**Addis Ababa Institute of Technology**

**Masters in Mineral Engineering (Mineral Engineering program)**

**Center for Ethio-Mines Development**

# APPLICATION OF MONTMORILLONITE TYPE BENTONITE CLAY FROM CHACHA AREA AS ALTERNATIVE FOR LOCAL CONSTRUCTION MATERIAL

Project submitted to Center for Ethio-Mines Development in Partial Fulfillment of the Requirements for the Degree of Master in Mineral Engineering

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**Addis Ababa, Ethiopia**

**DECLARATION**

I, the undersigned, hereby certify that the research project report titled "Application of Montmorillonite Type Bentonite Clay from Chacha Area as Alternative for Local Construction Material" is an original work and has not been submitted for credit at any other university. When necessary, all primary and secondary sources of information used for the project work have been properly acknowledged.

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Signature Date

This thesis has been submitted for the examination with my approval and university supervisors.

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## ABSTRACT

Hollow concrete block are produced from derbanPozolana Portland Cement (PPC), pumice and other aggregates (sand, scoria, gravel and clay). Mixing ratio and composition for HCBs although depend on the availability of materials. It is widely varying among the producers of cottage and industrial scale. However, all producers apply cement as a major constituent for binding. The demand of cement for HCBs and other construction materials is very high while the cement supply is very low. As a result, cost of production and sell price in the market is expensive and becoming not affordable for end users. The objective of this study is to investigate and evaluate the effect in using relatively cheaper bentoniteas cement replacement in HCBs production. Bentonite is available in a bulk when compared to cement. In the process focushas been given for curing and compressive strengthof HCB by varying the amount of cement and bentonite as major constituents in three ways (10kg bentonite replacing 10kg cement, 15 kg bentonite replacing 15 kg cement and 20 kg bentonite replacing 20 kg cement for a single batch /64 HCBs). All HCB samples were produced using 0.84 $m^3$ pumice, 40 liters' water. In addition silicate analysis (chemical composition) and physical properties (bulk density, moisture content and free swell test) of Chacha clay. Standard Compressive strength tests using (CES24:2013) method for HCBs of six sample replicates with average result on a total of 54 samples tests were made for 14, 21 and 28 age of curing time. For 28days' age the average compressive strength ($N/mm^2$) of 1.43, 1.27 and 1.23 were achieved by 10%, 15% and 20% bentonite replacement respectively. The compressive strength of HCBs is found to increase with increase of curing age and decreases with increase of the bentonite loading ratio. Generally, replacing of cement with bentonite at 28 days, a 10% bentonite replacement obtained the highest strength value, followed by a 15% bentonite loading ratio and a 20% bentonite loading ratio.

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## ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing and Material |
| BNT | Bentonite |
| EBCS | Ethiopian Building Code Standard |
| ES | Ethiopian Standard |
| $g/cm^3$ | gram per centimeter cube |
| HCB | Hollow Concrete Block |
| IS | Indian standard |
| $Kg/m^3$ | Kilo gram per meter cube |
| MPa | Mega Pascal |
| $N/mm^2$ | Newton per millimeter square |
| OPC | Ordinary Portland cement |
| PPC | Pozolana Portland cement |
| W/C | Water cement ratio |
| MBI | Modern Building Industry |
| GSE | Geological Survey of Ethiopia |
| CES | Customer Effort Score |
| PR-1 | Run procedure one |
| PR-2 | Run procedure two |
| PR-3 | Run procedure three |
| Mpa | Mega Pascal |

# CHAPTER ONE

# 1. INTRODUCTION

## 1.1 Background of the Study

Finding low-cost natural pozzolans to substitute cement is urgently needed in order to decrease energy consumption, achieve sustainable resources, safeguard the environment, and increase the durability of construction structures (Ahmed J. 2022). Natural pozzolans are particularly useful in mortar and concrete because they have several positive properties such as high ultimate strength, low heat of hydration, low permeability, and high sulfate resistance. This clay's principal constituent is a naturally occurring pozzolan. Depending on the intended use, the presence of these minerals may reduce or increase the industrial value of a resource. Bentonite has significant colloidal qualities and expands many times in volume when it comes into contact with water, resulting in a gelatinous and viscous fluid. Bentonite is important for a variety of uses and applications due to its unique features such as moisture content, swelling, water absorption, viscosity, and thixotropy (Mamo W. 2009; Nayak K. 2015). The standard technique is quarrying since the extracted bentonite is visibly solid even at a moisture content of about 30%. The material is first crushed, and then soda ash (Na2CO3) is added if necessary to activate it. Since the extracted bentonite is clearly solid even with a moisture level of about 30%, quarrying is the preferred method. The substance is first crushed, and if soda ash (Na2CO3) is required to activate it, it is then added. The bentonite is then dried (either forcedly or naturally) until its moisture content is about 15%. Bentonite is used to make hollow blocks instead of Portland cement because of its viscosity and plasticity. HCBs, or hollow concrete blocks, are frequently utilized in the construction of walls in modern buildings. The HCB is divided into four categories in accordance with Ethiopian standards: A, B, C, and D. Classes A through C apply to load-bearing walls. The basic components of this frequently used walling material are pumice aggregate and ordinary Portland cement, often known as OPC or Pozzolana Portland cement (PPC) (Pereira A. 2018). The majority of HCB makers employ pumice aggregate that has not been treated. Bentonite, a volcanic rock, has been used to partially replace cement, according to several studies. In order to create lightweight concerts and concert blocks used as binding (Lima G. 2014; Li J. 2021).Mechanical and financial performance are quite poor when compared to conventional block manufacture. Bentonite is an environmentally benign material that does not affect the environment and has a relatively low cost of production when compared to ordinary Portland cement.  Ethiopia has a sizable deposit of bentonite, which might be used to reduce imports. The study for this project focuses on exploiting bentonite deposits from the Debrebirhan region of northern Ethiopia to partially replace bentonite in the production of hollow blocks.

### 1.2 Statement of the problem

The use of commonly available, moderately priced alternatives as a binding agent, such as bentonite, could offset some of the local building costs.

Ordinary Portland cement has been the most often used binder in concrete since its discovery. Despite the fact that the current construction industry contributes significantly to greenhouse gas emissions through cement manufacture. Concrete is a material that is widely utilized in construction around the world due to its remarkable stability and compressive strength. Cement prices have risen considerably (by more than 150 percent in ten years).

As a result, researching cement alternatives is critical. In Ethiopia, average cement consumption increased from 39 kg to 62 kg per person. Nonetheless, this is far less than the global average of 500 kg per person. Ethiopia's capacity is woefully inadequate to fulfill the country's growing cement demand. As a result, more than a third of the cement used today is imported, driving up cement prices. Ethiopian cement production fell 5.5 million tons short of demand. Due to low levels of domestic manufacturing, there has been a cement shortage since 2020.

A serious shortage developed in 2018, with prices doubling in 2021. The shortage of cement and the high expense of local construction could be mitigated in part by using easily available, moderately priced alternatives as a binding agent, such as bentonite.

### 1.3 Objective of the Study

### 1.3.1 General Objective

The main goal of this study was to determine whether bentonite clay mineral might partially replace cement in the manufacture of hollow blocks.

### 1.3.2 Specific Objective

The Specific objective of the study will be;

1. To know the physio-chemical properties of Ethiopian natural raw Bentonite from Chacha (Debreberhan area).
2. To prepare experimental set up for producing HCB.
3. To collect and sample Chacha area bentonite.
4. To know the effect of Bentonite replacement and Curing time on the compressive strength of hollow concrete block.
5. To compare the average compressive strength obtained with loading ratio and curing time.

## 1.4 Significance of the Study

The inquiry will make a significant addition to our understanding of the variables to be taken into account when determining the hollow block's standard compressive strength. In this regard, the research can benefit businesses engaged in the construction industry as well as those entering it and other areas of commerce. The research effort will also add to the academic discourse and debate within this field and give researchers and university academics experimental values that will be helpful in a pilot scale testing.

## 1.5 Scope and Limitation of the Study

The goal of this study is to determine whether bentonite clay mineral is a suitable replacement for cement-based HCBs produced by small- and large-scale businesses. The study only examines a few chemical and physical tests of clay (bentonite) obtained from the Chacha area close to Debre berhan town (bulk density, free swell, liquid limit, plastic limit, and moisture content).

When used as a binding component in the manufacturing of HCB, Chacha bentonite underwent physicochemical comparisons. Examining the impact of various curing ages and bentonite loading ratios on the compressive strength of HCBs.

# CHAPTER TWO

# 2. LITERATURE REVIEW

## 2.1 Bentonite

The structure of bentonite is characterized by one Al octahedral sheet placed between two Si tetrahedral sheets (Fig. 2.1). These imbalanced charges in the interlayer space are balanced by the dominant cations, typically $Na^+$, $K^+$, $Mg^{2+}$, and $Ca^{2+}$. These cations are exchangeable due to their loose binding and this leads to a high cation exchange capacity of bentonite. (Vimonses, 2009)

To rub hands with it, bentonite feels oily and soap-like (Bates & Jackson, 1987). Bentonite is initially white to pale green or blue and gradually darkens with exposure to become yellow, red, or brown (Parker, 1988).

The ability to produce thixotrophic gels with water, the capacity to absorb significant amounts of water with an associated rise in volume of up to 12–15 times its dry bulk, and a high cation exchange capacity are some of bentonite's unique qualities. The use and market value of bentonite are influenced by its capacity to absorb water (Grim, 1962).

Calcium and sodium montmorillonite differ structurally primarily in the water layer, where calcium montmorillonite has two water layers in the interlayer position while sodium montmorillonite only has one (Murray, 2007). Calcium-bentonite and sodium montmorillonite have quite different characteristics with just one water layer in the interlayer location. The general formula for montmorillonite is as follows because sodium montmorillonite has a substantially larger swelling capacity and viscosity than calcium montmorillonite:

In addition to montmorillonite, bentonites also contain a range of accessory minerals, depending on the nature of their genesis. These minerals might include gypsum, calcite, quartz, and feldspar. The existence of these minerals may affect the deposit's industrial value, lowering or raising it depending on the use. Bentonite has significant colloidal characteristics, and when it interacts with water, its volume multiplies many times, resulting in a gelatinous and viscous fluid.

## 2.2 Montmorillonite

A key active ingredient of bentonite, montmorillonite is a multipurpose clay mineral with special swelling and adsorption capabilities. Due of these qualities, montmorillonite is frequently employed in industrial and medical applications. (Eisenhour D, 2009)(Carretero MI., 2010). Montmorillonite is the source of bentonite's swelling and adsorption abilities. For use in medical applications, pure montmorillonite must be acquired, and this can be done by purifying raw bentonite.Due to the odd hydrophilicity, swelling, adsorption, and fluidity characteristics of montmorillonite, these cations can be easily replaced by other organic or inorganic cations (Chen J, 2000).

### 2.2.1 Physical Properties of Montmorillonite

The fact that montmorillonite has a hydrophilic property and expands when exposed to water is one of its distinctive physical characteristics. Given the negative charge of a montmorillonite sheet's surface, water that has undergone autoionization can easily infiltrate the interlayer with H3O+ (Song S, 2005). The montmorillonite swells as a result of its hydrophobicity. Swelling is the physical transformation of an anhydrous solid into a gel. By absorbing water, sodium montmorillonite can expand up to 20 times its original volume. Water entering the 2:1 layers causes the swelling, which is followed by osmotic water absorption. The mineralogy, size, negative charge, and hydration energy of exchangeable cations all affect the swelling pattern (Xu YF, 2003).

## 2.3 Industrial Use of Bentonite Clay

Recent years have seen an increase in interest in the industrial and environmental uses of bentonite. Various rich minerals and clay minerals, such as kaolinite, goethite, dolomite, cristobalite, and palykorskite, have been used in the manufacturing process of cement (Taylor-

Lange, 2012). Particularly in highly attackable situations, the use of bentonite/cement slurry trench cutoff walls raises questions about endurance. When creating cut-off walls, durability and the physical-chemical interactions of the cement and bentonite clay mixture are crucial components in determining their possible service life and how long they will last in the soils(Shannag, 2000). Bentonite is typically utilized as a thixotropic, support, and lubricating agent in civil engineering applications such as horizontal directional drilling (HDD), tunneling, and diaphragm walls and foundations. Bentonite is also utilized in Portland cement and mortars because of its viscosity and plasticity (EUBA, 2011).

## 2.4 Bentonite Occurrences in Ethiopia

Bentonite is the main raw material in Ethiopia. The Ethiopian areas of Afar, Oromia, and Amhara have resources for bentonite clay. Due to their proximity to the main road, they are easily reachable. Ledi, Gewane, Hadar, and Warseiso are the important locations in Afar. The Afar region's entire resource is thought to be 170 million tons. The bentonite beds are clearly visible, and the overburden is made up of sandy clay and loamy gravel. Current tests show that some beds can be utilized for palletizing iron ore and preparing drilling mud, and if modified, they may also be used in foundries (Mesfin T., 2012).

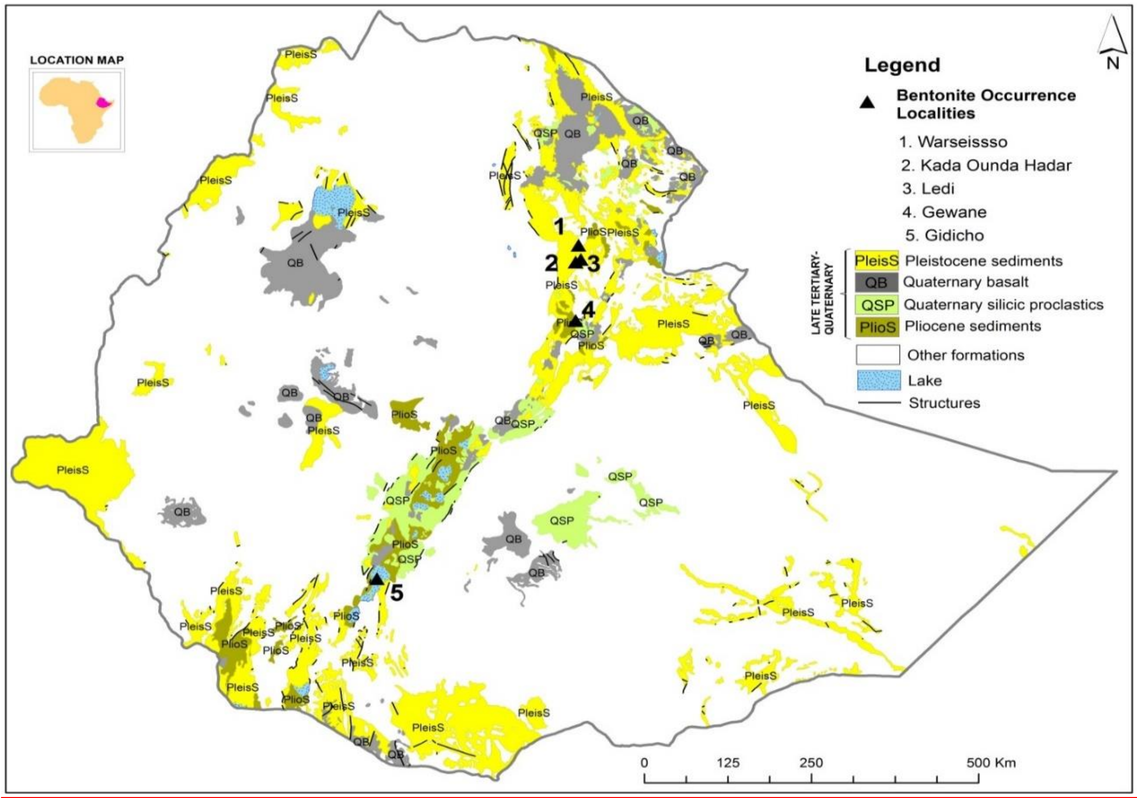



**Figure 2. 1**: Bentonite Occurrence map of Ethiopia

*(Source: Geological survey of Ethiopia)*

## 2.5 Application of bentonite clay of the montmorillonite type as a substitute for local building materials

(Lima-Guerra D. J, 2014), The results of the study on the primary variable proportion of bentonite in the natural and intercalated forms (2, 5, 10, 15, 20, 25, 30, and 35% by weight of cement) in the replacement showed that as the substitution of ordinary Portland cement by perceptual of natural and modified bentonite increased, the workability, density, and water absorption of fresh concrete decreased. The findings show that workability declined as natural bentonite content in the concrete dropped.

(Farhan M., 2022) studied the bentonite concrete that was made by replacing cement with amounts of bentonite that were 5, 10, and 15% by weight. Mechanical tests (compressive and splitting tensile strength) were performed. Also assessed and discussed were durability performance (mass loss) and specimen characteristics (elastic modulus, stress-strain behavior, ductility, and energy absorption). The findings showed that samples containing bentonite outperformed the control mix in terms of fire resistance. The mass loss of the specimens subjected to high temperatures was reduced by the addition of bentonite to concrete. Bentonite concrete performed better than ordinary concrete in terms of mechanical behavior (compressive and tensile strength), and it had a strong resistance to water absorption.

(Benyounes K., 2019) To demonstrate the impact of bentonite on the rheological behavior of the various grouts, several tests were conducted for a range of shear rates between 0.01 and 200 s1. Cement was substituted by bentonite at five different substitution rates (2%, 4%, 6%, 8%, and 10%), and the water/binder ratio was fixed at 0.5. According to the researcher's findings, the yield stress and consistency radically change when bentonite content rises, while the few index gradually declines as a result.

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Descriptions of the Study Area

Study area is found in Amhara Regional State Debrebran Chacha kebele. The license area, which covers 20.8km$^2$, is found in Chacha (0939 A4), DebreBirhan (0939 B3), AliyuAmba (0939 B4), Gorgo (0939 D2) and Gina Ager 0939 D1) sub sheets and bounded by UTM geographic coordinates, listed in table 1 below. The local geology of the study area is a part of Main Ethiopian Rift Valley Belt. The geology of the area is represented by volcanic rocks: Ignimbrite& associated tuff, welded tuff and basalt, bentonite, eluvail and alluvial sediment. The geologic name is given below based on physical observation of hand specimen by lens, not by thin section analysis.

Chacha kebele is reaches by driving about 120km from Addis Ababa by asphalt road. After reaching Chacha one turns toward east direction and travels about 7km to reach the project area by all weathered road which access to kitaliea (Fig.3.1).

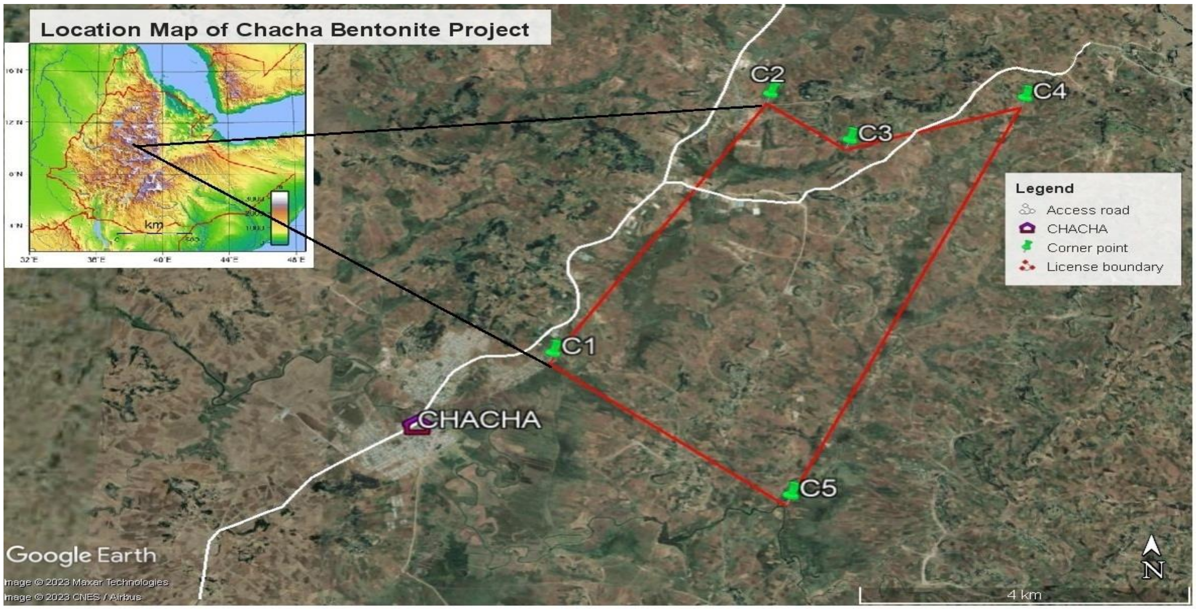



**Figure 3. 1**: Location map of Chacha Bentonite

**Table 3. 1:** Geographic coordinate points of Chacha bentonite Midroc exploration project

| Coordinate System Adindan UTM Datum | | |
|---|---|---|
| Corner point | Easting | Northing |
| C1 | 551600 | 1054600 |
| C2 | 554557 | 1059180 |
| C3 | 555614 | 1058326 |
| C4 | 558055 | 1059107 |
| C5 | 554607 | 1052310 |

*(Source: Midroc Geo Exploration Service PLC report)*

## 3.2 Study Design

The study was conducted in different steps. These include material preparation, determining physical and chemical property of materials, production of hollow blocks with a mixing proportion of class C hollow concrete block and determining its properties. In this study the amount and kind of pumice and water were constant, but quantity of Cement, and Bentonite was varied.

### 3.2.1 Method of Data Collection

Systematic hand pitting was excavated where the overburden is supposed to be thin. Hand pits were sunk at profile line spacing of 500m and pitting of 500m apart by hand with the help of shovel, mattocks, and iron bar, rope and soil pail. The dimension of each pit was 1m by1m and the vertical depth was varied from pit to pit. When pitting reached to the bentonite, samples weighting about 1kg to 2.5kg were then collected for analyses and corresponding section could be logged. Pits with no bentonite were rejected.

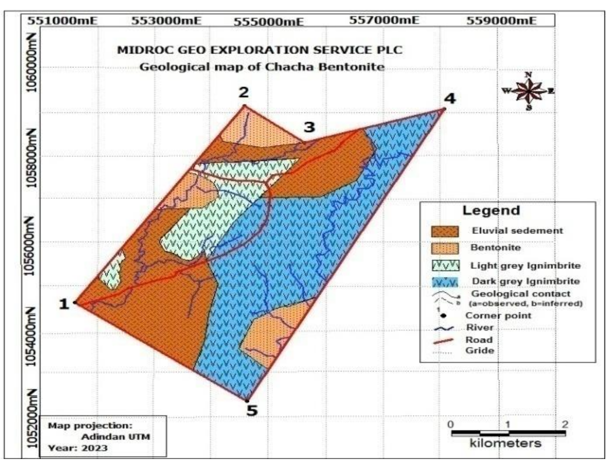
According to hand pitting distribution maps (figure 3.2 d.), the pits which show bentonite, are well spread in the northern and south eastern portion of the study area. This part of the explored area, northern part covers 0.8km$^2$and southern eastern part covers 1.1km$^2$ out of 20.8km$^2$, is delineated as promising target area for bentonite waiting for exploration decision.

In most case bentonite layer is found at shalow depthfrom 1m to 3m from the surface. The bentonite layer are varying in thickness.The maximum and minimum thickness of diatomite layer ranges from

0.5m to 2.5m.bulk sampling from the same pits was randomly collceted from the same  site by the reaearcher.

a. South eastern bentonite sampling

b. Shows Bentonite rock



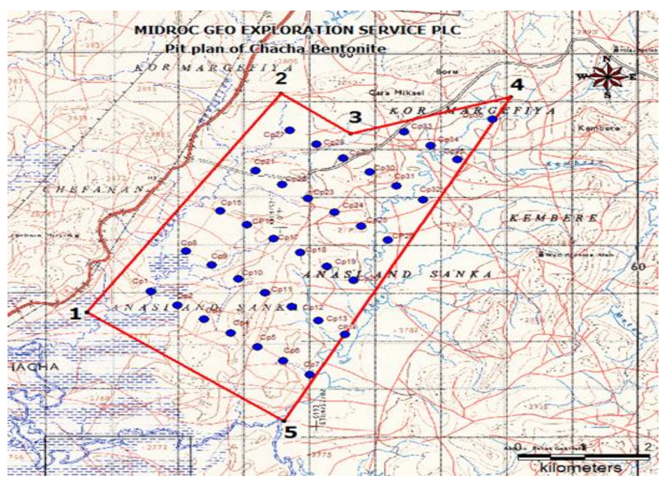




Fig c. geological map *Fig*

*d. Pit map of Chacha*

**Figure 3.  2:** Photos Map of Chacha Bentonite

*(Source: The author and Midroc Geo Exploration Service PLC report)*

## 3.3 Material Preparation

Water, cement, bentonite, pumice, and other raw materials were combined according to a predetermined standard mixing ratio.

### 3.3.1 Water

In this study, drinkable tap water supplied for Addis Ababa in Lemmi Kura sub city woreda 10 was used for concrete mixing and curing of specimens. The amount of water used was 40 liters (for summer season) per one term of production.

### 3.3.2 Cement

This experimental work was carried out using Ordinary Portland Cement (OPC) of 42.5 grades.

### 3.3.3 Pumice

Although the occurrence of pumice is widespread in Ethiopia, it is utilized mainly for the purpose of cement manufacturing. The best known deposit is at Gari Baldi, about 60 km east of the town of Adama. Other occurrences, including that at Kimbibit in the rift valley, require more detailed assessment. Pumice material obtained from Modern building industry (MBI) Stock piles Addis Ababa, Lemmi kura sub city woreda as Shown in Figure 3.5.

The crushed pumice (01) and manually crushed fine Bentonite from chacha area was used for the study.

### 3.3.4 Bentonite

The outcrops of bentonite are observed in river cut. According to geological mapping, most of the potential bentonite is located in the north, shouth easthern and north western part of the study area and is underlain by Ignimbrite rock (overburden).The maximum and minimum thickness of bentonite layer ranges from 0.80m to 2m. The chemical composition test results of Bentonite material of selected sites were identified by using complete silicate analysis at Ethiopian Mineral and Biofuel Corporation and physical test was conducted at Geological Survey Institute of Ethiopia.

#### 3.3.4.1 Preparation of Bentonite

For this research the bentonite collected from chacha kebele found in North shoa zone Amhara regional state was used after drying to sunlight and crushing it manually by hand. Both drying and crushing process was takes place in Summit lemmi  kura sub city MBI work station.

**Figure 3. 3**: Bentonite Sample preparation

*(Source: Field photo taken by the author)*

## 3.4 Experimental work procedures of material

### 3.4.1 Binder Ordinary Portland cement (OPC)

Ordinary Portland Cement (OPC) of 42.5 grades was used to conduct this experimental work. The study employed derba cement as a binder. Tables 3.2 and 3.3 found in appendix show its chemical composition and physical characteristics, respectively. In this study, bentonite clay from North Shoa Debrebirhan's district Chacha was employed. After collecting, the clay was heated to sunlight and manually crushed with a hand-handled hammer to get the passing size of 74 micron equals with cement product size for mixing with cement and pumice. The clay obtained from the natural source was in rough form and could be used directly in concrete production.

### 3.4.2 Physical properties of the cement used for Hollow Concrete Block production

#### 3.4.2.1 Properties of cement

Cement hydrates when combined with water and then solidifies into a mass. To make plain cement paste of a regular, standard consistency for various cement tests, the proper amount of water must be added to the cement. How much water is required for various cement tests relies on the typical consistency of the cement, which is determined by the compound, composition, and fineness of the cement (Musyimi, 2016).

#### 3.4.2.2 Physical and Chemical Properties of Bentonite

1. **Physical test conducted**

The physical properties like bulk density, moisture content and free swell was tested by taking a sample of Bentonite from Chacha and analyzed at Geological Survey of Ethiopia Mineralogy and Geotechnical laboratory to know the specific properties of the material.

Since Bentonite clay is a class of brittle material, plastic limit and liquid limit was difficult to test and the analysis of this result will be discussed in detail under chapter 4.

**2. Chemical test conducted Chacha Bentonite**

**C**hemical analysis is good indicator of quality; Chemical composition of bentonite shows considerable variations. Table 3.1 found in appendix

### 3.4.3 Mix Design

Crushed pumice aggregate (01), fine bentonite that has been manually crushed (fig. 3.3), regular Portland cement, and water make up each batch of concrete. For each of the three varied percentages of bentonite, the mix designs remained the same.

**Hollow block manufacturing process flow sheet**

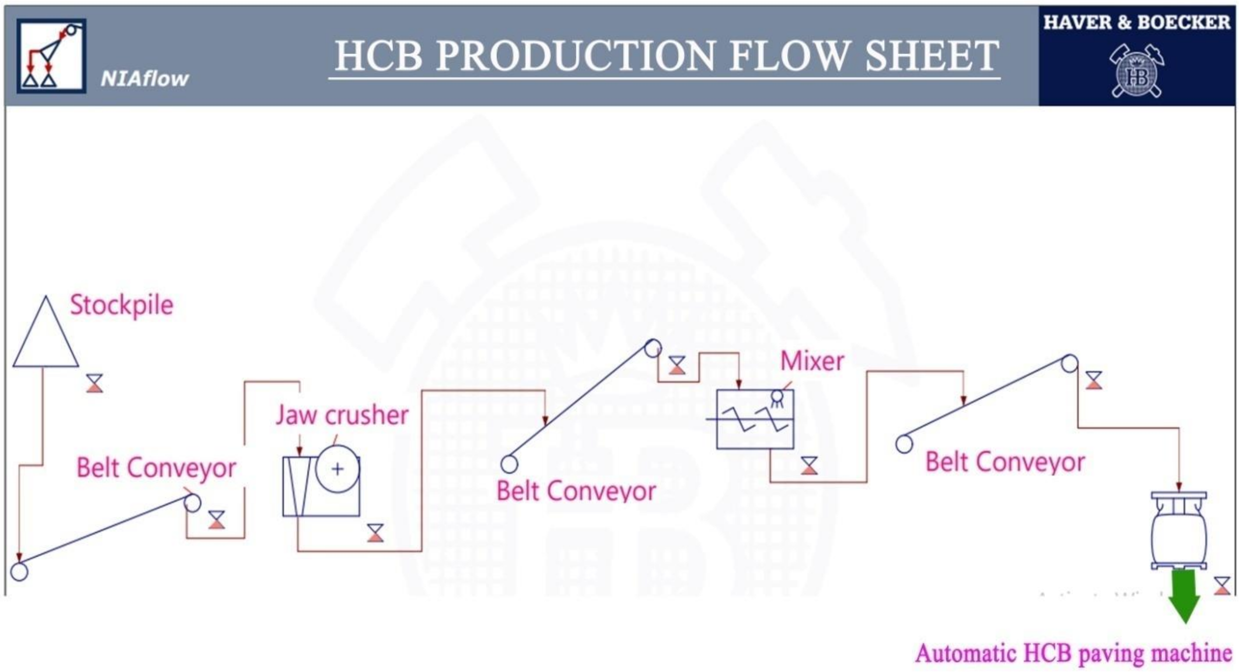



Figure 3. 4: Hollow block manufacturing flow process at designed by author

## 3.5 Production of hollow concrete block (HCB)

### 3.5.1 Mixing process

Two stages were used to complete the mixing process. In the first phase, dry pumice that has been crushed by a jaw crusher is placed in a bucket and transported by elevator to the mixing section, where a mixer automatically blends dry pumice with cement. The second process involved wet mixing cement and aggregates in an electrically powered mixer.


**Figure 3. 5**: Mixing Machine and mixing process

*(Source: Field photo taken by the author from the company)*

### 3.5.2 Casting process

The sample HCB was subsequently cast using a block manufacturing machine, which creates blocks with the typical dimensions of 40 cm x 20 cm x 20 cm (L, W, and H) utilizing vibration and pressure.


**Figure 3. 6**: Moulding Machine of hollow concrete block

*(Source: Field photo taken by the author from the company)*

### 3.5.3 Curing Process

After the HCB had been formed, it was allowed to dry out for 24 hours without being watered. Ten days later, the hollow concrete block was irrigated. Then the curing period was finished after 14, 21, and 28 days.

## 3.6 Sampling Procedure and Sample Size

The number of test specimens required to conduct compressive strength HCB determined the sample size. 54 of the 126 hollow concrete blocks that made up the sample were tested for compressive strength at 14, 21, and 28 days of age.

Figure 3.7: Hollow concrete block samples on the production place

*(Source: Field photo taken by the author from the company)*

## 3.7 Study Variables

### 3.7.1 Variables

Curing time and Bentonite loading ratio %.

### 3.7.2 Constant Variable

Pumice amount 0.84 $m^3$ and water amount 40 liter

### 3.7.3 Response Variable

Compressive strength of hallow block at age 14, 21 and 28 days.

## 3.8 Data Collection Process

Quantitative data was collected from MBI, GSE, Ministry of Mines, Webs, Chacha kebele, Midrock and Derba cement

## 3.9 Experimental or Laboratory Tests

The information was gathered via laboratory experimentation results that were properly formatted and recorded. The information was then used as input for an analytical analysis, with the results serving as some of the findings' outputs.

## 3.10 Experimental Setup

The experiment would have a completely randomized design. Cementing materials (Derban opc cement, chacha Bentonite), aggregates (0.84 $m^3$ pumice), 40liter Water and time of curing (14, 21 and 28 days) are used. Thus the experimental test result developed as in the Table 3.7 shown in appendix

## 3.11 Laboratory test hollow concrete block

### 3.11.1 Hollow concrete block test result

## 3.12 Data Processing and Analysis

To achieve these research goals, the data were gathered from laboratory tests and analyzed based on the experimental findings from the compressive strength, density, and moisture content test results. The outcome and conclusions were displayed using a table, chart, graph, or other appropriate form as needed. To understand the impact of the dependent variables' interactions with the response variables, design expert software was also used.

# CHAPTER FOUR

# RESULT AND DISCUSSION

## 4.1. Quality Parameters

Different clays that make up bentonite have the hygroscopic property of swelling when exposed to moisture. It makes up montmorillonite, a phyllosilicate mineral that is a member of the smectites family. It contains physical and chemical characteristics and mineralogical traits that make it suitable for a range of applications.(Mamo and Negassa 2009).

### 4.1.1 Mineralogical properties

Bentonite is a clay mineral that is generally produced by altering volcanic ash and is mostly composed of smectite particles, most commonly montmorillonite. Hectorite, saponite, beidelite, and nontronite are further members of the smectite group of minerals. Smectites are clay mineral, which means that each one of their individual crystallites has a maximum diameter of about 2 micrometers. Smectite crystallites are three-layer clay minerals by themselves (Farhan M., 2022).

Bentonites contain a range of auxiliary minerals in addition to montmorillonite, depending on the nature of their genesis. These minerals could include gypsum, quartz, feldspar, and calcite. Depending on the use, the existence of these minerals might affect a deposit's industrial value, lowering or raising it (Benyounes K., 2019).

### 4.1.2 Physical properties

When in contact with water, bentonite exhibits significant colloidal qualities and its volume multiplies many times, resulting in a gelatinous and viscous fluid.

The physical property of Bentonite from chacha analyzed at Geological Survey of Ethiopia Mineralogy and Geotechnical laboratory is presented in the table below

## 4.2 Bulk Density, Moisture Content and Free Swell

The physical property tested at laboratory was analyzed with the standard acceptable range as presented on table 4.1 in appendix.

From the above table the result of physical test for chacha bentonite done on bulk density, Moisture content and free swell test meets the acceptable range of Bentonite except bulk density. But still the quality of the bentonite is low since it has high silica it is very brittle.

## 4.3. Chemical Properties and Analysis of Cement and Bentonite

Chemical analysis is a good predictor of quality; bentonite's chemical composition exhibits wide variability. Table 3.4 The approximate oxide composition of chacha Bentonite

The physicochemical properties of the primary clay-based components of the chacha were studied after geochemical analysis of 15 samples was carried out at the Ethiopian Biofuel Corporation Laboratory. Chemical analysis is a good predictor of quality; bentonite's chemical composition exhibits wide variability. The raw clay materials under investigation are mineralogically made up primarily of quartz, with minor amounts of hematite, K-feldspar, and amphibole as well as the secondary clay minerals smectite and kaolinite. SiO2 and Fe2O3 are the main oxides in terms of geochemistry. The results show that iron (Fe2O3), magnesium (Mg), and silica (SiO2) are the three most common oxides.

Hematite is indicated by Fe2O3, but SiO2 ranged from 63.03 to 78.4%, indicating the presence of quartz/sand (Kagonbé et al., 2021).MgO ratios are favorable, with levels varying between 0.98% and 2.89% globally. The ratios of CaO and Na2O are likewise low. For CaO, they vary between 0% and 3.75%, and for Na2O, between 0.56% and 2.59%.With values below 1.68%, the proportions of P2O5, TiO2, and MnO are extremely low. Low, ranging between 6% and 15%, loss of ignition, a significant indicator of the degree of weathering (Kagonbé, 2021)

According to Sinha 1986, general rule may be applied;

Accordingly;

- If CaO> = 1% the bentonite turns towards non-swelling
  - $Na_2O/CaO$> 4, bentonite (excellent quality)
  - $Na_2O/CaO$ 2-3, bentonite (good quality)

- $Na_2O/CaO$ 1-2 bentonite (tolerable quality) requiring further processing

The ratio shows less than 4 which is 1.5. Generally, the chacha bentonite used is said to be tolerable quality which may require further processing before using it as cement replacement.

## 4.4 Hollow block concrete test resultn

### 4.4.1 Compressive strength test result analysis with different percentage of Bentonite is found in appendix in table 4.3

## 4.5 Test for Significance and Accuracy of the Model

### 4.5.1. Analysis of variance (ANOVA)

**Response1: Compressive strength see table 4.4 in appendix**

**ANOVA for Quadratic model**

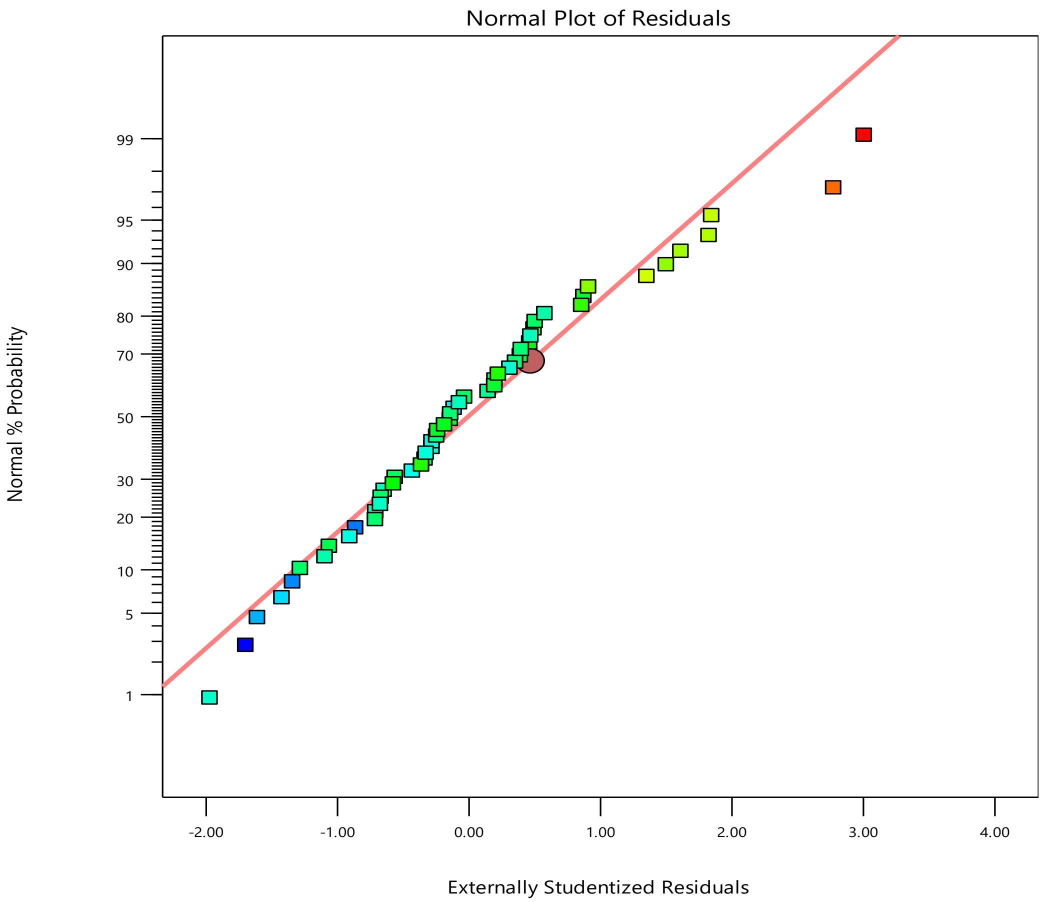
Response 2: Density see table 4.5 in appendix

The Model F-value of 10.89 shows that the model is significant, as shown in Table 4.4. A "Model F-Value" could happen as a result of noise only 0.01% of the time. When "Prob F" is less than 0.0500, it is likely that the model terms are important. The model terms A and B are significant in this case for the bentonite loading ratio and curing time, respectively. Where A and B stand for the respective curing time and bentonite loading ratio. This experiment demonstrates that changing those components affects the HCBs.

The models are significant, as shown by the Model F-value of 2.73 in Table 4.5. There is a 0.29% possibility that a noise-related "Model F-Value" will occur. However, values greater than 0.1000 for models A, AB, C, A2, and B2 imply that the model terms are not significant in this situation, even though B is a substantial model term. The curing time has a marginally significant impact on the coefficient. Additionally, it was found that the loading ratio and the curing duration do not interact.

### 4.5.2. Diagnostic test for the responses/Normal Probability plot

For model sufficiency for all responses, some diagnostic plots (such as the normal residual plot and the comparison of residuals to studentized residuals) are also looked at. The residuals' normal distribution and whether they therefore follow a straight line are displayed on the normal probability plot. Expect some scatter even with normal data. The graph therefore shows that the data is dispersed




regularly.

**Figure 4. 1**: Normal probability plot for experimental values for compressive strength

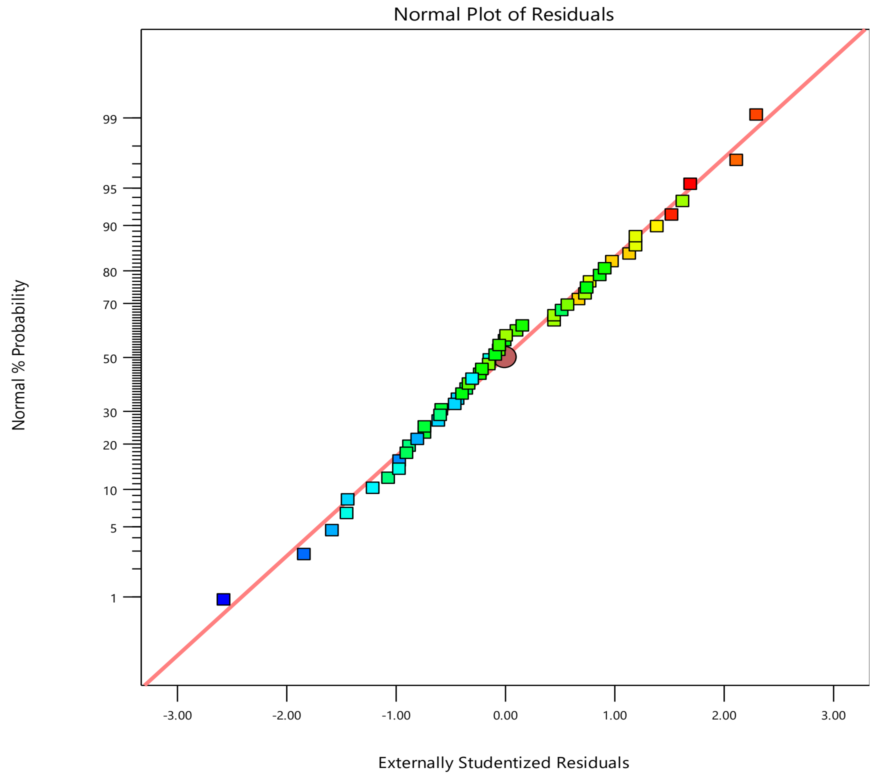



**Figure 4. 2**: Normal probability plot for experimental values for density

The residuals follow the normal% probability distribution, as illustrated by the normal probability plot, which is given below. The residual is the discrepancy between the actual experiment results and the results anticipated by the software. Plotted points for the experimental data in Figures 4.1 and 4.2 show a straight line's fit to the conducted experiment data, supporting the linear model's compliance with the analysis of variance (ANOVA), and showing that the error distribution is roughly normal.

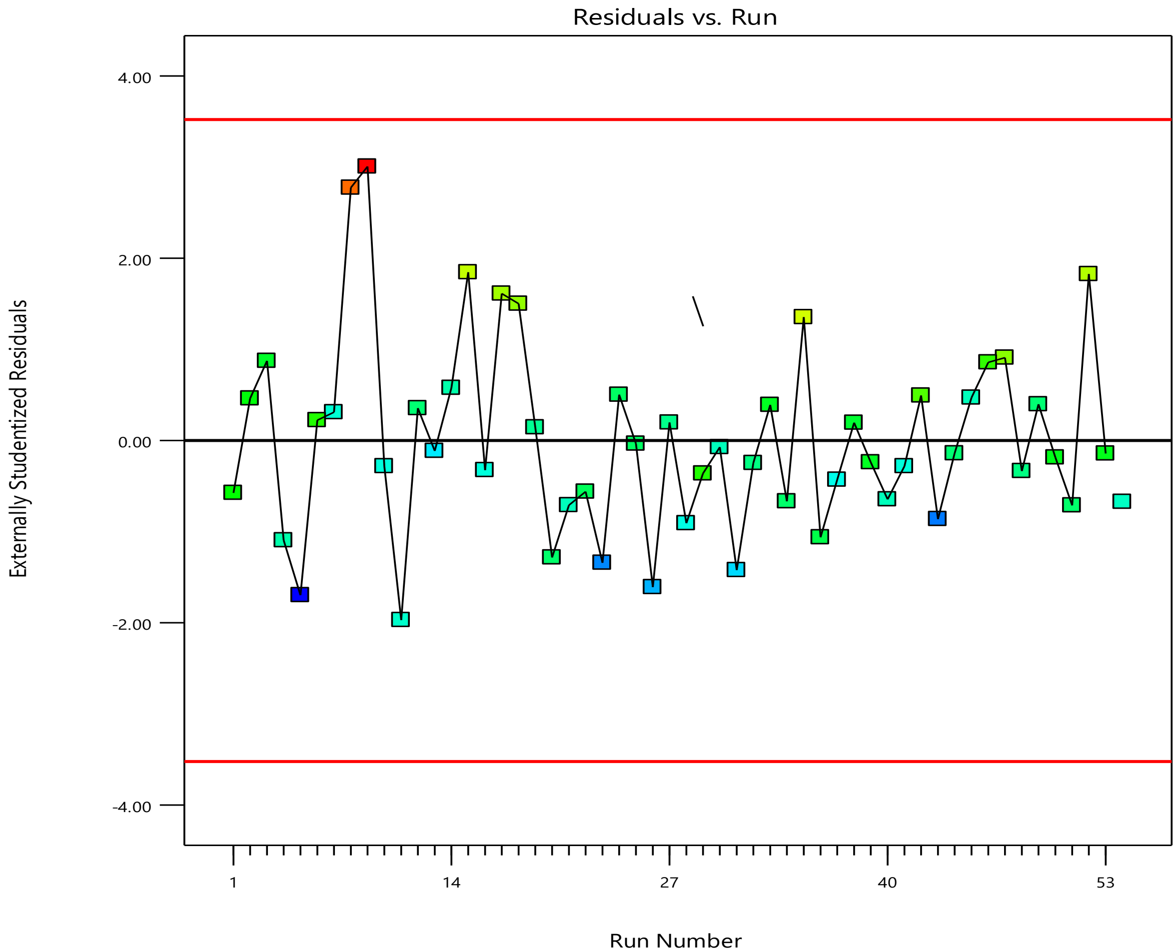



**Figure 4. 3**: Residuals vs Run for Compressive strength

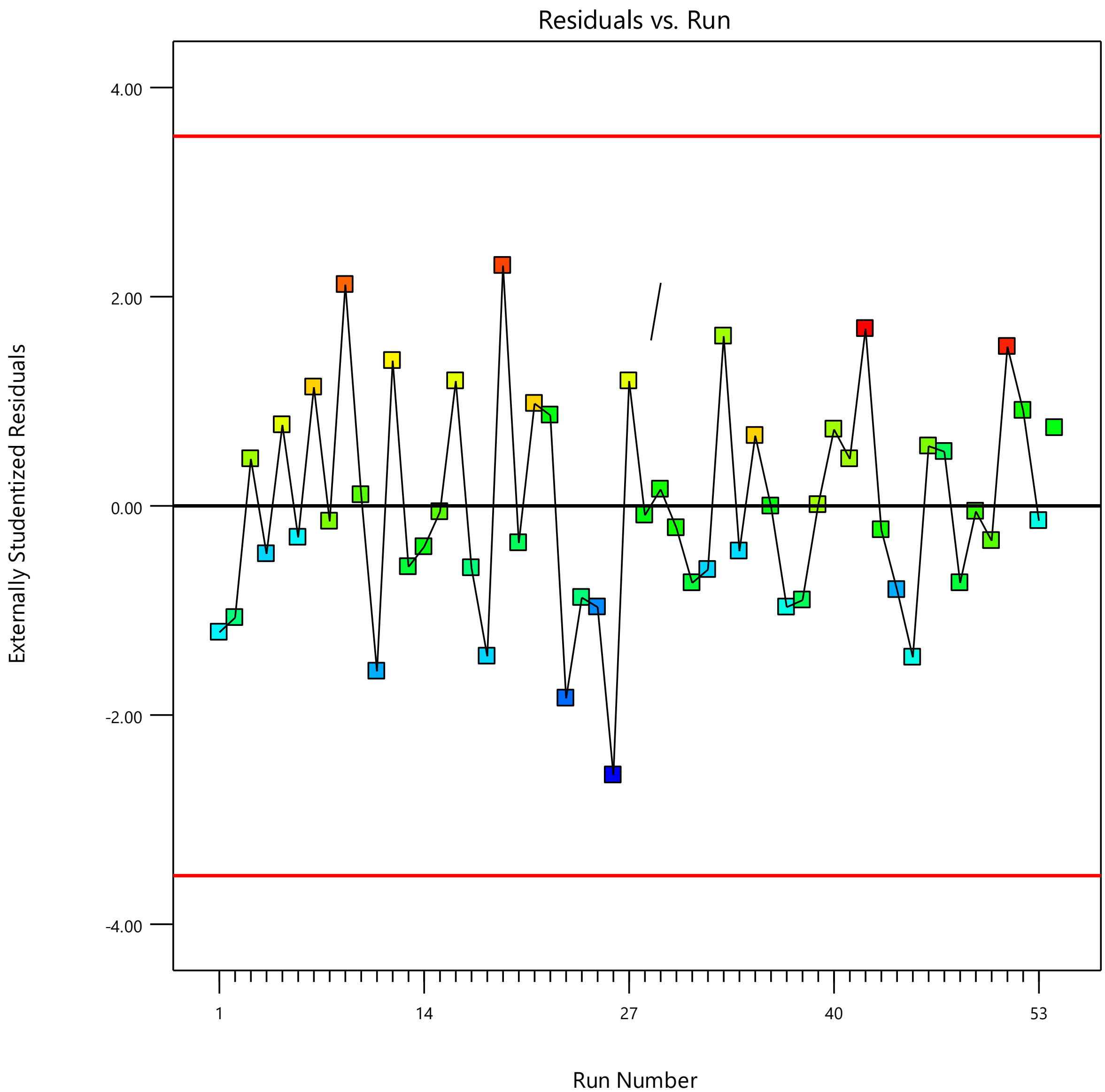



**Figure 4. 4**: Residuals vs Run for density

As seen in figures. 4.3 and 4.4, the observed points between residual and run number are used as tests for variables that might have influenced the response throughout the experiment.because there was a large range of experimental values both above and below the line. It shows how well the experiment run order was randomized, enabling one to have confidence in the model's forecasts and securely assess the model's coefficients. Compressive and density of HCB response variables are not simultaneously impacted by any factor.

## 4.6. Effect of Individual Parameters on compressive strength and density

Tables 4.4 and 4.5 show the impact of various factors on compressive strength and density. It has been noted that each element significantly affects the compressive strength of HCBs, however neither of the two parameters affects density. Curing time has a minor impact on density. Density reduces as cure time increases.

### 4.6.1. Effect of Bentonite Loading ratioon compressive strength and density

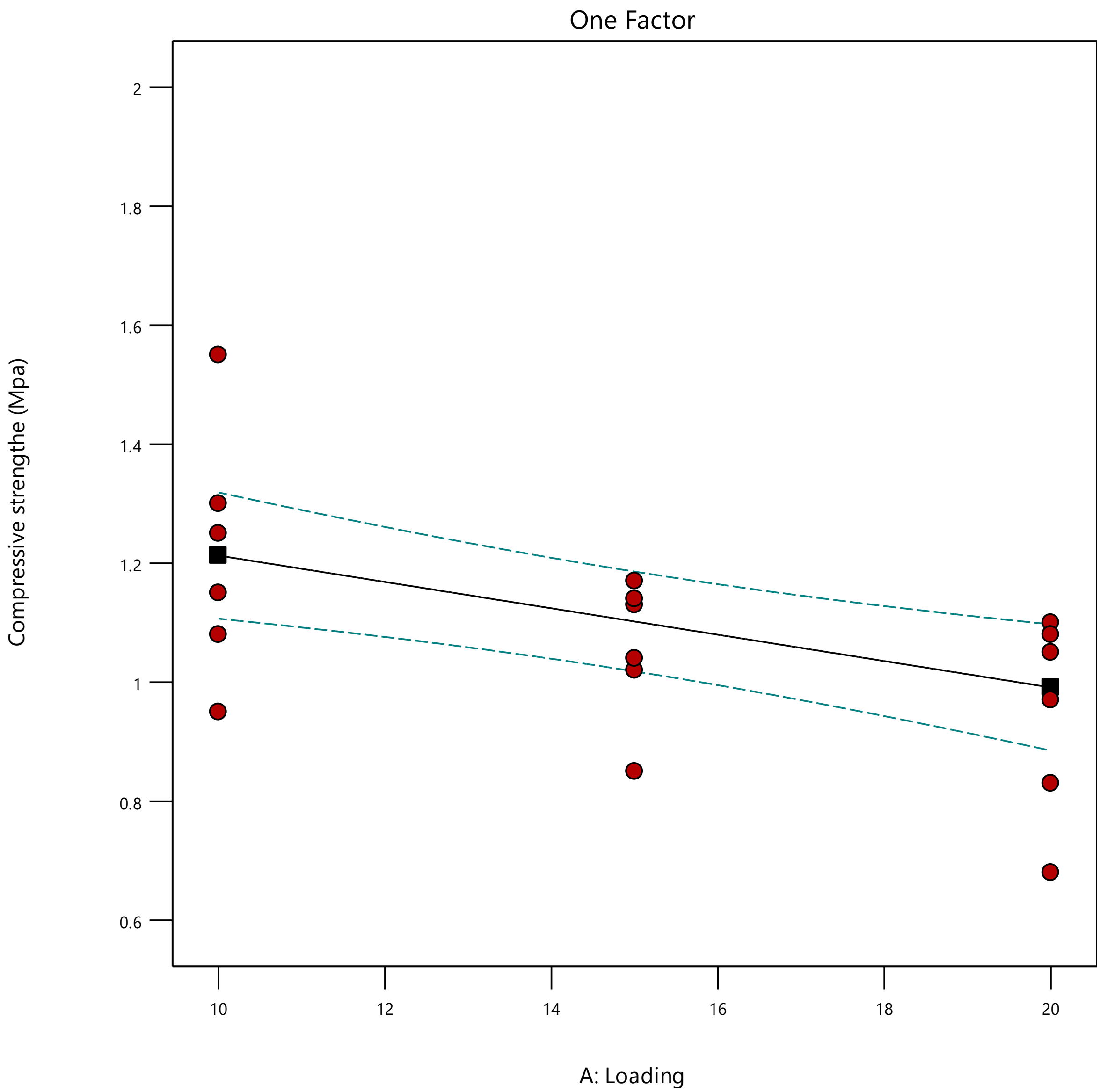



**Figure 4. 5:** Compressive strength and loading

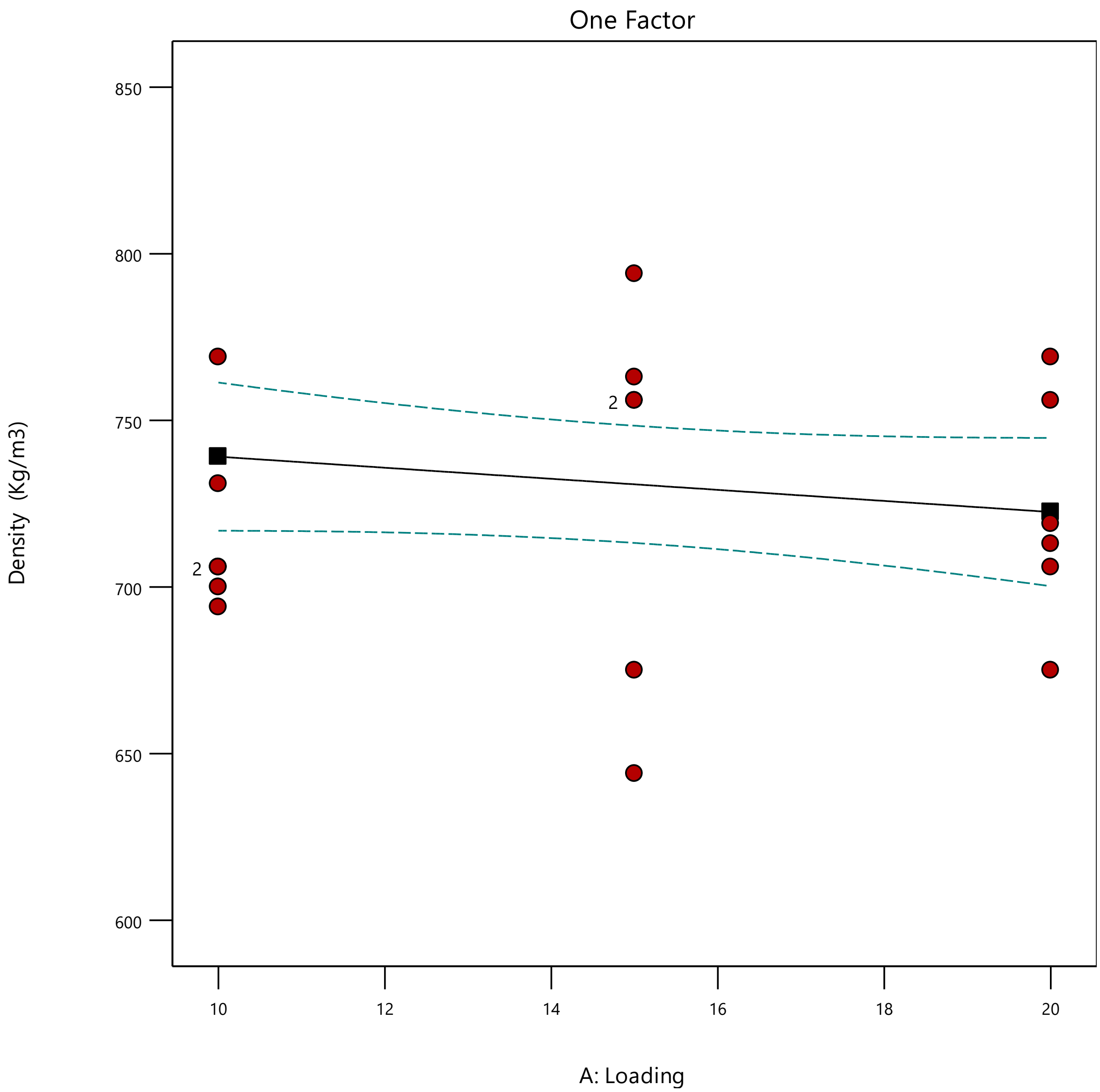



**Figure 4. 6**: Density and Loading ratio

The bentonite loading ratio has a detrimental impact on compressive strength, as demonstrated in Figure 4.5. The ratio of bentonite loading causes a reduction in compressive strength. It is clear from figure 4.6 that the loading ratio has no bearing on the density of HCB.

The performance of bentonite may vary depending on the quality and pretreatment since bentonite has varying quality and varieties based on physical and chemical properties. Concrete bonds better thanks to bentonite.

The process through which water interacts with cement, bentonite, and concrete is referred to as hydration. Several factors, such as the water cementitious materials ratio, additional cementitious materials, usage of admixtures, curing time, cement type, etc., affect the density and compressive strength of concrete cement paste(Gedik and Atmaca 2023). Bentonite concrete has been found to be more porous (has more voids), which results in it becoming less dense and compressive as its volume rises. The findings show that bentonite blends can replace conventional Portland cement up to a specific limit since clay content, when present in any concrete mix, negatively affects the concrete's compressive strength(Kumar 2021). To achieve the desired and acceptable compressive strength, no more than 20% of cement should be substituted. Lowest compressive strength due to spaces in the interior of the concrete cubes that are filled by the bentonite-cement gel (since bentonite swells when mixed with water), which expands in the voids and decreases the cohesiveness between particles. The low compressive strength measurements can potentially have been caused by the increased aggregate-cement ratio's increased workability and inadequate compaction. These characteristics arise from the capacity of clay materials to hold water for an extended amount of time in their pores, which is bad for compressive strength since it makes concrete brittle when squeezed or sheared.(Xie et al. 2018).

### 4.6.2 Effect of curing time compressive strength and density

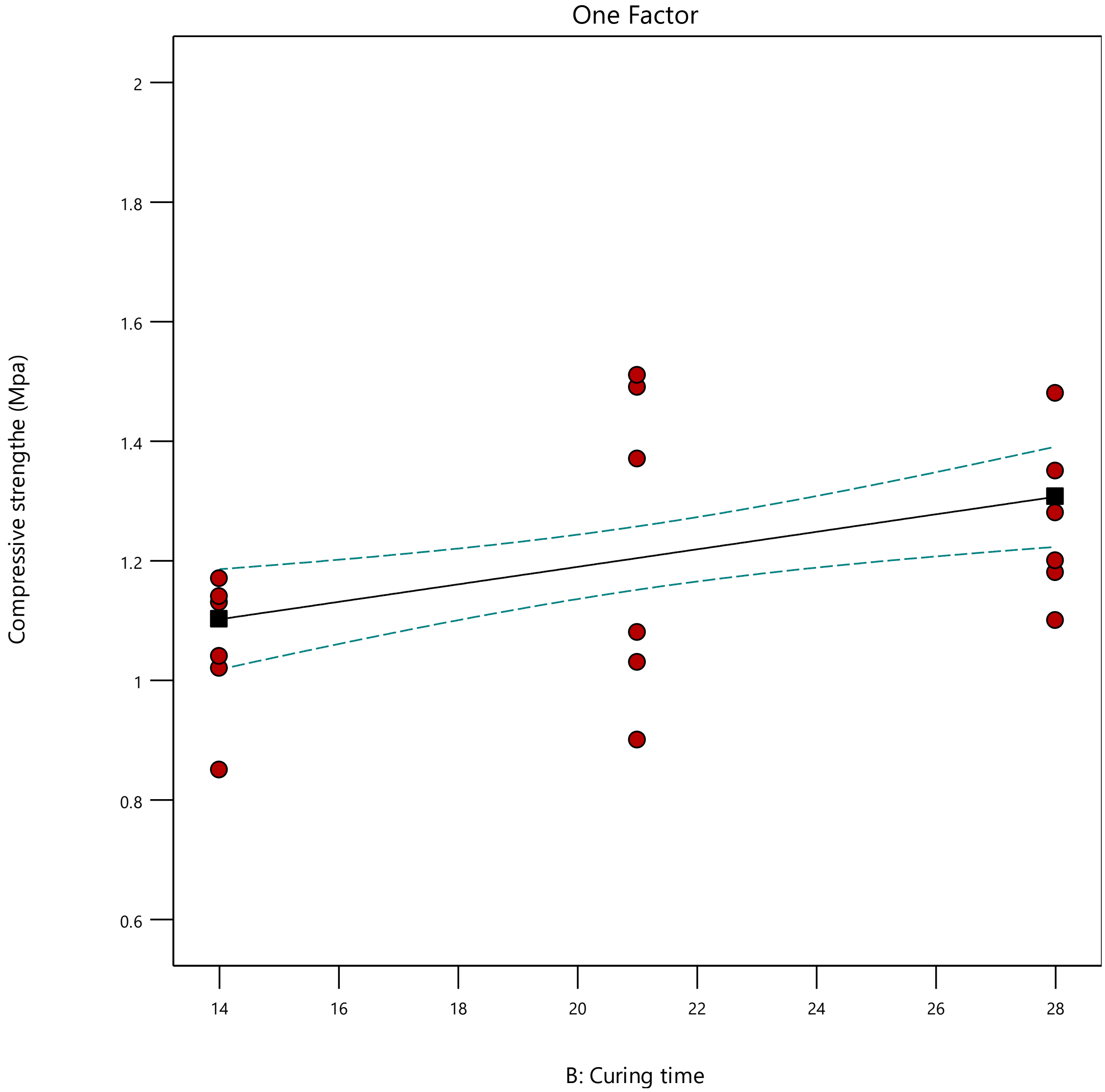



**Figure 4. 7**: Compressive Strength (MPa) and curing time (days)

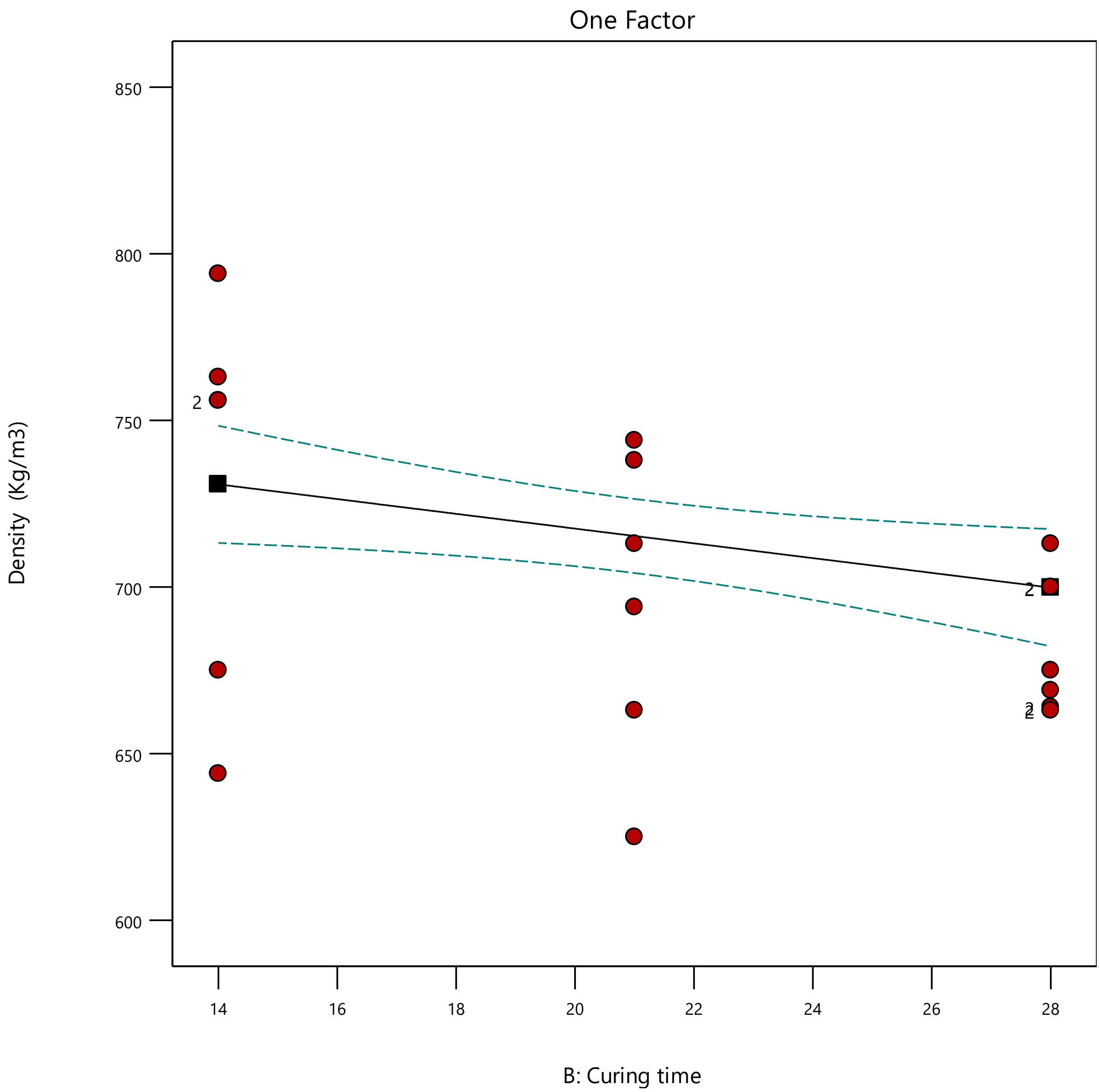



Figure 4.8: density and curing time

Figures 4.7 and 4.8 illustrate how curing time affects the compressive strength and density of HCB in opposite ways. While density will somewhat decrease as curing time increases, compressive strength will increase.

Curing, a procedure to improve cement hydration, involves managing the temperature and moisture transport into and out of the concrete. Concrete's density and compressive strength are significantly influenced by how the curing process is applied. The main effects of the hydration process include increased strength and durability. The mass ratio of free water to cementitious material in a concrete mix is known as the water-cement ratio (W/C)(Zaki, Hodhod, and Eid 2022).

According to the results of this experiment, compressive strength and density rise with time while decreasing with bentonite loading ratio. The density will decrease as the curing period increases because the weight of the block concrete will vanish when the moisture from the concrete is removed.

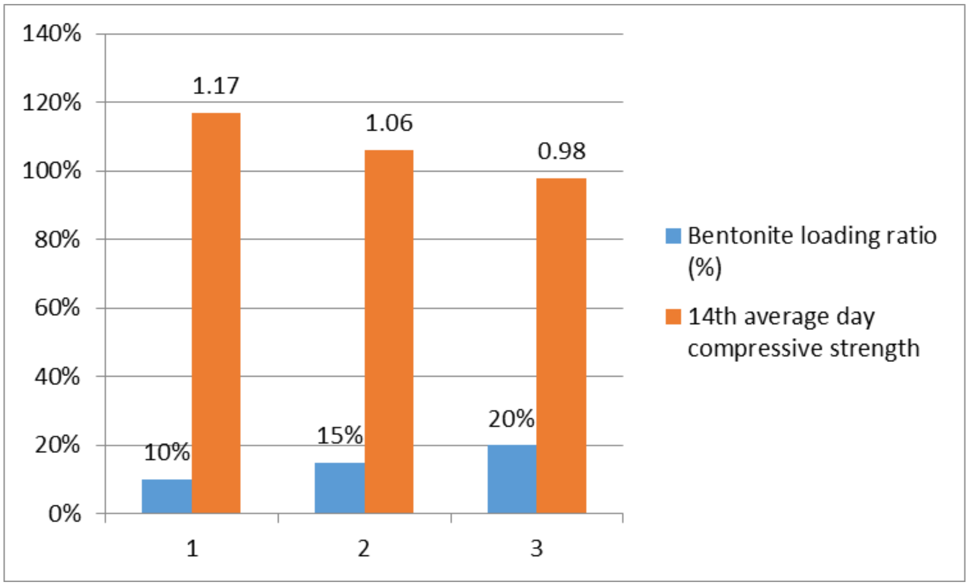



Figure 4. 9: Compressive strength at age 14$^{th}$ day

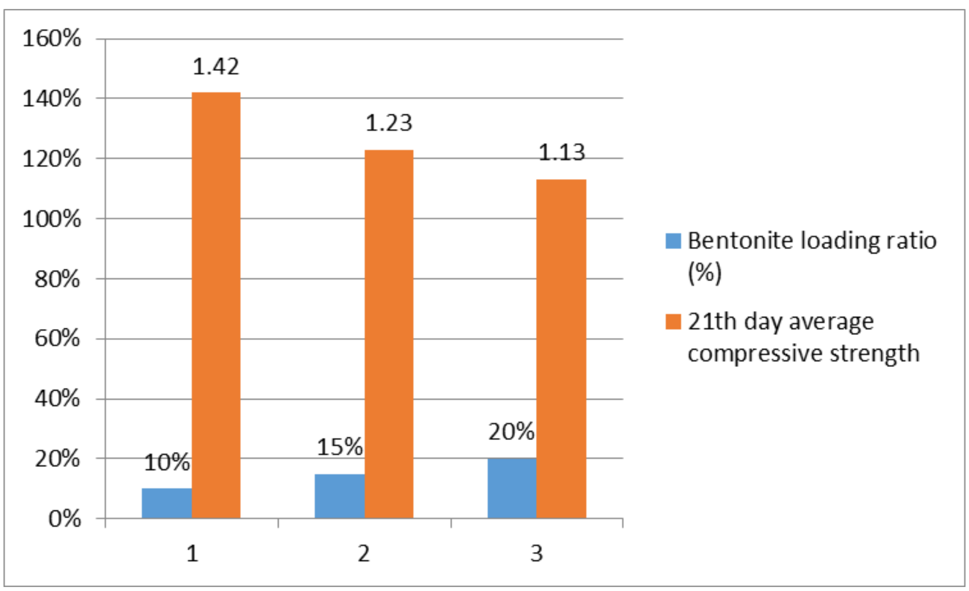



Figure 4. 10: Compressive strength at age 21$^{th}$ day

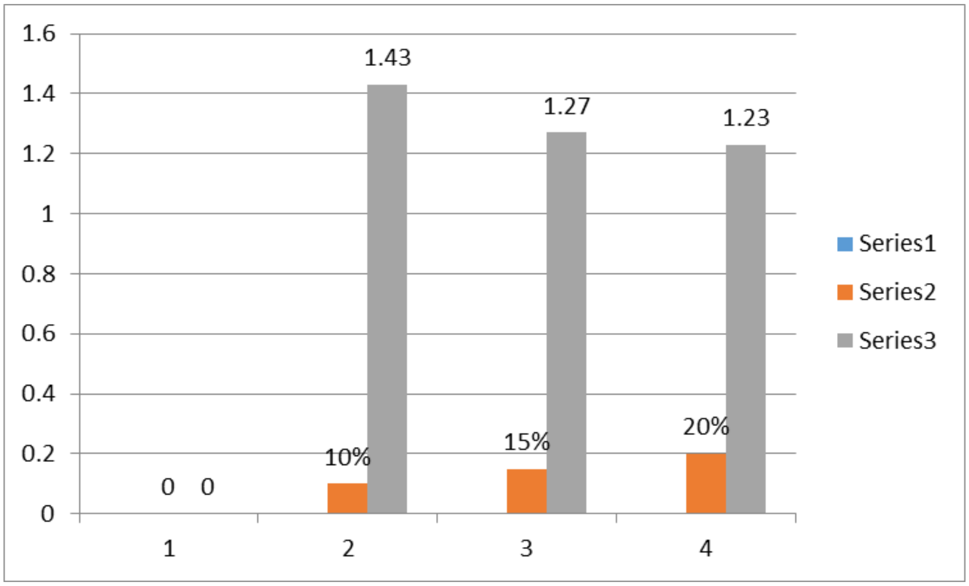



Figure 4. 11. Compressive strength at age 28th day

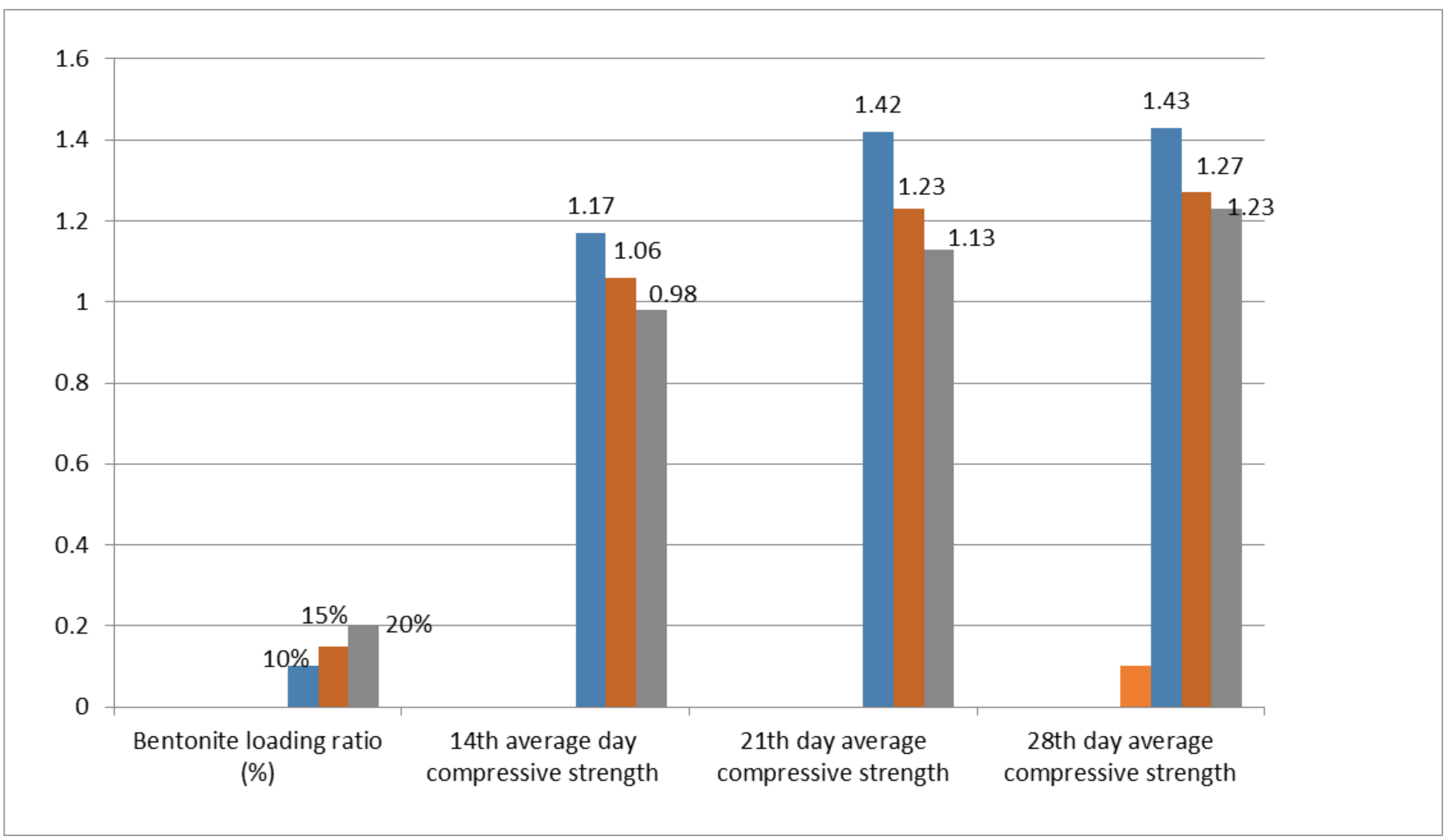



Figure 4. 12: Compressive strength test at age 14, 21 and 28th days

#### 4.6.3 Comparative Compressive strength with loading ratio and curing time

The compressive strength of hollow concrete blocks loaded with 10%, 15%, and 20% bentonite is compared on days 14, 21, and 28. In this investigation, the compressive strength of bentonite-containing blocks varied after 14, 21, and 28 days.

The compressive strength of each kind of block grew over time. After 28 days, a 10% bentonite replacement yielded the strongest results, followed by 15% and 20% bentonite loading ratios. The third finding is that, for different bentonite replacement percentages, there exist connections between the compressive strength at 14, 21, and 28 days. This outcome is consistent with a 2019 Chinese study that found that the sample with 10% bentonite had a higher compressive strength than the other samples (Luo, 2019).

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The purpose of this research is to investigate and evaluate the impact of using a relatively inexpensive clay material (bentonite) as a cement replacement in the production of HCBs. The curing and compressive strength of HCBs have been prioritized in the process by varying the amount of cement and bentonite as major constituents in three ways (10kg bentonite replacing 10kg cement, 15kg bentonite replacing 15kg cement, and 20kg bentonite replacing 20kg cement for a single batch/64 HCBs). All HCB samples were made with 0.84 m3 pumice and 40 liters of water.

Furthermore, silicate analysis (chemical composition) and physical properties of Chacha clay (bulk density, moisture content, and free swell test) were performed. Standard compressive strength tests were performed on HCBs using the (CES24:2013) method, with six sample replicates and an average result on a total of 54 tests for ages 14, 21, and 28. With 10%, 15%, and 20% bentonite replacement, the average compressive strength ($N/mm^2$) at 28 days was 1.43, 1.27, and 1.23, respectively.

Both bentonite and curing time have a significant effect on the compressive strength of hollow blocks, according to the study's findings. The loading ratio has a greater impact on bentonite compressive strength. In its natural state, bentonite cannot be used as a partial cement replacement in non-load bearing concrete type C. HCB tests with up to 10% bentonite replacement performed poorly at 14 days but very well at 28 days. The maximum bentonite replacement allowed to meet the required strength is 10%.

Additionally, the compressive strength test results show that with consistent bentonite replacement, the strength value decreases from 10% to 20%, with the highest value recorded at 10% bentonite replacement. The compressive strength increases with increasing curing time but decreases with increasing bentonite loading ratio. The compressive strength of HCBs is found to increase with curing age while decreasing with bentonite loading ratio. Generally, a 10% bentonite replacement obtained the highest strength value at 28 days, followed by a 15% bentonite loading ratio and a 20% bentonite loading ratio. This result also matches with earlier study done 2019 in china that conclude the sample containing 10% bentonite got a higher compressive strength than the other samples (Luo 2019).

## 5.2 Recommendations

Following the study's conclusion, recommendations were made to the appropriate bodies based on the findings.

- Because the construction industry relies heavily on natural resources such as cement, which can lead to resource depletion, the culture of using locally available materials as an input for the construction industry should be improved.
- The climate, calcinations, and further processing of the experiment must be performed to improve the strength of concrete, and these factors are observed.
- It is preferable if it is repeated with different mixing ratios, wetter to cement ratios, and aggregates in addition to pumice.
- It is more desirable to repeat the experiment with a different cement type and PPC.

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# APPENDIX

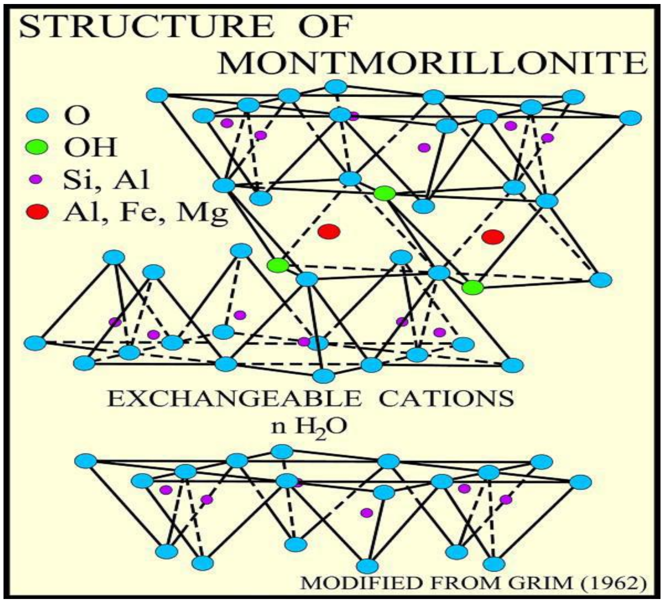



**Figure 2. 2**: Structure of montmorillonite

*{Source:* (Grim, 1962)*}*

The physical and chemical composition Derba cement is illustrated in Table 3 and 4 respectively.

**Table 3. 2**: Physical properties of Derba cement

| **Properties** | **Cement** |
|---|---|
| Moisture content ( % ) | Less than 0.5% |
| Specific Gravity | 3.1 |
| Bulk Density ( kg/m3) | 1540 |
| Fineness ( m2/kg) | 15% at 45 micron |
| pH | 12-13 |

*(Source: Derba cement factory Laboratory Result)*

**Table 3. 3**: Chemical composition of Derban cement

| **Oxide** | **Content (%)** |
|---|---|
| CaO | 60.95 |
| $SiO_2$ | 21.29 |
| $Al_2O_3$ | 5.55 |
| $Fe_2O_3$ | 3.52 |
| MgO | 1.94 |
| $SO_3$ | 2.5 |
| $K_2O$ | 0.45 |
| Na20 | 0.15 |
| Cl | 0.09 |
| **$CaO+SiO^2+Al_2O_3+Fe_2O_3$** | **Total= 91.3 %** |

*(Source: Derba cement factory Laboratory Result)*

The test result is presented in the table below.

**Table 3. 4:** Physical Test Results

| **No** | **Conducted Test** | **Sample used** | **Average Value** |
|---|---|---|---|
| 1 | Bulk Density | 200gm | 1.23 |
| 2 | Moisture Content | 72gm | 31.61% |
| 3 | Free Swell | 30ml | 25% (Degree of swelling in) |
| 3 | Plastic Limit | ND | |
| 4 | Liquid Limit | ND | |

*(Source: Geological Survey of Ethiopia; Mineralogy and Geotechnical Laboratory Result)*

Table 3.4: Chemicals Test Results

| **Collector code** | **Lab No** | **$SiO_2$** | **$Fe_2O_3$** | **Cao** | **Mgo** | **$Na_20$** | **$K_20$** | **$H_2O$** | **LOI** |
|---|---|---|---|---|---|---|---|---|---|
| **ICP-01/23** | **072/23** | 70.01 | 7.69 | 0.55 | 1.79 | 0.99 | 1.12 | 8.14 | 3.76 |
| **CIP-01/23** | 073/23 | 78.2 | 8.36 | 0.31 | 1.1 | 1.38 | 1.03 | 4.45 | 5.34 |
| **ECB-003/23** | **074/23** | 75.55 | 8.66 | 0.3 | 1.43 | 0.67 | 0.56 | 4.56 | 7 |
| **CFC-04/23** | 075/23 | 74.59 | 8.12 | 0.34 | 1.59 | 0.59 | 0.57 | 5.19 | 5.9 |
| **ICP03/23** | **076/23** | 72.77 | 8.31 | 0.4 | 1.56 | 0.81 | 0.84 | 4.53 | 10.85 |
| **ECB-001/23** | **077/23** | 73.9 | 5.84 | 0.17 | 1.46 | 0.58 | 0.92 | 7.18 | 5.84 |
| **SC-006/23** | 078/23 | 64.75 | 8.1 | 0.25 | 1.63 | 0.7 | 0.72 | 10.14 | 4.58 |
| **ESB-002/23** | **079/23** | 63.03 | 8.78 | 0.2 | 1.5 | 0.43 | 0.45 | 8.02 | 6.53 |
| **TC-002/23** | 080/23 | 72.98 | 5.45 | 0.43 | 2.16 | 0.34 | 0.33 | 9.07 | 3.85 |
| **CP-13/23** | 081/23 | 78.4 | 5.88 | 0.35 | 2 | 1.74 | 1.6 | 4.74 | 2.99 |
| **CFTP-04/23** | **082/23** | 68.59 | 7.27 | 0.19 | 2.53 | 0.35 | 1.01 | 6.49 | 6.18 |
| **CTP-2/23** | **083/23** | 75.8 | 5.64 | 0.21 | 2 | 0.48 | 0.73 | 6.49 | 4.91 |
| **CTP-2/23** | **084/23** | 65.62 | 4.54 | 0.34 | 2.15 | 0.42 | 0.56 | 8.81 | 4.45 |
| **CTP-1/23** | **085/23** | 72.32 | 2.72 | 0.2 | 1.77 | 1.17 | 0.37 | 6.41 | 7.64 |
| **CTP-03/23** | **086/23** | 72.41 | 3.85 | 0.18 | 2.06 | 0.37 | 0.66 | 7.33 | 7.54 |
|  | **072/23D** | 69.69 | 8.26 | 0.46 | 1.72 | 0.91 | 1.16 | 8.11 | 3.72 |
|  | **080/23D** | 73.79 | 5.16 | 0.5 | 2.11 | 0.33 | 0.43 | 8.79 | 4.21 |
|  | **Average** | **71.90** | **6.62** | **0.48** | **1.79** | **0.72** | **0.76** | **6.96** | **5.60** |

*[Source:Midroc geo exploration service PLC]*

The analysis of this result will be discussed in detail under chapter 4.

**Table 3. 5**: Total number of hollow concrete blocks sample required

| % of Bentonite | For Compressive Strength test | | | | | | For reserved | Total sum |
|---|---|---|---|---|---|---|---|---|
| | 14th Day | | 21th Day | | 28th Day | | | |
| | Test 1 | Reserve | T1 | Reserve | Test | Reserve | | |
| 10 | 6 | 6 | 6 | 6 | 6 | 6 | 36 | |
| 15 | 6 | 6 | 6 | 6 | 6 | 6 | 36 | |
| 20 | 6 | 6 | 6 | 6 | 6 | 6 | 36 | |
| | | | | | | | Total | 108 |

**Table 3. 6**: Experimental procedures

| Type of Experiment RP-run procedures | | | |
|---|---|---|---|
| | **First Run procedures(RP-1)** | **Second Run procedures( RP-2)** | **Third Run procedures ( RP-3)** |
| | Mix 0.84 $m^3$ pumice, 90% cement and 10% bentonite and 40-liter water at each age i.e. 14, 21 and 28 days. | Mix 0.84 $m^3$ pumice, 85% cement and 15% bentonite and 40-liter water at each age i.e. 14, 21 and 28 days. | Mix 0.84 $m^3$ pumice, 80% cement and 20% bentonite and 40-liter water at each age i.e. 14, 21 and 28 days. |

**Table 3. 7**: Compressive strength of HCB with different percentage of Bentonite

| Average Compressive Strength of Hollow Concrete Block (Mpa) | | | | |
|---|---|---|---|---|
| Compressive Strength | Bentonite loading ratio (%) | 10% | 15% | 20% |
| | 14th average day compressive strength | 1.17 | 1.07 | 0.98 |

| | | | | |
|---|---|---|---|---|
| | 21th day average compressive strength | 1.42 | 1.23 | 1.13 |
| | 28th day average compressive strength | 1.43 | 1.27 | 1.23 |

**Table 4.1**: Response: density

| Source | Squares | DF | Mean | F | p | |
|---|---|---|---|---|---|---|
| **Model** | 21195.44 | 5 | 4239.09 | 2.73 | 0.0299 | significant |
| A-Loading | 2483.36 | 1 | 2483.36 | 1.60 | 0.2120 | |
| B-Curing time | 8649.00 | 1 | 8649.00 | 5.57 | 0.0224 | |
| AB | 726.00 | 1 | 726.00 | 0.4678 | 0.4973 | |
| $A^2$ | 4294.08 | 1 | 4294.08 | 2.77 | 0.1028 | |
| $B^2$ | 5043.00 | 1 | 5043.00 | 3.25 | 0.0777 | |
| **Residual** | 74498.56 | 48 | 1552.05 | | | |
| Lack of Fit | 9417.22 | 3 | 3139.07 | 2.17 | 0.1046 | not significant |
| Pure Error | 65081.33 | 45 | 1446.25 | | | |
| **Cor Total** | 95694.00 | 53 | | | | |

**Table 4. 2**: Physical Test Results and Standard acceptable range

| No | Conducted Test | Sample used | Average Value | Acceptable range |
|---|---|---|---|---|
| 1 | Bulk Density | 200gm | 1.23 $gm/cm^3$ | 2-3 gm/cm3 |
| 2 | Moisture Content | 72gm | 31.61 % | Up to 40% |
| 3 | Free Swell | 30ml | 25% (Degree of swelling in) | 24ml-36 ml in % with degree of swelling in |
| 4 | Plastic Limit | | ND | |

| | | | | |
|---|---|---|---|---|
| 5 | Liquid Limit | | ND | |

**Table 4. 3**: Average compressive strength test result

| **Average Compressive Strength Of Hollow Concrete Block ( Mpa )** | | | | |
|---|---|---|---|---|
| Compressive Strength | **Bentonite loading ratio (%)** | **10%** | **15%** | **20%** |
| | 14th day average compressive strength | 1.17 | 1.07 | 0.98 |
| | 21th day average compressive strength | 1.42 | 1.23 | 1.13 |
| | 28th day average compressive strength | 1.43 | 1.27 | 1.23 |

**Table 4. 4**: Compressive strength of HCB with different percentage of Bentonite

| **Average Compressive Strength Of Hollow Concrete Block ( Mpa )** | | | | |
|---|---|---|---|---|
| Compressive Strength | **Bentonite loading ratio (%)** | **10%** | **15%** | **20%** |
| | 14th day average compressive strength | 1.17 | 1.07 | 0.98 |
| | 21th day average compressive strength | 1.42 | 1.23 | 1.13 |
| | 28th day average compressive strength | 1.43 | 1.27 | 1.23 |

## A. Chemical test result of Bentonite (Major Oxide)

Ethiopian mineral petroleum and bio fuel corporation
Laboratory service center

Form G0003

E-mail -emindvt@telecom.net.et | 011-6-613355 | ADDIS ABABA

Major Oxide Report Format | box 2543

FILE ID:-072/23pvt | Originator:-Midroc Geo-Exploration Survice PLC

Sample type:-Rock | Date submmitted:-Jan/31/2023

Preparation: -200 mesh | **Element to be determined :-Major Oxide**

NUMBER OF SAMPLES: 15

Analytical Method:-Fusion, AAS & Gravimeric Analysis

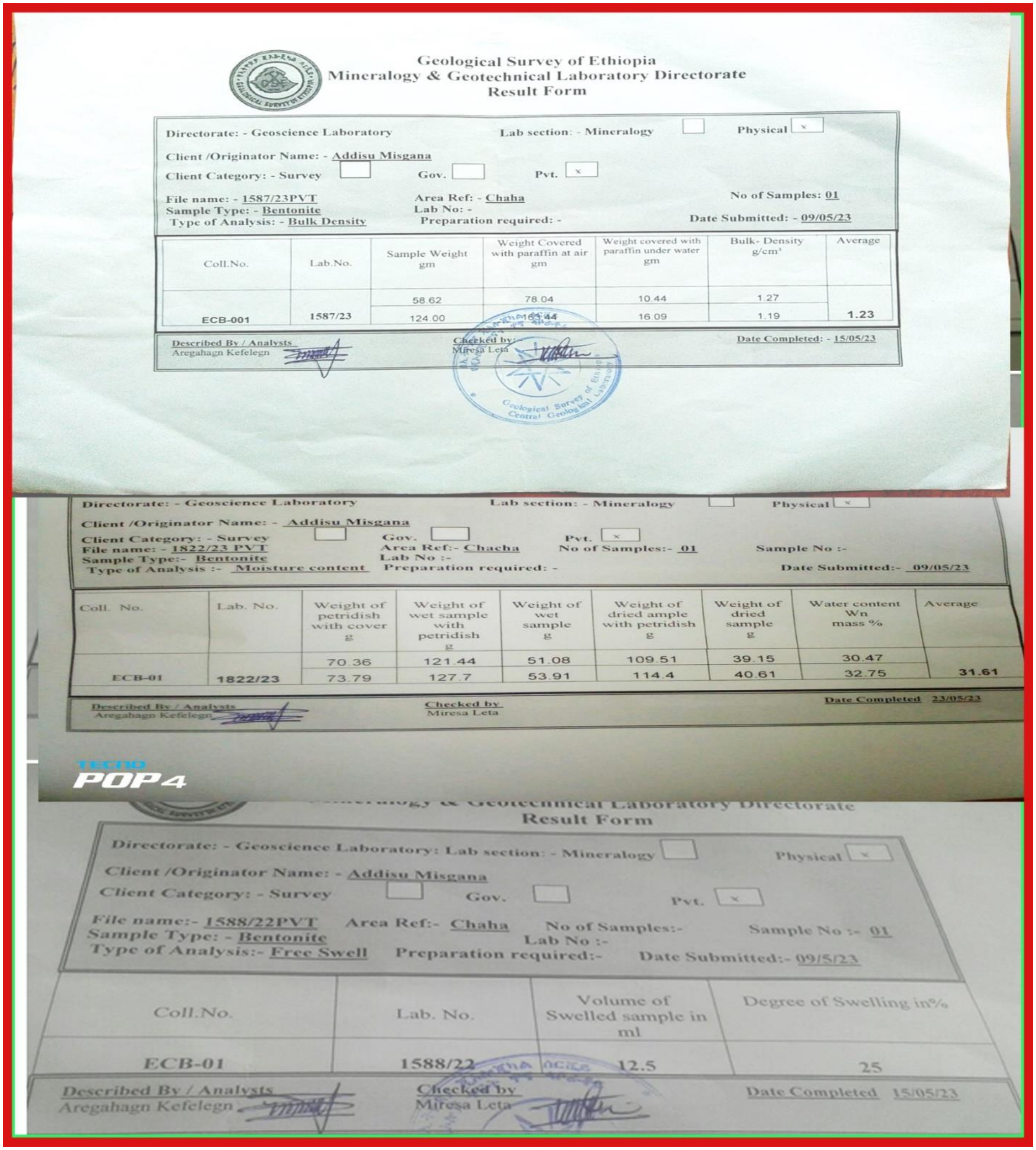
Analytical Results in %

| Field No | Lab No | $SiO_2$ | $Fe_2O_3$ | CaO(%) | MgO(%) | $Na_2O$(%) | $K_2O$(%) | $H_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|---|
| ICP-01/23 | 072/23 | 70.01 | 7.69 | 0.55 | 1.79 | 0.99 | 1.12 | 8.14 | 3.76 |
| CIP-01/23 | 073/23 | 78.20 | 8.36 | 0.31 | 1.10 | 1.38 | 1.03 | 4.45 | 5.34 |
| ECB-003/23 | 074/23 | 75.55 | 8.66 | 0.30 | 1.43 | 0.67 | 0.56 | 4.56 | 7.00 |
| CFC-04/23 | 075/23 | 74.59 | 8.12 | 0.34 | 1.59 | 0.59 | 0.57 | 5.19 | 5.90 |
| ICP03/23 | 076/23 | 72.77 | 8.31 | 0.40 | 1.56 | 0.81 | 0.84 | 4.53 | 10.85 |
| ECB-001/23 | 077/23 | 73.90 | 5.84 | 0.17 | 1.46 | 0.58 | 0.92 | 7.18 | 5.84 |
| SC-006/23 | 078/23 | 64.75 | 8.10 | 0.25 | 1.63 | 0.70 | 0.72 | 10.14 | 4.58 |
| ESB-002/23 | 079/23 | 63.03 | 8.78 | 0.20 | 1.50 | 0.43 | 0.45 | 8.02 | 6.53 |
| TC-002/23 | 080/23 | 72.98 | 5.45 | 0.43 | 2.16 | 0.34 | 0.33 | 9.07 | 3.85 |
| CP-13/23 | 081/23 | 78.40 | 5.88 | 0.35 | 2.00 | 1.74 | 1.60 | 4.74 | 2.99 |
| CFTP-04/23 | 082/23 | 68.59 | 7.27 | 0.19 | 2.53 | 0.35 | 1.01 | 6.49 | 6.18 |
| CTP-2/23 | 083/23 | 75.80 | 5.64 | 0.21 | 2.00 | 0.48 | 0.73 | 6.49 | 4.91 |
| CTP-2/23 | 084/23 | 65.62 | 4.54 | 0.34 | 2.15 | 0.42 | 0.56 | 8.81 | 4.45 |
| CTP-1/23 | 085/23 | 72.32 | 2.72 | 0.20 | 1.77 | 1.17 | 0.37 | 6.41 | 7.64 |
| CTP-03/23 | 086/23 | 72.41 | 3.85 | 0.18 | 2.06 | 0.37 | 0.66 | 7.33 | 7.54 |
| | 072/23D | 69.69 | 8.26 | 0.46 | 1.72 | 0.91 | 1.16 | 8.11 | 3.72 |
| | 080/23D | 73.79 | 5.16 | 0.50 | 2.11 | 0.33 | 0.43 | 8.79 | 4.21 |

Analysts Checked By | Approved by | Date Reroted

Kabtamu T | Worede Sahilu | Feb/28/2023

## B. Physical test result of Bentonite (Moisture Content, Free Swell and Bulk Density)



Geological Survey of Ethiopia
Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Geoscience Laboratory | Lab section: - Mineralogy | Physical ×
Client /Originator Name: - Addisu Misgana
Client Category: - Survey | Gov. | Pvt. ×
File name: - 1587/23PVT | Area Ref: - Chaha | No of Samples: 01
Sample Type: - Bentonite | Lab No: -
Type of Analysis: - Bulk Density | Preparation required: - | Date Submitted: - 09/05/23

| Coll.No. | Lab.No. | Sample Weight gm | Weight Covered with paraffin at air gm | Weight covered with paraffin under water gm | Bulk- Density g/cm³ | Average |
|---|---|---|---|---|---|---|
| | | 58.62 | 78.04 | 10.44 | 1.27 | |
| ECB-001 | 1587/23 | 124.00 | 163.44 | 16.09 | 1.19 | 1.23 |

Described By / Analysts
Aregahagn Kefelegn
Checked by:
Miresa Leta
Date Completed: - 15/05/23

Directorate: - Geoscience Laboratory | Lab section: - Mineralogy | Physical ×
Client /Originator Name: - Addisu Misgana
Client Category: - Survey | Gov. | Pvt. ×
File name: - 1822/23 PVT | Area Ref:- Chacha | No of Samples:- 01 | Sample No :-
Sample Type:- Bentonite | Lab No :-
Type of Analysis :- Moisture content | Preparation required: - | Date Submitted:- 09/05/23

| Coll. No. | Lab. No. | Weight of petridish with cover g | Weight of wet sample with petridish g | Weight of wet sample g | Weight of dried ample with petridish g | Weight of dried sample g | Water content Wn mass % | Average |
|---|---|---|---|---|---|---|---|---|
| | | 70.36 | 121.44 | 51.08 | 109.51 | 39.15 | 30.47 | |
| ECB-01 | 1822/23 | 73.79 | 127.7 | 53.91 | 114.4 | 40.61 | 32.75 | 31.61 |

Described By / Analysts
Aregahagn Kefelegn
Checked by
Miresa Leta
Date Completed 23/05/23

Mineralogy & Geotechnical Laboratory Directorate
Result Form

Directorate: - Geoscience Laboratory: Lab section: - Mineralogy | Physical ×
Client /Originator Name: - Addisu Misgana
Client Category: - Survey | Gov. | Pvt. ×
File name:- 1588/22PVT | Area Ref:- Chaha | No of Samples:- | Sample No :- 01
Sample Type: - Bentonite | Lab No :-
Type of Analysis:- Free Swell | Preparation required:- | Date Submitted:- 09/5/23

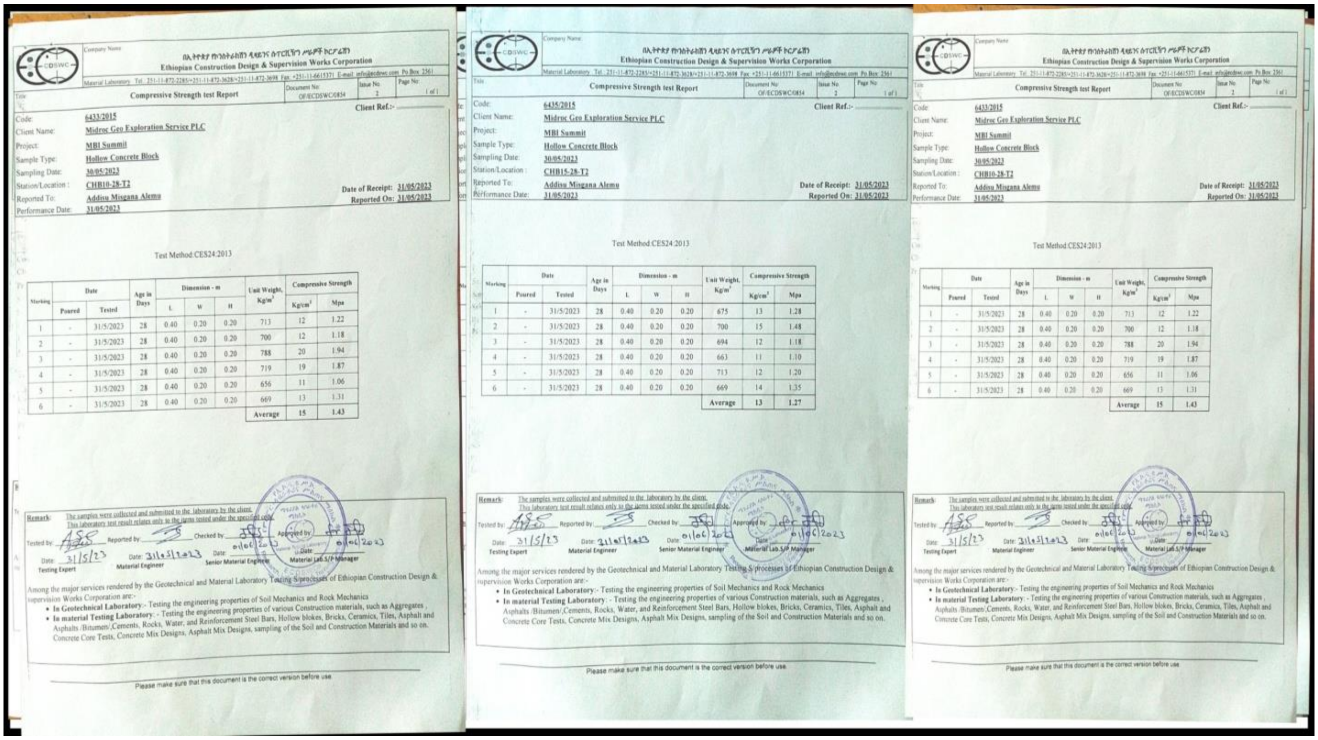
| Coll.No. | Lab. No. | Volume of Swelled sample in ml | Degree of Swelling in% |
|---|---|---|---|
| ECB-01 | 1588/22 | 12.5 | 25 |

Described By / Analysts
Aregahagn Kefelegn
Checked by
Miresa Leta
Date Completed 15/05/23

**C. Samples of compressive strength test result (MPa) for 14$^{th}$ day curing time.**

**D. Samples of compressive strength test result (MPa) for 21$^{th}$ day curing time**

**E. Samples of compressive strength test result (MPa) for 28$^{th}$ day curing time**



Company Name
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**Ethiopian Construction Design & Supervision Works Corporation**
Material Laboratory Tel.: 251-11-872-2285/+251-11-872-3628/+251-11-872-3698 Fax: +251-11-6615371 E-mail: info@ecdswc.com Po Box: 2561

Title: **Compressive Strength test Report** | Document No: OF/ECDSWC/0854 | Issue No: 2 | Page No: 1 of 1

Code: 6433/2015 **Client Ref.:-**
Client Name: Midroc Geo Exploration Service PLC
Project: MBI Summit
Sample Type: Hollow Concrete Block
Sampling Date: 30/05/2023
Station/Location : CHB10-28-T2
Reported To: Addisu Misgana Alemu **Date of Receipt: 31/05/2023**
Performance Date: 31/05/2023 **Reported On: 31/05/2023**

Test Method:CES24:2013

| Marking | Date | | Age in Days | Dimension - m | | | Unit Weight, $Kg/m^3$ | Compressive Strength | |
|---|---|---|---|---|---|---|---|---|---|
| | Poured | Tested | | L | W | H | | $Kg/cm^2$ | Mpa |
| 1 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 713 | 12 | 1.22 |
| 2 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 700 | 12 | 1.18 |
| 3 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 788 | 20 | 1.94 |
| 4 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 719 | 19 | 1.87 |
| 5 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 656 | 11 | 1.06 |
| 6 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 669 | 13 | 1.31 |
| | | | | | | | **Average** | **15** | **1.43** |

**Remark:** The samples were collected and submitted to the laboratory by the client.
This laboratory test result relates only to the items tested under the specified code.

Tested by: ______ Reported by: ______ Checked by: ______ Approved by: ______
Date: 31/5/23 Date: 31/05/2023 Date: 01/06/2023 Date: 01/06/2023
Testing Expert | Material Engineer | Senior Material Engineer | Material Lab.S/P Manager

Among the major services rendered by the Geotechnical and Material Laboratory Testing S/processes of Ethiopian Construction Design & supervision Works Corporation are:-

- **In Geotechnical Laboratory**:- Testing the engineering properties of Soil Mechanics and Rock Mechanics
- **In material Testing Laboratory**: - Testing the engineering properties of various Construction materials, such as Aggregates , Asphalts /Bitumen/,Cements, Rocks, Water, and Reinforcement Steel Bars, Hollow blokes, Bricks, Ceramics, Tiles, Asphalt and Concrete Core Tests, Concrete Mix Designs, Asphalt Mix Designs, sampling of the Soil and Construction Materials and so on.

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**Ethiopian Construction Design & Supervision Works Corporation**
Material Laboratory Tel.: 251-11-872-2285/+251-11-872-3628/+251-11-872-3698 Fax: +251-11-6615371 E-mail: info@ecdswc.com Po Box: 2561

Title: **Compressive Strength test Report** | Document No: OF/ECDSWC/0854 | Issue No: 2 | Page No: 1 of 1

Code: 6435/2015 **Client Ref.:-**
Client Name: Midroc Geo Exploration Service PLC
Project: MBI Summit
Sample Type: Hollow Concrete Block
Sampling Date: 30/05/2023
Station/Location : CHB15-28-T2
Reported To: Addisu Misgana Alemu **Date of Receipt: 31/05/2023**
Performance Date: 31/05/2023 **Reported On: 31/05/2023**

Test Method:CES24:2013

| Marking | Date | | Age in Days | Dimension - m | | | Unit Weight, $Kg/m^3$ | Compressive Strength | |
|---|---|---|---|---|---|---|---|---|---|
| | Poured | Tested | | L | W | H | | $Kg/cm^2$ | Mpa |
| 1 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 675 | 13 | 1.28 |
| 2 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 700 | 15 | 1.48 |
| 3 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 694 | 12 | 1.18 |
| 4 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 663 | 11 | 1.10 |
| 5 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 713 | 12 | 1.20 |
| 6 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 669 | 14 | 1.35 |
| | | | | | | | **Average** | **13** | **1.27** |

**Remark:** The samples were collected and submitted to the laboratory by the client.
This laboratory test result relates only to the items tested under the specified code.

Tested by: ______ Reported by: ______ Checked by: ______ Approved by: ______
Date: 31/5/23 Date: 31/05/2023 Date: 01/06/2023 Date: 01/06/2023
Testing Expert | Material Engineer | Senior Material Engineer | Material Lab.S/P Manager

Among the major services rendered by the Geotechnical and Material Laboratory Testing S/processes of Ethiopian Construction Design & supervision Works Corporation are:-

- **In Geotechnical Laboratory**:- Testing the engineering properties of Soil Mechanics and Rock Mechanics
- **In material Testing Laboratory**: - Testing the engineering properties of various Construction materials, such as Aggregates , Asphalts /Bitumen/,Cements, Rocks, Water, and Reinforcement Steel Bars, Hollow blokes, Bricks, Ceramics, Tiles, Asphalt and Concrete Core Tests, Concrete Mix Designs, Asphalt Mix Designs, sampling of the Soil and Construction Materials and so on.

Please make sure that this document is the correct version before use.

Company Name
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Material Laboratory Tel.: 251-11-872-2285/+251-11-872-3628/+251-11-872-3698 Fax: +251-11-6615371 E-mail: info@ecdswc.com Po Box: 2561

Title: **Compressive Strength test Report** | Document No: OF/ECDSWC/0854 | Issue No: 2 | Page No: 1 of 1

Code: 6433/2015 **Client Ref.:-**
Client Name: Midroc Geo Exploration Service PLC
Project: MBI Summit
Sample Type: Hollow Concrete Block
Sampling Date: 30/05/2023
Station/Location : CHB10-28-T2
Reported To: Addisu Misgana Alemu **Date of Receipt: 31/05/2023**
Performance Date: 31/05/2023 **Reported On: 31/05/2023**

Test Method:CES24:2013

| Marking | Date | | Age in Days | Dimension - m | | | Unit Weight, $Kg/m^3$ | Compressive Strength | |
|---|---|---|---|---|---|---|---|---|---|
| | Poured | Tested | | L | W | H | | $Kg/cm^2$ | Mpa |
| 1 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 713 | 12 | 1.22 |
| 2 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 700 | 12 | 1.18 |
| 3 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 788 | 20 | 1.94 |
| 4 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 719 | 19 | 1.87 |
| 5 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 656 | 11 | 1.06 |
| 6 | - | 31/5/2023 | 28 | 0.40 | 0.20 | 0.20 | 669 | 13 | 1.31 |
| | | | | | | | **Average** | **15** | **1.43** |

**Remark:** The samples were collected and submitted to the laboratory by the client.
This laboratory test result relates only to the items tested under the specified code.

Tested by: ______ Reported by: ______ Checked by: ______ Approved by: ______
Date: 31/5/23 Date: 31/05/2023 Date: 01/06/2023 Date: 01/06/2023
Testing Expert | Material Engineer | Senior Material Engineer | Material Lab.S/P Manager

Among the major services rendered by the Geotechnical and Material Laboratory Testing S/processes of Ethiopian Construction Design & supervision Works Corporation are:-

- **In Geotechnical Laboratory**:- Testing the engineering properties of Soil Mechanics and Rock Mechanics
- **In material Testing Laboratory**: - Testing the engineering properties of various Construction materials, such as Aggregates , Asphalts /Bitumen/,Cements, Rocks, Water, and Reinforcement Steel Bars, Hollow blokes, Bricks, Ceramics, Tiles, Asphalt and Concrete Core Tests, Concrete Mix Designs, Asphalt Mix Designs, sampling of the Soil and Construction Materials and so on.

Please make sure that this document is the correct version before use.

## F. Design Experiment data analysis result

### ANOVA for Linear model

**Response1: Compressive strength**

| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| **Model** | 0.8204 | 2 | 0.4102 | 10.89 | 0.0001 | significant |
| A-Loading | 0.4422 | 1 | 0.4422 | 11.74 | 0.0012 | |
| B-Curing time | 0.3782 | 1 | 0.3782 | 10.04 | 0.0026 | |
| **Residual** | 1.92 | 51 | 0.0377 | | | |
| Lack of Fit | 0.1491 | 6 | 0.0249 | 0.6309 | 0.7047 | not significant |
| Pure Error | 1.77 | 45 | 0.0394 | | | |
| **Cor Total** | 2.74 | 53 | | | | |

**Response 2: Density**

| Source | Sum of Squares | df | Mean Square | F-value | p-value | |
|---|---|---|---|---|---|---|
| **Model** | 21195.44 | 5 | 4239.09 | 2.73 | 0.0299 | significant |
| A-Loading | 2483.36 | 1 | 2483.36 | 1.60 | 0.2120 | |
| B-Curing time | 8649.00 | 1 | 8649.00 | 5.57 | 0.0224 | |
| AB | 726.00 | 1 | 726.00 | 0.4678 | 0.4973 | |
| $A^2$ | 4294.08 | 1 | 4294.08 | 2.77 | 0.1028 | |
| $B^2$ | 5043.00 | 1 | 5043.00 | 3.25 | 0.0777 | |
| **Residual** | 74498.56 | 48 | 1552.05 | | | |
| Lack of Fit | 9417.22 | 3 | 3139.07 | 2.17 | 0.1046 | not significant |
| Pure Error | 65081.33 | 45 | 1446.25 | | | |
| **Cor Total** | 95694.00 | 53 | | | | |

## G. Chacha Bentonite Sampling

**H. Experiment Sample preparation**

**I. HCB production process from mixing up to molding**

## I. Compressive strength lab test