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**ADDIS ABABA INSTITUTE OF TECHNOLOGY SCHOOL OF CIVIL AND**  
**ENVIRONMENTAL ENGINEERING**



**SOLID WASTE BOTTOM ASH AS A PARTIAL REPLACEMENT OF CEMENT IN**  
**CONCRETE PRODUCTION**

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**of AAiT in Partial Fulfillment of the Requirements for the Degree of Master of Science in**  
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## UNDERTAKING

I certify that research work titled “**Solid Waste Bottom Ash as a Partial Replacement of Cement in Concrete**” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

Samrawit Yeshaw

## ABSTRACT

Cement production is hazardous to the environment due to generation of high carbon dioxide (CO<sub>2</sub>) and heat. To reduce CO<sub>2</sub> emissions and protect the environment, researchers have found a wide variety of waste products that can be used as additional cementitious materials for concrete. The most common supplementary cementitious materials are fly ash, blast furnace, silica fume, bottom ash and others. Solid waste bottom ash is one of the supplementary cementitious materials. Solid waste resources are increasingly being used in the production of concrete. Particularly, using recycled solid waste in place of cement, a key component of concrete, has appealed due to its ability to reduce greenhouse gas emissions.

The purpose of this study is to investigate the use of Municipal Solid Waste Incinerator Bottom Ash (MSWI) as partial replacement of cement and study the properties of concrete. Concretes were casted to compare the compressive strength, splitting tensile strength, flexural strength. Moreover water permeability test is done on normal strength concrete when cement is partially replaced with municipal solid waste bottom ash at different percentages.

The workability of concrete decreased with an increase of percentage replacement of cement by Bottom ash. The obtained results of compressive, tensile and flexural strength show decrement with an increase of BA. However, the replaced concrete samples possess a better water tightness performance than the controlled sample. Solid waste bottom ash can be used to partially replace cement in a normal strength concrete.

**Key words:** Supplementary cementitious material, Municipal Solid Waste Incineration, Bottom Ash, Water permeability.

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## **LIST OF ABBREVIATIONS**

AAiT	Addis Ababa institute of Technology
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials Standard
BA	Bottom Ash
ISW	Incineration solid waste
MK	Metakaolin
MSWI	Municipal Solid Waste Incineration
OPC	Ordinary Portland cement
SCM	Supplementary Cementitious Material
SSD	Saturated Surface Dry
XRD	X-ray Diffraction

## 1. INTRODUCTION

### 1.1 Background

In the construction industry, concrete is the most commonly used material. Because most constructions prefer concrete over any other construction materials including bridges, building frames, pavements, and dams. Due to this reason there is a growing demand for cement.

Protection of the environment becomes a worldwide problem. Attention is being paid to the rise in CO<sub>2</sub> emissions. One of the main sources of pollution to the environment is cement production [1]. Because it generates a lot of heat and CO<sub>2</sub>, cement production poses a serious environmental risk. Half of the heat input of the kiln system is used in the process known as calcination, which converts limestone (CaCO<sub>3</sub>) into free lime (CaO) and carbon dioxide (CO<sub>2</sub>) [2].

Particularly with regard to cement replacement programs, there is currently a greater interest in substituting construction raw materials with alternative materials in order to reduce construction costs and save natural resources. Since the production of one tone of Portland cement produces roughly the same amount of carbon dioxide (CO<sub>2</sub>), research has focused on a variety of waste materials that could be used as sources, including recycled concrete, post-consumer glass, recycled tyres, recycled plastics, waste ceramics, waste bricks, cork, municipal solid waste and more [3]. The sustainability of the construction sector can be raised by using these materials partially in substitute of cement.

Due to the massive amounts of municipal solid waste that are produced today as a result of consumer society, mass production, and consumption of goods, incineration is used to reduce mass and volume, which is crucial for waste management and environmental protection. The most efficient method for managing waste and preserving landfill space is incineration, which results in a 70% mass reduction and a 90% volume reduction [4]. The use of Municipal Solid Waste Incinerator Bottom Ash (MSWI) as a component of cement raw material is looked at. By lowering the amount of resources used, CO<sub>2</sub> emissions, and energy used in cement production, the goal was to address some environmental issues in addition to disposing of the waste. With the exception of the fact that the SiO<sub>2</sub> component in MSWI was higher than that in OPC cement [5].

Reppi Waste to electricity Power Plant was built by Ethiopia Electric Power Authority and the Addis Ababa City Administration to use municipal solid waste as a source of renewable electricity. Reppi waste to Energy disposal facility, which is 13 kilometres from Addis Ababa's city center, can dispose of 420,000 tons of waste annually and is utilized to generate renewable electricity for the city of Addis Ababa (Reppi waste to energy, 2014). Even though this power plant utilized this MSW to produce useable electricity, it would still produce waste (bi-products) that would need a sizable disposal area and have an impact on the environment. Fly ash and bottom ash (BA) are two different types of wastes generated by this plant.

Bottom ash is the waste product of combustion. BA accounts for 20–30% of the original waste and is primarily produced by large combustion furnaces. It includes the portion of the waste feedstock that isn't combustible, such as metals, glass, stones, and ceramics. After metals are separated for recycling, the bottom ash might be used in building. Compared to fly ash, it has much coarser particles. It is a rough, angular substance with a porous surface roughness that is primarily sand-size. In addition to silica, alumina, and iron, the material also contains trace levels of calcium, magnesium, and sulphate. The particle size of the material typically ranges from fine sand to gravel in size. The type of the waste and the method may cause variations in the quality and chemical composition of ISWBA [5].

The most popular method of disposing BA is by filling up land, but this has a number of drawbacks, including high transportation costs, a lack of suitable sites, contamination of the land by heavy metal, fuel gases emission, etc. As a result, getting rid of BA will likely become a significant problem in the future. On the other hand, the rise in demand for building supplies brought on by recent development has necessitated the employment of alternate development strategies or building supplies from different sources. Based on this, numerous researchers have tried to employ BA as a construction material for alternative sustainable building materials and for environmental preservation, such as brick manufacturing, artificial aggregate production, ceramic production, glass production, etc.

According to this study, using solid waste bottom ash as a partial replacement of cement is acceptable. The aim of this research is to use Reppi waste to energy power plant BA

as partial replacement of cement for the production of concrete and study the properties of concrete.

## **1.2 Statement of the problem**

Today, the primary focus of material science in the field of sustainable civil engineering is on finding sustainable ways to improve the performance and functionality of conventional materials using modern technologies and local waste products.

The Reppie waste to energy power plant generates  $10.04 \times 10^4$  tons of bottom ash per year, which is currently dumped in landfills nearby. This requires a constant business that transforms/uses this by product into a usable ingredient [6]. Nowadays, it is typical to dispose a bottom ash for land filling in the majority of the world, but this practice comes with a number of drawbacks; including high transportation costs, difficulty obtaining suitable land-filling sites, contamination of the land by heavy metal, emission of fuel gases, etc. As a result, disposing of this bottom ash has grown to be a significant problem at the moment.

Additionally, because cement is an expensive building material, it serves as the binding agent in concrete. Due to the high process and production cost of cement is better to be replaced with other materials. One of the major alternative is MSWI BA which contains a pozzolanic material such as silicon, calcium, aluminum etc. which gives a cementitious property but we couldn't utilize this bottom ash yet. From previous studies, it was investigated that Reppi waste bottom ash have high silicon content which is good for cement can be partially replaced when making concrete. Thus, the current research work is launched to provide experimental evidence on the partial replacement of cement by solid waste bottom ash.

## **1.3 Objective**

### **1. 3.1 General objectives**

The basic objective of this study is to investigate the use of solid waste bottom ash as partial replacement of cement suitable in the construction industry.

### **1.3.2 Specific objectives**

The specific objectives of this study are:

- To examine the chemical composition of municipal solid waste bottom ash.
- To study the influence of percentage replacement of cement by municipal solid waste bottom ash on the physical, chemical and mechanical properties on normal strength concrete.
- To determine the water permeability of concrete.

### **1.4 Scope of the study**

The study involves testing concrete's mechanical performance in the laboratory to see how municipal solid waste bottom ash affects it. The mechanical characteristics of concrete are investigated using a series of experiments. To understand how the material acts during the hydration process, physical properties of cement and bottom ash from municipal solid waste are also determined, both separately and when mixed in a certain proportion.

The limitation of the study perceived to be; it might not cover whole concrete tests required to comprehend these properties of concrete and it unable to study to beyond 25% substitution level of the bottom ash considering the scope of recognizing whole the properties and substitution levels will make the thesis immense than anticipated.

### **1.5 Organization of the Thesis**

The five chapters of the thesis are organized as follows. Chapter one provides a basic introduction to the thesis along with some background information. It also discusses the justification of the research by highlighting the main difficulties associated with the partial substitution of municipal solid waste bottom ash for cement as well as the thesis's objectives, scope, and structure. The second chapter covers the relevant literature and quotes from several related publications in the field. The materials, techniques, and testing procedures are presented in the third chapter. The fourth chapter tries to summarize the outcomes of the tests in detail, followed by a discussion of the findings. Finally, the study's conclusion and recommendation are presented in Chapter 5.

## 2. LITERATURE REVIEW

### 2.1 Concrete

The Latin term *concretus*, which means "to grow together," is where the word "concrete" comes from. Generally, two ingredients are used to make concrete. The first main component is Portland cement, which is made into a paste using water. The paste and organization make up roughly 25% to 40% of the overall volume of concrete. Aggregates, which are often sand, gravel, or crushed stone, make up the second important constituent. As the cement and water undergo a chemical reaction, the paste hardens and fuses the aggregates into a rock-like mass. Concrete quality is determined by the paste, aggregate, and link between them. In a concrete that has been properly produced, the aggregate particles are entirely covered with paste, as well as all of the spaces between them. The general quality of the concrete is determined by the paste quality, aggregate, and the link between the three [7].

Factors influencing concrete properties

- w/c ratio (or w/b or w/p ratio)
- Cement content
- Aggregate
- Admixtures
- Mixing procedures
- Curing [8]

### 2.3 Cement

A finely powdered inorganic material called cement is a hydraulic binder that, when combined with water, forms a paste that hardens by a series of exothermic hydration reactions, and is thus able to combine solid fragments into a compact total solid [9].

Hydraulic cements, such as Portland cements, are primarily made of hydraulic calcium silicates. By chemically reacting with water, hydraulic cements bind, harden, and preserve their stability in the presence of water. Portland cement and mixed cements are examples of hydraulic cements [10].

However, the production of cement (the cement industry) is the second-largest source of CO<sub>2</sub> emissions, only behind power plants, due to its high energy and carbon requirements. 90% of CO<sub>2</sub> emissions from cement plants are accounted for by the manufacture of clinker (fuel combustion and chemical reactions between raw materials), while the remaining 10% are produced during the stages of raw material preparation and cement finishing [3].

### **2.3.1 Physical properties of cement**

Cement standards have limits on both its chemical and physical characteristics. While analyzing the results of cement testing, it can be beneficial to know the significance of particular physical features. The qualities in relation to the type of cement are restricted by cement specifications. ASTM C 183 should be followed while sampling cement. Cement standards have limits on both its chemical and physical characteristics.

#### **2.3.1.1 Particle size and Fineness**

The overall cement particle size distribution, which impacts the amount of heat emitted and the hydration rate, is referred to as "fineness." Higher cement fineness, or smaller cement particle size, encourages the development of strength by accelerating cement hydration. Within the first seven days, the relationship between fineness and paste strength is most visible. Fineness, which is a measure of the surface area of cement particles per unit mass, causes cements with finer particles to have greater surface areas. Portland cement, which is composed of distinct, angular particles of varied sizes, is the end product of grinding clinker. The average cement particle size is about 15 micrometres, and more than 95% of cement particles are less than 45 micrometres. Commonly used to assess fineness is the Blaine air permeability test, which use ASTM C 204 or AASHTO T 153 and indirectly assesses the surface area of cement particles per unit mass.

#### **2.3.1.2 Consistency**

Consistency describes the relative flow ability or mobility of a freshly prepared cement paste or mortar. Pastes are blended to a normal consistency for testing cement, which is demonstrated by a Vicat plunger penetration of  $10 \pm 1$  mm (see ASTM C 187 or AASHTO T 129). To control the amount of water in pastes and mortars that will be used in the

subsequent tests, the usual consistency method and the flow test are both utilized; both allow comparing diverse components with the same penetrability or flow [11].

### 2.3.1.3 Setting Time

To determine the initial set and final set of paste, setting time is performed. The amount of time needed for a paste to reach a particular hardness level is known as the final set, whereas the initial set is an amount of time that begins to count when water is added and ends when the paste stops being fluid. To find out whether a cement sets within the time restrictions specified in cement specifications, tests are conducted using either the Vicat apparatus (ASTM C 191 or AASHTO T 131) or the Gillmore needle (ASTM C 266 or AASHTO T 154). Both the initial and final sets of cement paste must not be too early or too late. The setting times reveal whether or not a paste is undergoing normal hydration reactions [11].

### 2.3.2 Mechanisms of Cement hydration

Adding water causes the minerals in the clinker to start reacting. The hydration process, which is a sequence of chemical reactions, involves several stages. Compounds of the kind found in cement can interact with water in two different ways. In the first, some water molecules are added directly, which is a real reaction of hydration. Hydrolysis is the second kind of water-related reaction [12]. A number of chemical reactions, including dissolution/dissociation, diffusion, growth, nucleation, complexity, and adsorption, are related during the hydration of cement [13].

Due to the strong exothermic nature of cement hydration reactions, one method for determining the rate of hydration is to use the evolution of the heat released during the process. Often found in Portland cement are  $C_3S$  (alite),  $C_2S$  (belite),  $C_3A$ , and  $C_4AF$  and gypsum. Immediately after being wet, calcium silicate hydrates (C-S-H) gel and calcium hydroxide are produced (portlandite). This causes early strength to accumulate [13].

The important strength-developing hydration reactions are those of  $C_3S$  and  $C_2S$ . Typical hydration reactions would be [12].



The hydration process can be divided into four stages [2].

1. Pre induction period (first few minutes)

Immediately following the Water and cement come into contact. At this point, both the hydrate phase formation and the quick dissociation of ionic species into the liquid phase start. As  $C_3S$  disintegrates, C-S-H covers the cement particles.

2. Induction (Dormant) Period (First few hours)

The hydration rate of clinker minerals slows down after a short period of fast hydration, and calcium hydroxide is less concentrated in the liquid phase. This is because the "second-stage" C-S-H phase formed from the bulk liquid.

3. Acceleration Stage (3–12 h after mixing)

The hydration rate increases again during this time and is controlled by the nucleation and evolution of hydration products. As the hydration rate of  $C_3S$  increases, the second stage of C-S-H occurs. The silicate hydration is also known as dicalcium ( $C_2S$ ).

4. Post-Acceleration Period

The rate of hydration steadily slows down as the amount of non-reactant is decreased, and the hydration becomes diffusely controlled.

## 2.4 Supplementary Cementitious Materials (SCMs)

One of the biggest successes in replacing or enhancing the usage of Portland cement over the past 40 years has been the use of Supplementary Cementitious Materials (SCMs), include rice husk ash, metakaolin, and silica fume. Undoubtedly, the discovery of cementitious ingredients and the outcomes of mixing dominate the assessment of newly developed cement research [2].

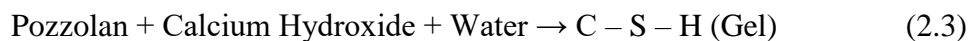
Materials known as SCMs are frequently utilized to replace some of the Portland clinker in blended cement because they exhibit properties that are comparable to those of cement. If the early strength mixing development is not compromised as the clinker contents are then decreased, it is essential to assess and enhance the reactivity of the available SCMs. Silicate-based compounds include the majority of SCMs. Either latent hydraulic or pozzolanic describes them. Upon activation, a latent hydraulic substance can continue its reaction with water without additional reagents. In contrast, extra portlandite is needed for pozzolanic materials. [14].

SCMs can be used in addition to or as a partial replacement for Portland cement or blended cement in concrete. They can also be used to improve a specific concrete quality, such as to alkali- aggregates reactivity resistance. Tests should be performed to determine the optimal amount of SCMs to determine if the material actually improves the property, and to regulate the proper dosing rate to avoid overdosing or under dosing, which may or may not be the desired one effect achieved. Fly ash, slag, calcined clay, calcined shale, and silica fume have all been used separately in concrete in the past. Due to easier availability to these components, concrete producers can now blend two or more of them to improve the qualities of the concrete they produce [11].

#### 2.4.1 Pozzolanas

According to ASTM C618, a pozzolan is a siliceous or siliceous and aluminous material that, by itself, has little to no cementitious value but that, when finely divided and exposed to moisture at room temperature, chemically reacts with calcium hydroxide (lime) to produce compounds with cementitious properties.

The term "pozzolanic reaction" refers to a chemical reaction between pozzolan and calcium hydroxide that takes place in the presence of water and produces cementitious compounds.



In any blended cement system, calcium hydroxide produced by the hydration of alite and belite serves as the initial component of the pozzolanic reaction. When mixed with water and pozzolana's silica, it produces more C-S-H binder, which is used to make cement responsible for improving the concrete paste's mechanical strength and durability. In fact, the C-S-H phase formed by pozzolanic reaction has a lower Ca/Si content because the pozzolanic silica consumes the calcium hydroxide produced by the hydration of the cement and reduces the amount of portlandite, leading to an increased uptake of aluminum in the C-S-H. As long as portlandite ( $\text{Ca}(\text{OH})_2$ ) is still present, the CSH phase is increasingly formed. After depletion of portlandite, the amount of CSH is almost constant [15]. It is also generally known that cement's ability to attain strength after hydration depends in proportion on the amount of calcium hydroxide present. The amount of calcium hydroxide in the paste can be used to measure the cement's progress during

the hydration process. Similar to this, observing the gradual decline in calcium hydroxide over time will allow you to determine how much pozzolanic reaction has occurred [16].

The physical and chemical specifications for pozzolanic materials are described in ASTM C 618. Natural pozzolans (class N) and byproduct products are examples of pozzolanic materials. In particular, volcanic ashes, diatomaceous earth, calcined clay, metakaoline clay, and rice hull ash are examples of natural pozzolans. Fly ash is the most common by-product material, and it is normally categorised as either class F or class C, depending on its chemical composition and place of origin. Class F fly ashes primarily have pozzolanic characteristics. Class C fly ashes often have pozzolanic and cementitious characteristics. Based on the amounts of the three oxides,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ , ASTM C618-12 distinguishes between fly ashes of Class C and Class F.  $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$  must be greater than or equal to 50% for Class C fly ash.  $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$  must be greater than or equal to 70% for Class F fly ash. Class C fly ashes differ from low-calcium Class F fly ashes in terms of performance since they essentially contain 15 to 25% more calcium.

**Table 2. 1 Standard Specification of Class C Pozzolans according to ASTM C 618**

Test /property	Requirement
$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ , %	$\geq 50$
$\text{SO}_3$ , %	$\leq 4.0$
Moisture content, %	$\leq 3.0$
Loss on Ignition,%	$\leq 6.0$
Amt retained when wet-sieved on 45 $\mu\text{m}$ (No.325) sieve,%	$\leq 34$
Strength activity index,7-day,% of control	$\geq 75$
Strength activity index,28-day,% of control	$\geq 75$
Water requirement,% of control	$\leq 105$
Soundness: autoclave expansion or contraction,%	$\leq 0.8$
Density, variation from average,%	$\leq 5.0$
Percentage retained on 45 $\mu\text{m}$ sieve, variation (percentage points from average)	$\leq 5.0$
Available alkalis,%	$\leq 1.5$

## 2.5 Bottom ash

The principal byproduct of municipal solid waste incineration (MSWI) that remains in the furnace after combustion is bottom ash (BA) made of solid waste. BA is an extremely

heterogeneous material with a wide particle size distribution and irregularly shaped particles.

A complex inorganic mixture, this substance is typically made up of melt products, minerals, metallic compounds, ceramics, and glass. 85–95 weight percent of BA comes from the incineration process.

Fly ash and bottom ash constitute most of the incinerator ash produced by the burning of solid waste. Fly ash is made up of partially burned organic material and its dust-like, grey particles, which have a diameter of roughly 1-500 micrometers [17].

Bottom ash is made up of slag, glasses, and organic components that haven't completely burnt. Typically, the diameter of the coarse sand ranges from 0.1 to 100 millimetres. But on the other hand. Different physical and chemical properties of the burned bottom ash exist depending on the type and source of the solid waste. In comparison to natural sand and gravel, MSWI bottom ash has a lower specific gravity, making it a lighter material. [17].

### **2.5.1 Applications of bottom ash**

The various application of using bottom ash is discussed below:

#### **1. Road Pavement**

Several road sections have utilized MSWI bottom ash in road construction. Replacing the components in the base course and sub-base is one potential usage for the MSWI bottom ash. Reusing the incineration ash is made easy and direct by using MSWI bottom ash in sub base layer of road pavement. It was discovered that the emission of Ca, Co, Fe, Mn, Ni, NO<sub>3</sub>-N (nitrate-nitrogen), and Pb to the environment was unaffected by replacing the gravel in the road base with bottom ash. According to a three-year study on the use of MSWI bottom ash in French road paving, the levels of heavy metals, fluorides, and pH values in the leachate were lower than those permitted for potable water. It stated that using bottom ash for road construction is safe [18].

#### **2. Glasses, Glass-Ceramics and Ceramics**

MSWI bottom ash and fly ash have been used as raw materials in the high temperature (>1,000 °C) manufacture of glasses, glass-ceramics, and ceramics.

Because to their high  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{CaO}$  contents, In the manufacture of ceramics, MSWI bottom ash and fly ash can partially replace clay without the need for pre-treatment. The possibility of using MSWI bottom ash and fly ash for the production of ceramic tiles body has been investigated. They discovered that adding bottom ash up to 20 weight percent did not significantly change the mineralogical and thermal characteristics of ceramic tiles [19].

### **3. Agriculture**

The three nutrients that are most important for plant growth are nitrogen, phosphorus, and potassium. The ability of MSWI fly ash and bottom ash to enrich soil with nutrients in agricultural applications has been evaluated. MSWI bottom ash can be used in place of commercial fertilisers in part because it has a phosphorus and potassium content that is acceptable [20].

### **4. Fine aggregate substitution**

Bottom ash from MSWI can be used as aggregate in concrete. The findings demonstrate that treated bottom ash, which was submerged in sodium hydroxide for 15 days, can replace up to 50% of gravel in concrete without compromising durability. If the ash is not treated, cracking and swelling take place because of the reaction between cement and metallic aluminum reacting [21]. Chang et al, (1999) studied the possibility of replacing fine aggregates in concrete entirely with MSWI BA. The 28-day compressive strength of the MSWI ash mixes was about 54.7 % lower than that of normal sand mixes [42].

According to some studies, bottom ash can replace up to 30% of the fine aggregate in concrete manufacturing. Hence, it is possible to manufacture concrete that has superior or equivalent strength to ordinary concrete by replacing fine aggregate in an appropriate ratio [22].

The splitting tensile strength of bottom ash concrete mixtures integrating 5%, 10%, 15%, 20%, and 25% bottom ash as fine aggregate was, according to a prior study, 14.28%, 12.11%, 10.8%, 11.48%, and 6.21% greater than that of the control concrete mixture, respectively, at the age of 28 days. The pozzolanic qualities of bottom ash enhance the paste's quality, and the paste's quality has a

greater impact on the concrete's splitting tensile strength than its compressive strength. In other words, when the replacement level rises, the workability of concrete declines because bottom ash has a high water absorption capacity [23].

## 5. Cement substitution

In fact, the largest industry activity that contributes to global warming is the manufacturing of cement, which uses enormous amounts of energy and generates big amounts of carbon dioxide. Using MSWI ash as a raw material for cement has several benefits, one of which is a decrease in carbon dioxide emissions, which lessens the impact on global warming. Since it takes a lot of energy to convert calcium carbonate ( $\text{CaCO}_3$ ) to lime ( $\text{CaO}$ ), a huge amount of carbon dioxide is emitted throughout the process. The use of BA as partial replacement can lower the carbon dioxide emission since MSWI bottom ash and fly ash are contain lime rather than calcium carbonate [24].

### 2.6 Previous research related to this study

In terms of the components of the raw materials needed to create cement, fly ash and bottom ash are comparable. Because MSWI ash contains  $\text{CaO}$ ,  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ , and  $\text{Al}_2\text{O}_3$  and since a significant amount of cement was used to make mortar and concrete. As a result, it may be used in place of raw materials to make Portland cement [25].

After screening, the untreated MSWI bottom ash was utilized in place of some cement in concrete. Although the resulting concrete had acceptable qualities, MSWI ash does not meet the requirements for normal admixtures in concrete due to its chemical composition. The material's 28-day compressive strength after 10% of the cement was replaced was comparable to the concrete used as a reference. The amount of MSWI ash in the prepared concrete was relatively small. Only when the MSWI bottom ash is properly chemically treated to prevent hydrogen gas evolution when used in concrete, which can eventually result in a significant reduction of the concrete strength, would a higher ash dosage be possible without any corresponding loss of concrete properties. However, in this scenario, additional costs would be incurred, which would reduce the appeal of using MSWI ashes. Comparing the compressive strength test results to the control cube (0% cement replacement), it can be seen that strength increases when ash replaces less than or equal to 10% of cement, but decreases when ash replaces more than 10% of cement. The cubes

are evaluated 7<sup>th</sup> and 28<sup>th</sup> day after being molded. Therefore, replacing up to 10% of municipal solid waste incinerator ash is appropriate for the construction of normal buildings [26].

Bottom ash's primary constituents, such as CaO, SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, and Al<sub>2</sub>O<sub>3</sub>, were found to be comparable to those of regular Portland cement, indicating that bottom ash had the potential to be used again as a cementitious material. Contrary to the variation in SiO<sub>2</sub> content in the bottom ash, the contents of CaO, SO<sub>3</sub>, and chloride in the bottom ash nearly decreased with increasing particle size. The Al<sub>2</sub>O<sub>3</sub> and Fe<sub>2</sub>O<sub>3</sub> content was relatively stable in the bottom ash with different particle sizes. Bottom ash contained large amounts of volatile substances that would erode the reinforcement, including chlorides, alkali metals, and sulphate. In order to decrease corrosion brought on by chloride, it is necessary to properly regulate the amounts of bottom ash, a substitute material used in the manufacturing of cement. [27].

It was examined into if bottom ash from incinerators (MSWI) might be used as a cement raw material. The goal was to reduce some environmental issues by reducing resource usage, CO<sub>2</sub> emissions, and energy consumption in cement manufacture in addition to disposing of the waste. The MSWI replacement rate in the cement mill was between 5 and 10%. The MSWI cements' compressive strength, setting times, and general characteristics were examined and compared to traditional cement. Except for the fact that MSWI cements had a larger SiO<sub>2</sub> component than control cements, the chemical compositions of MSWI cements and control cements were nearly identical. When MSWI was used as the primary cement-making raw materials, cement paste setting times were slower. Lower C<sub>3</sub>S and greater C<sub>2</sub>S concentrations than CC are responsible for the extended setting times of these cement pastes compared to control cements. Particularly when using a larger MSWI percentage, the mortar formed from MSWI cements had a somewhat lower compressive strength than the control cement mortar. [5].

The compressive strength of mortar cubes decreased as the percentage of MSWI-BA in the mixtures raised, and this is apparent for all curing times. For example, after a 14-day curing period, the compressive strength of the control combination is 22.5 MPa while the compressive strength of the mixture containing 10% MSWI-BA is 17.69 MPa. Similar to this, for mixtures containing 20%, 30%, and 40% MSWI-BA, the strength continues to decline to 14.5, 11.3 and 9.3 MPa, respectively. As the ratio of MSWI-BA replacing

cement increases from 10% to 40%, the compressive strength is significantly reduced. Also, it was discovered that MSWI-BA has only limited pozzolanic action, and its dosage should not go above 10 % [28].

After different curing ages, the flexural and compressive strengths of mortar containing bottom ash are evaluated. The strength of the reference mortars is measured in MPa after 1, 3, and 28 days of curing. Using treated bottom ashes in place of cement lowers mortars at all curing ages for all mixtures. For all of the combinations, the reduction in flexural strength is, however, less significant than the reduction in compressive strength. The large content of organic matter and lower pozzolanic qualities of raw bottom ash as a result of the burning of organic matter, which results in higher pozzolanic properties than BA, may be to responsible for the very high strength decrease for mortar containing BA at all curing ages [29].

Calcium and silica compositions in bottom ash and ordinary Portland cement were quite similar. According to the results of the slump test, concrete that contains 10% to 30% bottom ash causes the true slump. Concrete's capabilities and strength are determined using a water absorption test. As the fraction of bottom ash increases, the percentage of water absorbed rises. Concrete's compression test strength was 27.5 MPa for 10% bottom ash, which met the desired outcome. Increased bottom ash replacement percentage had an impact on the matrix's C-S-H (calcium silicate-hydrate) bond. These results are confirmed by measurements made using a scanning electron microscope and the interfacial transition zone surface. As a result, bottom ash from municipal solid waste incinerators can partially substitute cement in concrete, but not more than 30 % [30].

### 3. MATERIALS AND METHODS

#### 3.1 Introduction

In this chapter, the types and qualities of the materials, sample preparation techniques, experimental procedures, test settings used in the study and all laboratory tests conducted are briefly discussed. The detailed experimental programs, testing and material preparations took place in Construction materials lab at Addis Ababa Institute of Technology (AAiT).

The Geological Survey of Ethiopia conducted a complete silicate analysis of bottom ash. At AAU, XRD analysis was performed in the Chemistry department laboratory, whereas fineness testing of cement and bottom ash were carried out in the Chemical Engineering Laboratory.

#### 3.2 Materials

The materials used for this research include cement, fine aggregate, coarse aggregate, water and bottom ash.

##### 3.2.1 Cement

Ordinary Portland cement, Type-1 Dangote cement with a CEM 42.5R grade is used. The physical properties have been examined and are summarized in Table 3.1.

**Table 3. 1 Physical properties of cement**

Item No.	Description	Test Result	
1	Specific gravity( $\text{gm}/\text{cm}^3$ )	3.15	
2	Cement consistency test	Water to cement ratio (%)	26
		Water (gm)	130
		Penetration(mm)	10
3	Setting time	Initial setting time (min)	156.3
		Final setting time (min)	300

### 3.2.2 Aggregates

Testing has been done on the aggregate are gradation, bulk density, specific gravity, and moisture content to make sure it complies with specifications for concrete work and to evaluate processing requirements.

#### 3.2.2.1 Fine Aggregate

For this study, locally available kality river sand passing through 4.75mm sieve was used. The physical properties of the fine aggregate results are summarized in Table 3.2.

**Table 3. 2 physical properties of fine aggregate**

No	Test description	Test result	
1	Silt content	1.33%	
2	Moisture content	1.89%	
3	Absorption capacity	2.33%	
4	Fineness modulus	2.74	
5	Unit weight	1531.52 Kg/m <sup>3</sup>	
6	Specific gravity	Bulk	2.44
		Bulk (SSD)	2.5
		Apparent	2.59

The fine aggregate before use in all tests was washed until clear water came out. Then, the silt content of the sand was tested and was found to be 1.33 %. According to the Ethiopian standard the silt content of sand is recommended not to exceed a limit of 6% [31].

**Table 3. 3 The particle size distribution of fine aggregate**

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	Cumulative percent retained (%)	Cumulative passing (%)	ASTM C33 standard passing range (%)
9.75	0	0	0	100	100
4.75	1	0.2	0.2	99.8	95-100
2.36	23.2	4.6	4.8	95.2	80-100
1.18	80.35	16.037	20.837	79.163	50-85
0.6	194.65	38.85	59.687	40.313	25-60
0.3	152.85	30.50	90.187	9.813	5-30
0.15	40.7	8.123	98.31	1.69	0-10
Pan	7.95	1.586	99.89	0.11	0
Σ			274.02		

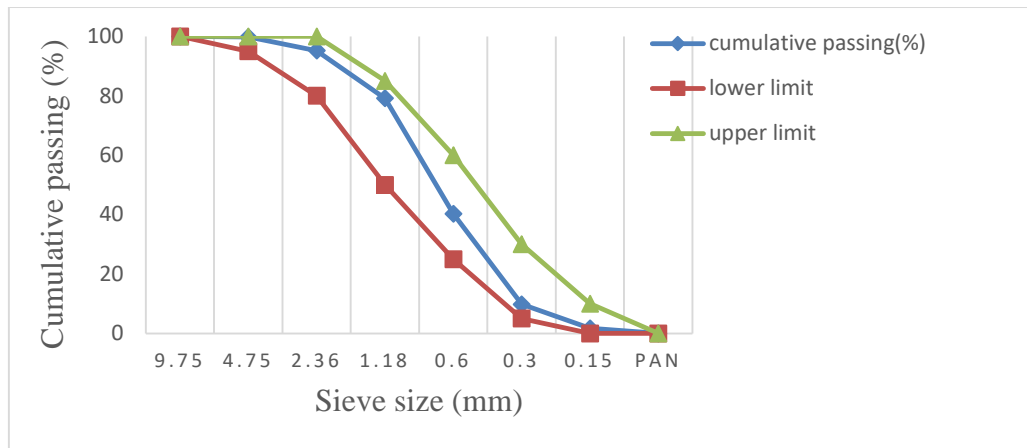


Figure 3.1 Gradation curve of fine aggregate

### 3.2.2.2 Coarse Aggregate

Coarse aggregate that has been used in this study is a goro basaltic crushed rock which was obtained from market. The nominal maximum size of the coarse aggregate used is 25 mm in accordance with requirements of ASTM C33 [32]. It uses sieve widths ranging from 25 mm to 4.75 mm. Table 3.4 summarizes the physical properties obtained from the laboratory test results.

Table 3. 4 Physical properties of coarse aggregate

No	Test description	Test result	
1	Moisture content	0.367%	
2	Absorption capacity	0.52%	
3	Fineness modulus	7.13	
4	Unit weight	1649.49 Kg/m <sup>3</sup>	
5	Specific gravity	Bulk	2.7
		Bulk (SSD)	2.73
		Apparent	2.76

Table 3. 5 the particle size distribution of coarse aggregate

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	Cumulative percent retained (%)	Cumulative passing (%)	ASTM C33 standard passing range (%)
25	0	0	0	100	95-100
19	445.5	22.275	22.275	77.725	-
12.5	833.7	41.685	63.96	36.04	25-60
9.5	398.5	19.925	83.885	16.115	-
4.75	313.3	15.665	99.55	0.45	0-10
Pan	0	0	99.55	0	0

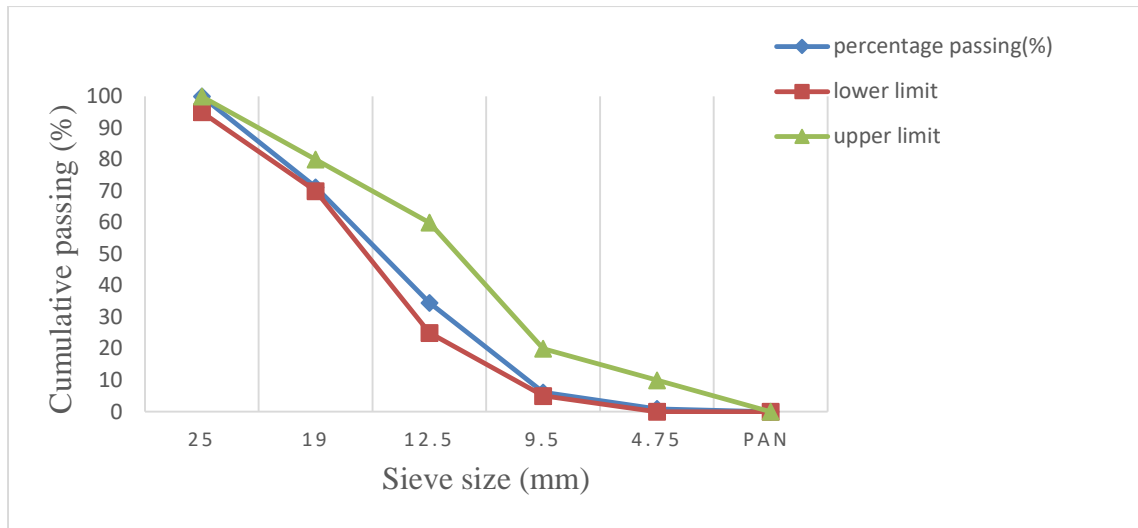


Figure 3.2 Gradation curve of coarse aggregate

### 3.2.3 Water

The Addis Ababa Institute of Technology's construction material laboratory's water supply line provided the tap water for this study.

### 3.2.4 Solid Waste Bottom Ash

The bottom ash used in this research is obtained from Reppie Waste to energy power plant which is located around 'qoshe' in Addis Ababa.

The extracted bottom ash material was packed in three bags of each 50 kg and transported by truck to home. The material brought into the house was spread on the floor for one week to remove the moisture and let it naturally dry; after drying it was carried for milling using jaw crusher machine and sieved through 150  $\mu\text{m}$  sieve. Bottom ash generated in the way described above is brought to Ethiopia's Geological Survey for chemical test. In order to determine its chemical composition, the following analytical techniques were used: LIBO<sub>2</sub> FUSION, HFattack, gravimetric, colorimetric, and AAS. The table below illustrates the result's high silica content.



Figure 3.3 Solid waste bottom ash sample before and after milling

Table 3. 6 Chemical composition of bottom ash and dangote opc

Investigated constituents	Chemical composition of bottom ash (%)	Chemical composition of Dangote OPC cement (%)
SiO <sub>2</sub>	34.42	26.62
Al <sub>2</sub> O <sub>3</sub>	16.16	6.08
Fe <sub>2</sub> O <sub>3</sub>	6.80	4.82
CaO	15.28	55.3
MgO	1.60	1.1
Na <sub>2</sub> O	1.2	0.2
K <sub>2</sub> O	2.36	0.16
MnO	0.12	0.01
P <sub>2</sub> O <sub>5</sub>	2.82	0.08
TiO <sub>2</sub>	0.4	0.24
H <sub>2</sub> O	3.07	0.51
LOI	14.3	3.0
SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub>	57.38	

#### 3.2.4.1 Fineness of Bottom Ash

According to ASTM C 204, an air-permeability test was used to measure the BA fineness. Similar to cement, BA are graded according to a specified surface area. The cement will be finer the higher the specific surface is. The basic idea behind the air permeability

method is to time how long it takes for a specific amount of air to pass through a bed of compacted cement with a given dimension and porosity. The Blain's fineness apparatus is utilized in this study.

Since the approach is comparative rather than absolute, an instrument calibration reference sample with a known particular surface is needed. A standard sample with a reference specific surface area of  $S_s$ , 3774 cm<sup>2</sup>/g was used to calibrate the equipment, and the corresponding manometer drop time for the standard sample was  $T_s=37.9$  sec.

As per ASTM C-204, the following equation is used to compute the specific surface area of BA;

$$S = S_s \frac{\sqrt{T}}{\sqrt{T_s}} \quad (3.1)$$

#### 3.2.4.2 Specific gravity of bottom ash

Le Chatelier's flask was used to determine the bottom ash's specific gravity. A flask containing already-existing kerosene free of water at 200<sup>0</sup>C was introduced with 500gm of weight BA passed through a 75 micron sieve. For the test, the ASTM C 188 standard had been used.

**Table 3. 7 Physical properties of bottom ash**

Item No.	Description	Test Result
1	Fineness (cm <sup>2</sup> /gm)	2553
2	Specific gravity(gm/cm <sup>3</sup> )	2.4

#### 3.2.4.3 Setting Time test

Setting time test were conducted with cement paste of normal consistency; initial setting time and final setting time of cement, cement and bottom ash blends were carried out according to Ethiopian standard. For setting time tests, mixes of 0%, 10%, 15%, 20%, and 25% replacement paste were made. Cement's initial setting time cannot be less than 45 minutes, and its final setting time cannot be longer than 10 hours [31]. Results for the setting time were shown in Table 3.8.

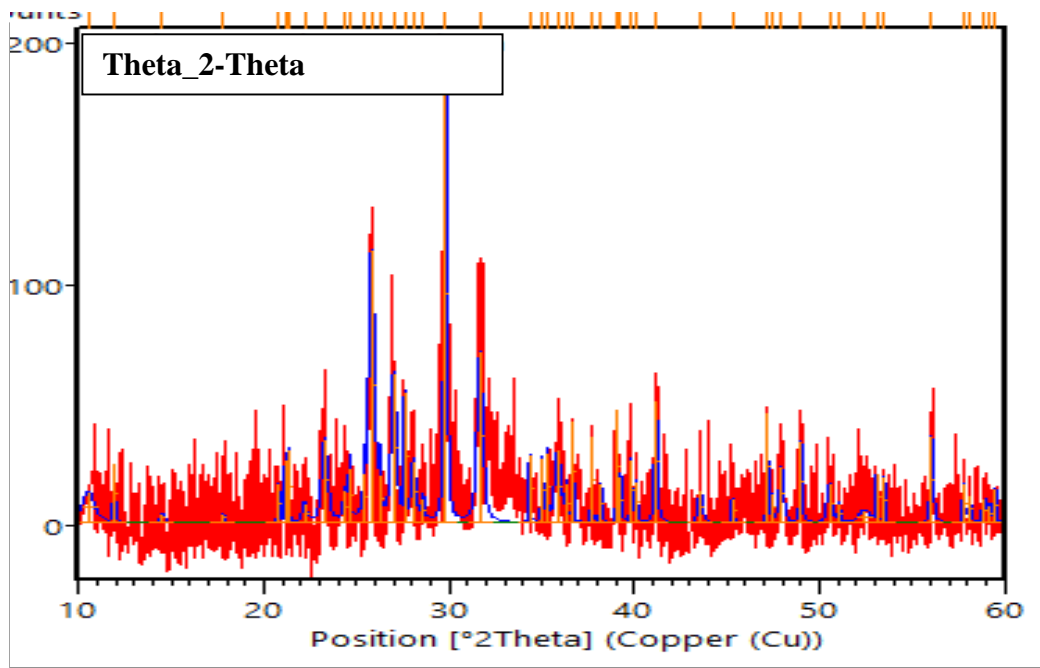
**Table 3. 8 Water demand for normal consistency and setting times**

Sample	Substitution level (%)		Water demand (%)	Setting time(min)	
	OPC	BA		Initial	Final
BA 0	100	0	26	156.31	300
BA 5	95	5	26	184.8	300
BA 10	90	10	26.5	190	330
BA 15	85	15	27	211	360
BA 20	80	20	27.5	240	330
BA 25	75	25	28	265	390

### 3.2.4.4 XRD Test

The potential applications of XRD power diffraction in the investigation of clinker and anhydrous cement include the quantitative and qualitative determination of phase composition, polymorphic modification, condition of crystallinity, and other individual phase properties.

In this study, the bottom ashes were brought to Addis Ababa University's chemical department for an X-ray diffraction (XRD) test. It is determined the BA crystalline and amorphous phases. The XRD data was examined using the software Xpert high score plus 3.0.5. Figure 3.4 depicts the XRD analysis results for the BA sample.



**Figure 3.4 XRD pattern of BA**

### 3.3 Methods

#### 3.3.1 Concrete mix design

Mix design has been done as per ACI 211.1-91 standard procedures [33]. The mix design is specified to the characteristic compressive strength of 25 MPa that translate to a required target mean compressive strength 33 MPa. The replacement of cement by BA was done by mass. The total quantity of each ingredient is given in Table 3.9. In Appendix E, the full calculation is shown.

**Table 3. 9 Quantity of materials required for unit volume concrete**

No	Ingredients	Weight (kg/m <sup>3</sup> )
1	Cement	387.55
2	Fine Aggregate	684.39
3	Coarse Aggregate	1115.05
4	Water	197.72

**Table 3. 10 Quantity of BA used for unit volume of concrete**

Mix name	Percentage of BA (%)	Fine aggregate (kg/m <sup>3</sup> )	Coarse aggregate (kg/m <sup>3</sup> )	Cement(kg/m <sup>3</sup> )		Water (kg/m <sup>3</sup> )
				cement	BA	
BA 0	0	684.39	1115.05	387.55	0	197.72
BA 5	5	684.39	1115.05	368.173	19.377	197.72
BA 10	10	684.39	1115.05	348.795	38.755	197.72
BA 15	15	684.39	1115.05	329.415	58.132	197.72
BA 20	20	684.39	1115.05	310.04	77.51	197.72
BA 25	25	684.39	1115.05	290.67	96.88	197.72

#### 3.3.2 Concrete mix

The concrete was mixed in laboratory with drum mixer. The mixer was first filled with the coarse aggregate, followed by the fine aggregate, and finally the cement. Two minutes of dry mixing the ingredients, then add two-thirds of water on top and another minute of mixing. The mix was then mixed slowly to get a homogenous consistency when the remaining water was added.

After the mixing process was complete, a slump test was used to determine whether the concrete was workable. Every each batch of concrete Slump Test performs according to ASTM C143 [35]. In order to test the concrete's workability, fresh concrete was added to

the slump cone after three layers of compaction. Before casted to the molds, the inner surfaces of the molds prepared were smeared with machine oil.

Finally, the concrete was poured into the ready moulds, and the finished product was vibrated using a table vibrator for 1 minutes on each layer to remove any remaining air and make it more compact and level. After 24 hours, the concrete samples were removed from their moulds and placed in a water tank to cure until the due date in room temperature. The laboratory's concrete test specimens were made and properly cured using the standards in ASTM C192 [34].

### **3.3.3 Testing methods**

Concrete's mechanical properties can be examined using a variety of techniques. In this study, tests for compressive strength, splitting tensile strength, and flexural strength were conducted.

#### **3.3.3.1 Compressive Strength Test**

After the concrete samples had reached their hardening time, they were taken out of the curing water tank and dried on the surface before being tested. The test was performed according to BS EN 12390-3 [36]. The samples were first weighed and tested on the compressive strength machine after seven, twenty-eight and fifty six days. The load was gradually applied at a loading rate of 0.28 MPa/s until the failure stage is reached. Three cubes for each mix were tested for the bottom ash powder's ability to combine with the cement during the compressive strength tests at 7, 28, and 56 days of concrete age. For this test, 54 cube samples were cast on cubes with dimensions of 150 mm. Figure 3.4 shows the compressive strength testing machine and the setup ready for testing. In Appendix F, all of the results of the compressive strength test are presented.



**Figure 3.4 Compressive strength machine**

### **3.3.3.2 Splitting tensile strength test**

The splitting tensile strength test was performed using the indirect tensile test method of measurement. According to ASTM C-496-96, this method involves applying a diametral compressive force throughout the length of a cylindrical concrete specimen with plywood strips inserted in the bottom and top centers at a constant rate of 689 kPa/min until failure occurs [37]. For the purpose of comparing the splitting tensile strength of the control and BA mixes as a partial replacement for cement, a total of 18 cylindrical specimens measuring 150 mm in diameter and 300 mm in length were casted. After a 28th day curing period, the concrete splitting strength of three cylindrical specimens of each concrete mixture was measured.



**Figure 3.5 Tensile Splitting test**

### 3.3.3.3 Flexural Strength Test

The purpose of this test is to find out the concrete's tensile strength. It is sometimes referred to as rupture or bend strength. It was carried out in accordance with ASTM C 78-94 [38]. The greatest stress experienced by the material at that particular moment is represented by the flexural strength of output. On a mold of a beam member with dimensions of 100 mm in width, 100 mm in height, and 500 mm in length, concrete was cast. There were 18 samples cast in all.



**Figure 3.6 Flexural strength testing machine a) under test b) after test**

### 3.3.3.4 Water penetration

Concrete's resistance to water penetration under water pressure is assessed using a water permeability test. In order to evaluate the water tightness of a concrete which is cement is partially replaced by BA in various percentages with the control one, the depth of water penetration under a pressure test was measured. A 150 mm x 150 mm x 150 mm concrete cube specimen were prepared for this test. The specimens were tested at the age of 28 day.

The specimens were taken out of the mould after the concrete had been placed for 24 hours, and the surface that had been exposed to the water pressure was roughened with a wire brush before placed in the curing tank. It was carefully avoided using water pressure on a sample's trowelled surface. A water pressure of 5 bar or 0.5 MPa was applied to the sample for 3 days (72 hours) to conduct a penetration test after the curing period was complete. Regular observations were taken throughout this time. The test was conducted using code [39].



**Figure 3.7 Water penetration test**

The samples split (in the direction that the pattern of depth of water penetration may clearly be displayed) at the end of the 72-hour test period after they had spent 72 consecutive hours in the testing device.



**Figure 3.8 Concrete sample just after splitting**

In order to observe the impact of BA on the concrete's water penetration depth, the maximum and average depth of water penetration were then recorded.

## 4. RESULTS AND DISCUSSIONS

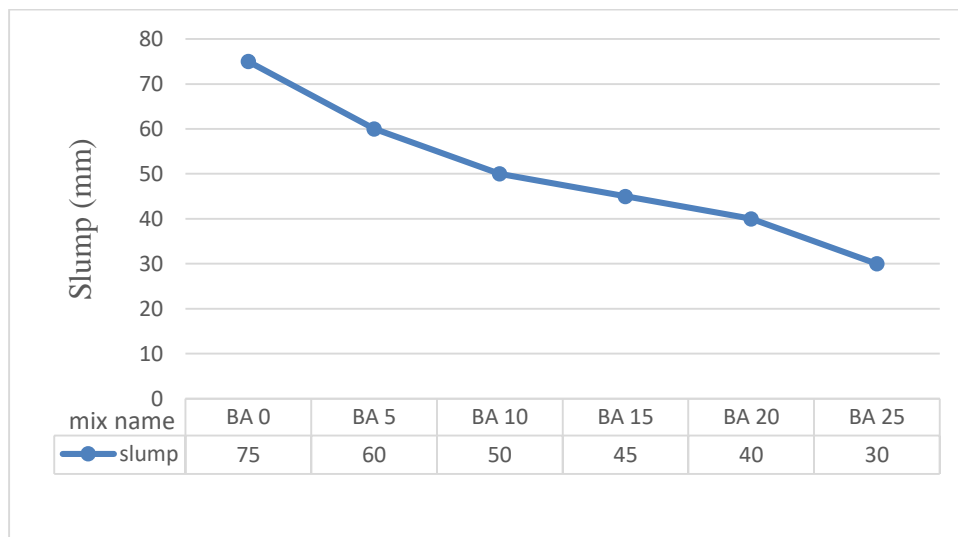
### 4.1 Introduction

The results of laboratory testing on BA to determine its suitability as a partial cement replacement material are presented and discussed in this section. The samples were evaluated against both the control mixes and with the standard to draw conclusions. In this section of the research, the results obtained from slump test, compressive strength test, splitting tensile strength test, flexural strength test and water permeability test done on normal strength concrete is addressed.

### 4.2 Fresh Concrete Properties

#### 4.2.1 Slump test

To determine if freshly prepared concretes are workable, a slump test is performed. Results of slump tests done at various levels of BA substitution for cement are presented together with their interpretations in the table below.



**Figure 4.1 Slump of Concrete**

As shown in Figure 4.1, the slump values show that at equal water to cement ratio, increasing BA addition will decrease workability of the concrete. Mixes BA 5, BA 10, BA 15, BA 20 and BA 25 show workability reduction of 20%, 33.34%, 40%, 46.67% and 60% respectively in comparison with the control mix.

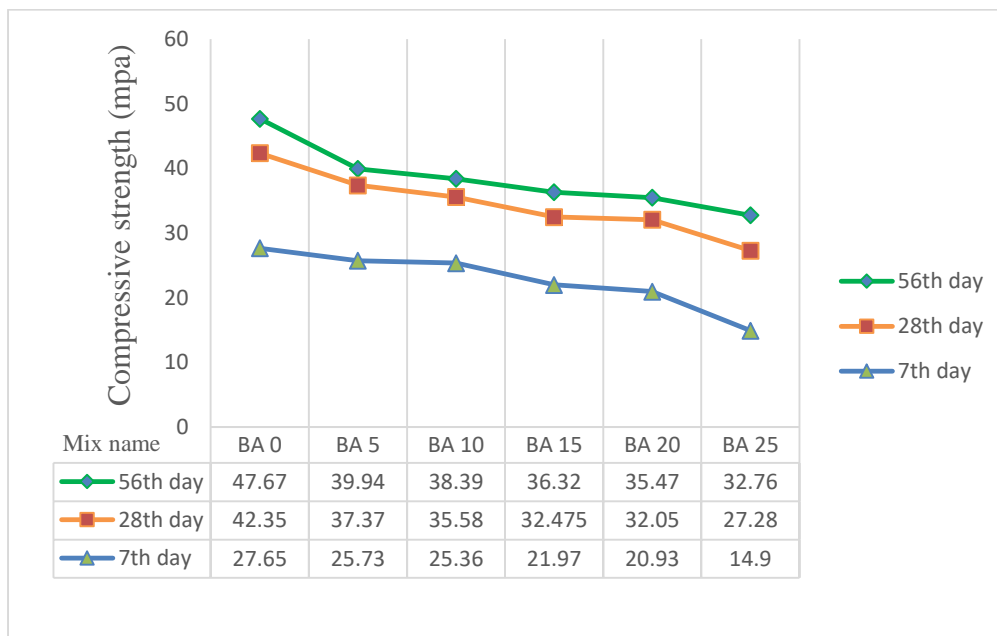
The findings indicate that the slump lessened as the BA level increased. This effect can be linked to BA having a greater tendency to absorb water than cement, which lowers the amount of water in the mix

### 4.3 Mechanical Test Results

#### 4.3.1 Compressive Strength of Concrete

The compressive strength of concrete was investigated and tested. Three samples of each concrete mix were taken on each test day, and an average result was used. The samples were examined after 7, 28, and 56 days of curing. The results of the compressive strength test are fully described in Appendix F.

Using different replacement levels of BA and varying curing times, the compressive strength of cubic specimens was determined. The possibility of using BA as a partial replacement for cement in the production of concrete is checked using a 95 percent confidence interval calculation which is described in Appendix J.



**Figure 4.2 7<sup>th</sup>, 28<sup>th</sup> and 56<sup>th</sup> Days compressive strength**

It can be seen from Figure 4.2 that the average compressive strength of specimens at the 7<sup>th</sup> day is 27.65 MPa for BA 0. Mixes BA 5, BA 10, BA 15, BA 20 and BA 25 show reduction of 6.9%, 8.3%, 20.55%, 24.31% and 53.88% respectively in comparison with the control mix (BA 0). Depending on the 95 percent confidence interval calculation, up to 10% substitution of BA with cement is close to the control sample.

At early age there is a very significant percent drop in compressive strength. This is a clear indication that bottom ash pozzolanic reaction is essentially insignificant at early ages [28].

Similarly Figure 4.2 presents the average compressive strength of specimens at 28<sup>th</sup> day is 42.35 MPa for BA 0, while mixes BA 5, BA 10, BA 15, BA 20 and BA 25 show reductions of 11.76%, 15.99%, and 23.33%, 24.33% and 35.59% respectively. At 56<sup>th</sup> day, the average compressive strength is 47.67 MPa for BA 0 Mixes BA 5, BA 10, BA 15, BA 20 and BA 25 show reduction of 16.22%, 19.47%, 23.81%, 25.6% and 31.28% respectively in comparison with the control mix (BA 0). Depending on the 95 percent confidence interval calculation, up to 10% substitution of BA with cement is close to the control sample.

### 4.3.2 Splitting Tensile Strength test

The splitting tensile strength of cylindrical specimens was tested at 28<sup>th</sup> days of curing for different replacement level of BA. For six different mixes with different replacement ratios, a mean value of three specimens was taken for each replacement of cement with BA. The splitting tensile strength test results presented on Figure 4.3 As shown below. The detailed splitting tensile test results are given in Appendix G.

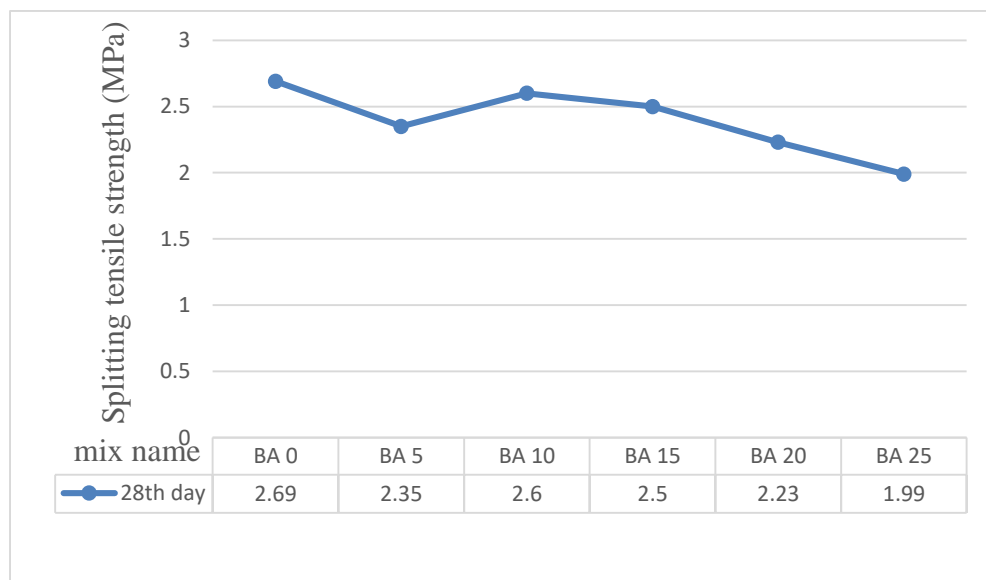


Figure 4.3 Average splitting tensile strength of concrete

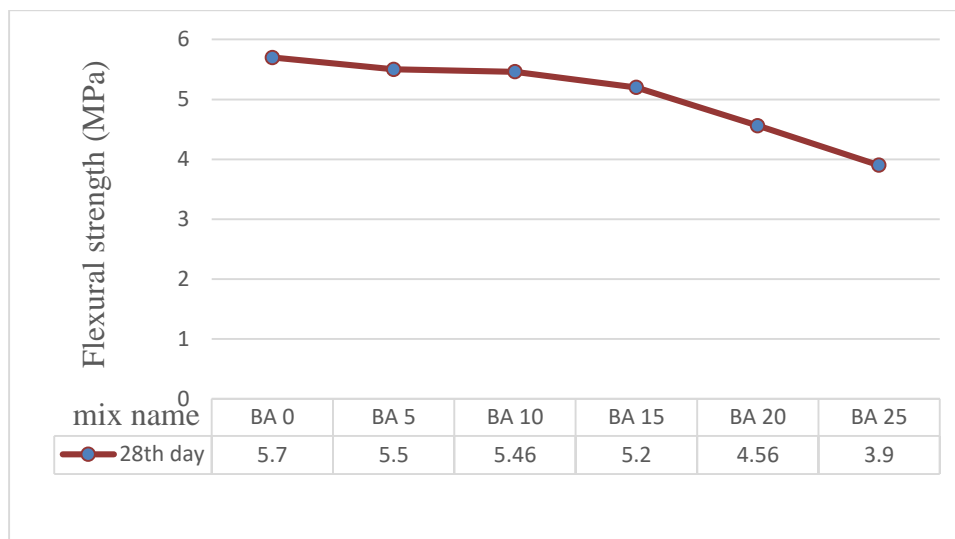
The result shown that the splitting tensile strength of control mixture (BA 0) has a better result than the substitute sample. The mixes BA 5, BA 10, BA 15, BA 20 and BA 25

shows reduction of 12.64%, 3.35%, 7.07%, 17.11% and 26.03% strength respectively, in comparison with the control mix BA 0. The use of 10% BA gives almost the same results with the control.

Even if the substituted sample has lower values than the control specimen. According to Eurocode 2 and also 95% confidence interval calculation, BA 5, BA 10 and BA 15 have an acceptable value. In Eurocode 2 the mean splitting tensile strength of C-25 concrete is 2.5 MPa [40].

### 4.3.3 Flexural strength test

The Flexural strength of specimens was tested at 28<sup>th</sup> days of curing for different replacement level of BA. For six different mixes with different replacement ratios, a mean value of three specimens was taken for each replacement of cement with BA. The Flexural strength test results presented on Figure 4.4. As shown below. The detailed The Flexural strength results are given in Appendix H.



**Figure 4. 4 Average flexural strength of concrete**

The result shown that the flexural strength of control mixture (BA 0) has a higher value than the substitute sample. The mixes BA 5, BA 10, BA 15, BA 20 and BA 25 shows reduction of 3.51%, 4.22%, 8.78%, 20% and 31.8% strength respectively, in comparison with the control mix BA 0.

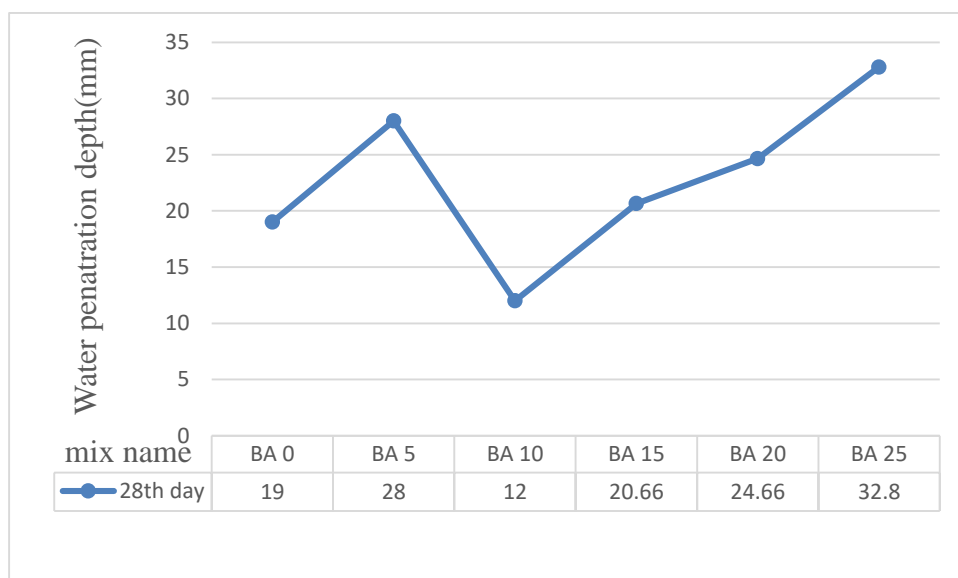
Even if the substituted sample has lower values than the control specimen. According to Eurocode 2 and also 95% confidence interval calculation up to BA 20 have an acceptable value. In Eurocode 2 the mean flexural strength of C-25 concrete is 3.3 MPa [40].

#### 4.3.4 Water Penetration

The Results of the water permeability are presented in Table 4.1 based on the full results on APPENDIX I, and the results of the water penetration with various percentage amounts of replacement of BA at 28 days of age are shown on Figure 4.5.

**Table 4.1 Water penetration test result**

Percentage replacement	BA 0	BA 5	BA 10	BA 15	BA 20	BA 25
28 day	19	28	12	20.66	24.66	32.8



**Figure 4.5 Maximum water penetration depth**

The maximum water penetration depth of concrete samples made without BA and samples made with 10% BA had showed a comparable value, even though the depth of penetration was lesser than that of the control sample. In comparison to the other sample groups, the 25% replacement ratio's maximum water penetration depth had the highest value. As a result, the 10% replacement performed well in terms of resistance to water penetration.

Neville defines impermeable concrete as having a water penetration depth of less than 50 mm, whereas impermeable concrete is defined as having a water penetration depth of less than 30 mm in aggressive conditions. As a result, each and every sample used in this research is impermeable [12].

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

The following research considered the experimental investigation of partial replacement of cement by municipal solid waste bottom ash. Based on the results obtained, the conclusions drawn are summarized as follows:

1. Reppie BA's chemical and physical characteristics made it appropriate for use as pozzolanic material in cement concrete production in accordance with ASTM C 618. Therefore, the sample BA can be categorised as an ASTM Class C pozzolan.
2. As the replacement proportion of BA rises, the workability of concrete declines. It can be because of the increased water absorption.
3. All substitution percentages had lower compressive strengths than the controlled sample for all curing periods, however the controlled sample's compressive strength is very close to those of the 5% and 10% substitutes.
4. The BA replacement sample's splitting tensile strength is lower than compared to the controls sample, but the results of up to 15% replacement samples are closely comparable to the controlled sample.
5. The BA replacement sample's flexural strength is lower than compared to the controls sample, but the results of up to 20% replacement samples are closely comparable to the controlled sample.
6. When compared to the controlled sample, BA 10 water permeability test at the 28th day of curing is lower. The controlled sample's water tightness performance is 10% lower than that of concrete samples.
7. Even though BA didn't have a significant effect on improving the mechanical properties of concrete, it can be used as an alternative cement replacement material.

## 5.2. Recommendations

The following recommendations are provided for studies with the goal of future success based on the research that was performed.

- Reppie BA can be used to partially replace Portland cement in concrete production.

For further extended research on other similar studies, the following recommendations are forwarded:

- The economic viability of using Reppie waste to energy bottom ash in place of Portland cement needs to be further investigated
- It is important to research chemical durability features such as resistance to sulphate attack, alkali-silica reaction, and chloride attack.
- Effect of BA in corrosion for reinforced concrete.

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## **APPENDIX**

Appendix A- Tests for Cement

Appendix B- Tests for Fine Aggregate Appendix

Appendix C- Tests for Coarse Aggregate Appendix

Appendix D- Tests for Bottom Ash

Appendix E- Mix Design

Appendix F- Test Results for Compressive strength of Concrete

Appendix G-Test Results for Splitting Tensile of Concrete

Appendix H- Test Results for Flexural Strength of Concrete

Appendix I- Test Results for water penetration depth of Concrete

Appendix J – 95% confidence interval calculation

## Appendix A - Tests for Cement

Item No.	Description	Test Result	
1	Fineness of cement	2.83%	
2	Specific gravity(gm/cm <sup>3</sup> )	3.15	
3	Cement consistency test	Water to cement ratio (%)	26
		Water (gm)	130
		Penetration(mm)	10
4	Setting time	Initial setting time (min)	156.3
		Final setting time (min)	300

## Appendix B- Fine Aggregate Test

### B-1: Sieve analysis result of fine aggregate

Sieve size (mm)	Weight retained (gm)	Percentage retained (%)	cumulative percent retained (%)	Cumulative passing (%)	ASTM C33 standard passing range (%)
9.75	0	0	0	100	100
4.75	1	0.2	0.2	99.8	95-100
2.36	23.2	4.6	4.8	95.2	80-100
1.18	80.35	16.037	20.837	79.163	50-85
0.6	194.65	38.85	59.687	40.313	25-60
0.3	152.85	30.50	90.187	9.813	5-30
0.15	40.7	8.123	98.31	1.69	0-10
Pan	7.95	1.586	99.89	0.11	0
∑			274.02		

$$FM = \sum(\text{cumulative percent retained}) / 100$$

$$= 274.02 / 100 = 2.74$$

$$FM = 2.7$$

### B-2: Moisture Content of fine aggregate

Weight of original sample (A) = 500g

Weight of oven-dry sample (B) = 490.7g

$$\text{Moisture content (\%)} = ((A-B)/B) * 100$$

$$= ((500-490.7)/490.7)*100$$

Moisture content (%) = 1.89%

### **B-3: Unit weight of fine aggregate**

Weight of measure= 4.85

Weight of measure and aggregate = 25.98

Net weight of aggregate = (weight of measure and aggregate) – weight of measure  
= 25.98- 4.85=21.135kg

Volume of measure (v) =  $\frac{\pi d^2}{4} *h$

d = 0.25m and h= 0.27m

$$\text{Volume of measure} = \frac{\pi(0.255)^2}{4} *0.27=0.0138\text{m}^3$$

$$\begin{aligned}\text{Unit weight of fine aggregate} &= \frac{\text{net weight of aggregate}}{\text{volume of measure}} \\ &= \frac{21.135}{0.0138} = 1531.52\text{kg/m}^3\end{aligned}$$

### **B-4: Specific gravity and absorption capacity for fine aggregate**

Weight of original sample = 500g

Weight of water + weight of pycnometer = 706.8g

Weight of sample + water + pycnometer = 1007.2g

Weight of oven dry sample = 488.6g

$$\text{Bulk specific gravity} = \frac{488.6}{706.8+500-1007.2} = 2.44$$

$$\text{Bulk specific gravity (SSD basis)} = \frac{500}{706.8+500-1007.2} = 2.5$$

$$\text{Apparent specific gravity} = \frac{488.6}{706.8+488.6-1007.2} = 2.59$$

$$\text{Absorption capacity} = \frac{500-488.6}{488.6} * 100 = 2.33 \%$$

**B-5: Silt content of the fine aggregate**

$$\text{Silt content (\%)} = \frac{\text{amount of silt content}}{\text{clean sand}} * 100$$

$$\text{Silt content (\%)} = \frac{0.4\text{mm}}{30\text{mm}} * 100 = 1.33\%$$

**Appendix C- Tests for Coarse Aggregate**

**C-1: Sieve analysis results of coarse aggregate**

Weight of sample taken (gm) = 2000gm

Sieve size (mm)	Weight of sieve (gm)	Weight of sieve and retained (gm)	Weight retained (gm)	Percentage retained (%)	cumulative percent retained (%)	Cumulative passing (%)	ASTM C33 standard passing range (%)
25	1199.8	1199.8	0	0	0	100	95-100
19	1380.2	1955.7	575.5	28.77	28.77	71.23	
12.5	1155.6	1889	733.4	36.67	65.44	34.56	25-60
9.5	1157.7	1726.6	568.9	28.445	93.885	6.115	
4.75	1177.5	1281.2	103.7	5.185	99.07	0.93	0-10
Pan	1059.4	1074.1	14.7	0.735	99.8	0	0
Σ							

Weight retained (gm)= Weight of sieve and retained (gm) - Weight of sieve (gm)....(must be approximately equal to weight of sample taken

Percentage retained (%) = Weight retained (gm)/ Weight of sample taken (gm)

cumulative percent retained (%) = Summing along column of percentage retained upto the respective row

Cumulative passing =100- cumulative percent retained (%)

**Fineness Modulus FM**

To determine the fineness modulus of coarse aggregate the values of intermediate sieves are not included. The following table shows the fineness modulus of coarse aggregate considering

38.1mm, 19mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, and 0.15 mm sieve sizes

Seive size (mm)	cumulative percent retained/ Cumulative coarser
38.1	0
19	28.77
9.5	93.885
4.75	99.07
2.36	100
1.18	100
0.6	100
0.3	100
0.15	100
Total	7.21

$$FM = \sum(\text{cumulative percent retained}) / 100$$

$$= 721.725 / 100$$

$$F.M = 7.21$$

### C-2: Moisture content of the coarse aggregate

Weight of original sample = 2000g

Weight of oven-dry sample = 1992.5g

$$\text{Moisture content (\%)} = \frac{\text{original sample weight} - \text{oven dry weight}}{\text{oven dry weight}} * 100$$

$$= \frac{2000 - 1992.5}{1992.5} * 100 = 0.376\%$$

### C-3: Unit weight of coarse aggregate

Weight of measure = 4.85

Weight of measure and aggregate = 27.601

Net weight of aggregate = (weight of measure and aggregate) – weight of measure

$$= 27.601 - 4.85 = 22.751 \text{kg}$$

$$\text{Volume of measure (v)} = \frac{\pi d^2}{4} * h$$
$$\frac{\pi(0.255^2)}{4} * 0.27 = 0.0138 \text{m}^3$$

$$\text{Unit weight of fine aggregate} = \text{Net weight of aggregate/volume of measure}$$
$$= 22.751/0.0138 = 1649.49 \text{ Kg/m}^3$$

#### **C-4: Specific gravity and absorption of coarse aggregate**

Weight of oven dry sample in air (A) = 4984 gm

Weight of saturated surface dry sample in air (B) = 5010 gm

Weight of saturated sample in water (C) = 3179.4 gm

$$\text{Bulk specific gravity} = \frac{A}{B-C} = \frac{4984}{5010-3179.4} = \frac{4984}{1830.6} = 2.7$$

$$\text{Bulk specific gravity (relative density) SSD} = \frac{B}{B-C} = \frac{5010}{5010-3179.4} = \frac{5010}{1830.6} = 2.73$$

$$\text{Apparent specific gravity} = \frac{4984}{4984-3179.4} = \frac{4984}{1804.6} = 2.76$$

$$\text{Absorption Capacity (\%)} = \frac{B-A}{A} = \frac{5010-4984}{4984} * 100 = \frac{26}{4984} * 100 = 0.52\%$$

#### **Appendix D- Test result of Bottom ash**

##### **D-1 Fineness of bottom ash**

Fineness is measured as a specific surface.

$$s = (s_s * \sqrt{T}) / \sqrt{T_s}$$

Where, S-Specific surface area of sample ( $\text{m}^2 / \text{Kg}$ )

S<sub>s</sub>-Specific surface area of sample used in calibration of the apparatus ( $\text{m}^2 / \text{Kg}$ )

T<sub>s</sub>- Measured time interval in second of manometer drop for standard sample used in the calibration apparatus.

T- Measured time interval in second of manometer drop for test sample

The following time intervals are obtained by using Baline's air permeability apparatus.

$$T_1 = 16.8 \text{ sec}$$

$$T_2 = 17.2 \text{ sec}$$

$$T_3 = 17.9 \text{ sec}$$

$$T_{avg} = \frac{16.8 + 17.2 + 17.9}{3} = 17.3 \text{ sec}$$

$$s = \frac{s_s \cdot \sqrt{T}}{\sqrt{T_s}}$$

$$= \frac{3774 \cdot \sqrt{17.3}}{\sqrt{37.8}} = 2553 \text{ cm}^2/\text{g}$$

#### D-2 Specific gravity of bottom ash

$$\rho = \frac{\text{mass of bottom ash (g)}}{\text{displaced volume (cm}^3\text{)}}$$

$$\rho = \frac{45.0072 \text{ g}}{18.4 \text{ ml} - 0.1 \text{ ml}} = 2.45$$

## Appendix E Mix Design for C-25 concrete

### Step 1: - Material Data

No	Test Description	Cement	Fine Aggregate	Coarse Aggregate
1	Specific Gravity	3.15	2.44	2.7
2	Unit Weight		1531.52 Kg/m <sup>3</sup>	1649.49 Kg/m <sup>3</sup>
3	Water absorption		2.33%	0.52%
4	Fineness modulus(FM)		2.74	7.13

### Step 2: - Choice of Slump

According to ACI 211 Table: 6.3.1 (Recommended slumps for various types of construction), the recommended slump to address more frequent constructions of concrete we considered Beams, Columns, and reinforced walls whose slump ranges between 25mm to 100mm where maximum slump= 100mm, and minimum slump= 25mm

### Step 3: - Choice of maximum aggregate size

Coarse aggregates =25mm

### Step 4: - Estimation of Mixing water and Air content

From Table 6.3.3 of ACI standards (Approximate mixing water and air content requirements for different slumps and nominal maximum aggregate of aggregates), considering non-air entrained concrete and for non-air-entrained and slump of 75 mm- 100 mm, the water in 1m<sup>3</sup> of concrete is 193kg.

### Step 5: - Selection of Water to Cement ratio (W/C)

According to Table 6.3.4 (a) (Relationship between water – cement or water – cementitious materials ratio and 33 MPa compressive strength of concrete), for the slump of 75mm to 100mm, water to cement ratio is 0.498

### Step 6: - Calculation of Cement content

Cement content (kg) per cubic meter of concrete is =  $water / (\frac{w}{c})$

Cement = 193/0.498

Cement = 387.55kg/m<sup>3</sup>

**Step 7: - Estimation of Coarse Aggregate (CA) content**

According to Table 6.3.6 (Volume of coarse aggregate per unit volume of concrete), for Fineness modulus of fine aggregate (F.M) = 2.74 and Maximum aggregate size = 25mm, the volume of oven dry – rodded coarse aggregate per cubic meter of concrete is 0.676. The mass of coarse aggregate can be estimated as:

$$\text{Coarse aggregate} = 0.676 * 1649 = 1115.05 \text{ kg/m}^3$$

**Step 8: - Estimation of fine Aggregates (FA) content**

Content of fine aggregate (F.A) = unit weight of concrete – (C.A + cement + water)

From Table 6.3.7.1 (First estimate of weight of fresh concrete), the unit weight of fresh concrete corresponding to the maximum aggregate size of 25mm and non-air entrained is 2380kg/m<sup>3</sup> .

$$\begin{aligned} \text{Fine aggregate} &= 2380 - (1115.05 + 387.55 + 193) \\ &= 2380 - 1695.6 \\ &= 684.39 \text{ kg/m}^3 \end{aligned}$$

**Step 9: - Adjustment for aggregate moisture**

If absorption capacity is greater than the moisture content of aggregate, we need to add water up to its moisture capacity.

$$\text{C.A water} = 0.52\% - 0.367\% = 0.153\%$$

$$\text{F.A water} = 2.33\% - 1.89\% = 0.44\%$$

$$\text{Total water required} = 193 + [684.39 * 0.44 + 1115.05 * 0.153] = 197.72 \text{ kg/m}^3$$

The estimated ingredients for a meter cube of concrete are, therefore, summarized as follows

No	Ingredients	Weight (kg/m <sup>3</sup> )
1	Cement	387.55
2	Fine Aggregate	684.39
3	Coarse Aggregate	1115.05
4	Water	197.72

**Appendix F - Test results for Compressive strength of concrete**

No	Test age (days)	Weight (gm)	Failure Load(KN)	Compressive strength (MPa)	Average Compressive strength (MPa)
BA 0	7	8460	629.6	27.58	27.65
		8347	631.6	28.07	
		8472	614.3	27.30	
	28	8398	969.7	43.1	42.35
		8580	921.4	40.95	
		8587	967.6	43.00	
	56	8577	1171.1	52.02	47.67
		8362	1053.4	46.8	
		8313	994.6	44.20	
BA 5	7	8075	572.4	25.44	25.73
		8031	601.3	26.72	
		8043	563.5	25.05	
	28	8192	860.4	38.24	37.37
		8110	831.0	36.94	
		8180	830.9	36.93	
	56	8180	905.8	40.2	39.94
		8195	913.7	40.58	
		8149	878.9	39.06	
BA 10	7	8187	572	25.42	25.36
		8158	577.1	25.65	
		8216	562.8	25.01	
	28	8255	833.8	37.06	35.58
		8466	850	37.78	
		8300	717.8	31.90	
	56	8117	924.9	41.01	38.39
		8173	755.0	33.55	
		8083	913.8	40.61	
BA 15	7	7939	504.1	22.40	21.97
		7987	463.8	20.58	
		7953	516.0	22.93	
	28	7968	747	33.2	32.47
		7954	730.65	32.475	
		7939	714.3	31.75	
	56	8066	809.6	35.98	36.32
		7989	817.0	36.31	
		8100	819.4	36.42	

Solid waste bottom ash as a partial replacement of cement in concrete production

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BA 20	7	8095	451.6	20.06	20.93
		8167	454	20.18	
		8106	507	22.53	
	28	8171	702.9	31.24	32.05
		8200	744.5	33.04	
		8215	717.2	31.87	
	56	7964	790.2	35.12	35.47
		8051	787.8	35.01	
		8284	816.5	36.29	
BA 25	7	7889	341.4	15.17	14.90
		7980	369.1	16.40	
		7849	295.6	13.14	
	28	7977	579.8	25.77	27.28
		7923	613.0	27.24	
		8006	649.5	28.85	
	56	8061	798.3	35.48	32.76
		8014	712.1	31.65	
		8042	701.17	31.17	

**Appendix G- Test results for splitting tensile strength of concrete**

No	Test age (days )	Weight (gm)	Failure Load(KN)	Splitting Tensile strength (MPa)	Average Splitting Tensile strength (MPa)
BA 0	28	13122	197.7	2.79	2.69
		13023	136.1	1.926	
		13120	237.1	3.35	
BA 5	28	12780	125.7	1.78	2.35
		12843	148.1	2.09	
		12778	224.5	3.17	
BA 10	28	12591	167	2.36	2.6
		12663	174.3	2.46	
		12628	210.2	2.97	
BA 15	28	12723	215	3.04	2.8
		12630	206	2.91	
		12690	178	2.51	
BA 20	28	12644	180	2.54	2.23
		12620	179.9	2.54	
		12610	114.8	2.51	
BA 25	28	12546	105.6	1.49	1.99
		12682	184.9	2.61	
		12691	132.1	1.86	

The following equation shows the splitting tensile.

$$T = \frac{2P}{\pi * l * d}$$

Where,

T= splitting tensile strength, psi (kPa)

P= maximum applied load (kN)

l= length of cylindrical specimen (m)

d = diameter of cylindrical specimen (m)

### Appendix H- Test Results for Flexural Strength

No	Test age (days )	Weight (gm)	Failure Load(KN)	Flexural strength (MPa)	Average Flexural strength (MPa)
BA 0	28	12281	13	5.02	5.70
		12236	13.6	5.8	
		12137	14.8	6.3	
BA 5	28	12117	13.4	5.82	5.5
		12220	13.5	5.8	
		12172	10.9	4.73	
BA 10	28	12043	12.8	5.75	5.46
		12075	11.2	5.03	
		12060	12.4	5.6	
BA 15	28	11919	11.5	5.16	5.2
		11948	12.5	5.62	
		11862	11.3	5.08	
BA 20	28	11827	9.4	4.25	4.56
		11783	11.3	5.1	
		11916	9.7	4.35	
BA 25	28	11544	8.4	3.79	3.9
		11604	8.3	3.72	
		11861	9.4	4.2	

The following equation shows the flexural strength.

$$R = \frac{PL}{bd^2}$$

Where:

R = modulus of rupture, psi, or MPa,

P = maximum applied load indicated by the testing machine, lbf, or N,

L = span length, in., or mm,

b = average width of specimen, in., or mm, at the fracture, and

d = average depth of specimen, in., or mm, at the fracture

For fracture occurs in the tension surface outside of the middle third of the span length by not more than 5 % of the span length, the modulus of rupture calculates as:

$$R = \frac{3Pa}{bd^2}$$

Where:

a = average distance between line of fracture and the nearest support measured on the tension surface of the beam, mm

When the fracture occurs in the tension surface outside of the middle third of the span length by more than 5 % of the span length, the results had been discarded.

**Appendix I– Water permeability**

No	Test age (days )	Weight (gm)	Water penetration(m m)	Average water penetration(mm)
BA 0	28	8398	14.66	15.8
		8580	19	
		8587	14	
	56	8577	20.66	23.6
		8200	18.66	
		8516	18.66	
BA 5	28	8192	13.33	20.66
		8110	28.66	
		8180	20	
	56	8061	24.33	25.56
		8101	25.66	
		8132	26.7	
BA 10	28	8278	12	11.11
		8268	9.33	
		8216	12	
	56	7959	22	20.33
		8050	20.4	
		8065	18	
BA 15	28	7914	20.66	23.77
		7886	18.66	
		7983	18.66	
	56	8002	25.33	26.22
		7989	26.19	
		8100	27.23	
BA 20	28	8014	19	26.22
		8131	24.66	
		7792	35	
	56	7964	46.66	37.21
		8051	48.33	
		8284	16.66	
BA 25	28	7938	28.6	30.4
		7880	30.1	
		7896	32.8	
	56	8061	38.7	38.5
		8014	39.33	
		8042	37.16	

**Appendix J– 95% Confidence Interval Calculation**

**1. Compressive strength**

a. 7<sup>th</sup> day compressive strength

$$C.I = \mu \pm z * \frac{\sigma}{\sqrt{n}}$$

BA 0	BA 5	BA 10	BA 15	BA 20	BA 25
27.65	25.73	25.36	21.97	20.93	14.9

$$\mu = 27.65$$

$$\sigma = \sqrt{\frac{(x - \mu)^2}{n - 1}}$$

$$= \sqrt{\frac{(27.65 - 27.65)^2 + (25.73 - 27.65)^2 + (25.36 - 27.65)^2 + (21.97 - 27.65)^2 + (20.93 - 27.65)^2 + (14.9 - 27.65)^2}{6 - 1}}$$

$$= \sqrt{\frac{0 + 3.686 + 5.244 + 32.262 + 45.15 + 162.56}{5}}$$

$$\sigma = 7.055$$

$$C.I = 27.65 \pm 1.96 * \frac{7.05}{\sqrt{6}} \quad \text{Where, } Z=1.96 \text{ from } Z \text{ table}$$

$$\text{Lower limit, } 27.65 - 1.96 * \frac{7.05}{\sqrt{6}} = 22.01$$

$$\text{Upper limit, } 27.65 + 1.96 * \frac{7.05}{\sqrt{6}} = 33.29$$

b. 28<sup>th</sup> day compressive strength

$$C.I = \mu \pm z * \frac{\sigma}{\sqrt{n}}$$

BA 0	BA 5	BA 10	BA 15	BA 20	BA 25
42.35	37.37	35.58	32.475	32.05	27.28

$$\mu = 42.35$$

$$\sigma = \sqrt{\frac{(x - \mu)^2}{n - 1}}$$

$$= \sqrt{\frac{(42.35 - 42.35)^2 + (37.37 - 42.35)^2 + (35.58 - 42.35)^2 + (32.475 - 42.35)^2 + (32.05 - 42.35)^2 + (27.28 - 42.35)^2}{6 - 1}}$$

$$= \sqrt{\frac{0 + 24.8 + 45.83 + 97.515 + 106.9 + 227.10}{5}}$$

$$\sigma = 10.2$$

$$C.I = 42.35 \pm 1.96 * \frac{10.02}{\sqrt{6}} \quad \text{Where, } Z=1.96 \text{ from Z table}$$

$$\text{Lower limit, } 42.35 - 1.96 * \frac{10.02}{\sqrt{6}} = 34.31$$

$$\text{Upper limit, } 42.35 + 1.96 * \frac{10.02}{\sqrt{6}} = 50.39$$

c. 56<sup>th</sup> day compressive strength

$$C.I = \mu \pm z * \frac{\sigma}{\sqrt{n}}$$

BA 0	BA 5	BA 10	BA 15	BA 20	BA 25
47.67	39.94	38.39	36.32	35.47	32.76

$$\mu = 47.67$$

$$\sigma = \sqrt{\frac{(x - \mu)^2}{n - 1}}$$

$$= \sqrt{\frac{(47.67 - 47.67)^2 + (39.94 - 47.67)^2 + (38.39 - 47.67)^2 + (36.32 - 47.67)^2 + (35.47 - 47.67)^2 + (32.76 - 47.67)^2}{6 - 1}}$$

$$= \sqrt{\frac{0 + 59.75 + 86.118 + 128.82 + 148.84 + 222.3}{5}}$$

$$\sigma = 11.36$$

$$C.I = 47.67 \pm 1.96 * \frac{11.36}{\sqrt{6}} \quad \text{Where, } Z = 1.96 \text{ from } Z \text{ table}$$

$$\text{Lower limit, } 47.67 - 1.96 * \frac{11.36}{\sqrt{6}} = 38.58$$

$$\text{Upper limit, } 47.67 + 1.96 * \frac{11.36}{\sqrt{6}} = 56.76$$

## 2. Splitting tensile strength

$$C.I = \mu \pm z * \frac{\sigma}{\sqrt{n}}$$

BA 0	BA 5	BA 10	BA 15	BA 20	BA 25
2.69	2.35	2.6	2.5	2.23	1.99

$$\mu = 2.69$$

$$\sigma = \sqrt{\frac{(x - \mu)^2}{n - 1}}$$

$$= \sqrt{\frac{(2.69 - 2.69)^2 + (2.35 - 2.69)^2 + (2.6 - 2.69)^2 + (2.5 - 2.69)^2 + (2.23 - 2.69)^2 + (1.99 - 2.69)^2}{6 - 1}}$$

$$= \sqrt{\frac{0 + 0.115 + 0.0081 + 0.0361 + 0.2116 + 0.49}{5}}$$

$$\sigma = 0.415$$

$$C.I = 27.65 \pm 1.96 * \frac{7.05}{\sqrt{6}} \quad \text{Where, } Z = 1.96 \text{ from } Z \text{ table}$$

$$\text{Lower limit, } 2.69 - 1.96 * \frac{0.415}{\sqrt{6}} = 2.35$$

$$\text{Upper limit, } 2.69 + 1.96 * \frac{0.415}{\sqrt{6}} = 3.022$$

### 3. Flexural strength

$$C.I = \mu \pm z * \frac{\sigma}{\sqrt{n}}$$

BA 0	BA 5	BA 10	BA 15	BA 20	BA 25
5.7	5.5	5.46	5.2	4.56	3.9

$$\mu = 5.7$$

$$\sigma = \sqrt{\frac{(x - \mu)^2}{n - 1}}$$

$$= \sqrt{\frac{(5.7 - 5.7)^2 + (5.5 - 5.7)^2 + (5.46 - 5.7)^2 + (5.2 - 5.7)^2 + (4.56 - 5.7)^2 + (3.9 - 5.7)^2}{6 - 1}}$$

$$= \sqrt{\frac{0 + 0.04 + 0.0576 + 0.25 + 1.299 + 3.24}{5}}$$


$$\sigma = 0.988$$

$$C.I = 5.7 \pm 1.96 * \frac{0.988}{\sqrt{6}} \quad \text{Where, } Z = 1.96 \text{ from } Z \text{ table}$$

$$\text{Lower limit, } 5.7 - 1.96 * \frac{0.988}{\sqrt{6}} = 4.91$$

$$\text{Upper limit, } 5.7 + 1.96 * \frac{0.988}{\sqrt{6}} = 6.49$$

Appendix H Test certificate

	<b>GEOLOGICAL SURVEY OF ETHIOPIA</b>	Doc Number: GLD/FS.10.1	Version No: 1
	<b>GEOCHEMICAL LABORATORY DIRECTORATE</b>		Page 1 of 1
Document Title:	<b>Complete Silicate Analysis Report</b>	Effective date:	May, 2017

Customer Name:- Samrawit Yeshaw

Issue Date:- 22/09/2022

Request No:- GLDRQ/29/22

Sample type :- Rock

Report No:- GLDRN/33/22

Date Submitted:- 27/07/2022

Sample Preparation:- 200 Mesh

Number of Sample:- One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: LiBO<sub>2</sub> FUSION, HF attack, GRAVIMETRIC, COLORIMETRIC and AAS.

Collector's code	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	MnO	P <sub>2</sub> O <sub>5</sub>	TiO <sub>2</sub>	H <sub>2</sub> O	LOI	Weight of Sample
S-Y-01	34.42	16.16	6.80	15.28	1.60	1.20	2.36	0.12	2.82	0.40	3.07	14.30	1.208g

Note: - This result represent only for the sample submitted to the laboratory.

Analyst

Gadisa Wakuma

Checked By

  
Lidat Endeshaw

Approved By

  
Yohannes Getachew

