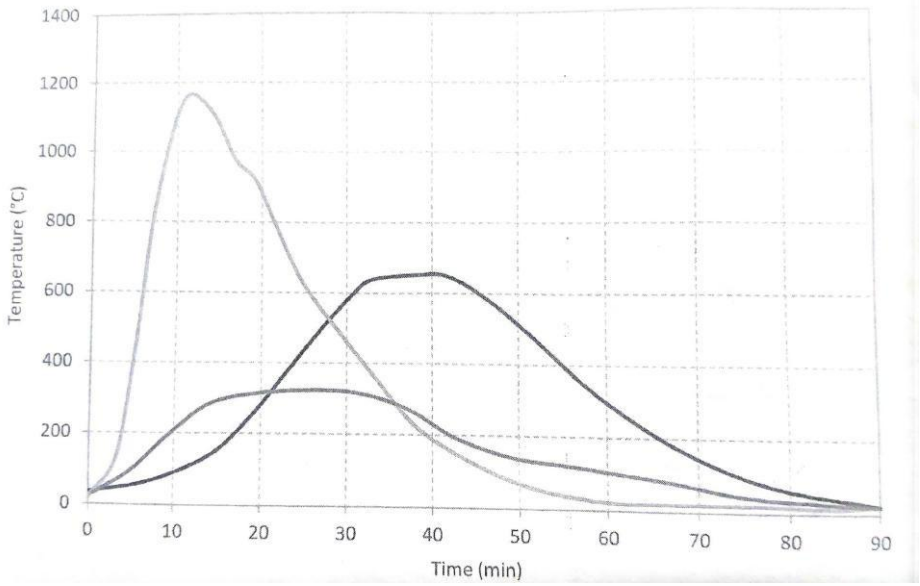
One of the main benefits of utilizing concrete as a structure material is that it can endure fire occurrences with no burning or requiring additional protective elements, in contrast to timber and steel construction. However, concrete is not entirely immune to fire exposure. An exposure temperature of 600 degrees Celsius can lower the compressive force of ordinary strength concrete (NSC) by as much as 55%, according to studies on the material (Phan, 2003).

The durability of concrete at high heat is known to be influenced by several material characteristics, including ambient durability, aggregate form, water-to-cement proportion, additives, and a standard prestress grade. The influence of these properties is well investigated in the existing experimental work and detailed in numerous textbooks and literature-review publications (Purkiss, 2007; Khoury 2000), Concrete strength is also affected by fire characteristics, such as rate of heating, maximum temperature level, exposure duration, and rule of cooling (Zhang B. 2001) The influence of the cooling rate is thoroughly discussed in the existing literature.

Designers must comprehend how fires behave and how they affect the compressive power of concrete. Existing performance-based models have shown that understanding these four fire characteristics is a necessary step to accurately modeling reinforced concrete beam and column behavior (Knchen, 2000).

2.2 THE NATURE FIRE

Time-temperature connections are commonly used to depict fire incidents, as demonstrated in Pipe The phrase "natural fire" is used to describe a fire occurrence as it would actually happen. Fires from nature are affected by a variety of environmental and compartmental factors, therefore no two will ever be the same. Figure 1 illustrates three possible fire profiles. Fire incidents might have high temperatures for brief periods of time, low temperatures for extended periods of time, or any combination of these.



The temperature-time graphs for natural fires are shown in Figure 2.1.

To define a natural fire, four fire characteristics can be calculated heating rate, maximum temperature, overall exposure duration, and cooling rate (Zhang, 2001) During the growth of

a fire, variable rates of heating can occur, ranging from slow heating to almost instantaneous flashover. The availability of oxygen and the existence of materials that are highly flammable have a significant impact on the pace of heating. The highest temperature during the height of a fire incident varies according to the fuel and oxygen supply's dependability, as does the length of exposure. There can be a variety of cooling rates once a fire starts to fade, from quick water cooling brought on by firefighting efforts to gradual air cooling in a smouldering compartment. The degradation of strength in concrete is significantly influenced by any one of these four flame properties. But our focus is how cooling rate greatly affect the compressive strength of concrete.

2.2.1 FIRE TRIANGLE

The fire triangle represents the three essential components required for fire to occur heat, fuel, and oxygen. Removing any of these elements extinguishes fire.

I. Heat. The ignition source that raises the temperature of materials to combustion levels.

II. Fuel. Any combustible material, such as wood, fabric, or hydrocarbons.

III. Oxygen Fire requires at least 16% oxygen in the air to sustain combustion.

2.3 HIGH TEMPERATURE'S IMPACT

The average comparative strength of the corresponding hot and residual assessments over a range of highest temperature exposures is shown in Figure 2. Results from 37 distinct research

make up the averaged values. The top and lower bounds of the assessed test data are provided to help comprehend the variance in the available data (a dotted line). Eurocode prescribed strength reductions for siliceous aggregate (dashed line) are also given (EN 1992-1-2, 2004; Leonardo, 2005).

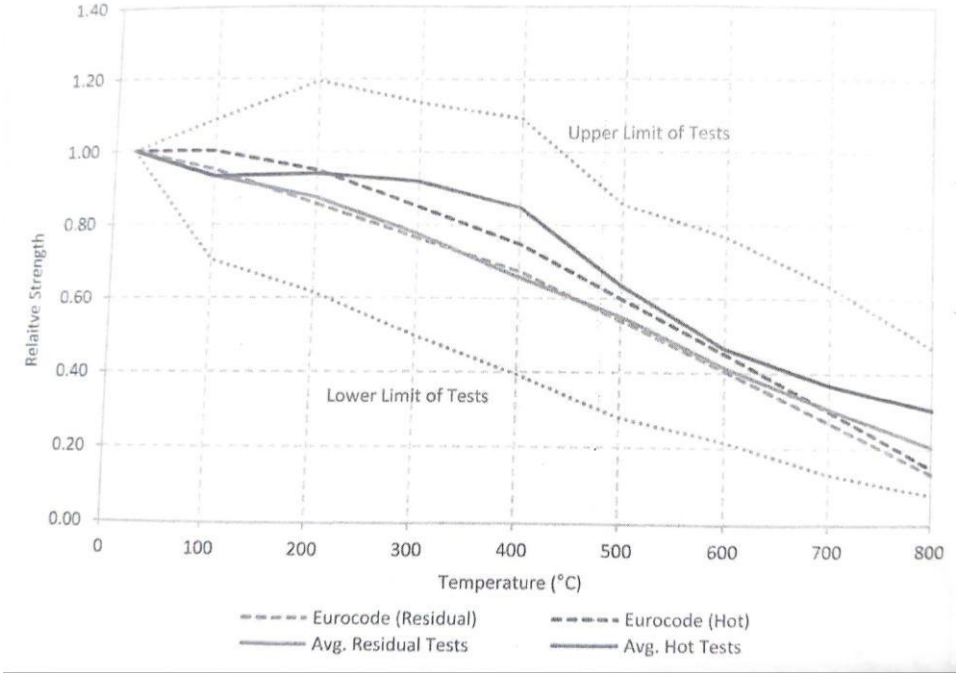


Figure 2.2 concrete's relative durability under residual and hot circumstances.

Concrete's strength is significantly impacted by raising the greatest temperature, according to the mean experimental results. When contrasted to hot tested concrete, concrete that has been cooled shows lower strength at all temperatures. The impact of cooling down which is discussed in Chapter 3, is primarily responsible for this association. The outcome of the hot evaluated profiling is the main topic of discussion in order to particularly address the impact of the highest temperature.

When subjected to high temperatures, concrete's durability shows three tendencies. Strength loss is negligible at temps below 350 degrees C. Some of the experimental work, such as by (Diederichs et al., 1988; Fu et al. 2005) even observed moderate strength gains in the low

temperature ranges. The extent of these gains can be seen in the steep rise of the dotted upper limit line. (Castillo and Durauni, 1990) proposed that this strength gain results from stiffening of the cement gel due to the evaporation of concrete moisture. Therefore, altering the porous nature and moisture level of concrete can significantly delay the loss of strength at reduced highest temperatures.

Strength drastically decreases between 350 and 600 degrees Celsius. The comparative strength readings of 45% and 41% are anticipated for hot and residual relaxation means by 600 C, respectively. The concrete gets significantly drained in this particular temperature range, allowing for the full impact of thermal expansion stresses, microcracking, and cement and aggregate breakdown.

Rapid deterioration is anticipated at 600 Celsius, with an 800° strength loss of up to 90%. This redaction demonstrates the significant impact that the highest temperature has on concrete's strength. Specimens can frequently be manually broken up into pebbles at these higher temperatures. However, compared to mid-range temperatures, the rate of strength decline is rather less noticeable above 600 C. The calcination or crystallization of aggregates could be the cause of this decreasing pace.

2.4 THE IMPACT OF EXPOSURE DURATION

Exposure duration refers to the time for which concrete is subjected to elevated temperatures. For a natural fire, exposure duration would intuitively be taken from the time when the fire starts to when it is fully extinguished. This overall duration, however, is not often reported in the literature. Instead, exposure duration is typically reported as the time from when heating ends to the time when hot testing or residual cooling begins During this period, the concrete

is exposed consistently to the maximum temperature. Defining exposure duration in this way makes temperature control caster during testing it also has the added benefit of allowing its influence on concrete strength to be separated from that of variable heating and cooling rate

To evaluate the influence of exposure duration, taking case studies from the work of (Carette et al. 1982, Mahamidhhai, 1990) Both studies specifically investigated variable exposure durations, ranging from hours to months. Complementary research designed with comparable thermal heating, latent cooling, calcareous granulates, and specimen sizes has been chosen for comparison.

The relative strength losses for concrete subjected to a maximum temperature of approximately 400 degrees Celsius for different lengths of time are shown in Figure 3. The same is shown with a temperature of 600 C in Figure 4. A "uniform" exposure duration means that the specimen was continuously exposed until its internal temperatures matched those of the furnace. The specimen started cooling as soon as the highest value burner temperature was attained, as indicated by an exposure length of "O-hr."

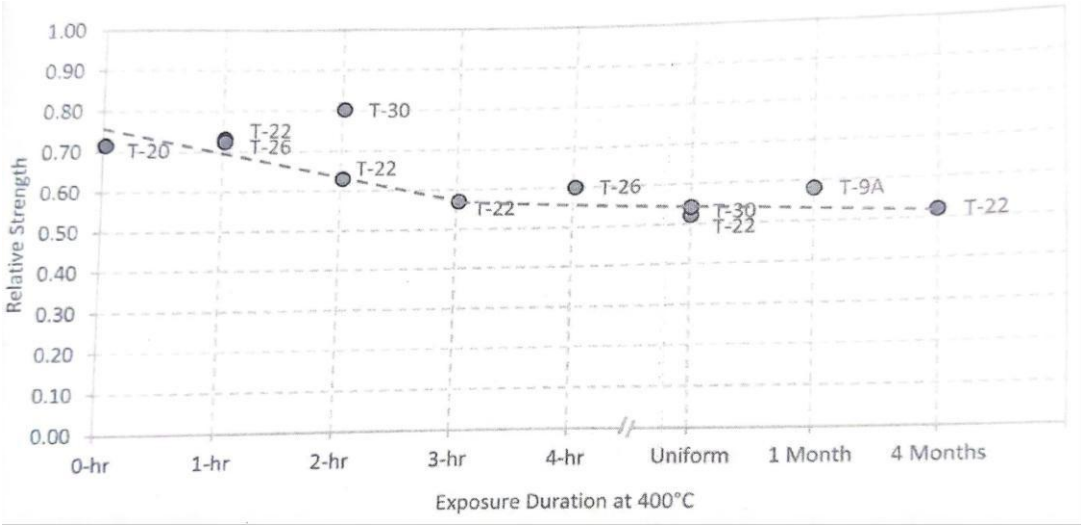


Figure 2.3: The concrete's corresponding relative strength at 400°C after different exposure times.

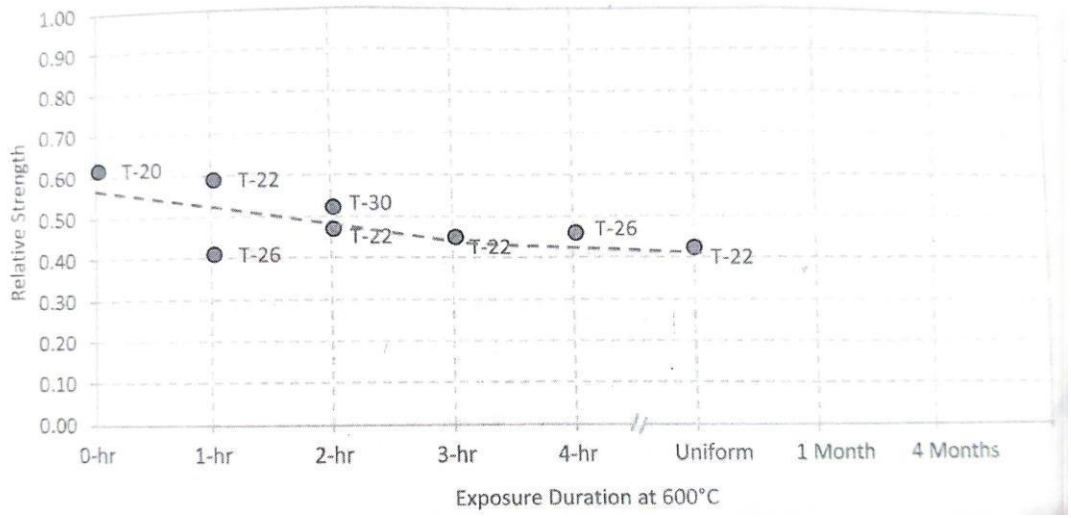


Figure 2.4 shows the concrete's relative strength measured at 600°C after different exposure times.

Intensity reduction exhibits two patterns as exposure time rises. Mild strength loss persists for three hours. Significant additional strength loss is seen after three hours. Strength stages are similar to the 3-hour and 4-hour exposure times, even at high periods of 1 and 4 months. The lines with dashes in Figures 3 and 4 show those two patterns.

The inner temperatures of the concrete provide the explanation for the link. There's an a thermal difference compared to the concrete's exterior and interior surfaces during shorter times. As the interior temperature rises throughout this time, cracks and strength loss continue. Strength loss processes become negligible once a consistent temperature within is attained.

2.5 INFLUENCE OF COOLING RATE

As relative to its hot strength, concrete's residual strength after cooling is noticeably lower. Corresponding to the heat process, the formation of inner temperature differences is the reason for this extra strength loss. These variations create new strains and cracks that further weaken concrete since they develop in the opposing direction of heating.

Different rates of freezing can occur when taking into account the influences of a natural environment. These rates can range from gradual cooling in a smouldering compartment to quick cooling from firefighting activities. The evaluated experimental testing is separated into two rates—air cooling and water cooling—to assess the impact of cooling. The rate of cooling in this research is calculated from the moment the sample departs the ambient temperature.

In research, water cooling is accomplished by subjecting the object being investigated to water throughout the cooling phase. Water quenching or showering procedures are usually used by immersing or showering the specimen with water at room temperature for an extended period of time. Caspeele and Botte found that quenching from an extreme temperature of 600 C is comparable to a normal cooling rate of 30–40 C/min in the particular case of 15 mm-cubed specimens. The experiment's findings show the range of potential cooling speeds that can happen in natural fire situations.

Air cooling occurs when the test specimen is taken outside into the ambient environment. Internal specimen temperature (Lee et al., 2006) showed that these two different cooling methods produce very comparable cooling rates (Savan et al., 2005 and Morita et al, 1996) indicated that slow cooling results in a rate of 0.4 -C/min to 1.0 C/min. Slow cooling can subsequently be defined as having a rate less than or equal to 1.0 C/min

A study by Poon et al. (2001) found that concrete specimens exposed to 800°C and cooled with water showed a reduction in compressive strength of more than 50%, compared to a smaller reduction for aircooled specimens. This highlights the need for careful consideration of the cooling method used after a fire, particularly in structural rehabilitation efforts.

Recovery of Post-Fire Strength Owing to Cooling Rate

Concrete that has been destroyed by fire can greatly restore its original strength when chilled with water thanks to a technique known as post-fire strength recovery. The cement's

dewatering is responsible for this recovery (Foon and CS, 2001). Increasing water exposure and giving yourself time to recuperate are crucial elements in promoting healing.

Since Crook and Murray initially noticed strength returns in 1970, the topic has been thoroughly studied in the literature. The effect of extended-term recuring methods, including soaking specimens for weeks, is frequently the subject of experimental research and evaluations. Thus, the time frame of water exposure is unusual in the context of an ordinary fire event. The following experimental work has been reviewed to demonstrate the influence of short-term recuring

(Abramowicz and Kowalski, 2005) explored the concept of very short duration water cooling. The specimens had either rapidly cooled by freezing for ten seconds, followed by additional gradual cooling in normal air, or they were slow chilled in ambient air. The following day, strength testing was finished. When compared to the benchmark slow-cooling specimens, this brief soaking and testing period had no discernible impact on the specimen's strength.

These outcomes indicate that significant strength restoration that is consistently helpful for design reasons cannot be induced by quick water cooling. There are two explanations for this. First of all, recuring takes time. Irrespective of water exposure, not enough time will have been given for recuring when taking into account the strength of the concrete during a natural fire occurrence and the protection of residents and emergency personnel.

Secondly, it is important to also consider the geometry of the concrete involved. Par larger amounts of water would be required for a building, versus 100 mm specimens to reliably

recreate the findings of (Poon et al 2001) an extended and intentional recuring effort would be required.

2.6 Compressive Strength of Fire-Exposed Concrete

Compressive strength is the primary parameter used to assess the load-bearing capacity of concrete. After fire exposure, the compressive strength of concrete is significantly reduced due to microstructural changes, as discussed earlier. The extent of strength loss depends on the maximum temperature reached and the duration of exposure Studies have shown that the compressive strength of concrete decreases by approximately 30-50% when exposed to temperatures between 400°C and 600°C, and by more than 70% when exposed to temperatures above 800°C (Khoury, 2000),

(Kodur & Phan 2007) found that the residual compressive strength of concrete is also influenced by the type of aggregate used. Lightweight aggregates tend to perform better under high temperatures compared to normal-weight aggregates, which can suffer from significant cracking and loss of cohesion. This factor should be considered when evaluating the fire performance of different types of concrete.

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA

This study uses an experimental methodology to determine how different cooling procedures affect the compressive strength of concrete after fire exposure Fire is used to heat the concrete specimens, which are then cooled using wo methods a and water Compressive strength tests are used to assess the effectiveness of each cooling method. The work is based on controlled laboratory tests that imitate real world fire conditions and cooling strategies

3.2 Materials

The materials used for this laboratory work are:

a) Ordinary Portland Cement (OPC)

b) Coarse aggregate

c) Fine aggregate

d) Water

3.2.1 Material sourcing

a) Procurement of ordinary Portland cement (OPC) The cement used for this experiment is Dangote cement, it was gotten from local suppliers in Ugbowo Benin city, Edo state, it conforms to the requirements of BS EN 197-1: 2000

b) Procurement of Coarse Aggregate: The coarse aggregate is granite, it was gotten from a local supplier at Uselu Benin City, Edo State. The aggregate is free from

c) organic matters, dirt and loam conforming to the requirements of BS EN 12620 (2008).

d) Procurement of Fine Aggregate: The fine aggregate used is sharp sand which free from clay, loam, dirt and any other organic of chemical matter, conforming to the requirements of BS EN 12620 (2008). It was gotten from a local supplier at Uselu Benin city, Ede State

e) Procurement of water. The water and will be clean anil portable water, free from impurities, conforming to the standard of BS EN 100% (2002). It was obtained from Civil Structural laboratory, University of Benin City, Edo state**.**

3.2.2 Material Preparation

In accordance with ASTM of regional standards, concrete specimens are made as cubes (100 x 100 x 100 mm cubes)

I. Mixing and Casting. Concrete is mixed according to the prescribed mix design (1:2:4) using a mechanical mixer to ensure uniform consistency. To eliminate air spaces, the newly mixed concrete is poured into molds and crushed

II. Curing To reach their maximum strength before testing, the specimens were demolded after 24 hours and cured by immersion in water for 28 days as per BS EN 12390-2-2019.

3.3 EXPERIMENTAL PROCEDURE

3.3.1 FIRE EXPOSURE

The specimens were heated in a laboratory furnace at three different temperatures 200°C, 400°C, and

600°C. The heating followed, 2 hours at target temperature

3.3.2 COOLING METHODS

Once the fire exposure is complete, two cooling methods are applied to the samples: At-and Water-Cooling methods

Air cooling method: Samples are left to cool naturally in ambient air, allowing gradual cooing ii. Water cooling method. Samples are sprayed with water, thus leading to rapid cooling.

3.3.3 COMPRESSIVE STRENGTH TESTING

Once the samples have been placed into the various cooling method. The samples were crushed by a universal testing machine in order to determine the compressive strength

All the compressive strength from the air-cooling method and the water-cooling method, from the different temperature levels was tabulated

3.3.4 DATA ANALYSIS

The collected data on the compressive strength of the two cooling methods (water and airy are analyzed to identify the differences in performance.

A graphical analysis was conducted, plotting compressive strength against temperature for both cooling methods. The trends revealed that air-cooled samples retained more strength compared to water-cooled samples, which experienced higher strength loss due to rapid cooling-induced microcracking. The findings indicate that gradual cooling minimizes thermal stress and preserves structural integrity.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter discusses the various experiments that were performed for the study. It clearly communicates the experimental findings through presentation and discussion of the obtained results. Experiments were conducted to determine the compressive strength of the sample

4.1 CONCRETE MIX DESIGN

Using concrete grade 325,

Aggregate size 20mm, natural gravel, slump from 30mm to 60mm

Concrete density-2400kg/m

4.1.1 DETERMINATION OF TARGET MEAN STRENGTH

Target mean strength,

$$F_m = F_c + KS$$

Where F_c characteristic strength = 30 MPA

K. Constant 1.64 (for a defective level)

S. Standard deviation = 4%

Therefore, $F_m = 30 + (1.64*4) = 36.56$

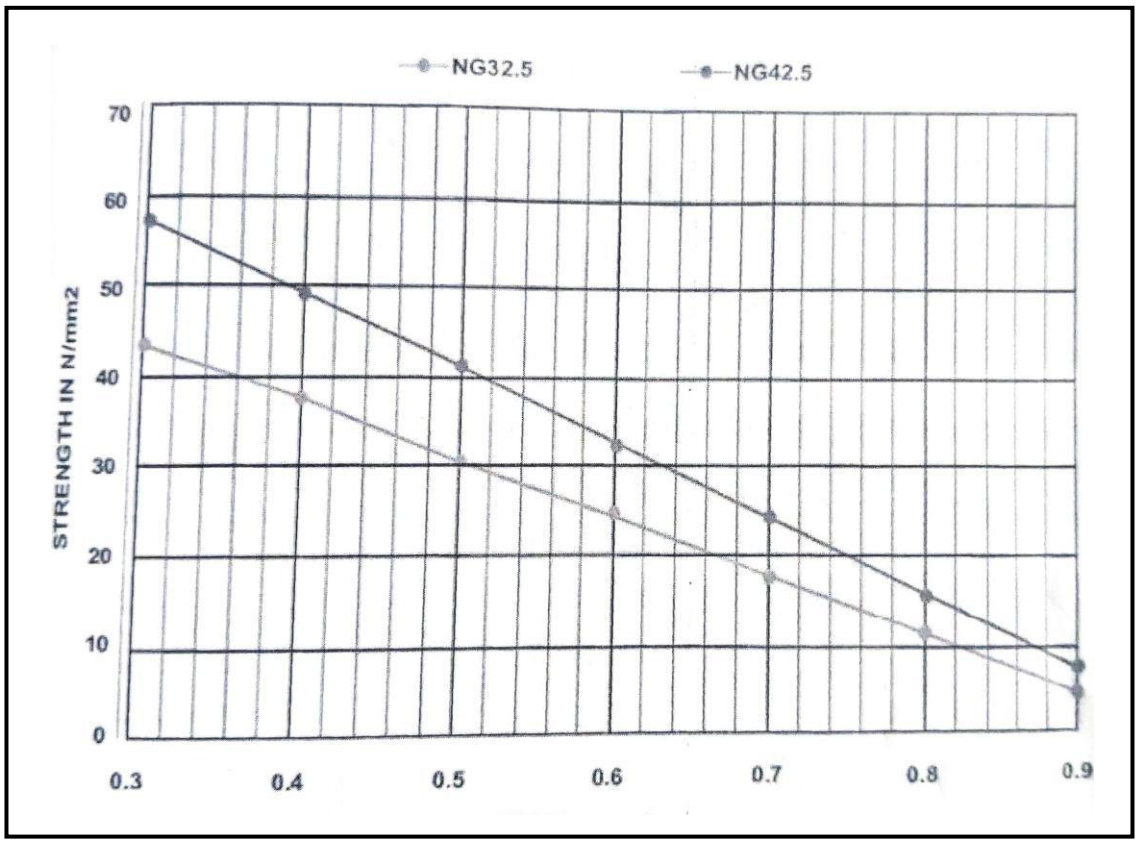


Figure 3.1: strength versus water/cement Ratio for Nigerian cements

Source: (Concrete mix design material, 2023)

From the graph above, the water-cement ratio = 0.55

Table 4.: Approximate Free water contents required to give various levels of workability

Maximum size of coarse aggregate	Aggregate Type	Slump 30-60	Slump 60-180
20	Uncrushed	180	205
	Crushed	210	235
40	Uncrused	160	185
	Crused	190	215

Source: (Concrete mix design material, 2023)

The water content is 180kg/m²

Since natural gravel is an uncrushed

material

Cement content = 180327.27 kg/m water-cement ratio

Aggregate content = Concrete density - Cement content - Water content

= 2400 - 327.27 – 180 = 1892.73kg/m²

Proportion of fine aggregate is 35%

Fine aggregate 662.46kg/m³

Coarse aggregate 1892.73-662.46-1230.27kg/m²

Mix ratio

Cement: Fine Aggregate: Coarse Aggregate

327.27:662:46. 1230.27, divide all by 327.27

We have. I: 2:4

4.1.2 QUANTITY ESTIMATION

Length of cubes 0.10m

Breadth of cube-0.10m

Height of cube-0. 10m

4.1.3 CALCULATION FOR CEMENT

Cement = (Volume of dry concrete/ A+B+C) x A

Volume = 0, 10 x 0.10 x 0.10 = 0.001m^3

Dry volume = 1.54 x wet volume or wet volume 54% of wet volume

Dry volume = 1.54 x 0.001 =0.00154m^3

Cement (0.00154/7) x 1 =0.00022m^3

Density of cement- 1440kg/m^3

Weight of cement for 1 cube = 1440 x 0.00022 = 0.3168kg

4.1.4 ESTIMATING BY WEIGHT

Water 0.3168kg x 0.5 = 0.1584 kg

Fine aggregate=0.3168kg x 2 = 06336 kg

Coarse aggregate 0.3168kg x 4 = 1.2672 kg

The weight-based assessment details the necessary quantities of water. cement, fine aggregate and coarse aggregate for producing a single concrete cube Six specimens serve as control samples; eighteen specimens are allocated for experimental purposes.

4.2 COMPRESSIVE STRENGTH TEST

This procedure is critical for evaluating the impact of fire exposure on concrete. The objective is to ascertain the concrete's resistance to compressive forces. This experiment utilizes a compressive testing machine, with results tabulated below. Strength is measured after 28 days. Six samples served as controls as shown in the table. Additional samples underwent heating to temperatures of 200, 400, and 600 degrees Celsius; these results are also included in the table

4.2.1 COMPRESSIVE STRENGHT OF CONTROL SAMPLES

The average compressive strength of unheated Grade 30 concrete was 29.98 N/tum This serves as the reference for evaluating the strength reduction after fire exposure.

Table 4:2: 28-Day Compressive Strength Test Results for Grade 30 Concrete Using 100 mm Cubes (6 Samples)

Sample No	Weight (Kg)	Density (Kg/m^3)	Failure Load (KN)	Compressive Strength (N/mm^2)
1	2.523	2523	297.03	29.70
2	2.541	2541	303.81	30.38
3	2.540	2540	298.15	29.82
4	2.534	2534	301.79	30.18
5	2.526	2526	285.92	38.59
6	2.548	2548	300.22	30.02

4.2.2 COMPRESSIVE STRENGTH AT THE DIFFERENT TEMPERATURE LEVELS

Table 4:3: 28-Day Compressive Strength of Grade 30 Concrete at 200°C (Using Air- and water-Cooling Methods)

Cooling Method	Sample No	Weight (Kg)	Density (Kg/m^3)	Failure Load (KN)	Compressive Strength (N/mm^2)
Air	A1	2.493	2493	280.02	28.002
	A 2	2.540	2540	285.14	28.514
	A 3	2.535	2535	275.26	27.526
Water	W1	2.500	2500	265.97	26.597
	W3	2.520	2520	270.05	27.005
	W3	2.550	2550	260.81	26.081

Average Compressive Strength

a) Air-Cooled: = 28.014 N/mm^2

b) Water-Cooled: = 26.561 N/mm^2

Table 4:4: 28-Day Compressive Strength of Grade 30 Concrete at 400^{o}C (Using Air- and water-Cooling Methods)

Cooling Method	**Sample No**	**Weight (Kg)**	**Density (Kg/m^3)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**
Air	A1	2.500	2500	240.27	24.027
	A 2	2.518	2518	242.13	24.213
	A 3	2.495	2495	238.09	23.809
Water	W 1	2.502	2502	225.02	22.502
	W2	2.510	2510	227.66	22.766
	W3	2.505	2505	223.48	22.348

Average Compressive Strength

a) Air-Cooled: = 24.016 N/mm^2

b) Water-Cooled: = 22.539 N/mm^2

Table 4:5: 28-Day Compressive Strength of Grade 30 Concrete at 600°C (Using Air- and water-Cooling

Methods)

Cooling Method	**Sample No**	**Weight (Kg)**	**Density (Kg/m^3)**	**Failure Load (KN)**	**Compressive Strength (N/mm^2)**
Air	A1	2.502	2502	199.98	19.998
	A 2	2.515	2515	205.11	20.511
	A 3	2.513	2513	198.64	19.864
Water	W1	2.509	2509	190.49	19.049
	W3	2.516	2516	185.15	18.515
	W3	2.521	2521	188.83	18.883

Average Compressive Strength

a) Air-Cooled: = 20.124 N/mm^2

b) Water-Cooled: = 18.816 N/mm^2

4.3 GRAPHICAL ANALYSIS

Table 4.6: Air-Cooled Samples

TEMPERATURE	**COMPRESSIVE STRENGTH**
0^Oc	29.98 N/mm^3
200^Oc	28.014 N/mm^3

400^{O}C	24.016 N/mm^{3}
600^{O}c	20.124 N/mm^{3}

Table 4.7: Air-Cooled Samples

TEMPERATURE	**COMPRESSIVE STRENGTH**
0^{O}c	29.98 N/mm^{3}
200^{O}c	26.561 N/mm^{3}
400^{O}C	22.539 N/mm^{3}
600^{O}c	18.816 N/mm^{3}

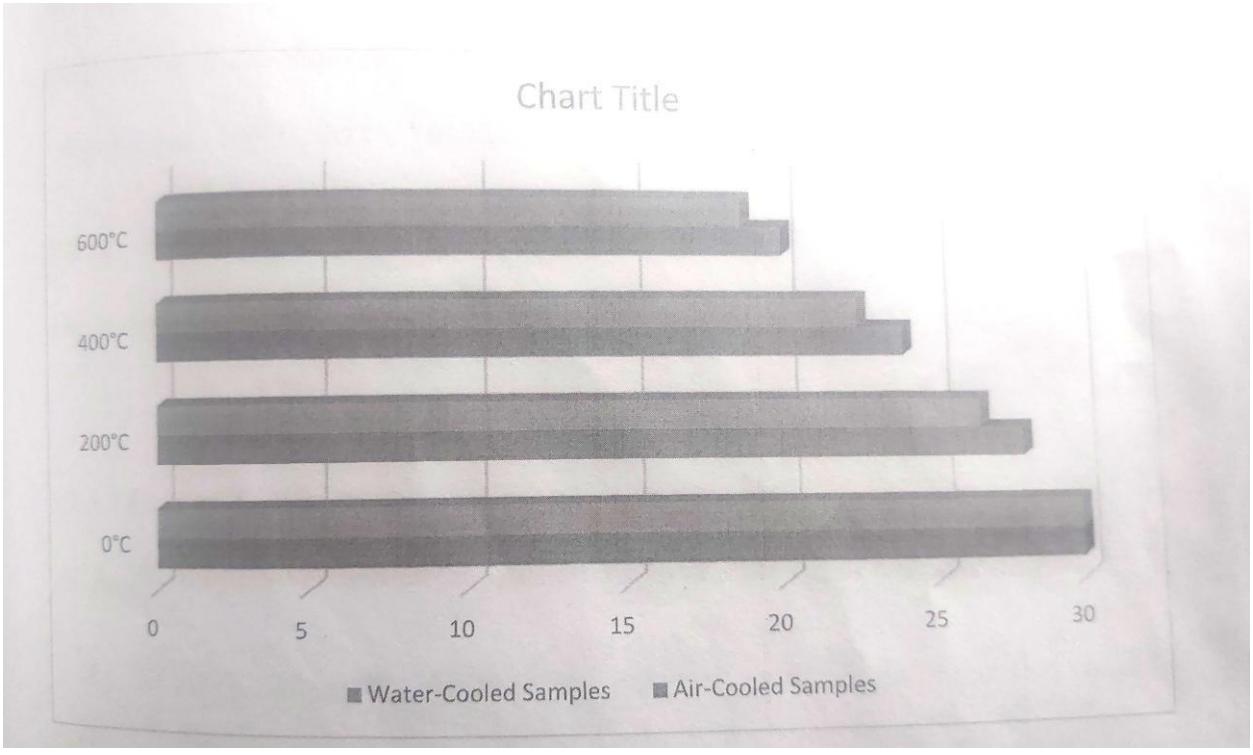


Figure 4.1: Bar Chart showing differences between Air-cooled and Water-cooled samples

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In summary, this investigation examined the impact of air and water-cooling methods on the compressive strength of Grade 30 concrete exposed to elevated temperatures (200 degrees C) 400 degrees C and 600 degrees C)

Based on the results and analyses performed in this research, the following conclusions were drawn:

5.1.1 Effect of Temperature on Compressive Strength

a) As temperature increased, the compressive strength of concrete decreased

b) At 200 degrees C strength reduction was minimal, explaining the fact that concrete retains much of its original strength at moderate heating

c) At 400 degrees C, a discernible decline was observed compared to room temperature.

d) At 600 degrees C the compressive strength dropped significantly, showing severe degradation due to high-temperature exposure

e) These findings align with BS EN 1992-1-2:2004 (Eurocode 2: Design of Concrete Structures-Structural Fire Design), which states that concrete loses strength rapidly when exposed to temperatures above 500 deg * C

5.1.2 COMPARISON OF COOLING METHODS

a) Air-cooled concrete consistently retained higher strength than water-cooled concrete at all temperature levels.

b) Water-cooled concrete showed significant strength loss, likely due to thermal shock and microcracking caused by rapid cooling

c) This confirms that sudden temperature changes negatively impact concretes structural integrity, making air cooling a more effective method for strength retention after fire exposure.

d) This observation is supported by ASTM E119-20 (Standard Test Methods for Fire Tests of Building

Construction and Materials), which highlights the impact of cooling rate on post-fire concrete strength.

5.3 RECOMMENDATION

a) Air cooling is recommended for post-fire concrete structures to reduce strength loss.

b) Further studies should explore the effect of different cooling rates and alternative cooling methods on concrete characteristics.

c) Future research should also examine adherence to ACI 216.1-14 (Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies) to assess fire-damaged concrete restoration techniques.

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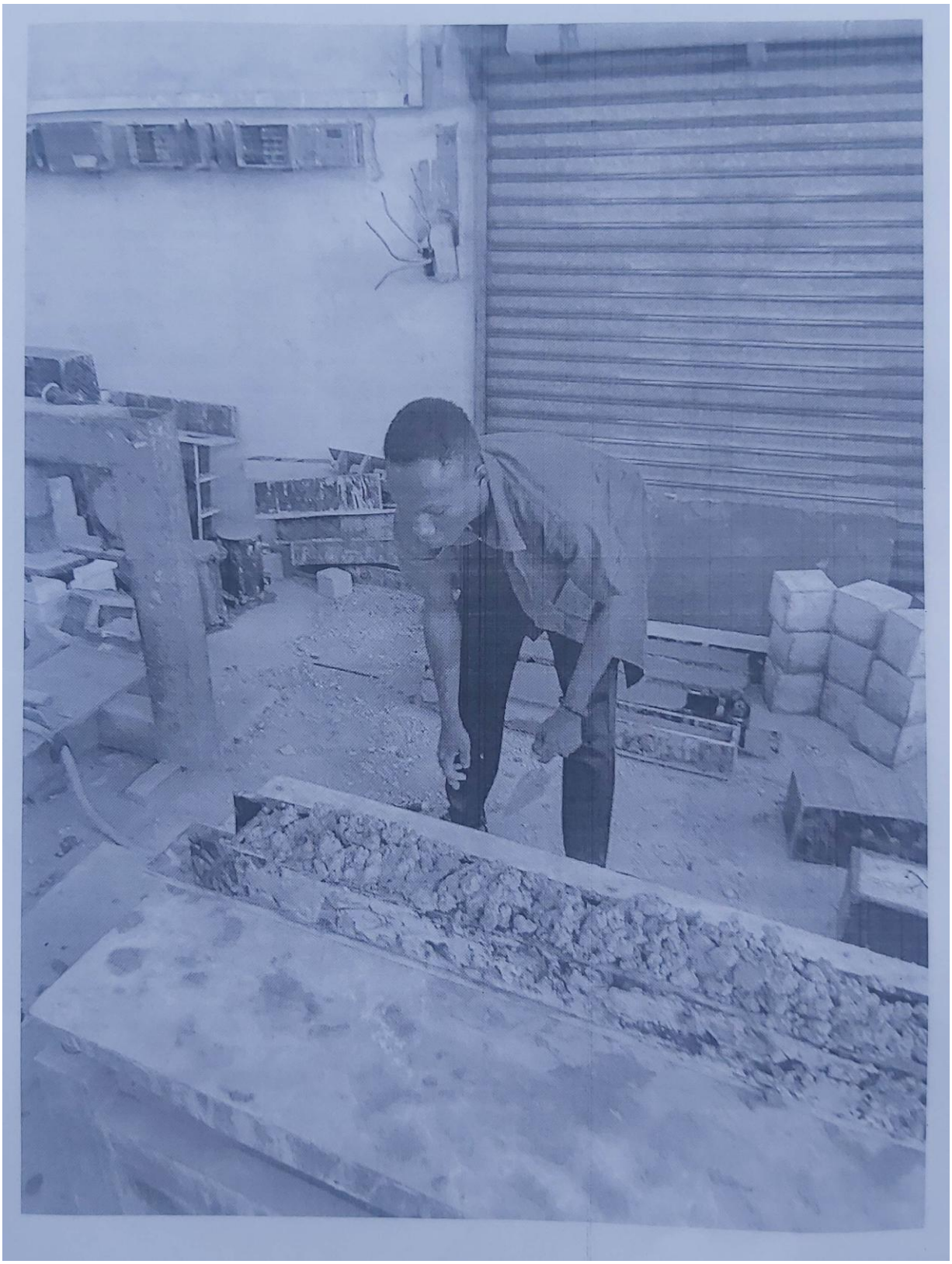
APPENDIX



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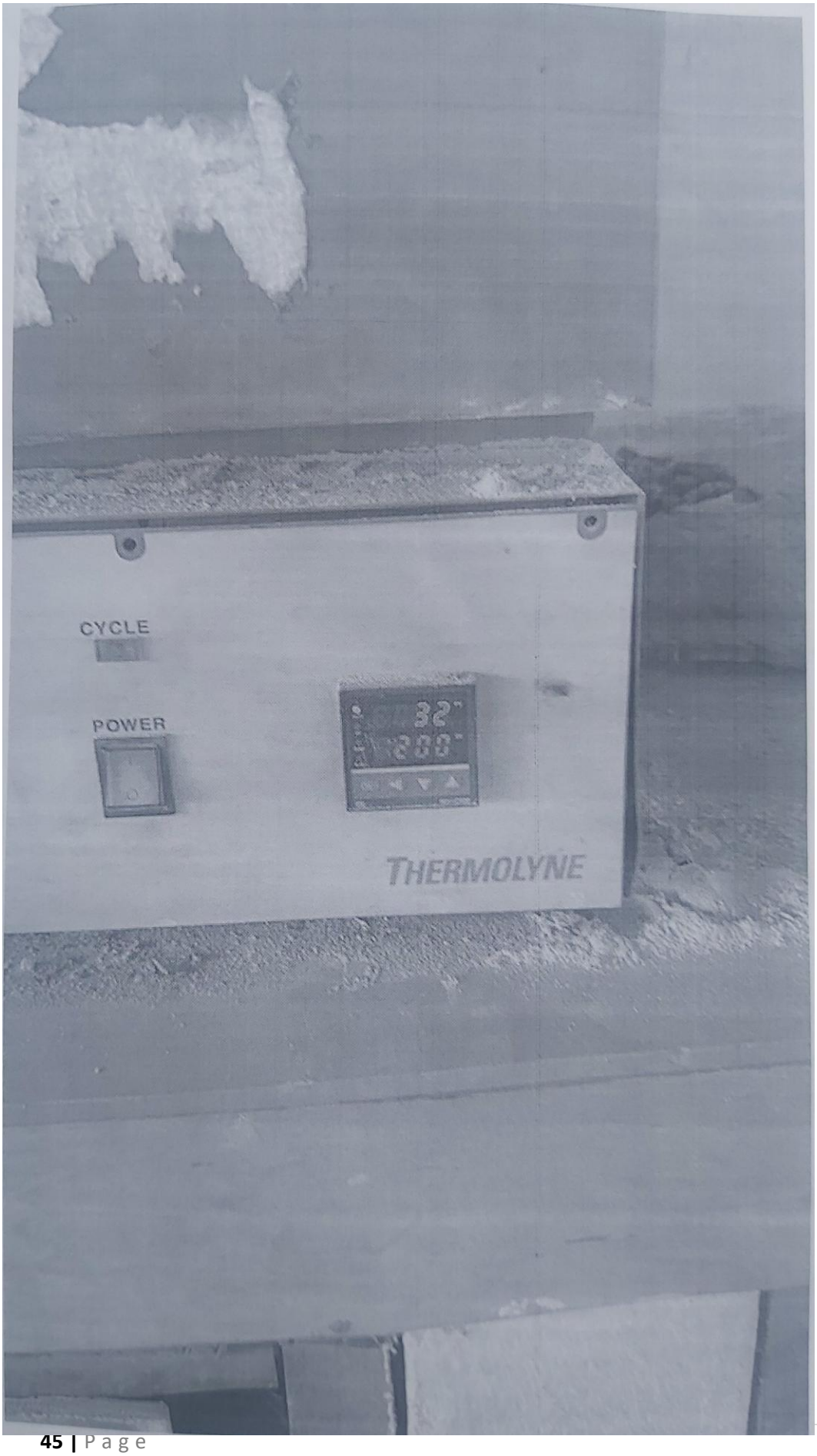
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