ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

EFFECT OF USING BOTTOM ASH AS FINE AGGREGATE REPLACEMENT IN CONCRETE: THE CASE OF REPPIE WASTE TO ENERGY POWER PLANT

A Thesis in Structural Engineering

By Abrham Assegid W/Mariam

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled '**Effect of Using Bottom Ash as Fine Aggregate Replacement in Concrete (The Case of Reppie Waste to Energy Power Plant)**' presented by **ABRHAM ASSEGID**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

Prof. Girma Zerayohannes	____________________	______________
Advisor	Signature	Date
Dr. Abraham Gebre	____________________	______________
Internal Examiner	Signature	Date
Dr. Esayas G/Yohannes	____________________	______________
External Examiner	Signature	Date
Dr. Mebruk Mohammed	____________________	______________
Chair person	Signature	Date

UNDERTAKING

I certify that, this research work entitled "Effect of Using Bottom Ash as Fine Aggregate Replacement in Concrete: The Case of Reppie Waste to Energy Power Plant" 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.

Signature of Student

Abrham Assegid

ABSTRACT

Thousands of tons of municipal solid waste are generated each year in Addis Ababa, necessitating a large area for disposal and negatively impacting the area's echo system. This urban solid waste is currently used to generate electricity at the Reppie waste-to-energy power plant. Reppie waste to energy power plant used this municipal solid waste to generate electric energy with a waste processing capacity of (394.7 kt/year). Even if this power plant uses municipal solid waste to generate usable electricity, it produces waste (bi-product) that has an effect on the echo system and necessitates a wide disposal area. The wastes produced from this power plant are of two types, namely, fly ash (15.21 kt/year) and bottom ash (BA) (100.4 kt/year).

On the other hand, fine aggregate (FA) has been used extensively as a key component of concrete production in the building industry. The over-exploitation of natural sand as a source of FA has resulted in depletion and environmental degradation.

This research is conducted to determine the effect of using Reppie waste to energy power plant bi-product BA as partial replacement of FA for production of concrete.

The test result showed that BA is a class C ash, light in weight material with more pores particles. When using it in concrete, the increase in percentage substitution of BA reduces the workability and slump value. On hardened concrete, the compressive strength rises up to 35% substitution and then start to decline beyond that, however up to 50% substitution, also gives a better result than the controlled result. The splitting tensile strength and flexural strength increase up to 50% substitution which has the value nearly similar with the control and starts to decrease at 65% substitution. The water penetration constantly decreases for all substitution of FA with BA. Furthermore, an ultrasonic pulse velocity test result indicated that all percentage substitution has a good concrete quality grading.

Based on the results, this BA can replace FA up to 50%, but the maximum results are obtained at 35% substitution, and this maximum result is obtained after 28 days of curing.

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LIST OF ABBREVIATIONS

AAiT	Addis Ababa Institute of technology
ACI	American Concrete Institute
Al_2O_3	Aluminium Oxide
ASTM	American Society for Testing and Materials
A_p	Pores Area
A_T	Total Area
A_t	Threshold area
a	Average distance between line of fracture and the nearest support
BA	Bottom Ash
BaO	Barium oxide
b	Average width of specimen
CA	Coarse Aggregate
$Ca_3Al_2O_6$	Calcium Aluminum oxide
$CaAl_2SiO$	Calcium Aluminum Silicate
$CaCO_3$	Calcium oxide
CaO	Calcium oxide
CES	Compulsory Ethiopian Standard
CMLM	Construction Material Laboratory Manual
CO_2	Carbon di-oxide
CEM	Cement

Cm	Centimetre
D	Diameter
d	Average depth of specimen
FA	Fine Aggregate
Fe_2O_3	Iron Oxide
f'c	Target mean strength
GPa	Giga Pascal
K_2O	Potassium Oxide
kPa	Giga Pascal
kg	kilo Gram
kg/m^3	Kilogram per meter cube
km/sec	Kilometer per second
kN	Kilo Newton
kt/year	Kiloton per year
L	Length
LOI	Loss on Ignition
MgO	Magnesium Oxide
$MgSiO_3$	Magnesium Silicate
mg/m^3	Milligram per meter cube
mm	Millimeter
MPa	Megapascal

N	Newton
OPC	Ordinary Portland cement
P	Failure Load
P	Porosity
PDF	Power diffraction file
P_2O_5	Phosphorous Oxide
PSD	Particle size distribution
R	Modules of rupture
SCC	Self-compacted concrete
SiO_2	Silicon di-oxide
SEM	Scanning electron microscopy
SSD	Saturated Surface dry
T	Tensile splitting Strength
t	Time
TiO_2	Titanium Oxide
UK	United Kingdom
V	Velocity
XRD	X-ray Diffraction
μm	Micro Meter

CHAPTER 1 INTRODUCTION

1.1 General background of the study

The construction industry has become a world leader by playing a significant role in global development. The discovery of concrete has had a significant impact on the construction industry. Concrete is primarily made up of aggregates, cement, and water, and may contain other cementitious materials and/or chemical admixtures. (ACI 211.1-91, 1991)

Every year, thousands of tons of municipal solid waste are generated in Addis Ababa, necessitating the disposal of a large area; additionally, it has a negative impact on the area echo system. Currently, this solid waste is used as a source of energy to generate electricity in a Reppie waste-to-energy power plant.

With a waste processing capacity of (394.7 kt/year), the Reppie waste to energy power plant used this municipal solid waste to generate usable electric energy. Even if, this power plant used this municipal solid waste to generate usable energy which has its own waste (bi-products) that affect the echo system and necessitate large disposal area. The wastes produced from this plant are two types classified as fly ash and bottom ash (BA).

BA comes from leaked ash from grate, boiler ash from the second and third flues of the boiler, boiler ash from superheated flue, boiler ash from economizer flue and incinerator slug. It has a quantity (100.4 kt/year) about one third of used municipal wastes. Fly ash is a fine powder that is produced from flue gas treatment in electric generation power plant. Which have a quantity of (15.21 kt/year) about two percent of used municipal wastes. (China National Electric Engineering Co., 2015)

Figure 1-1: Reppie waste to energy power plant a) General overview of the power plant b) Overall activity computer control c) Steam turbine d) Intake of municipal waste into burning unit

The common method of disposing the BA is using for land filling which have its own drawback like high cost of transportation, difficulty in getting suitable sites for land filling, heavy metal contamination of the land, emission of fuel gases etc. so for the future disposing of BA has become a major issue.

On the other hand, the increase in demand for construction materials in the recent years because of development has called for an alternative way to develop or drive construction materials from other sources. Based on this for alternative sustainable construction material and for environmental preservation many researchers have attempted to use BA as a construction material like bricks production, artificial aggregate, water in concrete mixtures, ceramic production, glass production etc.

The aim of this thesis research is to use this Reppie waste to energy power plant bi-product, BA, as a fine aggregate/sand partial replacement for the production of concrete and to compare the result with the property of control concrete made with natural fine aggregate (FA).

1.2 Statement of the problem

Reppie waste to energy power plant produce $10.04*10^4$ tons BA per year that currently disposed as landfilling in place around the power plant, which requires a consistent industry which converts/uses this bi-product to useful ingredient. Now a days, in most areas of the world, it is common disposing BA for land filling which has its own set of drawbacks such as high transportation costs and difficulty in obtaining suitable sites for land filling, heavy metal contamination of the land, emission of fuel gases etc. so currently disposing of this bi-product has become a major issue.

FA, on the other hand, has been widely used in the construction industry as a critical component of concrete production. The over-exploitation of natural sand as a source of FA has resulted in depletion and environmental degradation. As a result, alternative sources are being investigated for the prevention of depletion and the mitigation of negative environmental effects.

1.3 Objective of the study

1.3.1 General objective

To investigate the effect of using Reppie waste to energy power plant bi-product, BA, as partial replacement of FA for production of concrete.

1.3.2 Specific objective

- Knowing the chemical composition of the Reppie waste to energy power plant bi-product BA, which will be used in concrete production.
- To investigate the impact of partial replacement of natural FA with BA on the mechanical properties of concrete.
- To investigate the impact of partial replacement of natural FA with BA on concrete durability requirements.
- Reduce the cost of the projects by replacing the natural FA.

- To provide an additional sustainable construction row material source while reducing the need for a BA disposal area.

1.4 Scope of the study

- Review and research of concrete properties made of BA as FA replacement.
- Since the chemical property of BA depend on the waste it formed, so determine the chemistry of this BA and make necessary treatment (if required) to use as FA replacement in concrete.
- Determine the engineering property of materials used for concrete production i.e., CA, FA and BA.
- Conduct the mechanical property tests (cubic compressive strength, splitting tensile strength, flexural strength/modules of rupture, for 7, 28 and 56 days of concrete by partial substitution (0%, 20%, 35%, 50% and 65%) of BA as a FA.
- Conduct the water permeability tests for 28 and 56 days of concrete by partial substitution (0%, 20%, 35%, 50% and 65%) of BA as a FA.
- Ultrasonic pulse velocity test to determine the quality of concrete based on specific standard for 7, 28 and 56 days of curing period by partially (0%, 20%, 35%, 50% and 65%) replacing of FA with BA.

1.5 Limitations

- The scope of this analysis was constrained by the laboratory's inability to conduct other critical tests such as chloride penetration and dynamic elasticity modules.
- The other main barrier was financial limitation, which enforced to minimize the scope of the study, sample numbers and sample size.
- In addition, Covid-19 has an impact on the research by lengthening the time it takes to complete it and increasing the cost of the analysis by enforcing the rejection of prepared samples because their test day meets with the university's closed period.

1.6 Significance of the study

The recent increase in demand for construction materials has significantly increased the cost of construction, necessitating an alternative method of developing or driving construction materials other than natural sources. One of the best solutions to these problems is to use this BA for concrete production as a FA replacement. It also increases some useful concrete properties and significantly reduces the required disposal area of BA.

1.7 Thesis structure

This study is divided into six chapters. The first chapter emphasizes the overall idea, problem statement, objectives, scope, and significance of this research paper. The second chapter discusses previous studies on the use of BA as a construction material and the effect of partial replacement of BA as FA in concrete. The third chapter briefly describes the materials used for experimental investigation as well as their properties. The fourth chapter describes the experimental methods and procedures used in this study. The fifth chapter discusses the experiment results, followed by analysis and interpretation. Finally, in chapter six, conclusions and basic recommendations for future works are presented.

CHAPTER 2 LITRATURE REVIEW

2.1 General

As the need of peoples increase, the construction industry increases significantly in complexity and amount. The discovery of Concrete is one of the major solutions to fulfill these needs. The invention of concrete makes the construction easy to construct heavy and mega structures with less cost and time and insure the durability of structures. The name concrete comes from the Latin word "concretus", which means to grow together. Concrete is a combination of three major ingredients; cement and water (to form paste) and aggregate; FA (to form mortar) and coarse aggregate (FA) (to form concrete).

Researchers have conducted various studies on concrete to improve its performance and meet the demand for local materials for concrete production by adding admixtures and ingredients other than the major ingredients, using different types and kinds of materials, and mixing proportions, etc. Substituting FA with other substituent materials is one method of using different materials by partial or full substitution of one or more major ingredients.

The basic principles during substituting major ingredients of concrete:

1. The strength and durability requirements of concrete should not be less than the minimum requirement.
2. It should be problem solving (availability, transportation, cost, …)
3. It should cost lesser or at least equal to the substitute material.
4. It should achieve certain properties in concrete more effectively than other means.
5. It should keep the quality of concrete during the mixing, transporting, placing, and curing stages.
6. It needs to overcome certain emergencies during concreting operations.

2.1.1 Possible materials that can substitute natural fine aggregate for concrete production

1. Crushed Sand (Manufactured Sand): - produced by crushing rock.

2. Crushed Dust or Quarry Dust: - product of stone crushers while producing CA.
3. Washed Bottom Ash: - waste of fired coal in thermal power plants.
4. Granulated Blast Furnace Slag: - waste of steel industry.
5. Recycled Crushed Concrete: - demolished concrete, crushed and sieved.

2.1.2 Uses of aggregate in concrete

Using aggregate to produce concrete has the following main reasons;

1. To increase the strength.
2. To reduce the cost of construction.
3. To enhance thermal resistivity.
4. To increase the elastic property.
5. To maintain the dimensional and volumetric stability.
6. To control the shrinkage level and reduce cracking.
7. To provide abrasion resistance. (Baylinx M. INC., 2018)

2.2 Bottom ash

This sub chapter focuses on previous research studies on BA, its chemical and physical properties, its uses as a construction material and issues related to environmental and waste management.

Bottom Ash is used as a row material in the construction industry in the form of subgrade material for road construction, brick production in building construction, artificial aggregate for production of concrete, cement-like material after grinding in powder form in ceramic and glass production, etc. However, the use of BA is almost none in our country for construction industry. Therefore, the purpose of this research is to use Reppie waste to energy power plant bi-product BA as a FA/sand partial replacement for the production of concrete and to check its effect by comparing the result with the property of controlled concrete made with natural FA.

Definition - Bottom ash is part of the non- combustible residue of combustion in a power plant, boiler, furnace or incinerator. In an industrial context, it has traditionally referred to coal combustion and comprises trace of combustibles embedded in forming clinkers and sticking to hot sidewalls of a coal-burning furnace during its operation. The portion of the ash that escapes up the chimney or stack is however, referred to as fly ash. The clinker that fall by themselves into the bottom hopper of a coal-burning furnace and cooled there is referred to as BA.

According to the definition of (ACI 116R-00, 2000), fly ash is the finely divided residue resulting from the combustion of ground or powdered coal which is transported from the firebox through the boiler by the flue gases, known in the UK as pulverized fuel ash. Sizes may vary from less than 1µm to more than 80 µm and density of individual particles vary from less than 1 mg/m^3 hollow spheres to more than 3 mg/m^3 (ACI Committee 232, 2004). BA on the other hand has angular particles with a very porous surface texture. Its size ranges from gravel to fine sand with very low percentages of silt-clay sized particles. The ash is usually a well-graded material, although variation in particle size may encounter. (ACI Committee 232, 2004).

The total composition of chemical properties of $SiO_2 + Al_2O_3 + Fe_2O_3$ present altogether in the coal bottom ash that has been dried in the oven for 24 hours varied from 53.58% to 58.53% such coal bottom ash used in this study conformed to ASTM C 618-03 Class C ash which has a minimum content sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ which is 50%. Since bottom ash was included in class C it has pozzolanic property and also has some cementitious properties. Besides that, it may also contain lime (CaO) higher than 10%. To produce cementitious mixtures, bottom ash requires a cementing agent such as Portland cement, quicklime or hydrated lime that reacts with water. Similarly, the total composition properties of $SiO_2 + Al_2O_3 + Fe_2O_3$ present altogether in the natural river sand is 58.15 %. (Ramzi N.I.R., 2016)

The presence of silicon oxide is essential, as it is an important element during the mixing of concrete. However, other elements found exceptionally in bottom ash but not in river sand are magnesium oxide (MgO), sodium oxide (Na_2O), sulfur trioxide (SO_3), phosphorus pentoxide (P_2O_5) and barium oxide (BaO). Part of these elements are non-flammable compounds, part of them consisted of species that are significant pollutants while the rest of them are powerful desiccant and dehydrating agents. (Ramzi N.I.R., 2016)

The chemical composition of BA and FA from different locations presented below in tabular form.

Table 2-1: Chemical properties of BA according to different locations (Hannan, 2017)

Formula (%)	Natural River Sand	Coal Bottom Ash (Tangjung Bin)
SiO_2	51	33.7
Al_2O_3	6.83	12.9
Fe_2O_3	0.32	6.98
CaO	0.48	6.34
K_2O	0.4	1.19
TiO_2	0.58	0.89
MgO	-	0.65
SO_3	-	0.9
Na_2O	-	0.59
P_2O_4	-	0.3
BaO	-	0.22

Table 2-2: Chemical properties of BA according to different locations (Hannan, 2017)

Chemical Composition (%)	Spanish Power Plant [21]	Guru Hargobind Thermal Power Plant Bathinda, India [22]	TNB Electric Power Plant Perak, Malaysla [19]	Seocheon Coalfired thermal Power Plant, South Korea [23]
SiO_2	52.3	56.44	54.8	44.2
Al_2O_3	25.14	29.24	28.5	31.5
Fe_2O_3	9.23	8.44	8.49	8.9
CaO	2.37	0.75	4.2	2
MgO	1.84	0.4	0.35	2.6
Na_2O	0.66	0.09	0.08	-
K_2O	3.72	1.29	0.45	-
TiO_2	1.45	3.36	2.71	2.4
P_2O_5	0.25	-	0.28	-
SO_3	0.03	0.24	-	-
LOI	1.07	0.89	2.46	-

Table 2-3: Chemical properties of FA according to different locations (Kiambigi, 2018, October)

Chemical Composition (%)	Mwingi Sand	Kajiado Sand	Mlolongo Rock Sand	Machakos Sand	Naivasha Sand	Mlolongo Quarry dust
SiO_2	76	78	67	80	69	65
Al_2O_3	11	9	17	10	14	19
Fe_2O_3	1.4	1.2	4	1	5.5	4
CaO	1.6	1.5	1.4	2.5	1.3	1.4
MgO	0.8	1	0.05	0.02	0.04	0.08
Na_2O	2	1.4	1.5	1.8	3	4
K_2O	1	1	3	1	1.8	1.6
TiO_2	0.3	0.17	1.4	0.12	0.3	0.6
LOI	0.72	1.04	3.5	1.7	2	3.8

In addition to this, one of the basic characteristics of materials used in concrete is their porosity, which affects the engineering property of materials. The average porosity of marine sand collected from the offshore of Fort Walton Beach, Florida, and embedded with resin was determined to have a range of 39.30% to 45.45% with an average of

41.30%. From the review of published data, the average porosity of sand was determined to be 37.7%, 42.3%, and 46.3% for packed, natural (in situ), and loose packing conditions, respectively, for a range of sorting coefficients and grain sizes. (Curry C.W., 2004) BA is more pores material than FA, which have found to have around 67% porosity value. (Lawane A., 2019)

2.2.1 Bottom ash as a construction material

Researchers conduct some researches to use Bottom ash as a construction material for different civil engineering applications:

Use BA as aggregate – BA can be used as aggregate in foundation layers, sub-base, embankment and as capping material in road construction. When it is used in the hydraulic-bounded form, its washing is done prior to usage to prevent leaching of heavy metal at the point of use. Since this does not involve milling of ash, the washing process can be more effective in curbing aluminum-induced expansion. When used in bitumen-bounded applications, it resulted in higher bitumen demands due to its porosity compared to conventional aggregates. In landfills, where it is used as stabilizing layer to protect the geo-membrane, intermediate layer and as the leachate drainage layer. (Aneeta Mary Joseph, 2018)

BA as embankment - By making solidified and stabilized (solidified sludge) with various binders including Portland cement, lime, gypsum, and a combination of some of these binders, BA could possess higher strength and lower leachability of toxicity, and thus may be beneficial when used in dike construction, (Ping Chen, 2019) in roads, railway and dam embankments.

BA as brick - There is a possibility of using very high amount of bottom ash from municipal solid waste incinerator in the production of new-fired bricks with good performances. (R Taurino, 2017)

BA as cementitious material – Using ground coal BA as an alternative material for cement, with good durability performance, especially in chloride ingress (Sajjad Ali Mangi, 2018).

In addition, as Supplementary Cementing Material, note that the original coal BA is porous in nature and it cannot be used as a replacement of cement, but after the proper grinding, it will possess good Pozzolanic property and could be utilized to replace cement in concrete. (Sajjad Ali Mangi, 2018)

BA as FA substitution – BA, when used as partial replacement of FA in concrete has the following properties.

BA contains a Pozzolanic material, which gives a cementitious property when mixing with water. However, this Pozzolanic reaction not initiated at early ages so that the strength may not increase at the ages of 7 and 28 days. (Sajjad Ali Mangi, 2018) For the 7-day curing period, the compressive strength of concrete mixes containing 50% and 100% BA decreased about 9% and 15.16% compared to the strength of the control samples, however during the long-term duration of curing age, up to 60 days, the compressive strength increased up to 10%. Where 30% sand replacement is used in the concrete mix, the compressive strength recorded the highest value at the curing ages up to 60 days. Therefore, (M H Abdullah, 2019) concluded that concrete with BA content will reach its optimum strength beyond 28 days.

Since BA contained some cementitious properties, there is possibility that the strength to be slightly higher and more durable compared with the conventional concrete. 10% replacement by weight of total FA with BA in self-compacted concrete (SCC) showed a better durability, chloride penetration, carbonation depth and drying shrinkage compare to control SCC mix. (Aeslina Abdul Kadir, 2014)

Research also indicated that to achieve desired slump vales, demand for mixing water increases with the use of BA as partial sand replacement in concrete. This performance exhibited due to rough surface and irregular particles size of BA, which significantly changes the texture of concrete mix. Therefore, it increases the internal friction of particles, which is liable for low flow of fresh concrete. This behavior indicated the internal particle friction and more water absorbed during mixing of concrete, which caused reduction in slump value. (Sajjad Ali Mangi, 2018)

Generally, Using BA as a replacement of FA in concrete has the following property

- Better durability (Aeslina Abdul Kadir, 2014)
- Lower chloride penetration and carbonation depth (Aeslina Abdul Kadir, 2014)

- Decrease in drying shrinkage (Aeslina Abdul Kadir, 2014)
- Tensile strength of BA concrete generally increases with the increase in curing age (Abdulhameed Umar Abubakar, 2012)
- Produce noise reduction concrete (Nurul Izzati Raihan Ramzi Hannan, 2017)
- Optimum compressive strength could be attained beyond 28 days (M H Abdullah, 2019)
- Higher water absorption (M H Abdullah, 2019)
- Lower workability (M H Abdullah, 2019)
- Lower slump value (Sajjad Ali Mangi, 2018)
- High permeability (M H Abdullah, 2019)
- Protecting the environment (Nurul Izzati Raihan Ramzi Hannan, 2017)

It is also used in precast concrete, for ceramic production, as an artificial aggregate, for glass production etc.…

2.2.2 Environmental and waste management

Environmental management – Recent researches indicate environmental protection is becoming major issue in the world. Different standards, environmental agreements and rules including environmental impact assessment and mitigation, wastewater conveyance and treatment, contaminated land management and site remediation, solid waste management, etc. carried out in different countries to protect the environment.

Disposing BA as land filling affects the environment by creating difficulty in getting suitable sites for land filling, heavy metal contamination of the land, emission of fuel gases etc. (Krishna Priya Nair, 2013) And using natural material for construction degrade the natural resource and affect the environment. Therefore, using sustainable waste management needs a great attention for protecting pollution of sites, the land from further degradation, preserving the present situation and enhancing the cleanliness of the environment.

Waste management – Different types of wastes are produced from different process and activities. Among these wastes, some are highly dangerous and affect life and the environment. Therefore, waste management is crucial this time. Recycling wastes for different purposes like source of energy to produce electric power, converting them to other usable form, converting them to energy etc. is the most common and effective way to manage wastes.

Using BA for concrete production is one of the recycling methods to use wastes by converting to other usable form, which has benefits including: -

- Protect natural resource
- Give an advantage of alternative sustainable construction raw material
- Protect the environment

2.2.3 Tests conducted to check the performance of Bottom Ash in concrete

2.2.3.1 Workability

The property of freshly mixed concrete or mortar that determines the ease, with which it could be mixed, placed, consolidated, and finished to a homogenous condition (ACI 116R-00, 2000). Workability has so far been discussed merely as a property of fresh concrete; it is also a vital property as far as the finished product is concerned. Concrete must have workability such that compaction to maximum density is possible with a reasonable amount of work or with the amount that we are prepared to put in under given conditions (Neville A.M., 1995). Slump test is one of the most known tests to measure the consistency of concrete (ACI 116R-00, 2000).

Factors affecting workability

- Water content of the mix
- Maximum size of aggregate
- Grading of aggregate
- Shape and texture of aggregate

2.2.3.2 Compressive strength of concrete

Compressive strength of concrete is the ability of concrete to withstand loads that will decrease the size of the concrete, commonly considered as its most valuable property. This test conducts using cylindrical or cubic specimens.

Factors affecting compressive strength of concrete

- Water to cement ratio
- Maximum size of aggregate
- Compaction of concrete
- Grading of aggregate
- Age of concrete
- The rate of loading
- Quality of raw material
- Curing of concrete
- Shape of aggregate
- Weather condition

2.2.3.3 Tensile strength of concrete

Tensile strength of concrete is the condition under which cracks form and propagate on the tension side of concrete. It is also formed as a result of shear and torsion. Determining the true tensile strength of concrete in direct tensile test is very difficult due to minor misalignment and stress concentration in the gripping device, which could affect the true value. So that the tensile strength of concrete is determined, indirectly using modulus of rupture or split cylinder test.

Factors affecting tensile strength of concrete

- Strength of bond between hardened cement paste and aggregate
- Tensile strength of the porous aggregate for lightweight concrete
- Molecular structure of material
- Temperature
- The composition of material

2.2.3.4 Flexural strength of concrete and modules of rupture

It is the ability of a beam or slab to resist failure in bending. It is measured by loading unreinforced concrete beams with a span three times the depth. The flexural strength is expressed as Modulus of Rupture. And modulus of rupture defined as the measure of maximum load carrying capacity and the stress at which the material breaks or ruptures.

Factors affecting flexural strength of concrete

- Level of stress
- Size of concrete member
- Age
- Confinement of concrete member

2.2.3.5 Water permeability

Water permeability is defined as the property of concrete that controls the rate of flow of water into the pours of concrete.

Factors affecting water permeability

- Water to cement ratio
- Compaction of concrete
- Curing of concrete
- Age of concrete and hydration reaction

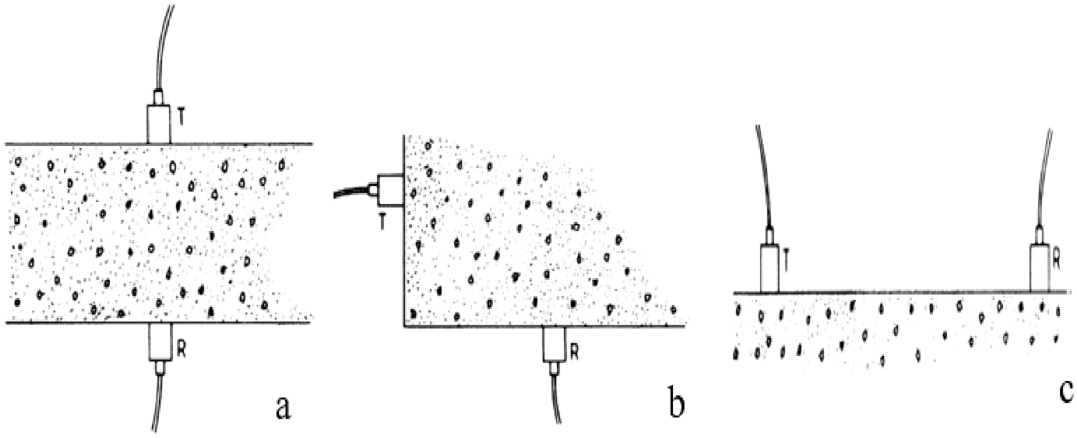
2.2.3.6 Ultrasonic pulse velocity

The ultrasonic pulse velocity test is a non-destructive testing of concrete in the form of plane, reinforced and pre stressed test specimens, precast components and structures. This is conducted by generating ultrasonic pulse using electroacoustic transducer and receiving transducer. The traveled time is displayed on electronic timing device.

The ultrasonic pulse velocity is applicable to assess the determination of the uniformity of concrete in or between members, and relative quality of concrete, to indicate the presence of voids, cracks and other defects, and to evaluate the effectiveness of crack repairs. Since this test is a non-destructive test it is applicable to indicate changes in the properties of a specific concrete with time, and in the survey of structures, to estimate the severity of deterioration or cracking. It could also be used to monitor changes in condition over time, the quality of the concrete in relation to standard requirements and determination of the values of dynamic elastic modulus of the concrete.

There are three methods of determinations of pulse velocity

- Direct transmission
- Semi-direct transmission and
- Indirect of surface transmission



Key: - Transmitter (T) and Receiver (R)

Figure 2-1: Methods of propagating and receiving ultrasonic pulses

Factors affecting ultrasonic pulse velocity

- Surface condition and moisture content
- Path Length, Shape and Size of the specimen
- Temperature of Concrete
- Stress
- Presence of Reinforcing Bars

2.2.3.7 Scanning electron microscope (SEM)

Scanning Electron Microscope (SEM) test is a process that scans a sample of materials with an electron microscope released on a focused beam of electrons to produce a magnified image for analysis. The Electron microscopy is performed at high magnifications, generates high-resolution images and precisely measures very small features and objects. Scanning electron microscope is widely used in microanalysis and failure analysis of solid inorganic materials such as soils. Secondary electron SEM images provide information on surface topography, size, and size distribution of nanoparticles. (Kowoll T., 2017)

The resulting image is further analyzed using different software's, in this thesis. ImageJ software is used for analysis of SEM image result to determine the porosity of material.

Factors affecting SEM image analysis

- Threshold value (transfer the grey images to binary image within the limit 0-255)
- Observation area and location
- window size
- Image magnification ratio (Tang C.S., 2013)

2.2.3.8 X-Ray Diffraction (XRD)

X-ray diffraction is a powerful nondestructive technique for characterizing crystalline materials. It provides information on structures, phases, preferred crystal orientations (texture), and other structural parameters, such as average grain size, crystallinity, strain, and crystal defects. XRD peaks are produced by constructive interference of a monochromatic beam of X-rays scattered at specific angles from each set of lattice planes in a sample. The peak intensities are determined by the atomic positions within the lattice planes. Consequently, the XRD pattern is the fingerprint of periodic atomic arrangements in a given material.

XRD is used in qualitative phase identification. Qualitative phase analysis is done by comparing peaks in a measured XRD pattern to a database of peak patterns of predefined phases. The most commonly used general-purpose database is the powder diffraction file (PDF) published by the International Centre for Diffraction Data and using such kind of database along with chemical or categorical filters will minimize the number of possible patterns (Scrivener, 2018)

The result is further analyzed using different software's; in this thesis High Score Plus software is used for analysis of XRD test result to determine the chemical phases on BA.

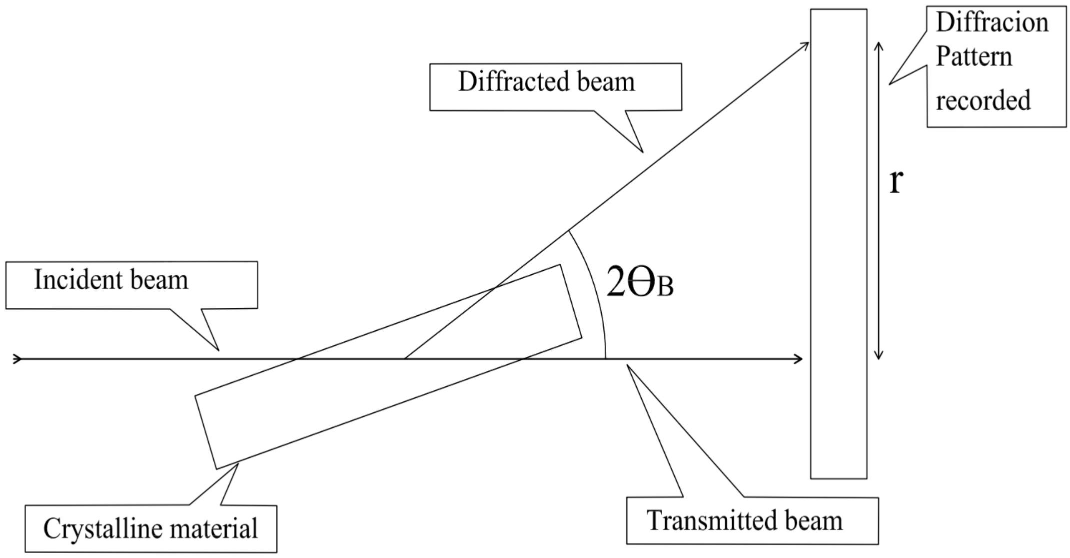


Figure 2-2: XRD test setup

CHAPTER 3 MATERIAL AND THEIR PROPERTIES

In this chapter, the types of materials used for this research and their properties have discussed briefly. All the materials physical property and preparation of concrete spacemen and cubic compressive strength, splitting tensile strength and flexural strength are carried out in Addis Ababa Institute of Technology Construction Material Laboratory. The cylindrical ultrasonic pulse velocity test is conducted in and SEM image for both BA and FA was taken from Addis Ababa Science and Technology University. The SEM image analysis is done using ImageJ version 1.53c software. BA XRD results was taken from Addis Ababa University, College of Natural and Computational Science and the XRD Pattern Analysis is done using High Score Plus version 3.0e (3.0.5) software the chemical composition of BA result is taken from Geological survey of Ethiopia Geochemical laboratory.

3.1 Cement

The Cement used for this experimental study is Dangote Ordinary Portland Cement (OPC CEMI\42.5N) compatible with (CES 28, 2013). I bought it from one of the Addis Ababa’s building material shops.

3.2 Aggregate

Concrete aggregates can define as stone and sand, in coarse and fine grade. Aggregates make up 60-80% of the volume of concrete and 70-85% of the mass of concrete. That is the material the cement pastes coats together and ties them together. There are several reasons to use aggregate in concrete. Using aggregate as filler can help concrete production with a minimum cost. In general, cement costs seven to eight times of the cost for stone and sand. Cement is necessary, but it can still maintain strength by using well-graded aggregates that cost considerably less. The aggregate's composition, shape and size have a significant effect on the concrete's workability, durability, strength, thermal and elastic properties of concrete, dimensional and volume stability and weight and shrinkage. Cement is more likely affected by shrinkage. Including aggregate in the mix can control the shrinkage level and prevent cracking. Aggregate may also affect the surface appearance of the cast, which is particularly important consideration in concrete mixes (The concrete countertop institute, 2020).

3.2.1 Coarse aggregate

Coarse aggregates defined as material, which has retained in 4.75 mm /#4 sieve. The relevant tests were made to identify the properties of the aggregates, which are used for this research to ensure the compliance of property with the required standards and specifications. In general, aggregates should be well graded, hard and strong, free of undesirable impurities, and chemically stable. Soft, porous rock can limit strength and wear resistance; it may also break down during mixing and adversely affect workability by increasing the quantity of fines.

In this research, in order to avoid any differences resulting by using aggregates from a different source, the aggregate was supplied from the same source. The CA has a nominal maximum size of 25mm graded according to (ASTM C33, 2017) requirement and ranges between 25mm to 4.75mm sieve sizes and sampling is done as per (A.S.T.M. D75, 2009) sampling of aggregates. The basic CA properties collected from the laboratory test are presented below.

Table 3-1: Basic physical properties of CA

No	Test description	Test method	Test result
1	Nominal Maximum Size [mm]	ASTM C33-17	25
2	Surface Moisture Content [%]	ASTM C70-13	0.832
3	Water Absorption Capacity [%]	ASTM C127-15	1.712
5	Bulk density [kg/m3]	ASTM C29-97	1703.12
Specific Gravity	Bulk	ASTM C127-15	2.67
	Bulk (SSD)	ASTM C127-15	2.716
	Apparent	ASTM C127-15	2.798

Table 3-2: PSD of CA

Sieve size (mm)	Percent retained (%)	ASTM C 33-18 Standard passing range (%)
37.5	0	100
25	5	90-100
19	50	40-85
12.5	30	10-40
9.5	10	0-15
4.75	5	0-5
Pan	0	0

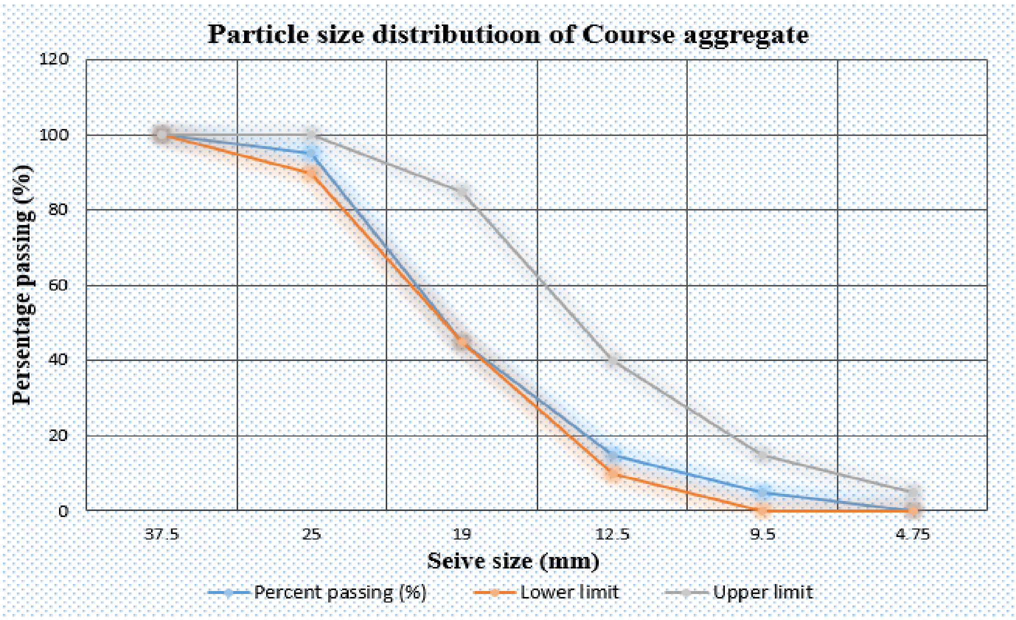


Figure 3-1: The PSD curve of course aggregate

Figure 3-2: Aggregates in stock

3.2.2 Fine aggregate

Generally, CA is blended with finer aggregates (such as sand) to fill in the spaces left between the large pieces and to "lock" the larger pieces together. This reduces the amount of cement paste required and decreases the amount of shrinkage that could occur. Fine aggregates are materials that can pass through a sieve 4.75 mm/# 4 and retained on a sieve # 200.

The FA used for this research is natural river sand. Necessary laboratory investigations were carried out to this FA in order to ensure compliance with the relevant standards and requirements for FA. The basic FA properties gathered from the laboratory test are presented below.

Table 3-3: The Determined basic Physical properties of FA

No	Test description	Test method	Test result
1	Silt Content [%]	CMLM	3.93
2	Surface Moisture Content [%]	ASTM C70-13	6.29
3	Water Absorption Capacity [%]	ASTM C128-16	2.71
4	Finesse Modulus [%]	ASTM C136	2.81
5	Unit weight [Kg/m^3]	ASTM C29-97	1577.5
Specific Gravity	Bulk	ASTM C128-15	2.437
	Bulk (SSD)	ASTM C128-16	2.493
	Apparent	ASTM C1287-16	2.582

Table 3-4: The PSD of FA (based on ASTM C136)

Sieve size (mm)	Percent retained (%)	Cumulative Courser (%)	ASTM C 33-18 Standard passing range (%)	
			Lower limit	Upper limit
9.5	0	0	100	100
4.75	2	2	95	100
2.36	4	6	80	100
1.18	10	16	50	85
0.6	46	62	25	60
0.3	33	95	5	30
0.15	5	100	0	10
Pan	0			
Total	100	281		
Fineness Modules			2.81	

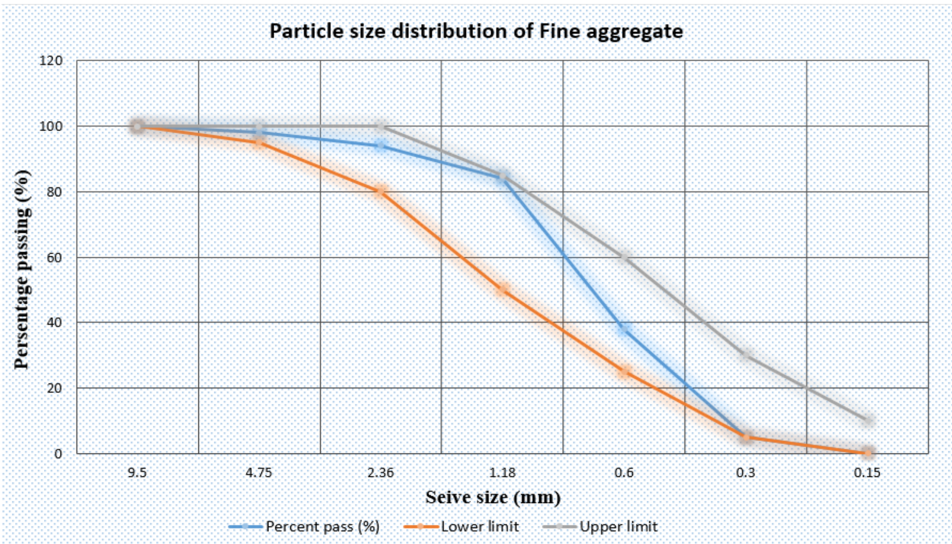


Figure 3-3: The PSD curve of FA

The scanning electron microscope (SEM) test was conducted to determine the porosity of FA.

SEM result is brought from Addis Ababa Science and Technology University is analyzed using ImageJ 1.53c software. The SEM results are opened in ImageJ software and duplicate it for further analysis in order to secure the original file unchanged. Then a constant area by varying thresholds determined the porous area of the material by using equation 1 and porosity with equation 2.

$$A_p = A_T - A_t \quad (1)$$

$$p = \frac{A_p}{A_T} * 100 \quad (2)$$

Where:

A_p = Pores Area, MPa

A_T = Total Area, mm^2

A_t = Threshold area, mm

p = Porosity, %

Table 3-5: SEM Result for FA

R.No.	Threshold %	length (mm)	Width (mm)	Total Area (mm^2)	Threshold Area (mm^2)	Pores Area (mm^2)	Poresity %
1	133.00	31.84	27.54	876.79	303.23	573.55	65.42
2	118.00	31.84	27.54	876.79	397.44	479.35	54.67
3	109.00	31.84	27.54	876.79	451.70	425.09	48.48
4	96.00	31.84	27.54	876.79	548.11	328.68	37.49
5	79.00	31.84	27.54	876.79	662.78	214.01	24.41
6	73.00	31.84	27.54	876.79	703.34	173.45	19.78

3.3 Bottom ash

The sample of BA used in this experimental study is taken directly from Reppie waste to energy power plant BA collector slag pit, which is located in Addis Ababa around Reepi "Qoshe". This BA currently disposed as land fill near the plant.

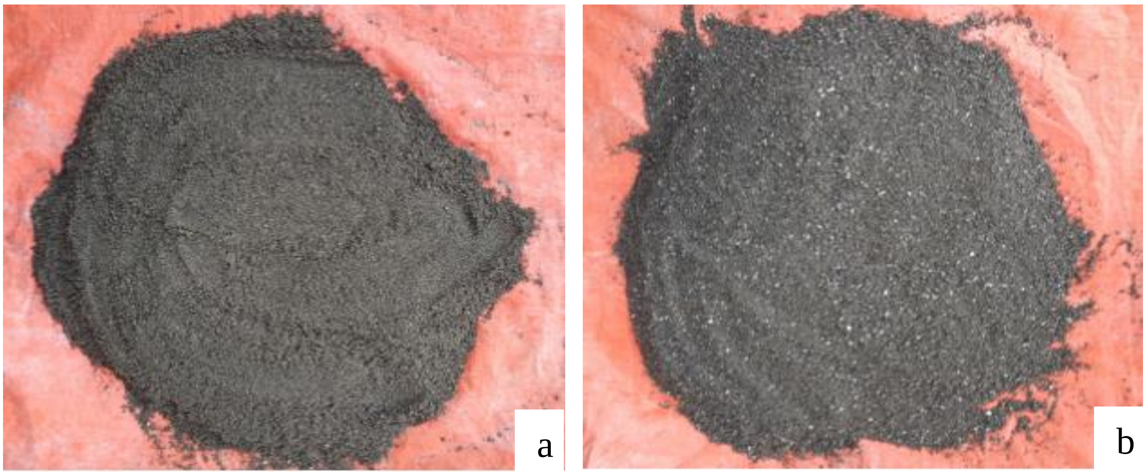


Figure 3-4: Image for FA Vs BA a) FA b) BA

The BA was washed to minimize its excess silt content from 9.5% original silt content to make it within allowable range below 6% (Dinku A., 2002). After washing, the percentage of silt content becomes 2.85%. In addition, sieve analysis was conducted based on (A.S.T.M. C136, 96).

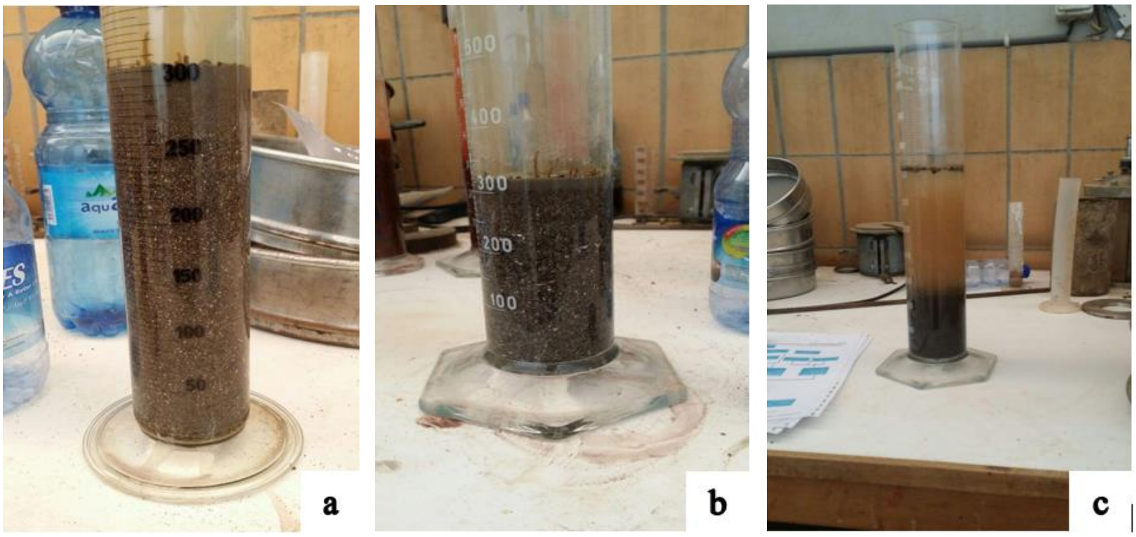


Figure 3-5: Silt content determination a) Original silt content of BA b) Silt content of BA after washing c) Silt content of FA

The basic BA properties getting from laboratory test presented below.

Table 3-6: The Determined basic Physical properties of BA

No	Test description	Test method	Test result
1	Orignal Silt Content [%]	CMLM	9.5
2	Silt Content [%]	CMLM	2.85
3	Surface Moisture Content [%]	ASTM C70-13	-2.194
4	Water Absorption Capacity [%]	ASTM C128-16	9.481
5	Finesse Modulus [%]	ASTM C136-96	3.15
6	Unit weight [Kg/m^3]	ASTM C29-97	1250.5
Specific Gravity	Bulk	ASTM C128-15	2.02
	Bulk (SSD)	ASTM C128-16	2.211
	Apparent	ASTM C1287-16	2.498

Table 3-7: The PSD of BA

Sieve size (mm)	Percent retained (%)	Cumulative Courser (%)	ASTM C 33 Standard passing range (%)	
			Lower limit	Upper limit
9.5	0	0	100	100
4.75	1.96	1.96	95	100
2.36	16.28	18.24	80	100
1.18	20.42	38.66	50	85
0.6	30.02	68.68	25	60
0.3	20.58	89.26	5	30
0.15	8.54	97.8	0	10
Pan	2.2			
Total	100	314.6		
Fineness Modules			3.15	

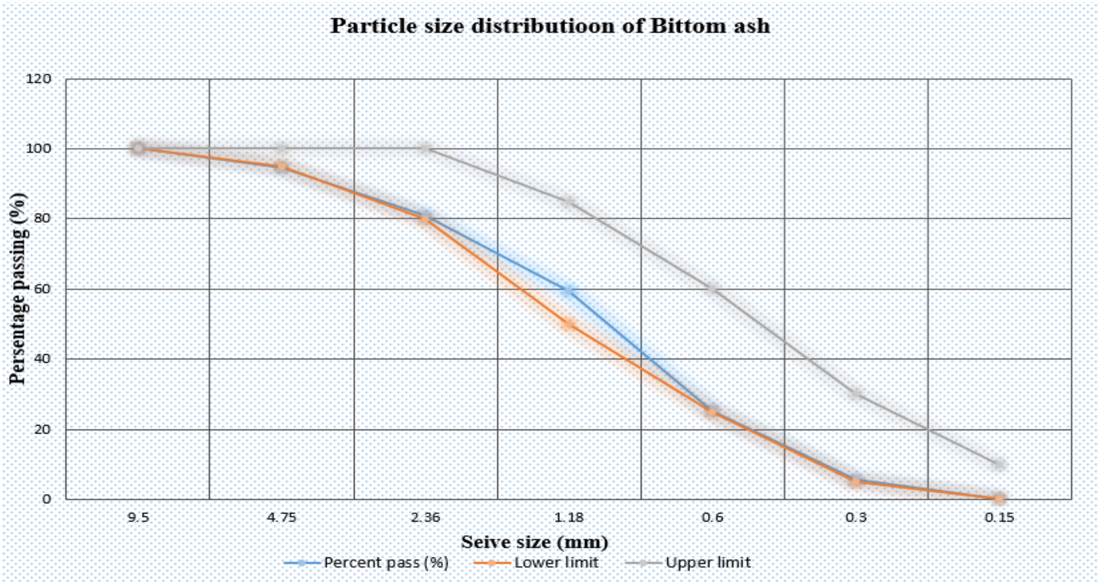


Figure 3-6: The PSD curve of BA

Chemical property of BA brought from Geological survey of Ethiopia presented below and the test result from Geological survey of Ethiopia is attached in APPENDIX A.

Table 3-8: Chemical properties of BA

Chemical Composition (%)	RWTEPP (%)
SiO_2	39.28
Al_2O_3	11.19
Fe_2O_3	9.36
CaO	17.26
MgO	1.96
Na_2O	2.54
K_2O	2.64
MnO	0.26
TiO_2	0.43
P_2O_5	3.51
H_2O	0.56
SO_3	1.25
Cl^{-1}	0.23
LOI	8.15

$$SiO_2 + Al_2O_3 + Fe_2O_3 = 59.83\% \quad (3)$$

$$SO_3 = 1.25\% < 5\% \quad (4)$$

From the chemical property test result shown in the above table, BA used in this study conformed to (ASTM C618-05, 2005), Class C ash which has a minimum content sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ which is 50%, in addition to having pozzolanic properties, also has some cementitious properties.

The presence of SiO_2 and Al_2O_3 contribute to the pozzolanic reaction in concrete by combining with free lime (CaO) in the presence of water to form calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) with cementitious properties which is the binder in concrete. And Fineness, calcium content, surface area, and particle size distribution all influence the amount of pozzolanic activity.

BA has higher LOI value, which is 8.15 due to the presence of more CO_2 that come from the incomplete burning process which results in increased water demand during mixing process and air entraining problems because of absorption of free water with unburned carbon particles.

After analyzing the XRD result the chemical phases of BA were determined. Determined phases are presented below and the detailed result is presented in APPENDIX B.

Table 3-9: Chemical properties of BA

R.No.	Score	Compound Name	Scale Factor	Chemical Formula
1	27	Silicon Oxide	0.229	$Si\ O_2$
2	20	Calcium Carbonate	0.693	$Ca\ C\ O_3$
3	4	Calcium Aluminum Oxide	0.034	$Ca_3\ Al_2\ O_6$
4	4	Calcium Aluminum Silicate	0.149	$Ca\ Al_2\ Si\ O_6$
5	7	Magnesium Silicate	0.175	$Mg\ Si\ O_3$

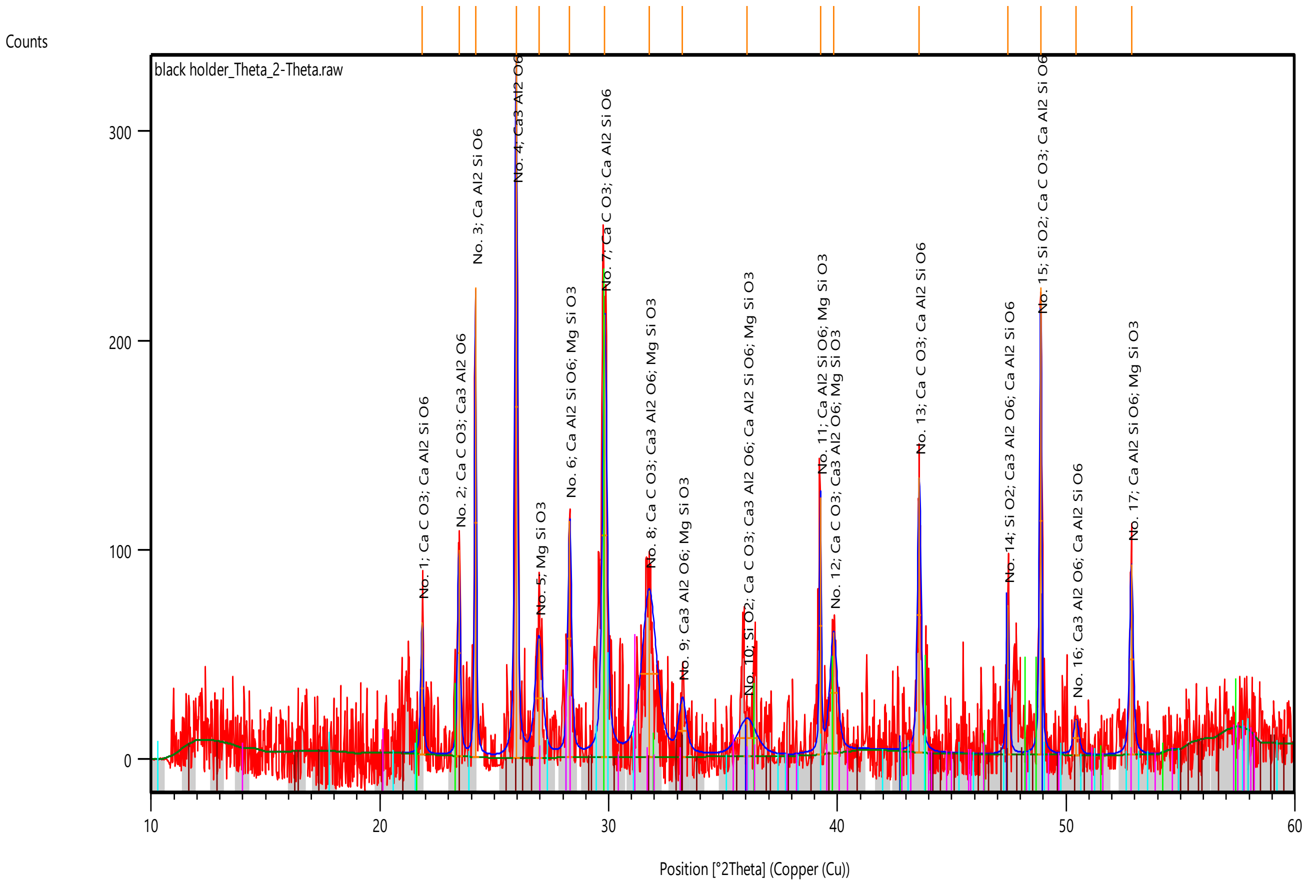


Figure 3-7: Threshold Vs porosity for FA and BA

Also, after analyzing SEM result the porosity of FA and BA were determined for different threshold values. The result getting from analysis is presented blow.

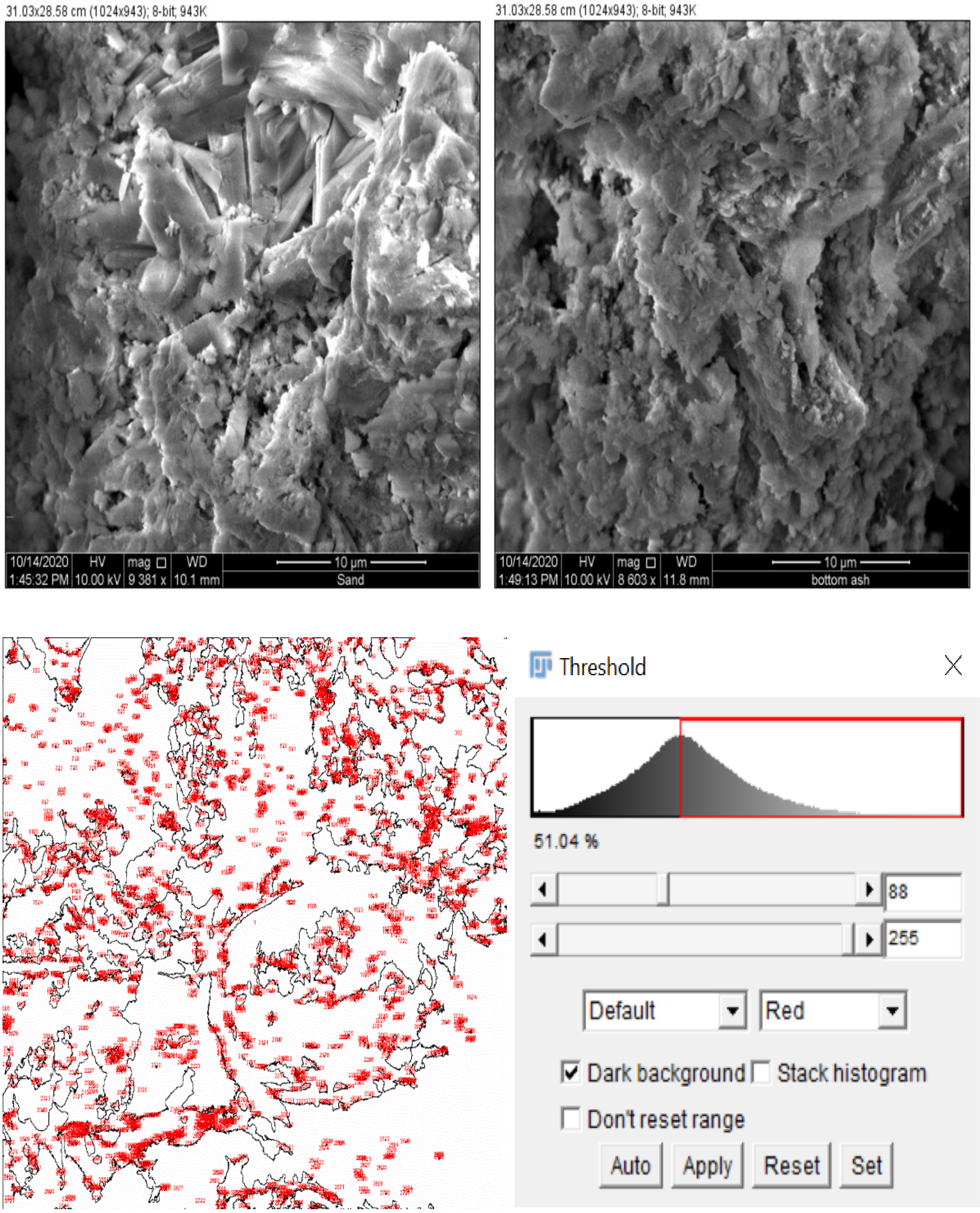


Figure 3-8: CEM analysis a) Original image for FA b) Original image for BA c) histogram of image (a) (d) Thresholding adjustment

Table 3-10: Threshold Vs porosity value of FA and BA

R.No.	Threshold %	Poresity of FA %	Poresity of BA %
1	64	13.46	19.39
2	70	17.54	24.64
3	73	19.77	27.67
4	79	24.40	34.59
5	81	25.94	37.17
6	89	32.10	47.97
7	94	35.94	54.67
8	96	37.47	57.25
9	103	42.98	65.56
10	109	47.69	71.77
11	118	54.66	79.45
12	133	65.41	88.44

The shaded rows are more matches with the FA results and the unshaded results are match with BA results. From the observation at a threshold value of 96 which have a porosity value for FA 37.47% is more reliable result. Similarly, for BA a threshold value of 89 which have a porosity value of 47.97 is more reliable.

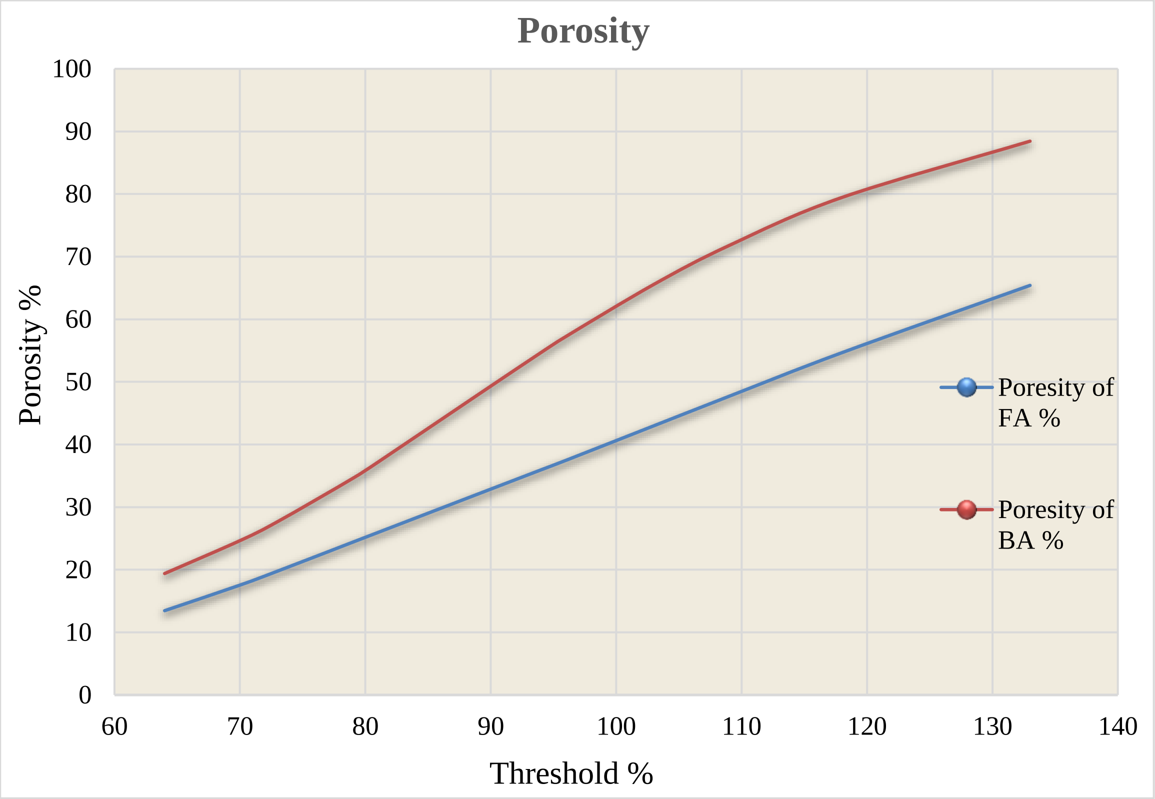


Figure 3-9: Threshold Vs porosity for FA and BA

From the result observed that the porosity of BA is higher than the porosity of FA for all threshold value.

3.4 Water

The quality of water plays a significant role on strength of concrete. Impurities in water may affect the strength of concrete by interfering with the setting of cement and leading the reinforcement to corrosion. Therefore, the water used for concrete mixing as well as curing shall be as clean as possible. The water used for this research during washing, mixing and curing is a tap water found in the Construction Material Laboratory in Addis Ababa institute of Technology.

CHAPTER 4 EXPERIMENTAL PROGRAM

The main objective of this research is to carry out an experimental study on the effect of using Reppie waste to energy power plant bi-product BA as partial replacement of FA for the production of concrete. This includes studying its chemical and physical properties and performing concrete physical and durability tests by replacing part of the FA with BA in different percentages. These were done in Addis Ababa Institute of Technology material laboratory.

Six major tests were conducted in two stages of concrete in order to achieve these objectives. In the first stage, the slump test was done on fresh concrete to determine the workability of the mix. In the second stage, on hardened concrete, the first experiment was done on the cubic compressive strength test to determine the compressive strength of the replaced concrete. The second experiment was to determine the flexural strength and the modulus of rupture of the replaced concrete. The third experimental test were done on splitting tensile strength to know the splitting strength capacity of the replaced concrete. The fourth experiment was done on an ultrasonic pulse velocity test on a cylindrical specimen to compare the quality of substitute concrete specimens. And the last test was conducted on the water permeability of replaced concrete to check its durability.

4.1 Test specimens and setup

4.1.1 Mix design

The primary aim of a mix design method is to obtain proportions of concrete ingredients such as CA, FA, cement and water that had to be used for a first trial batch to produce a certain concrete for a particular strength. A mix design provides a starting mix proportions that will have to be more or less modified to meet the desired concrete characteristics. The concrete mix design should satisfy the workability, strength and durability requirements.

In this research, the mix design was prepared based on (ACI 214R-11, 2011). All concrete mixes were prepared using the same proportion determined by the mix design procedure. At the beginning, there was four concrete mixes were prepared for four types of tests namely, compressive strength, splitting tensile strength, flexural strength and water permeability tests and four partial replacement differences 0% for control, 20%, 35%, and 50% by volume partial replacement of FA with BA. However, the test conducted gives a better result, which encourages continuing the substitution beyond 50% so that additional test was conducted for partial replacement of 65% by volume for partial replacement of FA with BA. The mix was conducted in the following steps.

1. Adding weighted CA and some water then FA and Cement,
2. Dry mixing for about one minute
3. Adding water and mix for another three minutes by using mixer
4. During mixing, uneven distribution was corrected by hand
5. Immediately after mixing the concrete, the workability was measured using a slump test
6. The fresh concrete was poured to the pre-determined molds. The molds were primarily prepared by removing all dusts and smear oil for making de-molding ease. All the mixes done using a mixer installed at AAiT mechanical laboratory.

Figure 4-1: Concrete Mixing and Molding at the Laboratory

The characteristic compressive strength is 25MPa that translate to a required target mean compressive strength 33MPa, the selected nominal maximum size of aggregate is 25mm, the chosen slump value is 75-100 mm and non-air entrained condition. The selected water cement ratio is 0.498.

The basic mix proportion resulted from the mix design is presented below.

Table 4-1: Basic mix proportion

Ingridents	Volume (l)	Mass (kg)
Water	172.11	172.11
Cement	123.00	387.45
Coarse aggregate	423.11	1149.16
Fine aggregate	266.86	665.28
Air	15.00	
Total	1,000.08	2,374.00

4.1.2 Slump test for fresh concrete

To assess the relative slump value of concrete containing natural FA and concrete containing natural FA partially replaced by BA fresh concrete mix slump test were conducted for both controlled as well as all substitution percentage mixes. This test was carried out based on (A.S.T.M. C143, 2013). The concrete mix placed in a frustum of cone mold in three layers and each layer was stroked with a tamping rod for 25 blows. For second- and third-layers strokes, care had been taken for the blow not to pass the current layer. Immediately after completion of compaction, the cone was removed vertically. The vertical difference of the top of the mold height and the top surface of the displaced specimen had been taken as a slump value.

Figure 4-2: Slump test for fresh concrete

4.1.3 Compressive strength test

To determine the compressive strength of concrete containing natural FA and concrete containing natural FA partially replaced by BA, a total of 45, nine for each percentage (0%, 20%, 35%, 50% and 65%) substitutions, 15cm*15cm*15cm cubic specimens were casted. Both mixing of the concrete and compaction process were made with machine. The casted specimens placed within the laboratory for 24 hours to secure prevention of excessive moisture release and soaking. Each specimen labeled its own code to identify it easily in the later stage. Immediately after 24 hours, each specimen was de-molded and cured in a water container for their respective curing time until the test date.

The compressive strength test was carried out base on (BS EN 12390-3, 2002). Each percentage substitution was tested using compressive strength machine for 7, 28 and 56-days curing period at their surface dried condition. Before making a test, each specimen was weighted. All the test results were carefully recorded on a logbook. The average stress (MPa) of the three specimens was calculated and taken as the compressive strength of the specimen for a specified percentage substitution.

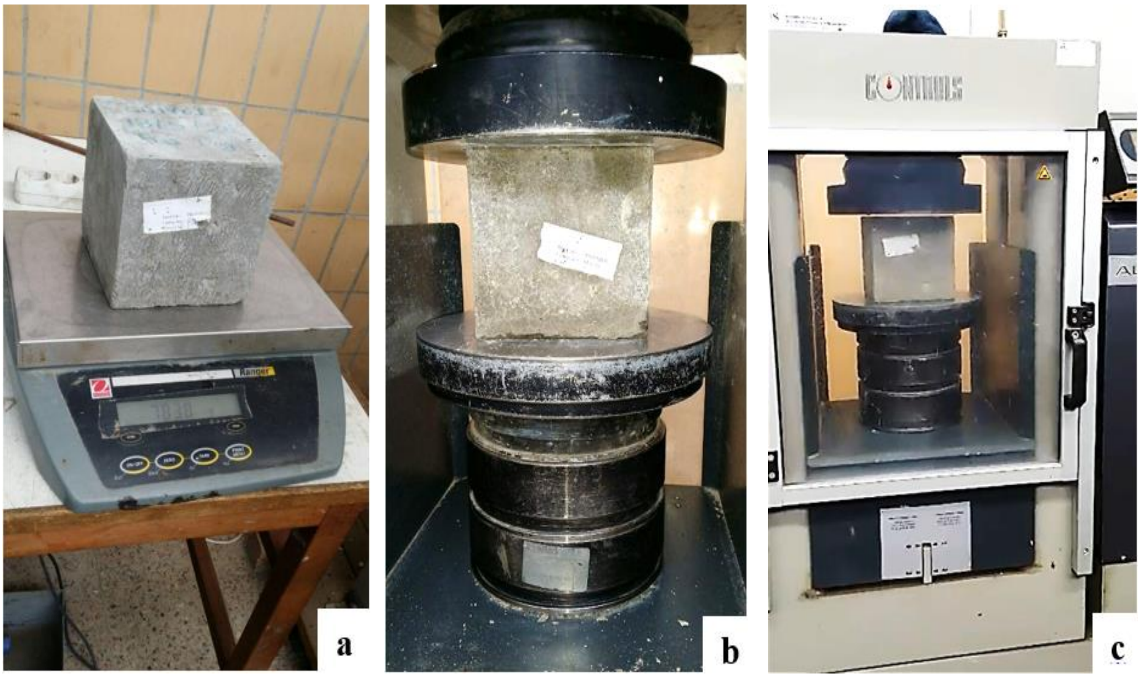


Figure 4-3: Cubic compressive test setup a) Weighting specimen b) test setup c) Machine under run

4.1.4 Splitting tensile strength test

A total of 45 cylindrical specimens of size 15 cm in diameter and 30 cm in length were casted to compare the splitting tensile strength of controlled and for all BA as partial substitution of FA. The test was carried out using compressive strength machine for all the 7, 28, and 56 days of curing period based on (A.S.T.M. C496-96, 1996). The maximum applied load indicated by the testing machine (kN) was taken and splitting tensile strength (T in kPa) calculated using equation:

$$T = \frac{(2 * P)}{(\pi * L * D\ )} \tag{5}$$

where:

T = splitting tensile strength, (kPa),

P = maximum applied load indicated by the testing machine, (kN),

L = length, (m) and

D = diameter, (m)

Figure 4-4: Splitting tensile strength test setup

4.1.5 Flexural strength test and modulus of rupture

For determining the flexural strength of concrete 45 simple beam specimens with a size of 10 cm, 10 cm and 50 cm were casted. The test was conducted immediately after removing from curing tank without surface drying using these simple beams with third-point loading based on (A.S.T.M. C78-02, 2002). The load at the failure (P) read from the test machine and the flexural strength calculated as a flexural strength using the equations below. Before the test was carried out, the beam was marked by dividing the span length into three equal lengths in order to determine where the fracture is occurred after the test was conducted.

For fracture initiates in the tension surface within the middle third of the span length, the modulus of rupture calculated as:

$$R = \frac{(P * L)}{(b * d^2)} \qquad (6)$$

Where:

R = modulus of rupture, MPa

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

L = span length (the length between the two end supports), mm

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

d = average depth of specimen, 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:

$$R = \frac{3 * P * a}{b * d^2} \quad (7)$$

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.

a

Figure 4-5: Flexural strength test setup a) Marked test specimen b) Specimen under test c) Specimen after test

4.1.6 Water penetration

To compare the water tightness of a concrete made of BA in different percentage substitution of FA with the controlled one, the depth of penetration of water under pressure test was conducted. For this test a concrete cube specimen with a size of 15cm x 15cm x 15cm were casted. The test was conducted for 28 and 56 curing period of specimens.

After 24 hours of casting the concrete, the specimens was removed from the mold and the surface that will exposed to water pressure was roughened with wire brush before it is immersed into the curing tank. Care has been taken not to apply the water pressure to a troweled surface of a specimen. After curing period completed, the specimen placed in the water apparatus of penetration test and a water pressure of 5 bar or 0.5 MPa was applied for 3 days (72 hour) and periodic observations has been taken. The test was conducted based on (BS. EN. 12390-8, 2000). After the pressure has been applied for the specified time, the specimen was removed from the apparatus and the face on which the water pressure was applied, was wiped. Without losing any time, the specimen was put in the compressive strength machine facing down the surface under water pressure and split the specimen in half, perpendicularly to the face on which the water pressure was applied. Then the splitting face has been dried to an extent to which the water penetration front could be clearly seen, the waterfront was marked and the maximum measured depth of penetration under the test area in millimeter was recorded as a water penetration depth.

Figure 4-6: Water penetration test setup a) Test setup b) Splitting process c) Marked Specimen after splitting

4.1.7 Ultra-sonic Pulse Velocity

This test covers the determination of the propagation velocity of longitudinal stress wave pulses through concrete made of BA in different percentage substitution of FA with the controlled one.

Pulses of longitudinal stress waves are generated by an electro-acoustical transducer that is held in contact with one surface of the concrete under test. After traversing through the concrete, the pulses are received and converted into electrical energy by a second transducer located a distance L from the transmitting transducer. The transit time T is measured electronically. The pulse velocity V is calculated by dividing L by t (IS: 13311 (Part-1), 1992),.

For conducting this test 15 concrete cylindrical specimen (3 for each substitution) with a size of 10 cm in diameter and 20 cm in length were casted. During casting of these concretes, special attention was given to make the troweled surface smoothen as much as possible. The test was conducted for 7, 28 and 56-days curing period of specimens using a direct transmission method based on (IS: 13311 (Part-1), 1992)

After 24 hours of casting, the specimens were removed from the molds and immersed in to the curing tank. After each curing period, the specimens was removed from the water tank and putted at room temperature for surface drying. After drying, grease was applied on both troweled and opposite surface as a coupling agent. Before the test conducted, a zero-time adjustment were made on the ultrasonic pulse velocity equipment by apply coupling agent to the ends of the reference bar, and press the transducers firmly against the ends of the bar until a stable transit time is displayed and adjust the zero reference until the displayed transit time agrees with the value marked on the bar. Once the zero-time adjusted each specimen were tested by firmly pressed a transducer on the opposite ends until a stable transit time is displayed, which have been recorded as a transit time in micro second.

The pulse velocity is calculated using the equation:

$$V = \frac{L}{t} \tag{8}$$

where:

V = pulse velocity, km/s,

L = distance between centers of transducer faces, mm, and

t = transit time, μs.

After determining the pulse velocity, the quality of concrete is determined according to (IS: 13311 (Part-1), 1992).

Table 4-2: Velocity criterion for concrete quality grading

SI No.	Pulse velocity (km/sec)	Concrete quality grading
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.0 to 3.5	Medium
4	Below 3.0	Doubtgul

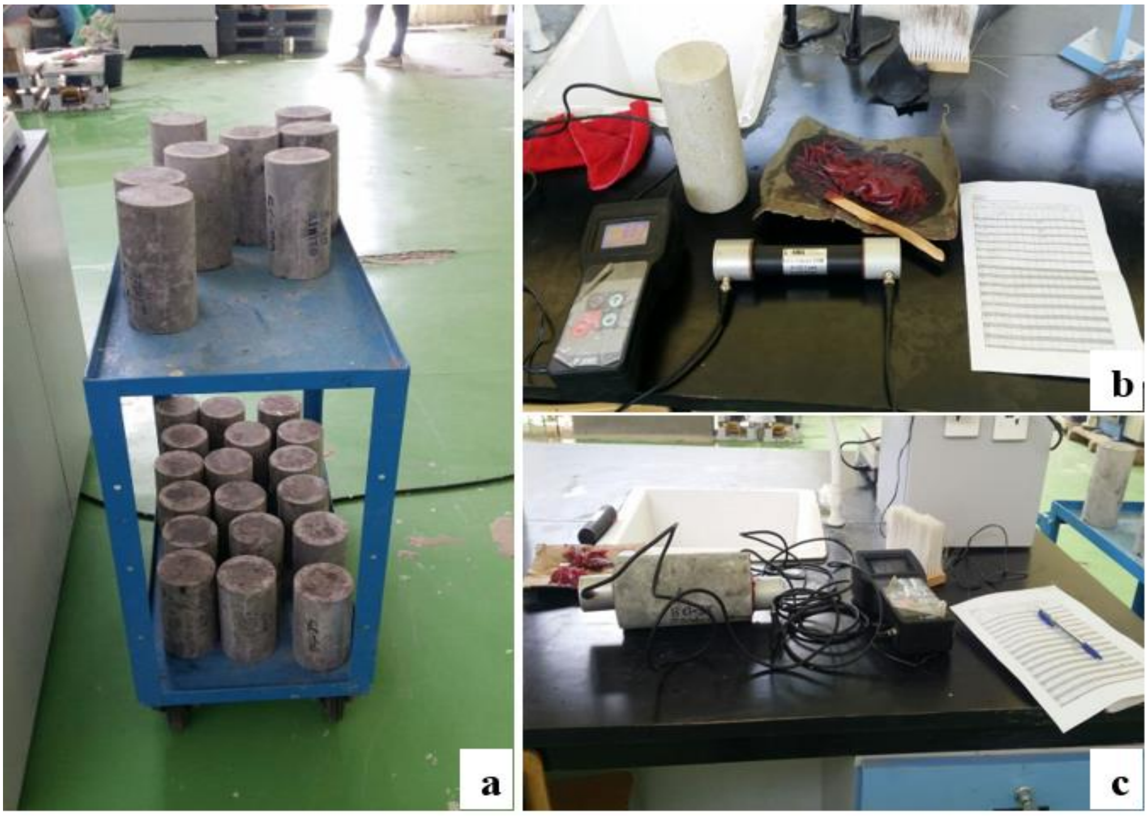


Figure 4-7: Ultrasonic Pulse velocity test setup a) Test specimens b) Instrument calibration c) Testing specimens

4.1.8 Curing of specimens

Moist curing process were conducted for all casted test specimens immediately after d-molding by maintaining free water on the entire surface area for all the times until the test was conducted. This condition was met by using water storage tanks. The storage tank that was used for curing was placed in a vibration-free environment. This process was carried out based on (A.S.T.M. C192/C192M, 2014). For curing purpose, a tap water in AAiT mechanical laboratory was used.

Figure 4-8: Curing of specimens

CHAPTER 5 RESULT AND DISCUSSION

In this section, the test results of the experimental programs, which are presented in chapter four are presented, analyzed and discussed.

5.1 Slump test for fresh concrete (Rafat Siddique., 2014)

Slump test is carried out to check the workability of freshly made concretes. The result of slump tests conducted for different percentage of substitution of FA with BA and their interpretations are presented as follows.

Table 5-1: Slump test result for different substitution

Subistitution percentage	0%	20%	35%	50%	65%
Slump(mm)	82	73	65	57	52

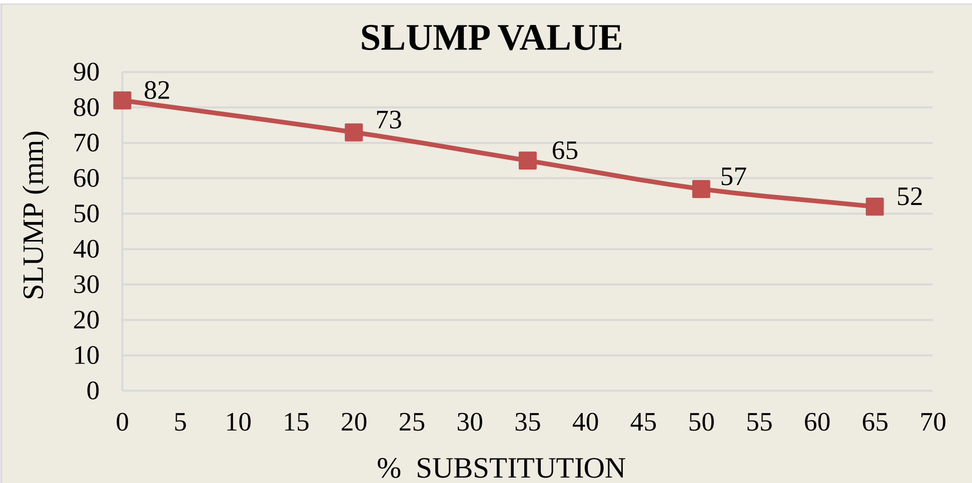


Figure 5-1: Slump value for different substitution of BA

The result of the slump test shows that the value of slump decreases with the substitution percentage of BA in concrete increases. This is because of bottom ash has a higher fineness module which indicates more larger particles are presented, it had rough surface texture and its irregular shape increase the frictional resistance of freshly mixed concrete which led to the reduction of slump value. This concept was previously proposed by

(Rafat Siddique., 2014) and (Remya Raju, 2014). Furthermore, because of the absorption of free water by unburned carbon particles, comes from the presence of CO_2 because of the incomplete burning process, which raises the LOI value, results in increased water demand during the mixing process.

5.2 Compressive strength test result

The result of compressive strength test shows that, at 7 days curing period, the control sample has a higher compressive strength value and at the substitution values of 20% and 35% it shows nearly similar compressive strength value. Better result was observed compared to the theoretical value, even if they have lower results from the controlled sample, which has higher value than the theoretical value. Whereas at 28 days curing period, 35 % substitution sample has a higher compressive strength value than others and the incremental slop of 35%, 50% and 65% substitutions give nearly similar but a little bit higher values from the theoretical value. 20% substitutions give a lower incremental slop from other substitution percentages; however, its incremental slop was a higher value than the controlled sample. At 56 days curing period 20%, 35% and 50% substitutions give a higher compressive strength than the controlled one and their incremental slope almost 3 times the incremental slop of the controlled sample which gives almost nearly a flat slope. At all stages 65% substitution gives a lowest compressive strength value.

From the test result indicated the compressive strength of concrete with a substitution of FA with BA its rate of reaction is slow at early stage at 7 days curing period which results the lower compressive strength result. Between 7 and 28 days of curing period, the rate of reaction is higher and much of the reaction processes conducted in this stage, which increases the compressive strength result significantly. Unlike the controlled sample, the substitute samples' reactions actively continued after 28 days with a relatively lower reaction rate, consequently the compressive strength increases significantly after 28 days curing period.

As a conclusion the compressive strength of partial substitution of FA with BA increase up to 35% replacement percentage and start to decrease beyond that. Up to 50% replacement, percentage gives a better result compared to the controlled sample.

The results of average compressive strength and the incremental slope in compressive strength are given in Table 5-2. Based on the detailed result on APPENDIX D and result of the compressive strength of Concrete cube with different Percentage amount of replacement of BA for different age of curing illustrated on Figure 5-2 and the compressive strength for different substitution percentage at curing age 56 days is illustrated by Figure 5-3.

Table 5-2: Compressive strength test result and comparison of incremental slop

Percentage replacement	Theoretical		0%		20%		35%		50%		65%	
	Value	Inc. Slop	Value	Inc. Slop	Value	Inc. Slop	Value	Inc. Slop	Value	Inc. Slop	Value	Inc. Slop
7 day	21.45		26.01		24.21		25.05		19.68		17.23	
28 day	33.00	0.55	34.24	0.39	33.75	0.45	36.94	0.57	32.18	0.59	28.52	0.54
56 day	33.33	0.01	35.30	0.04	37.11	0.12	40.67	0.13	35.84	0.13	30.84	0.08

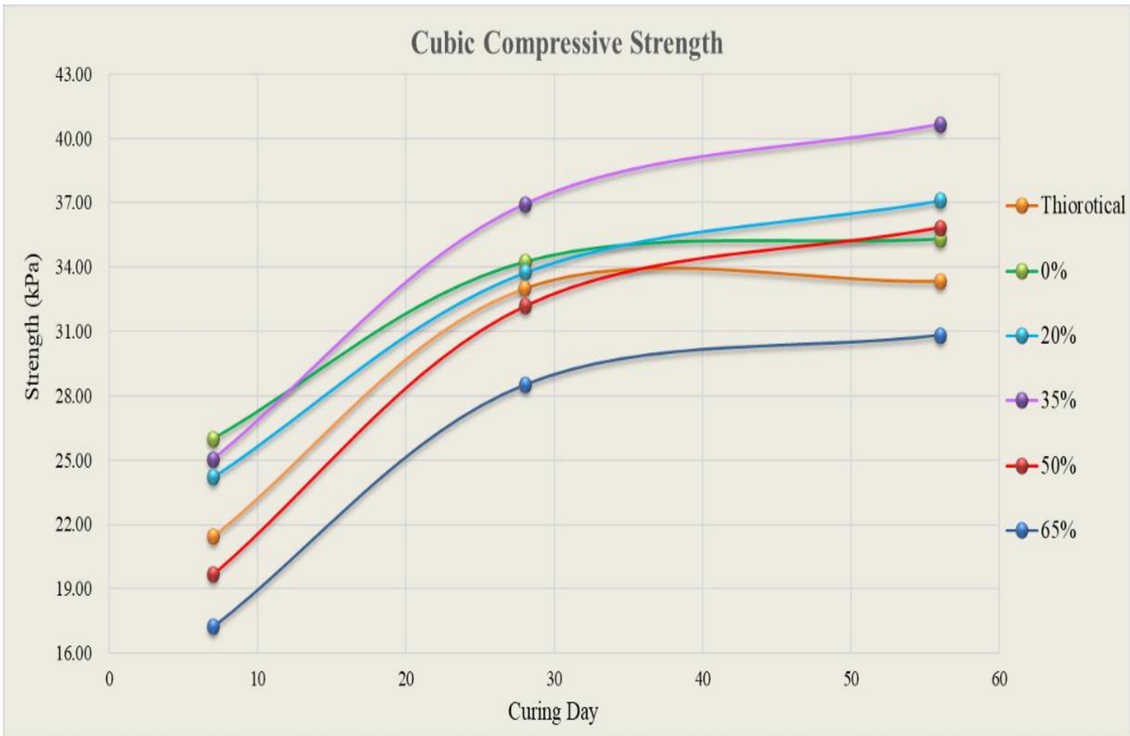


Figure 5-2: Compressive strength value for different substitution of BA at different curing day

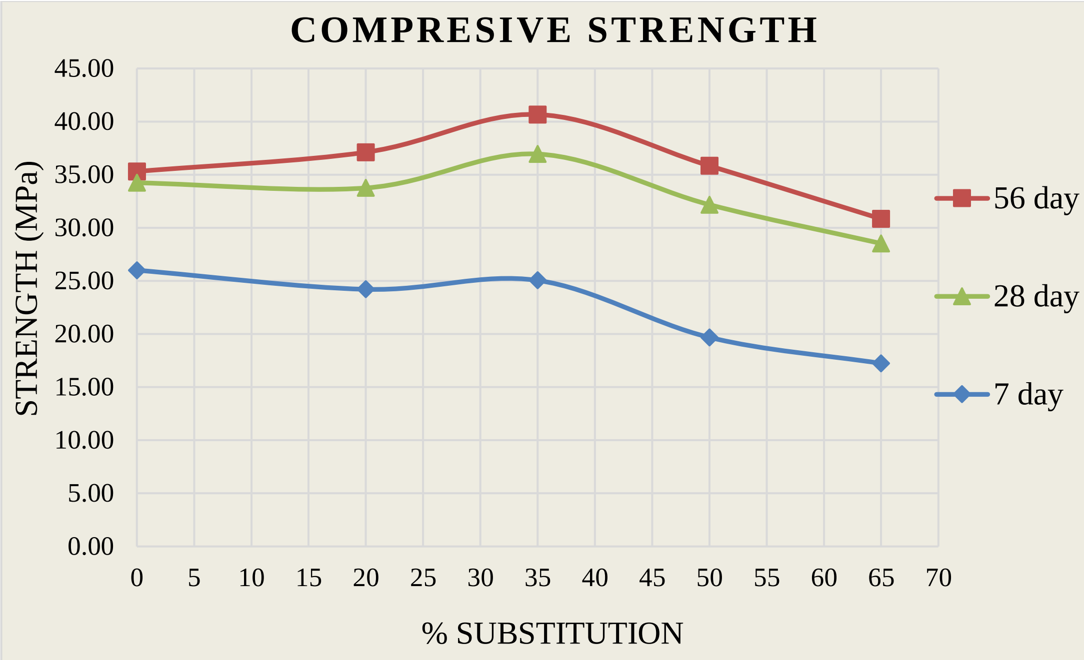


Figure 5-3: Compressive strength Vs replacement percentage of BA

The compressive strength of substitute samples increases due to the reason that BA has a pozzolanic reaction which acts as a binding material after reacting with calcium oxide in the presence of water. This maximum compressive strength result of substitute samples occurs after 28 days of curing period (in the later age). This is because BA has a larger particle which led to the pozzolanic reaction starts lately or in a slower rate at the early stage. This idea also forwarded previously by (Abdulhameed Umar Abubakar, 2012). The BA reaction is more prevalent in dicalcium silicate (2CaO.SiO2), which has a slower reaction and hardening to give a later strength rather than tricalcium silicate ($3CaO.SiO_2$), which has a rapid reaction and hardening as well as high heat generation to give an early strength.

The increase in porosity of concrete due to the increase of BA is more dominant than the incidence of pozzolanic reaction from the contribution of BA, which is why compressive strength begins to decline after 35% substitution.

5.3 Splitting tensile strength test result

The splitting tensile strength result determined from the test conducted, shows the controlled sample has a better result than the substitute samples. However, the splitting tensile strength result of the substitute samples were within the standard specification as per Eurocode 2, i.e., the mean splitting tensile strength is 2.5 kPa (European Standard, 1992).

It is evident from Table 5-3 values that, increasing the BA content up to 50% improves the splitting tensile strength of concrete constantly and starts to decrease at 65% replacement of BA.

The results of mean splitting tensile strength are given in Table 5-3 based on the detailed result on APPENDIX D and result of the splitting tensile strength with different Percentage amount of replacement of BA at different curing age i.e., 7, 28 and 56 days is illustrated with Figure 5-4.

Table 5-3: Splitting tensile strength test result

Percentage replacement	0%	20%	35%	50%	65%
7 day	2.00	2.45	2.44	2.54	2.40
28 day	2.86	2.79	2.82	2.86	2.63
56 day	3.02	2.83	2.87	2.93	2.64

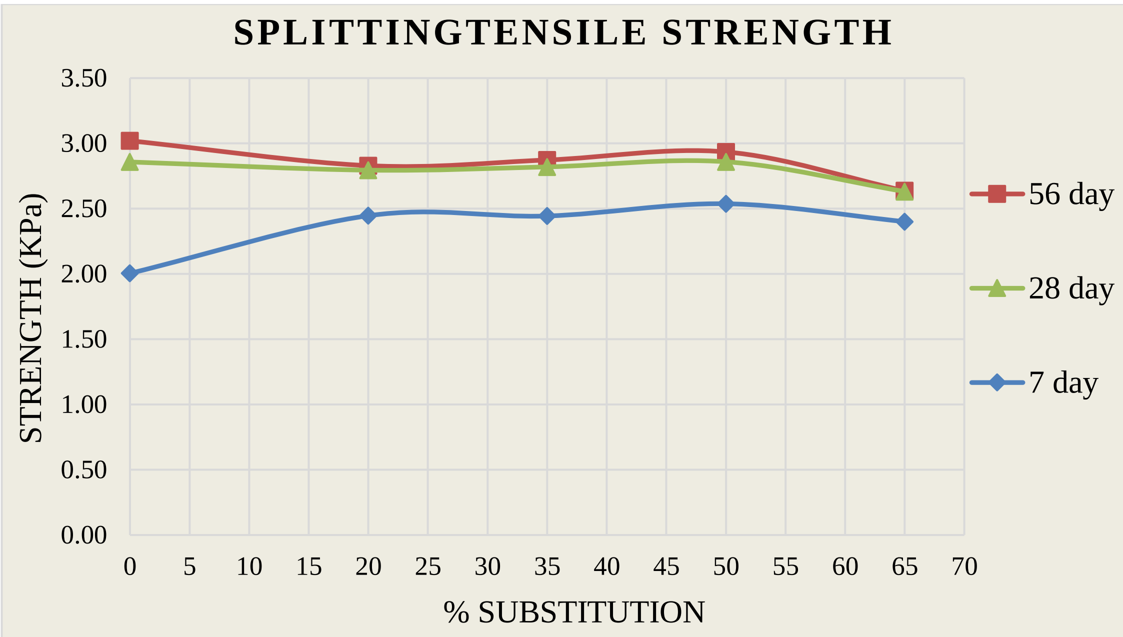


Figure 5-4: Splitting tensile strength Vs replacement percentage of BA

The Splitting tensile strength of substitute samples reduces due to BA particles is more spherical and porous nature which results weak interlocking between the aggregates. This idea also forwarded previously by (Mohd Haziman Wan Ibrahim, 2016).

5.4 Flexural strength and modulus of rupture test result

The flexural strength result determined by the test conducted exhibited that a 50% replacement concrete has equivalent strength with a controlled one and which has a better result than the other BA substitute samples. However, the flexural strength result of the substitute samples is within the standard specification of Eurocode 2, i.e., the mean flexural tensile strength is 3.3 MPa (European Standard, 1992).

It is evident from Table 5-4 values that, with increasing in the BA content up to 50%, the flexural strength of concrete increases constantly and starts to decrease at 65% replacement of BA.

The results of mean splitting tensile strength are given in Table 5-4 based on the detailed result on APPENDIX E and the result of splitting tensile strength with different Percentages of BA replacement at different curing age i.e., 7, 28 and 56 days is illustrated by Figure 5-5.

Table 5-4: Flexural strength test result

Percentage replacement	0%	20%	35%	50%	65%
7 day	2.35	2.91	3.72	3.20	2.72
28 day	4.34	3.89	4.14	4.25	3.53
56 day	4.64	4.21	4.37	4.74	4.17

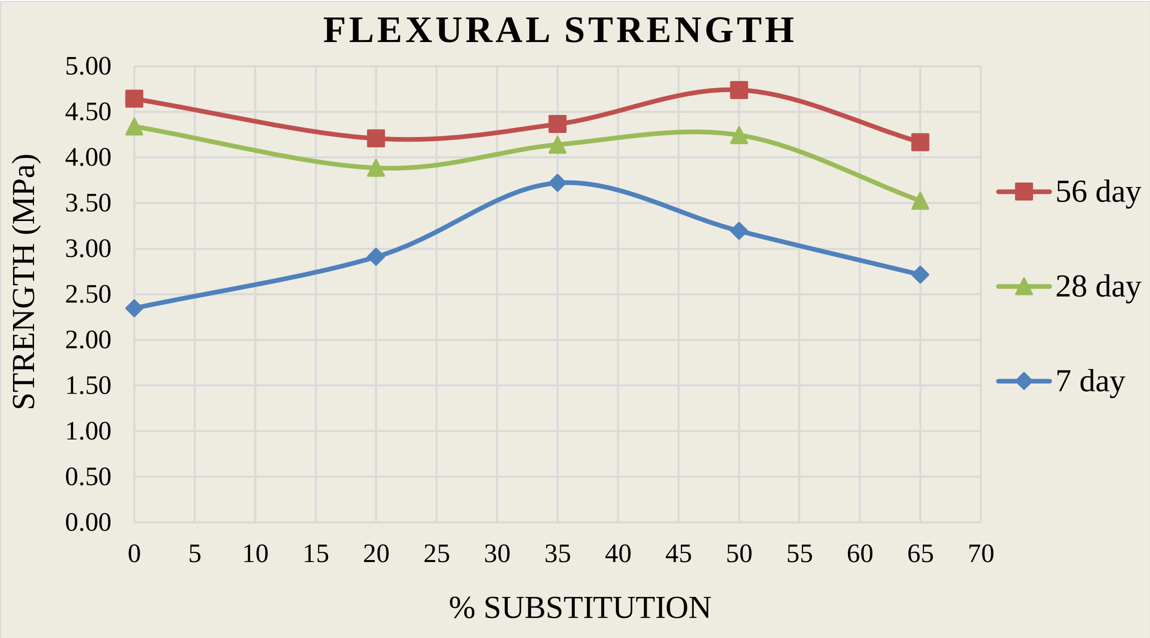


Figure 5-5: Flexural strength Vs replacement percentage of BA

The flexural strength of substitute samples reduces due to BA particles are more spherical and porous nature which resulting poor interlocking between the aggregates. This idea also forwarded previously by (Mohd Haziman Wan Ibrahim, 2016).

5.5 Water Penetration

Unlike the result observed by (Remya Raju, 2014) the Water penetration result determined from the test conducted showed that as the percentage replacement of BA increases, the water penetration depth through the concrete decreases. Therefore, the replaced concretes are a better water tightness performance than the controlled sample.

At the age of 28 days curing period, the controlled sample was the list permeable compared to the substitute samples. However, at 56 days curing period, the highest substitute percentage i.e., 65% replacement becomes the list permeable sample.

It is evident from Table 5-5 values that with increasing the BA content, the water permeability resistance of concrete improves.

The results of water permeability are given in Table 5-5 based on the detailed result on APPENDIX F and result of the water penetration with different Percentage amount of replacement of BA at different curing age i.e., 28 and 56 days is illustrated by Figure 5-6.

Table 5-5: Water penetration test result

Percentage replacement	0%	20%	35%	50%	65%
28 day	34.67	35.00	38.33	43.33	41.36
56 day	24.33	21.00	19.00	16.70	15.87

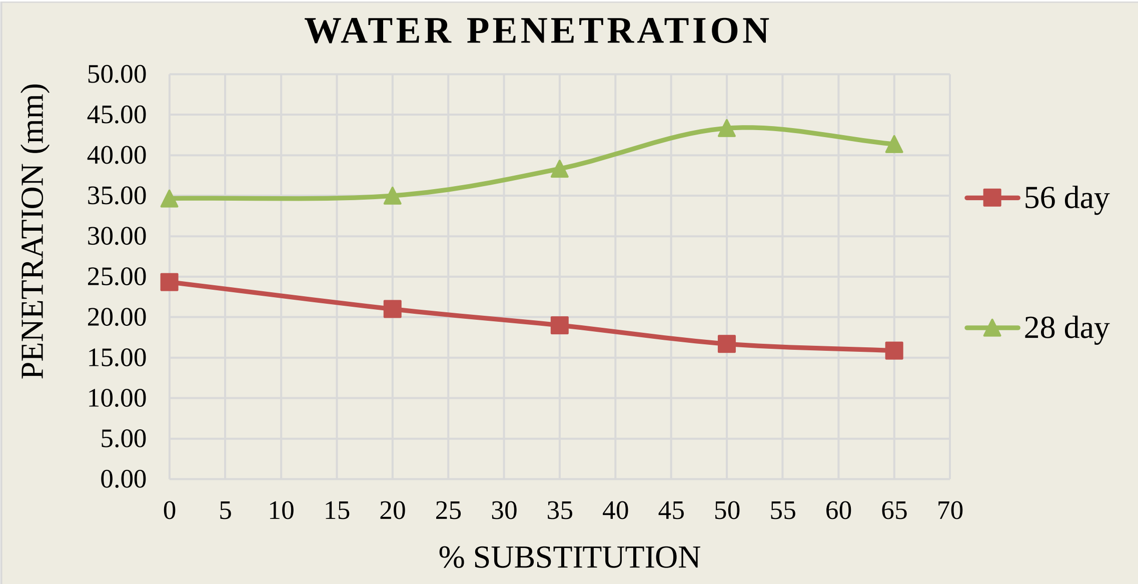


Figure 5-6: Water penetration Vs replacement percentage of BA

The water permeability of substitute samples is reduced because of the BA contribution for binding material in concrete and the slower rate of pozzolanic reaction of BA reduce the heat generation at early age and reduce the potential of internal crack formation.

5.6 Ultrasonic pulse velocity test result

The ultrasonic pulse velocity result determined from the test conducted showed that as the percentage replacement of BA increases, the quality of concrete increases up to 35% replacement. After 35% replacement, the quality goes to decrease. However, the quality of concrete made with BA replacement under a good range for all replacement percentage.

Up to the age of 28 days curing period, the controlled sample was the one that exhibits the higher transmission of pulse velocity compared with the substitute samples. However, at 56 days curing period, the highest transmission of pulse velocity occurs in a 35% replacement sample.

It also observed from the result that, the transmission of pulse velocity of controlled sample becomes nearly constant after 28 days curing period whereas in the substitute samples it continues to increase after 28 days curing period.

The results of Ultrasonic pulse velocity are given in Table 5-6 and Figure 5-7 based on the detailed result on APPENDIX G and the result of Ultrasonic pulse velocity with different Percentage amount of replacement of BA at different curing age i.e., 7, 28 and 56 days is illustrated by Table 5-7 and Figure 5-8.

Table 5-6: Ultrasonic pulse velocity test result

Percentage replacement	0%	20%	35%	50%	65%
7 day	4.08	3.94	4.03	3.97	3.83
28 day	4.19	4.11	4.19	4.10	3.95
56 day	4.20	4.15	4.26	4.14	4.09

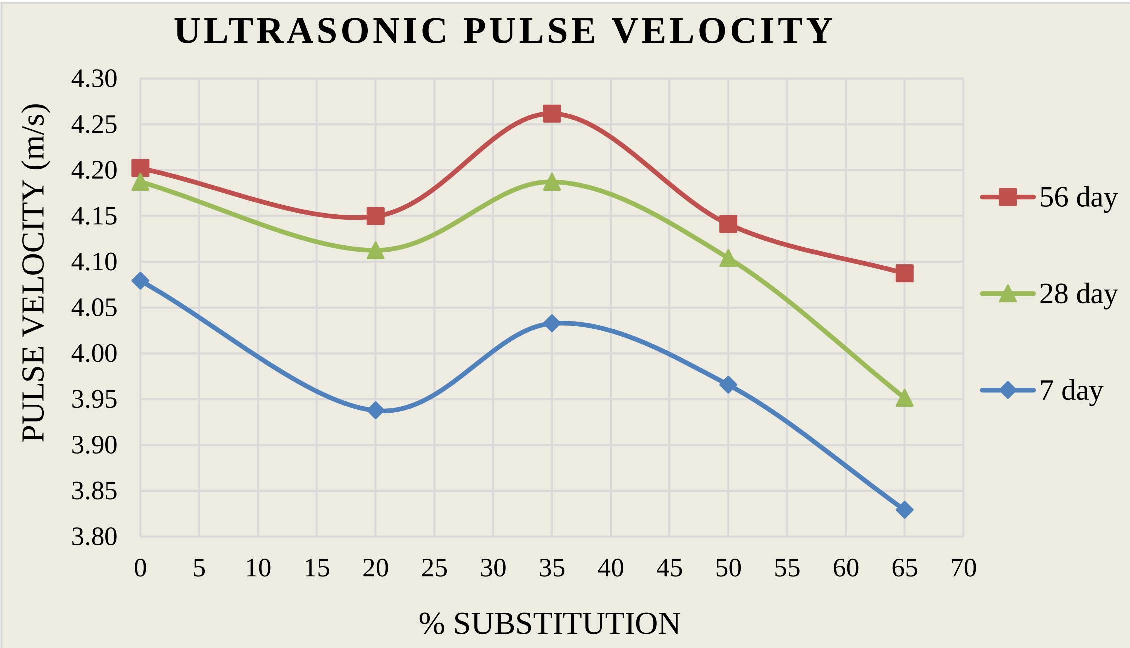


Figure 5-7: Ultrasonic pulse velocity Vs percentage replacement of BA

Table 5-7: Ultrasonic pulse velocity test result

Percentage replacement	Curing period (day)		
	7	28	56
0%	4.08	4.19	4.20
20%	3.94	4.11	4.15
35%	4.03	4.19	4.26
50%	3.97	4.10	4.14
65%	3.83	3.95	4.09

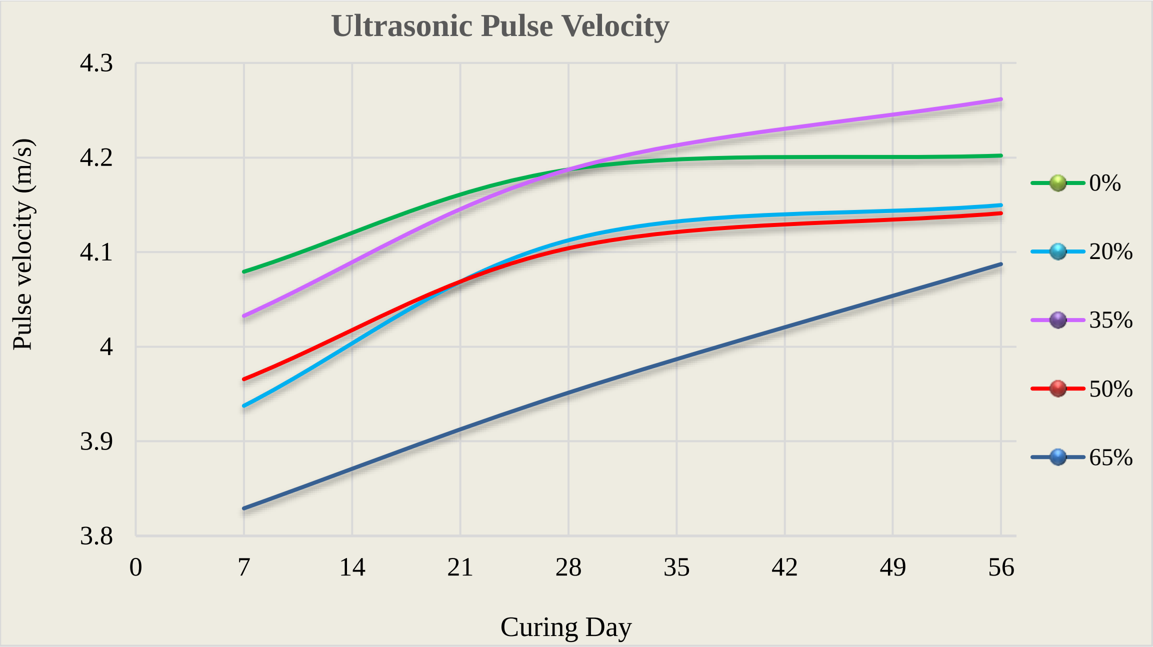


Figure 5-8: Ultrasonic pulse velocity Vs Curing period for different percentage substitution of BA

CHAPTER 6 CONCLUSIONS AND RECCOMENDATIONS

6.1 Conclusions

In this thesis, the effect of fine aggregate replacement with Reppie Waste to Energy Power Plant bottom ash in concrete production and its property has been investigated with laboratory tests.

Based on the observation of these test results, the following conclusions are drawn.

- The visual inspection reveals that the texture and grain size distribution of FA and BA are almost identical.
- BA is a Class C ash, light in weight, has high water absorbency, and is more porous with coarser particles.
- It has higher LOI and Fineness modules value
- The workability of concrete made with partial substitution of FA with BA decreases with increase in BA replacement and the concrete becomes stiffer and its slump value decreases.
- The compressive strength of substitute samples during the 7th day curing period is lower than the controlled sample for all substitution percentages; however 20% and 35% substitutions have compressive strengths that are close to the controlled sample.
- After 28 days of curing period, the compressive strength of the 35% substitution sample is higher than that of the controlled sample, while the compressive strength of the 20% and 50% substitutions is near to the result of that of the controlled sample.
- Compressive strength of 20%, 35% and 50% substitutions were higher than the controlled sample in the 56th day curing Period, whereas the 65% substitution has a lower result in all curing periods.
- The maximum compressive strength is obtained at 35% BA substitution, while 50% substitution also gives a better result to use as FA substitution in concrete.
- Due to the additional cementitious properties of BA, BA substitution samples continue to gain additional strength after the 28th day of curing age.
- The splitting tensile strength of BA replacement reveals a lower result compared to the controlled one, however, 35% and 50% replacement samples have nearly equivalent result with the controlled one.

- The flexural tensile strength of the 50% BA replacement sample is slightly higher than the controlled sample, whereas the sample of 35% BA replacement is slightly lower. The flexural strength of the other BA replacements samples is lower than the controlled sample.

- The water permeability test at 28th day curing period results in higher value for all percentage replacement samples compared with the controlled sample however, at 56th day curing period, the water penetration decreases as the partial replacement increases. As a result, the replaced concrete samples possess a better water tightness performance than the controlled sample.

- The ultrasonic pulse velocity test result indicates that, the quality of concrete for all substitutions of BA is in a good range and the 35% substitution has a higher pulse transmission velocity than both the other substitutions and that of the controlled one at 56th days curing period.

- The use of BA as fine aggregate replacement can reduce the cost of construction and helps to protect the environment.

6.2 Recommendations

Based on the findings of this research, the following recommendations are forwarded:

- BA can substitute fine aggregate in concrete up to 50% replacement.

- BA can be used to enhance the compressive strength of concrete up to 15% at 35% replacement.

- During burning municipal waste, requirements for the combination of waste form and burning time should be established in order to monitor chemical properties and minimize the LOI value.

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

- Durability tests such as chemical attacks and chloride penetration.

- Long term requirements such as shrinkage and creep tests.

- The strength beyond 56 days curing period.

- Effect of temperature on concrete made with BA substitution.

- The elastic modules property of concrete made with partial replacement of BA

- Effect of BA in corrosion for reinforced concrete.

- The use of BA on concrete for partial replacement of cement.

- Detailed analysis of BA using SEM and XRD at different age of concrete after concrete production.

- The use of BA for non-structural elements such as Bricks, Hollow concrete blocks, Terrazzo tiles etc.

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APPENDIX

APPENDIX A

Chemical composition of Bottom Ash

	GEOLOGICAL SURVEY OF ETHIOPIA	**Doc.Number: GLD/F5.10.2**	**Version No: 1**
	GEOCHEMICAL LABORATORY DIRECTORATE		Page 1 of **1**
Document Title:	**Complete Silicate Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: -12/11/2020

Customer Name: -Abrham Assegid

Request No:- GLD/RQ/256/20

Report No:- GLD/RN/741/20

Sample type:- Bottom Ash

Sample Preparation: - 200 Mesh

Date Submitted: - 08/10/2020

Number of Sample:- One (01)

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

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	SO_3	Cl^{-1}
ABA	39.28	11.19	9.36	17.26	1.96	2.54	2.64	0.26	3.51	0.43	0.56	8.15	1.25	0.23

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

Analysts	Checked By	Approved By	Quality Control
Lidet Endeshaw	For Tizita Zemene	Yohannes Getac	Gosa Haile
Nigist Fikadu			

APPENDIX B

Bottom ash XRD analysis result

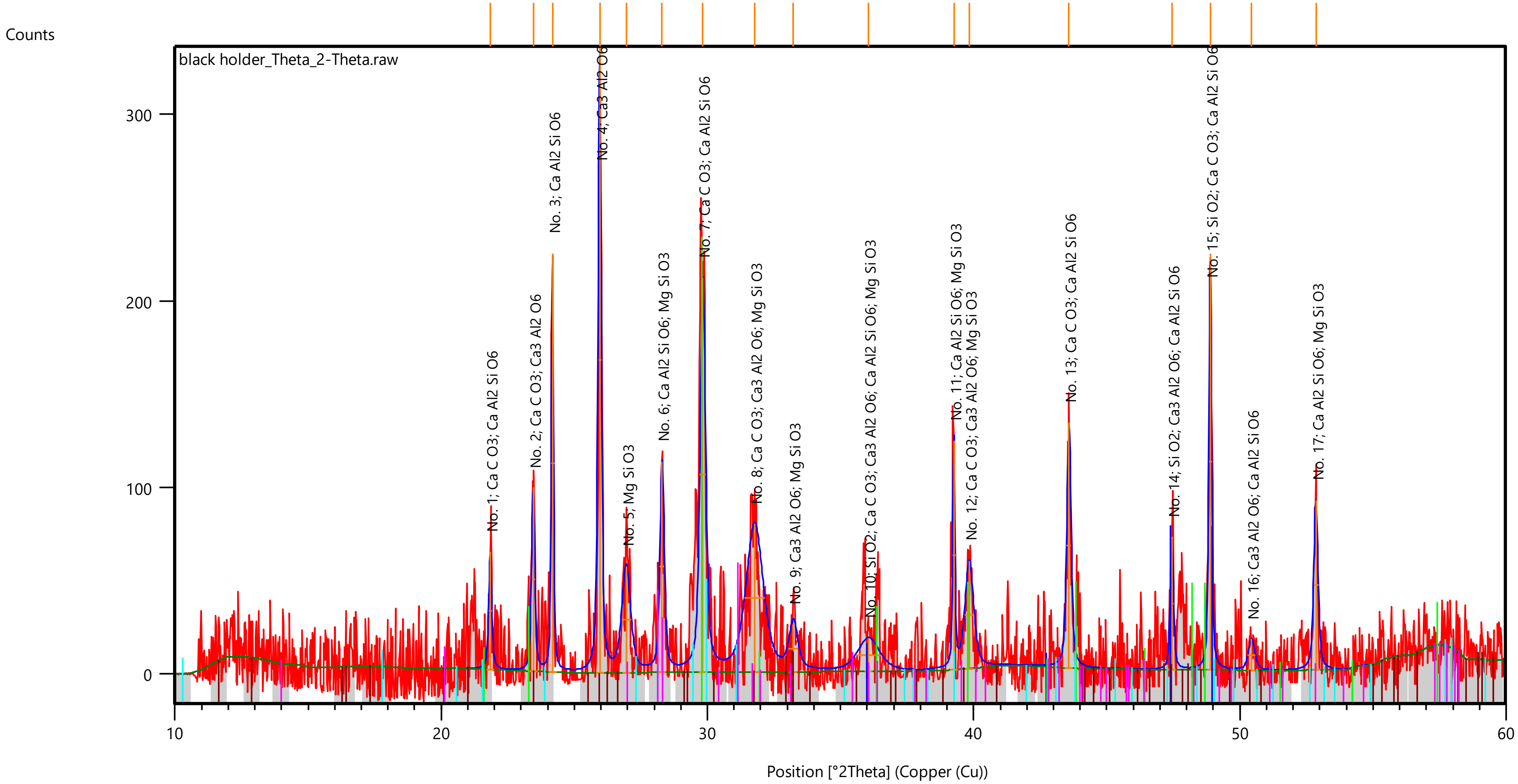
- Identified Patterns List:

Number	Ref. Code	Score	Compound Name	Scale Factor	Chemical Formula
1	00-047-1301	27	Silicon Oxide	0.229	Si O2
2	00-029-0305	20	Calcium Carbonate	0.693	Ca C O3
3	00-032-0148	4	Calcium Aluminum Oxide	0.034	Ca3 Al2 O6
4	00-025-1456	4	Calcium Aluminum Silicate	0.149	Ca Al2 Si O6
5	00-019-0768	7	Magnesium Silicate	0.175	Mg Si O3

- Peak List:

Pos. [°2Th.]	Height [cts]	FWHM Left [°2Th.]	d-spacing [Å]	Rel. Int. [%]	Tip Width
21.8423	62.96	0.144	4.0658	18.75	0.1728
23.4555	98.77	0.144	3.7897	29.42	0.1728
24.1782	224.54	0.096	3.67803	66.88	0.1152
25.9576	335.73	0.144	3.42979	100	0.1728
26.9503	57.01	0.384	3.30567	16.98	0.4608
28.2964	113.08	0.192	3.1514	33.68	0.2304
29.8332	211.69	0.24	2.99247	63.05	0.288
31.7745	79.71	0.768	2.81393	23.74	0.9216
33.2335	25.55	0.384	2.69365	7.61	0.4608
36.0555	17.78	0.96	2.48903	5.3	1.152
39.2599	122.93	0.096	2.29294	36.62	0.1152
39.8397	57.58	0.384	2.2609	17.15	0.4608
43.5821	131.49	0.192	2.07503	39.17	0.2304
47.4445	71.15	0.144	1.91472	21.19	0.1728
48.8903	223.32	0.12	1.86143	66.52	0.144
50.4378	16.89	0.288	1.80788	5.03	0.3456

- Graphics: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No. 4; Ca3 Al2 O6
No. 5; Mg Si O3
No. 6; Ca Al2 Si O6; Mg Si O3
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No. 11; Ca Al2 Si O6; Mg Si O3
No. 12; Ca C O3; Ca3 Al2 O6; Mg Si O3
No. 13; Ca C O3; Ca Al2 Si O6
No. 14; Si O2; Ca3 Al2 O6; Ca Al2 Si O6
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30
40
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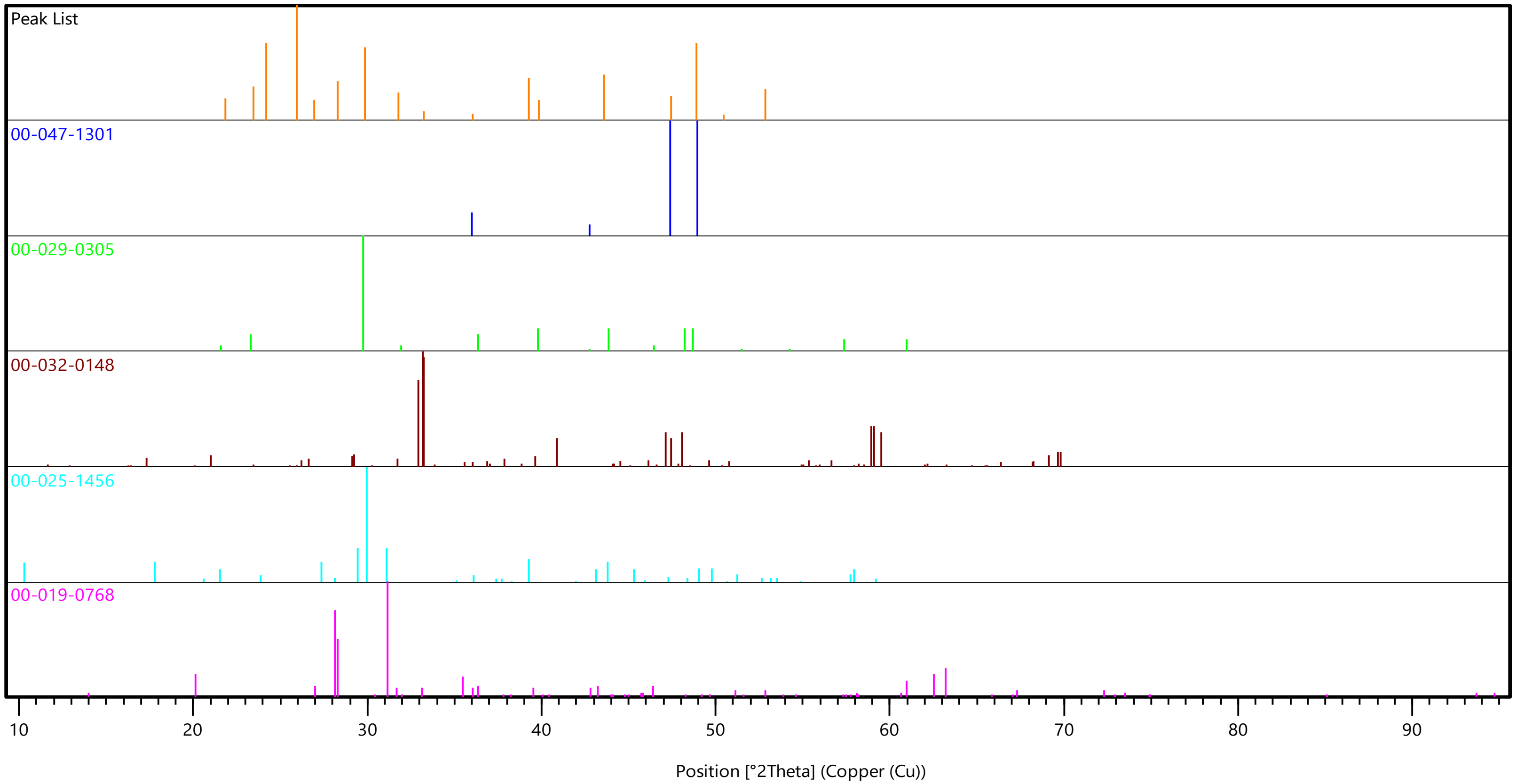
Position [°2Theta] (Copper (Cu))

- Plot of Identified Phases:



APPENDIX C

Cubic Compressive Strength, (Size = 15cm*15cm*15cm)

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Area cm^2	Weight Of Specimen [kg]	Failure Load [kN]	Failure Stress [kPa]	Percentage of f'c (%)
1	Control	1	7	225	7.839	609.90	27.11	82%
		2			7.938	576.40	25.62	78%
		3			7.708	569.10	25.29	77%
		Average			**7.83**	**585.13**	**26.01**	**79%**
2	Bo - 20	1	7	225	7.837	559.90	24.88	75%
		2			7.753	489.10	21.74	66%
		3			7.973	585.00	26.00	79%
		Average			**7.85**	**544.67**	**24.21**	**73%**
3	Bo - 35	1	7	225	8.033	559.30	24.86	75%
		2			7.987	571.00	25.38	77%
		3			7.993	560.20	24.90	75%
		Average			**8.00**	**563.50**	**25.05**	**76%**
4	Bo - 50	1	7	225	7.988	403.60	17.94	54%
		2			7.909	455.40	20.24	61%
		3			7.987	469.60	20.87	63%
		Average			**7.96**	**442.87**	**19.68**	**60%**
5	Bo - 65	1	7	225	7.683	398.51	17.71	54%
		2			7.820	385.95	17.15	52%
		3			7.960	378.82	16.84	51%
		Average			**7.82**	**387.76**	**17.23**	**52%**

For curing age of 7 days

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Area cm^2	Weight Of Specimen [kg]	Failure Load [kN]	Failure Stress [kPa]	Percentage of f'c (%)
6	Control	1	28	225	8.086	725.50	32.24	98%
		2			8.011	785.30	34.90	106%
		3			7.986	800.30	35.57	108%
		Average			**8.03**	**770.37**	**34.24**	**104%**
7	Bo - 20	1	28	225	7.837	744.20	33.08	100%
		2			7.956	742.20	32.98	100%
		3			8.012	791.70	35.19	107%
		Average			**7.94**	**759.37**	**33.75**	**102%**
8	Bo - 35	1	28	225	8.052	797.00	35.42	107%
		2			8.096	861.00	38.27	116%
		3			8.152	835.70	37.14	113%
		Average			**8.10**	**831.23**	**36.94**	**112%**
9	Bo - 50	1	28	225	7.968	713.50	31.71	96%
		2			7.962	734.10	32.63	99%
		3			7.921	724.30	32.19	98%
		Average			**7.95**	**723.97**	**32.18**	**98%**
10	Bo - 65	1	28	225	7.900	621.90	27.64	84%
		2			7.810	663.75	29.50	89%
		3			7.960	639.68	28.43	86%
		Average			**7.89**	**641.78**	**28.52**	**86%**

For curing age of 28 days

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Area cm^2	Weight Of Specimen [kg]	Failure Load [kN]	Failure Stress [kPa]	Percentage of f'c (%)
11	Control	1	56	225	8.123	783.10	34.80	105%
		2			7.836	794.03	35.29	107%
		3			7.956	806.00	35.82	109%
		Average			**7.97**	**794.38**	**35.30**	**107%**
12	Bo - 20	1	56	225	7.866	851.80	37.86	115%
		2			7.779	809.20	35.96	109%
		3			7.933	844.20	37.52	114%
		Average			**7.86**	**835.07**	**37.11**	**112%**
13	Bo - 35	1	56	225	7.951	921.70	40.96	124%
		2			8.240	901.20	40.05	121%
		3			7.954	922.30	40.99	124%
		Average			**8.05**	**915.07**	**40.67**	**123%**
14	Bo - 50	1	56	225	8.048	736.65	32.74	99%
		2			7.981	845.10	37.56	114%
		3			8.048	837.20	37.21	113%
		Average			**8.03**	**806.32**	**35.84**	**109%**
15	Bo - 65	1	56	225	7.548	691.65	30.74	93%
		2			7.981	710.10	31.56	96%
		3			7.408	679.70	30.21	92%
		Average			**7.65**	**693.82**	**30.84**	**93%**

For curing age of 56 days

APPENDIX D

Cylindrical Splitting tensile strength, (Size = 30cm*15cm)

- T = (2*P)/(pi*L*d)

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen [kg]	Failure Load [kN]	Tensile spliting strength [kPa]
1	Control	1	7	13	138.300	1.96
		2		12.75	147.700	2.09
		3		12.64	139.100	1.97
		Average		**12.68**	**141.70**	**2.00**
2	Bo - 20	1	7	13	185.800	2.63
		2		12.93	189.100	2.68
		3		12.85	143.800	2.03
		Average		**12.89**	**172.90**	**2.45**
3	Bo - 35	1	7	12	174.700	2.47
		2		12.51	173.900	2.46
		3		12.86	169.600	2.40
		Average		**12.58**	**172.73**	**2.44**
4	Bo - 50	1	7	13	171.400	2.42
		2		12.75	193.900	2.74
		3		12.78	172.800	2.44
		Average		**12.74**	**179.37**	**2.54**
5	Bo - 65	1	7	13	169.300	2.40
		2		12.57	171.100	2.42
		3		12.61	168.700	2.39
		Average		**12.62**	**169.70**	**2.40**

For curing age of 7 days

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen [kg]	Failure Load [kN]	Tensile spliting strength [kPa]
6	Control	1	28	13	203.200	2.87
		2		12.80	212.600	3.01
		3		12.77	190.200	2.69
		Average		**12.73**	**202.00**	**2.86**
7	Bo - 20	1	28	13	193.400	2.74
		2		12.64	196.700	2.78
		3		12.56	202.600	2.87
		Average		**12.57**	**197.57**	**2.79**
8	Bo - 35	1	28	12	197.300	2.79
		2		12.66	197.400	2.79
		3		12.82	203.300	2.88
		Average		**12.66**	**199.33**	**2.82**
9	Bo - 50	1	28	13	214.000	3.03
		2		12.65	194.200	2.75
		3		12.71	198.100	2.80
		Average		**12.70**	**202.10**	**2.86**
10	Bo - 65	1	28	12	167.300	2.37
		2		12.11	187.400	2.65
		3		12.16	203.300	2.88
		Average		**12.24**	**186.00**	**2.63**

For curing age of 28 days

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen [kg]	Failure Load [kN]	Tensile spliting strength [kPa]
11	Control	1	56	12	181.400	2.57
		2		12.39	226.800	3.21
		3		12.30	232.200	3.28
		Average		**12.35**	**213.47**	**3.02**
12	Bo - 20	1	56	12	196.700	2.78
		2		12.31	200.700	2.84
		3		12.34	202.600	2.87
		Average		**12.34**	**200.00**	**2.83**
13	Bo - 35	1	56	13	209.800	2.97
		2		12.66	202.500	2.86
		3		12.68	196.900	2.79
		Average		**12.65**	**203.07**	**2.87**
14	Bo - 50	1	56	13	228.700	3.24
		2		12.57	182.700	2.58
		3		12.68	210.900	2.98
		Average		**12.61**	**207.43**	**2.93**
15	Bo - 65	1	56	12	179.800	2.54
		2		12.43	182.500	2.58
		3		12.58	196.900	2.79
		Average		**12.48**	**186.40**	**2.64**

For curing age of 56 days

APPENDIX E

Flexural strength, (Size = 10cm*10cm*50cm)

- M.R=PL/bd^2 If location of fracture within the middle third
- M.R=3Pa/bd^2 If location of fracture within 5% of the supported span length

R. No.	Percentage substitution	Specimen No.	Age Of Concret	Weight Of Specimen	Failure Load [kN]	Location of fracture	Failure Stress [kPa]	Modules of rupture (Mpa)
1	Control	1	7	12	5.700	Middle third	2.56	2.57
		2		11.81	5.000	Middle third	2.26	2.25
		3		11.86	5.500	135.00	2.49	2.23
		Average		**11.81**	**5.40**		**2.44**	**2.35**
2	Bo - 20	1	7	12	6.500	Middle third	2.93	2.93
		2		12.04	6.600	Middle third	2.97	2.97
		3		11.94	6.300	Middle third	2.83	2.84
		Average		**12.01**	**6.47**		**2.91**	**2.91**
3	Bo - 35	1	7	12	8.300	Middle third	3.75	3.74
		2		12.04	9.200	Middle third	4.18	4.14
		3		12.07	7.300	Middle third	3.27	3.29
		Average		**12.03**	**8.27**		**3.73**	**3.72**
4	Bo - 50	1	7	12	6.900	Middle third	3.09	3.11
		2		11.81	7.400	Middle third	3.34	3.33
		3		11.89	7.000	Middle third	3.12	3.15
		Average		**11.86**	**7.10**		**3.18**	**3.20**
5	Bo - 65	4	7	12	5.900	Middle third	2.69	2.66
		5		11.80	6.000	Middle third	2.71	2.70
		6		11.87	6.200	Middle third	3.79	2.79
		Average		**11.88**	**6.03**		**3.06**	**2.72**

For curing age of 7 days

R. No.	Percentage substitution	Specimen No.	Age Of Concrete	Weight Of Specimen	Failure Load [kN]	Location of fracture	Failure Stress	Modules of rupture (Mpa)
6	Control	1	28	12	8.700	Middle third	3.19	3.92
		2		11.53	9.500	Middle third	4.27	4.28
		3		11.60	11.100	145.00	4.98	4.83
		Average		**11.60**	**9.77**		**4.15**	**4.34**
7	Bo - 20	1	28	12	7.700	Middle third	3.47	3.47
		2		11.93	9.900	Middle third	4.46	4.46
		3		12.05	8.300	Middle third	3.74	3.74
		Average		**12.00**	**8.63**		**3.89**	**3.89**
8	Bo - 35	1	28	12	8.300	Middle third	4.29	3.74
		2		11.98	9.600	Middle third	4.11	4.32
		3		12.10	9.700	Middle third	3.61	4.37
		Average		**12.00**	**9.20**		**4.00**	**4.14**
9	Bo - 50	1	28	12	9.600	Middle third	3.71	4.32
		2		12.05	9.200	Middle third	4.32	4.14
		3		11.94	9.500	Middle third	4.32	4.28
		Average		**11.95**	**9.43**		**4.12**	**4.25**
10	Bo - 65	1	28	12	7.800	Middle third	3.51	3.51
		2		11.79	7.600	Middle third	3.42	3.42
		3		11.84	8.100	Middle third	3.61	3.65
		Average		**11.82**	**7.83**		**3.51**	**3.53**

For curing age of 28 days

R. No.	Percentage substitution	Specimen No.	Age Of Concrete	Weight Of Specimen [kg]	Failure Load [kN]	Location of fracture	Failure Stress	Modules of rupture (Mpa)
11	Control	1	56	12	9.900	Middle third	4.46	4.46
		2		11.61	10.900	141.00	4.88	4.61
		3		11.70	10.800	Middle third	4.86	4.86
		Average		**11.64**	**10.53**		**4.73**	**4.64**
12	Bo - 20	1	56	12	9.600	Middle third	4.30	4.32
		2		11.98	9.500	Middle third	4.28	4.28
		3		12.11	9.800	137.00	4.64	4.03
		Average		**12.02**	**9.63**		**4.41**	**4.21**
13	Bo - 35	1	56	12	9.600	Middle third	4.32	4.32
		2		11.68	10.000	Middle third	4.50	4.50
		3		11.84	9.500	Middle third	4.32	4.28
		Average		**11.71**	**9.70**		**4.38**	**4.37**
14	Bo - 50	1	56	12	11.000	Middle third	4.96	4.95
		2		11.90	10.200	Middle third	4.57	4.59
		3		11.92	10.400	Middle third	4.42	4.68
		Average		**11.97**	**10.53**		**4.65**	**4.74**
15	Bo - 65	1	56	11	9.700	Middle third	4.96	4.37
		2		11.82	8.900	148.00	4.57	3.95
		3		11.64	9.300	Middle third	4.42	4.19
		Average		**11.55**	**9.30**		**4.65**	**4.17**

For curing age of 56 days

APPENDIX F

Water permeability, (Size = 15*15*15)

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen [kg]	water penetration (mm)
1	Control	1	28	8	32.000
		2		7.96	34.000
		3		7.86	38.000
		Average		**7.90**	**34.67**
2	Bo - 20	1	28	8	36.000
		2		7.89	33.500
		3		7.96	35.500
		Average		**7.92**	**35.00**
3	Bo - 35	1	28	8	22.000
		2		7.86	59.000
		3		7.84	34.000
		Average		**7.89**	**38.33**
4	Bo - 50	1	28	8	44.000
		2		7.72	43.000
		3		7.86	43.000
		Average		**7.81**	**43.33**
5	Bo - 65	1	28	8	39.340
		2		7.82	42.610
		3		7.83	42.140
		Average		**7.83**	**41.36**

For curing age of 28 days

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen [kg]	water penetration (mm)
6	Control	1	56	8	24.000
		2		8.02	21.000
		3		7.95	28.000
		Average		**8.00**	**24.33**
7	Bo - 20	1	56	8	16.000
		2		7.98	27.500
		3		8.00	19.500
		Average		**7.98**	**21.00**
8	Bo - 35	1	56	8	17.500
		2		7.92	17.500
		3		7.96	22.000
		Average		**7.95**	**19.00**
9	Bo - 50	1	56	8	18.500
		2		7.95	15.500
		3		7.89	16.100
		Average		**7.92**	**16.70**
10	Bo - 65	1	56	8	16.300
		2		7.96	15.800
		3		7.89	15.500
		Average		**7.96**	**15.87**

For curing age of 56 days

APPENDIX G

Cylindrical Ultrasonic pulse velocity, (Size = 10cm*20cm)

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen	Path length (mm)	Traveld time (micro.s)	Pulse velocity (km/s)
1	Control	1	7	3.71	200.00	49.7	4.02
		2		3.76	200.00	48.5	4.12
		3		3.77	200.00	48.9	4.09
		Average		**3.75**	**200.00**	**49.03**	**4.08**
2	Bo - 20	1	7	3.71	200.00	51.4	3.89
		2		3.71	200.00	51	3.92
		3		3.75	200.00	50	4.00
		Average		**3.72**	**200.00**	**50.80**	**3.94**
3	Bo - 35	1	7	3.73	200.00	50.2	3.98
		2		3.71	200.00	49.4	4.05
		3		3.66	200.00	49.2	4.07
		Average		**3.70**	**200.00**	**49.60**	**4.03**
4	Bo - 50	1	7	3.74	200.00	50.5	3.96
		2		3.70	200.00	50.4	3.97
		3		3.66	200.00	50.4	3.97
		Average		**3.70**	**200.00**	**50.43**	**3.97**
5	Bo - 65	1	7	3.77	200.00	52.2	3.83
		2		3.73	200.00	51.9	3.85
		3		3.76	200.00	52.6	3.80
		Average		**3.75**	**200.00**	**52.23**	**3.83**

For curing age of 7 days

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen	Path length (mm)	Traveld time (micro.s)	Pulse velocity (km/s)
1	Control	1	28	3.71	200.00	48.3	4.14
		2		3.76	200.00	47.6	4.20
		3		3.77	200.00	47.4	4.22
		Average		**3.75**	**200.00**	**47.77**	**4.19**
2	Bo - 20	1	28	3.71	200.00	48.6	4.12
		2		3.71	200.00	48.9	4.09
		3		3.75	200.00	48.4	4.13
		Average		**3.72**	**200.00**	**48.63**	**4.11**
3	Bo - 35	1	28	3.73	200.00	48.1	4.16
		2		3.71	200.00	47.9	4.18
		3		3.66	200.00	47.3	4.23
		Average		**3.70**	**200.00**	**47.77**	**4.19**
4	Bo - 50	1	28	3.74	200.00	48.9	4.09
		2		3.70	200.00	48.4	4.13
		3		3.66	200.00	48.9	4.09
		Average		**3.70**	**200.00**	**48.73**	**4.10**
5	Bo - 65	1	28	3.77	200.00	50.4	3.97
		2		3.73	200.00	49.6	4.03
		3		3.76	200.00	51.9	3.85
		Average		**3.75**	**200.00**	**50.63**	**3.95**

For curing age of 28 days

R. No.	Percentage substitution	Sample No.	Age Of Concrete	Weight Of Specimen	Path length (mm)	Traveld time (micro.s)	Pulse velocity (km/s)
1	Control	1	56	3.71	200.00	48.3	4.14
		2		3.76	200.00	47.6	4.20
		3		3.77	200.00	47.4	4.22
		Average		**3.75**	**200.00**	**47.77**	**4.19**
2	Bo - 20	1	56	3.71	200.00	48.6	4.12
		2		3.71	200.00	48.9	4.09
		3		3.75	200.00	48.4	4.13
		Average		**3.72**	**200.00**	**48.63**	**4.11**
3	Bo - 35	1	56	3.73	200.00	48.1	4.16
		2		3.71	200.00	47.9	4.18
		3		3.66	200.00	47.3	4.23
		Average		**3.70**	**200.00**	**47.77**	**4.19**
4	Bo - 50	1	56	3.74	200.00	48.9	4.09
		2		3.70	200.00	48.4	4.13
		3		3.66	200.00	48.9	4.09
		Average		**3.70**	**200.00**	**48.73**	**4.10**
5	Bo - 65	1	56	3.77	200.00	50.4	3.97
		2		3.73	200.00	49.6	4.03
		3		3.76	200.00	51.9	3.85
		Average		**3.75**	**200.00**	**50.63**	**3.95**

For curing age of 56 days