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SCHOOL OF CHEMICAL AND BIOENGINEERING

Study on the Possibility of using Municipal Solid Waste Incineration Bottom Ash as Partial Replacement of Aggregates in Concrete Mixes (The case in Repie waste to energy plant)

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, in Partial Fulfilment of the Requirements, for the Degree of Master of Science in School of Chemical and Bio Engineering (Environmental Engineering Stream)

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Abstract

A huge sum of civil strong waste (MSW) are created each year. The most way of Waste administration and utilization are major concern in numerous parts of the world. Because it may generate power from garbage, burning could be an important process for handling municipal solid waste (MSW). Specifically, municipal solid waste incineration (MSWI) generates two types of ash: bottom ashes (BA) and fly ashes (FA). The lack of space for land fill and the resulting natural pollution is the primary drawback of incineration technology, thus the use of MSWI ash displays a tremendous dedication to waste reduction and asset conservation. This research paper investigated to study the possibility of the Repie waste to energy incinerator plant bottom ash to produce the concrete materials by partial replacement of aggregates in the standards of concrete mix ratio. First the physical and chemical properties of the Repie MSWI BA was investigated in detail and the result obtained with the moisture content of the ash was 30.76wt % having high moisture content. Its particle size distribution was in the range of coarse to fine. The most abundant oxide composition in the bottom ash was found to be SiO_2 which reaches up to 48.88%. From the experiment all the three parameters, substitution ratio, particle size and curing time had significant effect on the compressive strength. The optimum condition for maximum CS of 21.21MPa were 10% ratio substitution, with particle size 3.01mm and 28th days curing time for the concrete

Keywords: municipal incineration bottom ash; fly ash; waste management;

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Acronyms

APC - Air Pollution Control

BA - Bottom Ash

CS - compressive strength

FA - Fly Ash

MSW - Municipal Solid Waste

MSWI - Municipal Solid Waste Incineration

TCLP - Toxicity Characteristic Leaching Procedure

WTE - Waste to Energy

AAS - Atomic Absorption spectrometer

ASTM - American Society for Testing and Materia

ACI - American Concrete institute

Chapter 1

1. Introduction

1.1 Background

Solid waste management is a problem in many of the world's largest areas as populations increased to cities continues to grow. This has led to ever-increasing quantities of domestic solid waste where space for disposal decreases. Municipal managers are looking to the development of environmentally safe landfills around the surrounding of their cities as a primary solution.

The Waste-to-Energy plant established at Repie is to receive 1,400 tons of municipal waste per day, resulting an annual solid waste-disposal ability of 420,000 tons, and is a vital solid waste disposal and renewable-electricity production facility for the capital city of Ethiopia, Addis Ababa. The facility is designed with a redundant energy generation and evacuation system for added reliability and extended operation. By changing waste from landfills and by following to the strict European environmental standards for WTE, the Repie. In the operation over 80% of this waste is eliminated and remains is converted into bottom ash and fly ash.

Large amount of solid waste are produced by industries. The disposal of these solid waste materials becomes an environmental hazard for the entire surrounding living things. Various types of pollutions are caused by these wastes like air pollution, water pollution, land pollution, etc. These pollutions lead to the various types of diseases to the life on the planet and the waste production is increasing time to time so the disposal of these wastes is a serious issue and also the matter of concern, previous researches observed that because of increasing environmental concerns and sustainable issues, the utilization of solid waste materials is the need of the hour. The productive use of solid waste materials is the best way to alleviate the problems associated with their disposal. This problem can be solved by the construction industry by using these solid wastes in the production of structural elements like concrete elements, bricks, tiles, etc. Based on the research reports some solid waste materials such as fly ash, silica fume, grounded blast furnace slag etc. have been put in use in manufacturing of either cement or concrete.[3]

Currently, production and utilization of consumer goods creates a production of large amount of municipal solid waste. Previously, no attention was given to the environmental burden of mass consumerism, and municipal waste was destined in for dumps disposal. Since the 1960s, increasing concern about society health and ecological risks have required the implementation of best waste management systems in well-developed parts of the world. The introduction of legislation and public waste management organization aims to reduce the impact of waste disposal and control emissions of pollutants to the environment. In many industrialized and more-populated locations, waste minimization, collection, separation of reusable or degradable materials, and removal of the residual to landfills or incineration facilities have now become best practices in solid waste management [3]

The major types of wastes injected to incineration are municipal solid wastes. The incineration operation generates heat, and this is recovered and utilized as or converted to electrical energy. The effect of the residues depends mainly on their environmental quality. Basically two fractions of ash are generated from incineration technology, which are called bottom ash and fly ash. The fly ash goes with the flue-gases through the exhaust system and is caught in the flue-gas cleaning system, for example an electric filter. Bottom ash is the type of ash that comes down and found at the bottom of the furnace. In general, the bottom ash has been more investigated, considering the engineering and environmental properties, probably due to the fact that bottom ash is produced in higher amounts than the fly ash. Bottom ash is generally regarded as non-hazardous, and can thus be used in a variety of applications, such as the partial substitution of aggregates in the normal concrete ratio in the manufacturing of concrete building material. Concrete is the world's most consumed construction material because of its excellent mechanical and durability properties. Worldwide, the concrete industry produces over 10 billion tons of concrete annually (Meyer 2006). At] present, concrete industry is cursed with the scarcity of the aggregates and environment pollution from cement production [2].

Generally the waste produced from MSWI can be ended as disposal or recycling as a raw material for other material production. Environmental policies in most industrialized countries, where land is scarce and environmental management is strict, tend to reduce landfill disposals as much as feasible [1].Besides, the natural resources of aggregates are decreasing from time to time due to the high rate of infrastructure development throughout the world. The prohibition on mining in some areas creates shortage of natural aggregates availability. The high cost of construction and operation of incineration plants together with shortage of landfills have required to the need for reduction of waste and recycling. Therefore, it becomes very important and more significant to substitutes both for cement as well as natural aggregates. In addition to that, the continuous growth of municipal solid waste incineration bottom ash generation is the major cause of most environmental concerns and burdens which can be decreased by using these wastes into the useful materials which can be used in concrete construction [2]

1.2 Statement of the Problem

These things lead to a pollution of the environmental. It becomes a problem for the modern solid waste management unable to manage it in a sustainable way.

Mixed bottom ash from MSWI can be recycled in a variety of ways. Bottom ash is utilized as a best gravel alternative as subbase material when used with a concrete cover to minimize direct contact with soil or water in many countries, including the United States, Germany, Sweden, France, Denmark, and Japan. They're also utilized for landfills, hot mix asphalt, interlocking blocks, and road foundation materials for asphalt paving after chemically treating or melting the bottom ash.

The high cost of treatment or transfer, the scarcity of available fill space, and the increased natural issue in populated areas have necessitated the need to find alternate uses for the burned foot scorching remains other than transfer [5]. Aside from a lack of arrival space for the transport of metropolitan strong waste blazing foot fire debris, the limited asset of totals and fetched of mining becomes critical. Depending on the type of MSW delivered, the composition of civil strong waste varies from region to region. The chemical and physical characterization of flaming residues is mostly determined by the compositions of crude metropolitan strong squander, operational conditions, and the type of incinerator and contamination control framework plan used._As a result, it's vital to look into repurposing Repie civil strong waste burning foot cinder for the production of concrete by fractional substitution of regular totals inside concrete mixes.

1.3 Objective of the Research

1.3.1 General Objective

The general objective of the present research is to investigate potential use of the Repie waste to energy plant municipal solid waste incineration bottom ash as partial replacement of aggregates in concrete mixes.

1.3.2 Specific objective

- To characterize the physical and chemical characteristics of MSWI bottom ash collected from the Repie WTE incineration plant
- To Produce concrete using Repie WTE incinerator plant bottom ash by partial replacement of aggregates
- To optimize the mechanical strength of the concrete
- To investigate the mechanical strength and the heavy metal leachates for the selected specimen
- To measure Moisture content, density and water absorption of concrete at optimum parameter.

1.4 Significance of the study

The significance of this research can be observed from various angle. Primarily it can contribute to utilize the ash for construction material both to benefit the economic and environmental protection issue, besides it also helps to create job opportunities for unemployed citizens of the country.

Chapter 2

1. Literature Review

2.1 Introduction

Municipal solid waste (MSW) is a type of wastes consisting of daily items discarded as unwanted matter from human activities, which can be generally divided into several categories according to its source - domestic solid waste from households and public areas, commercial solid waste from restaurants, offices, and markets, etc.,

The disposal of these solid wastes and their management have drawn attention widely, and awareness on the development of systematic recycling of these solid wastes has been risen recent years all over the word due to the following reasons .To begin with, these wastes contain recyclable components such as plastic, metals, and other such items. To some extent, the immediate dumping or landfilling of these wastes is a waste of potential resources. Second, incorrect waste management may result in pollution of the natural environment, soil, and water, among other things, harming humans. Finally, but certainly not least, the expense of resolving pollution or unanticipated environmental damage caused by waste disposal can be considerably minimized. As a result, proper waste management is critical.

2.2 Solid Waste Management in Different Countries

The quantity of MIBA produced presents a significant management problem, however as a useful secondary resource for potential use in construction, the material offers great opportunity. European countries such as Belgium, Denmark, Germany and The Netherlands are taking advantage of this potential, using 100, 98, 86 and 80% of the MIBA produced, respectively, predominantly as fill and road construction materials (An et al., 2014; Qing and Yu, 2013). Around half of the MIBA generated in the UK is used in construction, including as an aggregate in concrete blocks (Dhir et al., 70 2011, ISWA, 2006, Qing and Yu, 2013)

In general the waste remained after the municipal solid waste is incinerated finally transfer as landfill or utilized as an input material for the production of other materials. Since in many of populated and urbanized area the shortage of land is a problem for disposing these residue as land fill. In the same manner the environmental protection control agencies strictly bans the removal of these residues in the form of land fill because of the environmental pollution issue. [1-3]. several efforts were done in Japan almost 80% the municipal solid waste incineration residues are recycling it many ways. [4-7]. But in China above 80% of the MSWI residue disposed as land fill rather than reusing as a secondary raw materials.[8]

Studies show that municipal solid waste incineration residues contains high content of harmful heavy metals and other compounds like salt, organic pollutants and chlorides which inhibits the reusing of the residue. So it needs some special attention in applying appropriate treatment to reduce the contamination reuse the residue. [9-13]

2.3 Incineration Technology

Incineration is the process of burning an unwanted materials considered as sloid waste to reduce the volume of the waste for minimizing the space needed for land fill and generate energy from the burning process.it is the best method of administrating the municipal solid waste produced. One of the best advantage of employing incineration technology to manage the municipal solid waste. It reduces the production of methane gas emission from waste management process, besides it provides energy recovery to the production of electricity. But it has also disadvantage because of the other wastes are produced after the process which requires proper handling not to pollute the environment and its high cost of investment.

Generally there are different by products produced during the process of municipal solid waste incineration facilities:

- Fly ash: - is the fine particles that floats out from the combustion chamber with the exhaust gases which comprises a small fraction of the original municipal solid waste volume.
- Bottom ash: - this is the ash that comprises a large percentage fraction of the solid waste injected to the incineration. It is appearance to a porous, greyish and sand with gravel

with the mixture of variable particle size. It is collected from the bottom of the combustion after being quenched in water tank.

- Air pollution residue: - is a byproduct formed as a residue from the incineration plant facility. It can be in solid or liquid form on the basis of the process of the incineration.

Generally depending upon the way of burning the municipal solid waste, there are different types of incineration facilities are available.

Since the increasing rate of MSW production alerts to find out the best technology to reduce the waste by incinerating to ash to 75% accompanied by generation of electricity as a result of the process of combustion of the waste. The most recent incinerator technology includes an energy recovery mechanism known as WTE. In the incineration process, around 80 to 90 percent of the MSW is BA and 10 to 20 percent is FA [6].

During the process the municipal solid waste is changed to useful material for more than a century. Nowadays the municipal solid waste incineration technology has been taken as the best way of administrating MSW with best environmental protection solution. The main residue of obtained after the incineration of municipal solid waste which is collected after the process, i.e bottom ash contains noncombustible residues like metals, glass making materials, silicates and oxide minerals. Chimenos et al. (1999) reported that the main crystalline components in the mineral fraction are quartz (SiO2), calcium carbonates ($CaCO_3$), lime (CaO) and feldspars ($CaO·Al_2O_3·2SiO_2$, anorthite). Besides the particle size distribution of the bottom ash has been investigated and ranges from 63 µm to greater than 40mm. The mineral fraction and the metal fraction of the bottom ash have a recycling potential, where the mineral fraction may be used as an aggregate or be inserted in cement, concrete or asphalt ash that is generated from the combustion contains most of the elements found in society and they are distributed between the bottom ash and the fly ash.. The inorganic content of the bottom ash depends on the type of waste that is combusted, type of boiler and the conditions during the combustion, but the concentrations of elements are usually in the same range [14].

2.3.1. Mass Burn (MB) Incinerator

Mass burn incinerator is a type of combustor or incinerator designed to burn the municipal solid waste collected from the society and the city. All the waste received at the facility is injected to the incinerator without being prior separation. This type of incinerator has its own disadvantage. Since the waste is not segregated or sorted it produces a significant emission of pollutants to the environment than the other segregated solid waste incineration facility. The result of the residual ashes obtained from this type of incineration process may contain toxic substances and require appropriate treatments for the disposal or using of it for the other purposes.

2.3.2. Rotary kiln incinerator

A rotary kiln incinerator has plenty of application which can be complete or partial rotation vessel. Simply the incineration in the rotary kiln is a two-step process in which it consists a kiln and a separate combustion chamber. The kiln is the first combustion chamber and is inclined down wards from the inlet part. Then the rotary moves the waste to the kiln to effectively to get air and combustion.

2.3.3. Fluidized Bed Incinerators

A fluidized bed incinerator is used to have high possibility of intact between the gases and solid in the chamber which allows a complete combustion of the waste. In fluidized bed the contact of the solid waste with the hot fluidization medium is greatly enhanced when compared to packed beds. One of the advantage of using this type of incinerator for municipal solid waste combustion over the other incinerator is that it reduces the emission of sulfur dioxide and nitrogen oxide to the environment because of effective burning process.

2.4 Characterization of MSWI bottom ash

Today the world population and urbanization increasing highly from time to time. This drastic change of population number results in the production of large amount of municipal solid waste. One of the best modern way of management of municipal solid waste is employing effective technology of incineration. Unfortunately the incineration technology adversely develops other wastes that require strong management strategy to protect the environmental pollution.

Bottom ash produced as a result of municipal solid waste incineration process is a major by product obtained from it. Thus the bottom ash produced has its own physical and chemical properties varying depending on the applied incineration technology and the type of waste.

In general it is very important to know the basic physical properties and chemical properties to select the best way of the material to be recycled or utilized.in order to that physical properties like moisture content, particle size distribution density porosity water absorption are the main characteristics to be studied. Similarly it is also essential to investigate the chemical properties like oxide composition, organic constituent heavy metal content and loss of ignition.

It is known that municipal solid waste incineration bottom ash is produced under high temperature process and is mainly characterized by its oxide composition. The oxide composition of the bottom ash differs depending upon the type of incineration technology and type of waste generated from the area and injected to the incinerator. For example a study done at two different Portuguese municipal solid waste incineration plants presented in table 1. [39]

Table 1. *Chemical composition of MSWI BA from various sources (wt. %)*

Component	Source I	Source II
SiO_2	52.0	52.2
Al_2O_3	5.9	7.7
Fe_2O_3	6.8	6.8
CaO	14.0	13.6
MgO	2.0	3.0
Na_2O	6.0	3.6
K_2O	2.0	2.2
MnO	0.1	0.1
P_2O_5	5.5	2.9
TiO	0.5	0.7
LOI	5.5	7.2

From the table 1 above it shows that in both plants the major oxides components are SiO2, but CaO, Na_2O, Fe2O3 and Al_2O_3 are present in a reasonable amount the rest are in minor amount but as it can be seen from the table there is different composition of oxide contents obtained from the two plants this shows that bottom ash properties strongly depends on the generated solid waste composition and the incineration technology [1]

2.5 Utilization of MSWI Ashes in the world

In most developed countries incineration is employed as the most suitable solid waste management since from 1960. Even though the incineration is used to manage and reduce the volume of raw solid waste nearly by 90% and helps to recover the energy for the production of electricity it leaves a byproduct as a residue like bottom ash and fly ash. (Rincon et al 1999 and Boccioni et al 2000). So these developed countries practiced successfully utilized as a raw material commonly for road construction, cement and glass making material. [2, 4, 39]. According to the European waste categorization bottom ash is classified as a non-hazardous waste.

2.5.1 Asphalt and Road Paving Application

Municipal solid waste incineration residues are replacing natural aggregates and gravel in the construction of road as sub base selected material. [2, 7, and 8].

Sweden actively promoted MSWI BA as a sub-base material instead of gravel in the test road, proving that there would be no impact on the environment through heavy metal discharge [20]. In France, a three-year study about the use of MSWI BA in road pavement found that leachate concentrations of heavy metals were below the acceptable limits of drinkable water, confirming that MSWI BA is environmentally safe [20]. Around half of the MSWI ashes produced in Germany have been put too much better use in road construction.

With many years of expertise managing MSWI FA, the Netherlands has implemented the use of FA in asphalt uses as a substitute for natural aggregate without generating harmful leaching in the environment [3, 7, and 8]. Because of its pozzolanic reactivity, one proposed application for MSWI FA is soil stabilization as a supplement for lime or cement. MSWI FA might potentially be used as a filler material, according to the researchers. Environmental concerns about toxins leaching into soil and groundwater can be alleviated by pre-treatment of ash washing, which can considerably reduce leaching and, as a result, improve the potential for MSWI ashes to be used. MSWI ashes have been researched in the United States and have showed excellent performance in demonstration projects for more than 20 years [3]. In the road base layer, unbound ashes by asphalt or cement were utilized as a gravel and aggregate alternative. Substituting MSWI ashes with reduced particle sizes lower than 3/4 inches for rock aggregate in asphalt concrete showed a feasible use option for MSWI ashes in many projects in the United States with no environmental impact. [3]. MSWI ashes are ideal for use as a base and filler material because of their excellent stability and low density, with the caveat that they are not very durable [3].

The Federal Highway Administration (FHWA) has a comprehensive set of standards for using MSWI BA and mixed ashes in pavement building. According to the FHWA, ash passing a 34-inch screen can be used to replace 10% to 25% of natural aggregate in bituminous surface courses and up to 50% in base and binder courses once metal has been removed. A 2 percent by weight addition of hydrated lime to MSWI ash has also been suggested to avoid stripping of asphalt binder from the ash. In order to stabilize possible reactive materials, ash must be stored for 30 days until 20% of the pavement material has been replaced. It has been suggested that ash passing 12 inch screening after 1 to 3 months of maturity be used in granular base applications [3].

2.5.2 Concrete Application

MSWI ashes are thought to generate pozzolanic reactivity when the Ca component from APC devices is maintained in the ash, and the ash can then be used to partially replace Portland cement, and MSWI BA can be used as a rock aggregate in PCC [3, 23]. MSWI ashes have also been used as a rock aggregate substitute in concrete blocks in states across the country around the United States [3]. MSWI ashes in PCC appeared promising, however before to use, metals, glass, and soluble salts must be eliminated, which reduce the final product's strength [3].

In any event, a handful of the PCC applications' negative effects have been described. Despite the fact that MSWI FA is sometimes thought to have properties similar to cement [20], further investigation reveals that both fiery debris contain a significant amount of metallic Al that can produce hydrogen gas, tends to result in volume development, splits, and voids in cement glue examples [21, 22,].

Chapter 3

3. Materials and Methods.

3.1 Material and equipment

- **material**

The materials used in this research paper work are municipal Solid waste incineration (MSWI) bottom ash, cement, fine aggregate, coarse aggregates and water.

3.1.1 Repie Municipal Solid waste incineration (MSWI) bottom ash

A total of 30kg of sample was gathered from different locations in the recently quenched BA dumps at Repie MSWI. Due to the variation of the bottom ash, samples were taken at random from a variety of locations and depths (10 different points).

3.1.2. Cement

In this research, ordinary Portland cement (OPC), were bought from the market produced by the local cement factory, Mugher was used as raw materials and throughout the study, Potable tap water was used for the concrete mix and curing

3.1.3 Fine aggregate

Normal sand with greatest estimate of 5mm was utilized as fine totals. The fine total was acquired from the adjacent advertise and washed altogether with tap water so as to expel the residue on it.

3.1.4 Coarse aggregate

The coarse total utilized for the study was bought from the market with greatest estimate of 20mm.

- equipment

- Plastic bag: - to collect and transport the bottom ash sample from the Repie WTE incineration plant.
- Oven :- to dry the sample
- Analytical Balance:- to weight samples
- Mechanical Shaker:- to perform the sieve the sample and the concrete mix fine and coarse aggregates materials
- Rectangular cast:- to make the concrete to be determined

3.2 Experimental methods

3.2.1 Physical properties of the Repie MSWI BA

The physical properties of the bottom ash were conducted in the laboratories of AAiT's school of chemical and bio engineering, civil and environmental engineering,

i) **The particle size distribution:**

The particle size distribution of the Repie MSWI bottom ash was determined according to the (ASTMC136-01). Accordingly, the sample was dried using oven to constant mass at a temperature of 110 ^{0}C for 24 hrs. The suitable sieve were selected and the sieves were nested in order of decreasing size of opening from top to bottom and the sample were placed on the top sieve. The sieve were agitated by mechanical sieve shaker for sufficient period. After the sample retained on each sieve were recorded then, percentage of retained weight, cumulative coarser and cumulative passing percentage were calculated, and the detailed result of the test were shown in Table 5 in the discussion part of this paper.

ii) Moisture content

The Repie MSWI BA moisture content was determined after collected and air dried. The test was done according to ASTM C566. Accordingly, 1 gram of sample was oven dried for 24 hrs. at a temperature of 110± 5̊ C .and after cooled the moisture content was calculated by the formula

$$\% \text{ of moisture} = \frac{W1-W2}{W1-W3} \times 100$$

Where:

W_1= weight of sample and crucible before drying

W_2= weight of sample and crucible @105˚C for 24 hrs after drying

W_3= weight of empty crucible

The detailed calculation part is also included in appendix I. A (i and ii)

iii) Bulk density

The bulk density of the Repie MSWI BA sample used in this research study was determined according to ASTM C 128 by the Roding method. Accordingly, the test was carried in the following procedure

- One third of the sample was filled and the layer was rodded 25 stokes of the tamping rod evenly distributed over the surface.
- Again two third of the sample is added to it and rodded again as above.
- Finally the sample was filled over flowed and rodded again.
- Then the level of the surface was fingered with straight edge.
- After all measured data was recorded the loose bulk density and compact(rodded) bulk density was calculated by using the following formula

Loose bulk density= $D=\frac{M1-M2}{M3-M2}$

Where D = loose bulk density of the BA

M1= Mass of the bottom ash plus the cylinder

M2= mass of empty cylinder=

M3 = mass of the cylinder plus water of the cylinder

Compact bulk density= $D=\frac{M1-M2}{M3-M2}$

Where

D_r= rodded (compact) bulk density

M1= mass of the cylinder + rodded BA sample

M2= mass of empty cylinder

M3 = mass of the cylinder plus water of the cylinder

The detailed calculation is presented in appendix I, B (i and ii respectively)

iv) Specific gravity and Absorption capacity

The specific gravity, apparent specific gravity and water absorption of the Repie MSWI BA was determined in the school of chemical and bio engineering lab as per ASTM C128-01 by pycnometer. Accordingly, the measurement were carried out using the following procedures:

- 1 kg of air dried bottom ash sample was measured then the air dried sample was soaked in water for 24 hours.
- After 24 hours the water is drained from the sample and the water is removed from the sample with clean cloth.
- The sample was placed in the pycnometer and filled with distilled water until it was full and the entrapped air was removed by rotating the pycnometer.
- After all the data is recorded the specific gravity, apparent specific gravity and water absorption was calculated with the following formulas;

Specific gravity (sp.g) = $\frac{D}{A-(B-C)}$

Apparent specific gravity= $\frac{D}{D-(B-C)}$

Water absorption = $\frac{A-D}{D}$ *100

Where A= weight in g of saturated surface dry sample

B= weight in g of pycnometer + sample and filled with distilled water

C= weight in gram of pycnometer +water

D= weight in g of oven dried sample

The detailed calculation were presented in appendix I C (i, ii and iii, respectively)

v) Fineness of module

The aggregate fineness module (FM) was an empirical factor calculated by multiplying the total number of aggregate retained on each of a series of standard sieves by 100

$$F.M= \frac{\Sigma \text{ cumulative coarse } (\%)}{100}$$

The detailed calculation was presented in appendix I, (D)

3.2.2 Chemical composition of the bottom ash

The complete silicate analysis of the ash collected from the Repie MSWI bottom ash was conducted at geological survey of Ethiopia laboratory using the analytical method of $LiBO_2$ fusion, HF attack, gravimetric colorimetric and AAS. The result obtained from the test was displayed in Table 7 of the result and discussion section.

3.3 Experimental design method of the process and data analysis

The experiments were designed to determine the effect of the main parameters in the concrete mix as well as to optimize all the affecting parameters collectively by statistical experimental design response surface methodology. Specifically, Box-Benkhen statistical experiment design (BBD) was applied to conduct the experiment with one factor and three level patterns. The objective was to obtain an optimum compressive strength of the condition taking into account the desired value of the response function. As shown in Table 2, the experiments were performed in a completely randomized design with three factors at three levels. A total of 17 randomized experiments were performed based on the Box-Benkhen statistical experiment design (BBD) as presented in Table 3.

The result of the experimental design were studied and interpreted by statistical software package Design Expert 7.0.0 to estimate the response of the dependent variable. The model equation sufficiency was evaluated using analysis of variance (ANOVA). Quality of fit of the model equations and their statistical significance were expressed using F-test, coefficient of determination (R^2), prediction coefficients of determination (Pred R^2), adjusted coefficients of determination (adj-R^2), and coefficients of variation (CV).

Table 2 Experimental range and level of dependent variables

Code symbol	**Factor**	**Unit**	**Levels**		
			Low(-1)	Medium(0)	High(+1)
A	Particle size	Mm	1.18	2.84	4.5
B	substitution ratio	% percentage	10	30	50
C	Curing Time	Day	3	15.5	28

3.3.1 Concrete mix design experimental procedure

The percentages of cement, fine aggregate, and coarse aggregate in concrete were 1:1.5:3, with a water to cement ratio of 0.45. The mix proportions of test series Concrete cube of cast 100x100x100mm were prepared and 17 samples were made by replacing the aggregates with 10%, 20%, 30%, 40%and 50% and the reference with standards concrete mix ratio. The center point of the particle size, ratio of bottom ash to be replaced and number of days required for the concrete cube to be cured i.e. (2.84, 30 and 15.5 respectively) was replicated five times. The experiment for all 17 runs were carried out at the laboratory scale

After the area for the material to be mixed in the production of concrete were cleaned and carried out using the following procedure:-

- The materials for the concrete mix were weighed and mixed together for two minutes in dry condition.

- The required amount of water was added on the mixed material and mixed evenly for three minutes.
- The prepared concrete cast mold were cleaned, oiled and placed leveled and the mixed material were added to the cast with proper vibration.
- After the vibration the top surface were finished.
- The concrete were removed from the cast after 24 hour were cured in the water bath according to the days required by the test runs.

The cement, coarse aggregate and the amount of water were taken similar ratio in all concrete production but the fine aggregate (sand) and the bottom ash (BA) were varied as per the replacement ratio and particle size of the BA according to the experimental run.

Table 3 Concrete mix ratio of BA, particle size of BA and number of days the concrete cube to cure.

Experiment run	PS of the BA	% of BA replacing sand	No of days to cure the concrete	Compressive strength(MPa)
1	2.84	30	15.5	18.32
2	2.84	30	15.5	18.01
3	2.84	30	15.5	18.22
4	2.84	30	15.5	17.98
5	2.84	30	15.5	18.02
6	2.84	10	28	21.32
7	2.84	10	3	19.78
8	2.84	50	3	17.12
9	2.84	50	28	19.54
10	1.18	10	15.5	19.25
11	1.18	50	15.5	17.51
12	1.18	30	28	19.01
13	1.18	30	3	16.92
14	4.5	30	28	18.56
15	4.5	30	3	17.65
16	4.5	10	15.5	20.15
17	4.5	50	15.5	17.34

3.4 Experimental tests procedure

- The comprehensive strength of the samples were tested for 3, 15.5, and 28 days cube.
- The leachability of toxic heavy metals from the selected specimen was determined using toxicity characteristics leaching procedure (TCLP).
- The moisture content and the compressive strength of selected specimen after the 28^{th} day cured time of the concrete was determined in terms of percentage per dry weight.
- The density and water absorption of the selected concrete sample was determined.

CHAPTER 4

4. RESULT AND DISCUSSION

4.1. Physical Properties of the Repie Municipal Waste Incineration (MSWI) Bottom Ash.

The physical properties of the MSWI bottom ash is very important to use it as a recycling resource for construction material.

4.1.1 Moisture content of the Repie MSWI BA

It is important to determine the moisture contents of the aggregates prior to mixing, because it affects the proportion of mix water needed to achieve the desired water to cement ratio. Based on this the BA was determined and the result of the analysis was presented in Table 4.

Table 4 moisture content of the Repie MSWI bottom ash

Parameter	Condition of test	
	BA from source	After air dry
Moisture content [%]	57	30.76

The moisture content of the Repie MSWI BA was 57% from the source which was more than 50 wt. % of the total weight of the fresh BA but after air for 35 days dried in air the moisture content decreased to 30.76wt %which shows that the sample decrease its moisture content with time. In order to get less moisture content for the concrete mix purpose the BA must have enough drying time to get the appropriate water to cement ratio.

4.1.2 Particle size distribution

This test was used primarily to determine the grading of the sample proposed for use as an aggregate or being used as an aggregate. The particle size distribution of the collected MSWI bottom ash from Repie waste to energy plant was tested by sieve analysis. The summery of result obtained from the test was presented in the Table 5. The evaluating and reviewing limits are ordinarily communicated as the rate of fabric passing each sifter. Table 5 Summery of particle size distribution

Sieve size [mm]	Weight retained[m]	% Retained	Cumulative coarser[%]	Cumulative passing[%]	*Standard passing range
9.50	0.00	0.00	0.00	100.00	100.00
4.75	52.77	10.55	10.55	89.45	95 to 100
2.36	82.60	16.52	27.08	79.92	80 to 100
1.18	86.30	17.26	44.34	55.66	50 to 85
0.60	81.60	16.32	60.66	39.34	25 to 60
0.03	70.90	14.18	74.84	25.16	5 to 30
0.15	75.90	15.18	90.02	9.98	0 to 10
Pan	49.90	9.96	100.00	0.00	

*Source ASTM designation C33-3

The particle size distribution of the Repie MSWI BA grading curve was shown in the Figure 1.

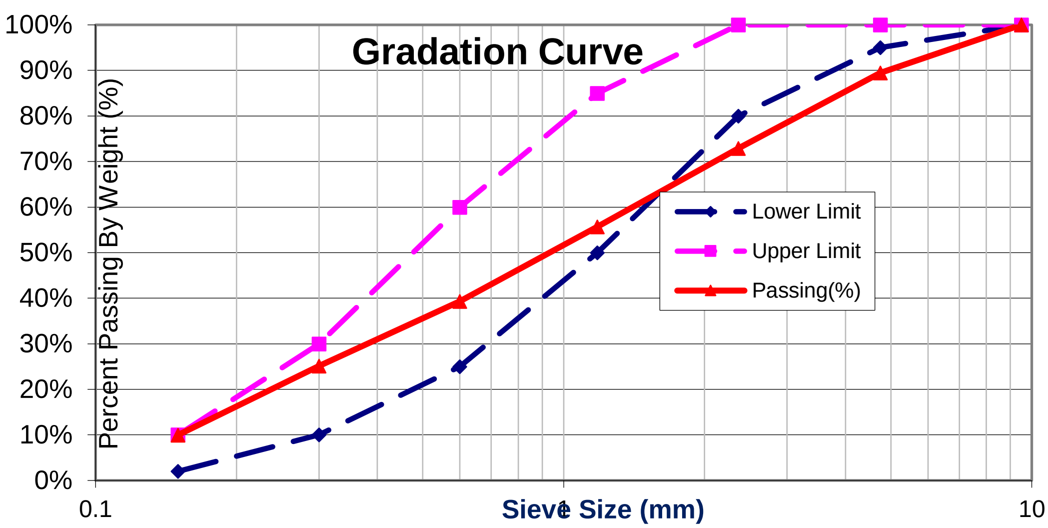

Figure 1 Grading curve of the bottom ash

The result indicated that most of the percent passing of the particle size were in the range of the standard specification of the limit (Table 4 and Figure 1). This indicated that the present result was in line to the standard specification where by the bottom ash have below 45% passing any sieve and retained on the next consecutive sieve which was the accepted range. The uniformity of concrete from group to lump can be influenced by a variety of methodological approaches. Extremely fine sands are typically uneconomical, whereas extremely coarse sands and coarse totals can produce a harsh, unworkable blend. In general, totals that don't have a significant absence or abundance of any parameter and provide a smooth evaluating curve will produce pleasant results [4].

4.1.3 Bulk density

The bulk density or unit weight of an aggregate is defined as mass of the aggregate per unit volume. It is often used to determine for selecting proportion for concrete mixture which was necessary for the construction work. The loose and compacted bulk density obtained from the test result is 0.909g/l and 1.07g/l respectively. From literature the loose bulk density of aggregates ranges from 0.940 to 1.013g/l and the compacted bulk density ranges from 1.65 g/l to 1.85 g/l [45] The experimental value of this study was in the acceptable limit for the loose bulk density whereas the compacted bulk density is relatively low due to increases the void spaces between the particles and there by reduces weight of material required to fill a unit volume.

4.1.4 Specific gravity and water absorption

The weight of a certain volume aggregate divided by the weight of an equal volume of water is known as specific gravity. It assesses the material's tensile strength or quality. Whereas the water absorption determines the water holding capacity of the aggregate. The present result of the test was presented in Table 6.

Table 6 Specific gravity and water absorption of BA

parameter	Test result	ASTM C127 recommended range
Specific gravity	2.69	1.2-2.8
Water absorption	3.16	1-3

The specific gravity of bottom ash is in the range of the specification recommended for natural sand as per ASTM C127. From the result the water absorption of the bottom ash is slightly higher than typical natural sand aggregate which indicates the porous nature of the material. The absorption properties of the material are substantially higher than natural sand which is typically 1- 3% (Neville, 1995).

4.1.5 Fineness of module (FM)

From Table 5, the fineness of modules was determined and recorded 3.99 value which was much more than the standard fine aggregate requirement. ASTM C33 requires the FM of fine aggregate to be between 2.3 and 3.1. This implies that Fineness of modules is a measure of a total's fineness; the more the FM, the rougher the total. It's possible that different total reviews have almost the same FM. Good whole FM is useful for determining the proportion of fine and coarse total in normal concrete mix [44].

4.2. Chemical Composition of the MSWI Bottom Ash

The chemical composition of the Repie municipal waste incineration bottom ash was determined by Atomic Absorption spectrometer (AAS) and the results of oxides were presented in Table 7.

Table 7 Chemical composition of Repie MSWI BA

Oxide composition	Test result of the Repie BA Mass%	**Natural sand
SiO_2	48.88	80.78
Al_2O_3	14.5	10.52
Fe_2O_3	8.60	1.75
CaO	15.20	3.21
MgO	2.18	1.37
Na2O	3.12	0.77
K2O	1.86	1.28
MnO	0.26	-
P2O5	2.39	-
TiO2	0.46	1.21
H2O	1.08	-
LOI	2.94	0.37

**source Mir, 2015

According to the test result obtained, the Repie MSWI bottom ash SiO_2, Al_2O_3, Fe_2O3 and CaO are the major oxide compounds. Whereas the rest oxides are in low concentration as shown in Table 7. The predominant compound in compound in the Repie MSWI BA was SiO_2 which reaches up to 48.88%. Whereas the natural sand used as fine aggregate in concrete mix has also SiO_2 (silica) as the major compound in it. The present result implies that the high content of silica make it inert.

A loss on ignition is another important aspect that determines whether MSWI bottom ash may be used (LOI). The current result revealed a 2.94 percent drop of ignition value. Furthermore, a study in Denmark discovered that LOI varies from less than 2% to 9% depending on the productivity of the burning prepare [36]

4.3 statistical analysis

The experiment data was analyzed by the design expert 7.0.0 software and quadratic model are suggested to best fit the response, comprehensive strength (CS).

4.3.1 Analysis Of Variance (ANOVA) For Compressive Strength

Based on the analysis of variance (ANOVA) as shown in Table 8 the model which correlate the study parameters with the response (compressive strength) were found significant with F-value of 74.32 ($p<0.0001$). In the table, the values of "Prob>F" less than 0.05 indicate model terms are significant, whereas values greater than 0.1000 indicate the model terms are not significant. Accordingly, the model terms A, B, C, AC, BC, A^2, B^2, and C^2 were found to be significant model terms

Table 8 Analysis of variance (ANOVA) for compressive strength

Source	Sum of sequence	DF	Mean square	F value	Prob>F	
Model	22.29	9	2.48	74.32	<0.0001	Significant
A	0.13	1	0.13	3.83	0.0913	
B	10.10	1	10.10	303.22	0.0001	
C	6.06	1	6.06	181.74	0.0001	
A	0.96	1	0.96	28.66	0.0011	
B	3.63	1	3.63	109.01	0.0001	
C	0.68	1	0.68	20.35	0.0028	
AB	0.29	1	0.29	8.59	0.0022	
AC	0.35	1	0.35	10.45	0.0144	
BC	0.19	1	0.19	5.81	0.0467	
Residual	0.23	7	0.033			
Lack of fit	0.14	3	0.047	2.08	0.2461	Not significant
Pure error	0.021	4	0.023			
Cor total	22.52	16				

4.3.2 The fit statistics for compressive strength

The fitness and similarity of the developed regression model to the experimental results were further analyzed by the coefficient of determination (R^2). Table 9 explains the regression coefficient of the quadratic model developed for the response

Table 9 Table of fit statistics for compressive strength

Std. Dev	0.48	R^2	0.9896
Mean	18.51	Adj. R^2	0.9763
C.V	0.99	Pred. R^2	0.8928
Press	2.41	Adeq. precision	31.930

An R^2 value 0.9896 was reported for the compressive strength (CS) model. This value means that the model can explain 98.96% of the variable in compressive strength and only 1.04% was a result of chance.

Furthermore, the "Pred R^2" value of 0.8928 is in reasonable agreement with the "Adj R^2 "of 0.9763. The "Ade- precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. In this case an adequate precision of 31.93 is obtained from the result which shows that noise is very low.

An empirical relationship between the response and the input test variables in actual units can be expressed by the following equation generated based on the coded factors and the actual factors respectively.

Final Equation in Terms of Coded Factors:

$$CS = +18.11+0.13 * A-1.12 * B +0.87 * C -0.48 * A^2 +0.93 * B^2 +0.40 * C^2 -0.2* A *B-0.29*A*C+0.22*B*C$$

Final Equation in Terms of Actual Factors:

$$CS =+18.91040+1.51981 * A -0.18626 * B +3.96790E-003* C -0.17283 * A^2 +2.32188E-003 * B^2 +2.56800E-003 * C^2 -8.05723E-003 * A * B -0.014217 *C*C +8.80000E-004 * B*C$$

4.3.3 Diagnostic plots

The adequacy of the models was further checked by constructing different diagnostic plots in order to find out whether the model equations would give sufficient approximations to the actual values. The model diagnostic test was performed using the predicted and actual values for the response.

i. Predicted vs Actual

The predicted vs. actual value shows the compressive strength response. fig 2 show that the normal % probability plot of residuals for the responses are normally distributed, as the data lie reasonably close to the straight line and show no deviation of the variance, which indicates that the model is well defined.

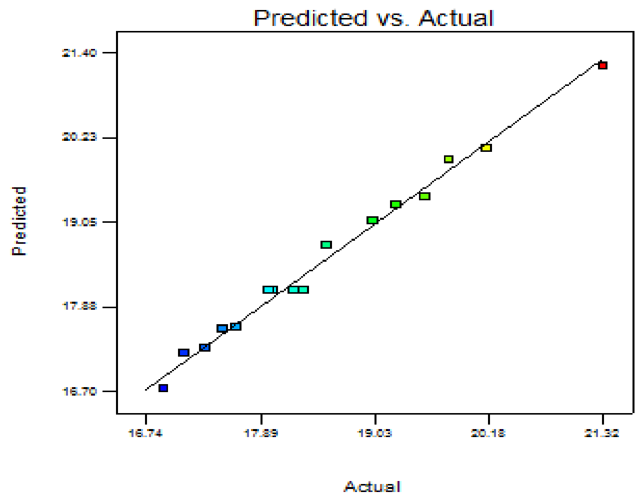

Figure 2 Plot of predicted vs actual response value compressive strength.

ii. Residual vs. predicted

The residual vs. predicted response as shown in Figure 3 revealed that data points were random scattered without obvious pattern and unusual structure which indicates that model proposed was adequate.

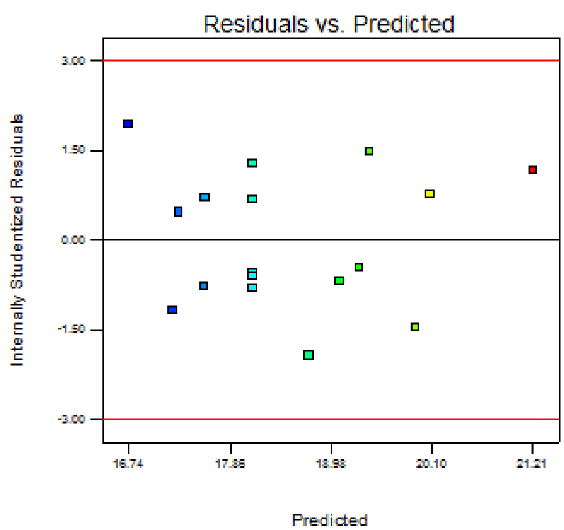

Figure 3 Plot of residual vs. predicted

iii. Residuals vs. Run

This is a plot of the residuals versus the experimental run order. It checks for lurking variables that may have influenced the response during the experiment. The plot as shown in Figure 4 are a random scatter which indicates model is well defined.

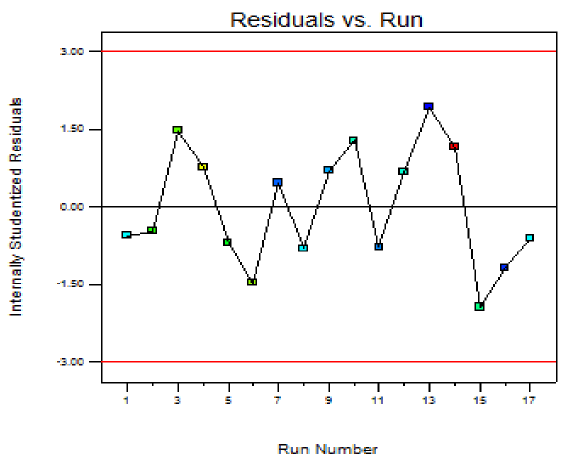

Figure 4 Plot of residual vs. run

4.4 Individual and interaction Effect of factors on the compressive strength

4.4.1 Effect of particle size and ratio on compressive strength.

The interaction of particle size and ratio on compressive strength was shown in Figure 5 as 3D diagram .The compressive strength increases as the particle size increases up to 2.84 mm and starts to decline. In the case of substitution ratio maximum compressive strength is produced around 10% and starts to decline after that between 40 % and 50 % slightly increase.

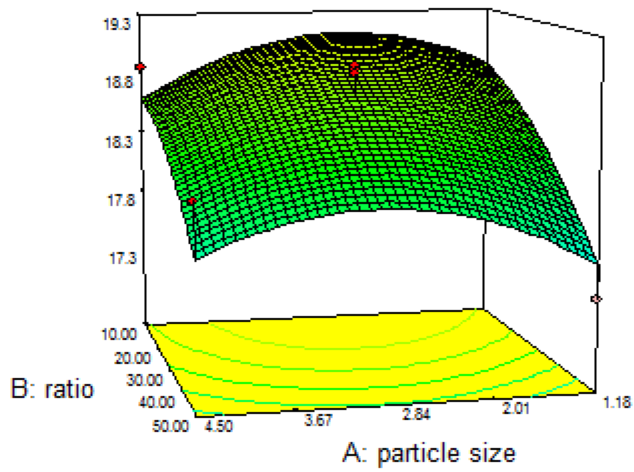

Figure 5 interaction effects of particle size and ratio on CS

4.5.2 Interaction effect of particle size and time on CS

The interaction effect of particle size and time was displayed in Figure 6 as 3D diagram. The result shows maximum CS was obtained around particle size 3.00 mm and the CS starts to decrease slightly as the particle size increases. Whereas the CS increases as the time increases.

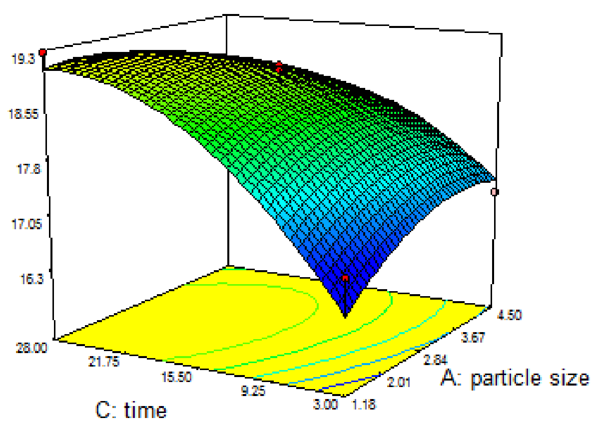

Figure 6 interaction effects of particle size and ratio on CS

4.5.3. Interaction effect of ratio and time on CS

The interaction effect of ratio and time was shown in Figure 7 as 3D diagram. The graph shows as the ratio increases CS decreases in the case of time compressive strength increases as the curing time increases.

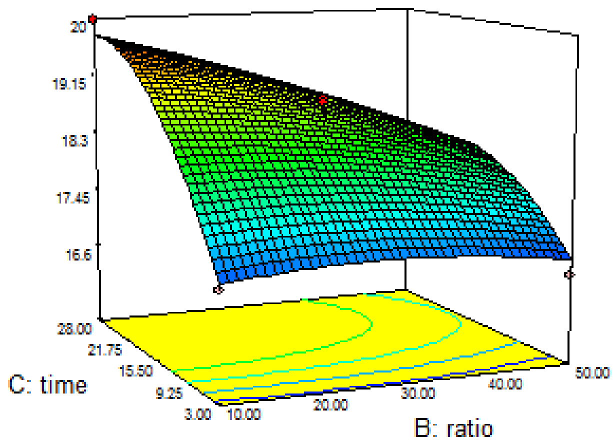

Figure 7 Interaction effect of ratio and time on CS

4.6 Optimization of the process variable

The optimum of factors and the response can be obtained using numerical and graphical optimization techniques by the Box-Benkhen Design**,** response surface methodology.in order to determine the optimum processing condition the factors were set to be in the range and the response, compressive strength were to be maximized. Based on the report Table below showed that the suitable optimum particle size, the ratio of bottom ash substitution and curing time with highest desirability were selected.

	Solutions					
Number	**particle size**	**ratio**	**time**	**compressive strength**	**Desirability**	
1	3.02mm	10.00%	28.00days	21.21MPA	0.977	Selected

The numerical optimization ramps graphically showed each optimal solutions for the process in Figure 8. the red points indicates the optimal factors setting.

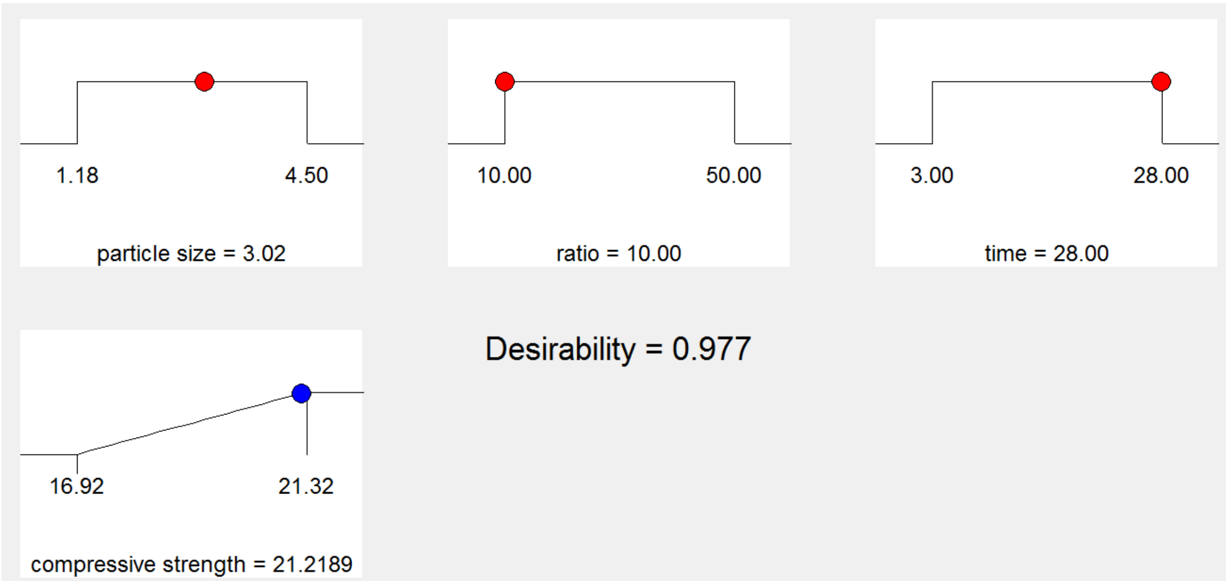

Figure 8 Numerical Optimization Ramps

4.7 Tests of the selected concrete

4.7.1 Compressive strength of the optimized concrete

Compressive strength was determined by ASTM C 109 procedures. The test was done on 10 x 10 x 10 cm^3 cubic specimens. The compressive strength test results of the selected specimen concrete cube were obtained from an average of nine cubic specimens and the control concrete cube determined at the curing age 28th days is presented in the Table 10.

Table 10 Average compressive strength of the optimized cubes

Specimen	28^{th} day compressive strength in, MPa
Control	24 .1
Selected specimen	21.88

The compressive strength of the control specimen were recorded as 24.1MPa but the average compressive strength of the selected specimen was 21.88 which is less than the controlled one by 9.21%. Strength of concrete is acceptable for most structural concrete applications since it is compressive strength more than 20 MPa at 28 days [Aggarwal 2007]. This result showed that that the Repie municipal solid waste incineration bottom ash has a potential replacement for aggregates, if proper pretreatment techniques or modification are use.

4.7.2 Leaching test of hardened concrete

The leaching test results were presented in Table 11 with USEPA concentration limit. The obtained results of leaching test in the selected concrete specimen's showed all these heavy metals leachability were below the allowable limit as given in US EPA standards. So that, the Repie MSWI bottom ash has possibility to use as a partial substitution of fine aggregates for concrete mix in safe environmental impact.

Table 11 Leaching test of heavy metal concentration of the optimized concrete.

Heavy metals	Results, mg/l	**USEPA concentration limit, mg/l
Copper(Cu)	0.008	100
Iron(Fe)	0.021	--
Zinc (Zn)	<0.001	500
Nickel(Ni)	<0.001	1.3
Cobalt(Co)	0.004	---
Manganese(Mn)	<0.0002	260
Chromium(Cr)	0.26	5
Cadmium(Cd)	<0.0001	1
Mercury(Hg)	0.063	0.2
Lead(Pb)	<0.005	5
Arsenic(As)	0.031	5
Boron(b)	0.051	--

**Source (Rem, 2014)

4.7.3 Water absorption and density of the selected concrete

Water absorption test of the selected specimen and the control concrete cube were determined and the result was presented in the table below12.

Table 12 Water absorption and density of the 28th days hardened concrete

Specimen	Dry wt. of concrete, in g	Wet wt. of concrete, in g	% of water absorption	Density Kg/m^3
Control	8345	8466	1.42	2389
Selected	8364	8506	1.66	2360

Although the water absorption a hardened concrete cannot be used as a measure of the quality of a good concrete the result obtained from the result was within the range. As shown from Table 12 the result obtained for concrete density of control and selected specimen were 2389 Kg/m^3 and 2360 Kg/m3 respectively. The density of the selected specimen decreased by 1.21%. As many researchers reported that when using MSWI bottom ash as a partial replacement of sand decreases the density of the concrete [46].

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CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research on the possibility of using MSWI bottom ash as a partial replacement of aggregates in concrete mixes obtained from the Repie waste to energy plant focuses on the optimization parameters like particle size, substitution ratio and curing time for the maximal compressive strength of the concrete made from it. In the first place the characteristics of the MSWI bottom ash obtained from the Repie waste to energy plant were investigated in details. The results from the experiment has shown that the bottom ash can be used by replacing the fine aggregate with 10% substitution ratio, with a 3.02 particle size and 28 days curing in the concrete mix to obtain maximum compressive strength of 21.21. Regarding the result of leachability of the heavy metals from the concrete made from the partial substitution of the Repie MSWI BA showed that all the heavy metals were under the threshold limit of the USEPA standard

Also from the experiment all the three parameters has significant effect on the compressive strength. Therefore it is possible to recycle the Repie municipal solid waste incineration bottom ash with minimum environmental consequences.

5.2 Recommendation

This research suggested that the Repie waste to energy plant should able to use the bottom ash for the partial replacement of the natural fine aggregates in the concrete mix in minimizing the waste obtained from the plant as well as the cost of natural fine aggregates. The Addis Ababa city administration should give special attention in recycling this material in the construction of concrete for different purposes. Especially the chemical composition of the Repie MSWI BA showed that it is rich in CaO which lets the material to be used as a raw material for production of cement.

Due to its potential amount of this materials the city administration can able to create job opportunities for the citizens in the preparation of this material for the replacement purpose.

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APPENDICES

Appendix I. Physical properties of the Repie MSWI BA

A. Moisture content of the BA

The moisture content of sample was determined by weighing 1g of sample into pre weighed crucible and drying it in an oven at a temperature of 105 °C for 24 hours till the constant weight dry matter was obtained. The percentage of moisture content computed by this formula**:**

% of moisture= $\frac{W1-W2}{W1-W3}$ x 100

i) Moisture content of the fresh Repie MSWI BA calculation

% of moisture= $\frac{W1-W2}{W1-W3}$ x 100

Where: W1= weight of sample and crucible before drying=31.06

W_2= weight of sample and crucible @105˚C for 24 hrs after drying= 30.45

W_3= weight of empty crucible=30.06

%of moisture= $\frac{31.06-30.49}{31.06-30.06}$ x100

= **57%**

ii) Moisture content of the air dried MSWI BA calculation

% of moisture= $\frac{W1-W2}{W1-W3}$ x 100

Where: W1= Mass of crucible plus sample=30.19

W2= Mass of crucible plus ash sample= 30.16

W3= Mass of empty crucible= 30.06

%of moisture= $\frac{30.19-30.16}{31.19-30.06}$ x100

=**23.08**

B. Bulk density

The bulk density of the dried in air sample is done by rodding method as per the ASTMC29/C29m-97.based on this one third of the measured sample was filled to the cylinder and the layer was rodded 25 times strokes of the tamping rod evenly distributed over the surface. Similarly two third of the measured sample was added to the cylinder and rodded again as above. Finally the sample was filled overflowed and rodded as above, then the level of top surface was fingered with straight edge.

Then:-

i. loose bulk density of the BA was calculated by using the formula

$$D= \frac{M1-M2}{M3-M2}$$

Where

D = loose bulk density of the BA

M1= Mass of the bottom ash plus the cylinder= 1283.2g

M2= mass of empty cylinder=908.1g

M3 = mass of the cylinder plus water of the cylinder=1320.7g

$$D= \frac{1283.2g-908.1g}{1320.7g-908.1g}$$

= <u>**0.909g/l**</u>

ii. Rodded (compact) bulk density can also be determined by the formula

$$D= \frac{M1-M2}{M3-M2}$$

Where

D_r= rodded (compact) bulk density

M1= mass of the cylinder + rodded BA sample=1348.4g

M2= mass of empty cylinder= 908.1g

M3 = mass of the cylinder plus water of the cylinder=1320.7g

D= $\frac{1283.2g-908.1g}{1320.7g-908.1g}$

=**1.067135g/l**

iii. Specific gravity and water absorption of the BA

The specific gravity apparent specific gravity and water absorption of the Repie MSWI BA were determined in school of chemical and bio engineering material lab as per ASTMC128-01 procedure as follow.

A 500g of air dried sample was measured dried in oven for 24hrs. After the sample was removed from the oven and cooled the sample was soaked in the water for 24 hrs. Then the water is drained from the sample and removed from the sample with clean cloth and recorded. The sample was placed in pycnometer and filled with water until it was full. The entrapped water was removed by rotating the pycnometer and recorded. Then the specific, apparent specific gravity and water absorption was calculated as follows

Specific gravity= $\frac{D}{(A-(B-C))}$

Apparent specific gravity= $\frac{D}{(D-(B-C))}$ and

Water absorption =$100\,\frac{(A-D)}{d}$

a) Specific gravity

Specific gravity= $\frac{D}{(A-(B-C))}$

Where: A= weight in g of saturated surface dry sample= 24.4529

B=weight in g of pycnometer, sample and filled with distilled water= 90.9275

C= Weight in g of pycnometer and filled with distilled water= 78.624

D= Weight in g of oven dried sample= 32.8g

Specific gravity= $\frac{32.8}{(24.4529-(90.9275-78.624))}$

= **2.69**

b) Apparent specific gravity= $\frac{D}{(D-(B-C))}$

Where

A= weight in g of SSD sample =24.4529

B=weight in gram of pycnometer, sample and filled with water= 90.9275

C= Weight in gram of pycnometer and filled with water= 78.624

D= Weight in gram of oven dried sample= 32.8g

Specific gravity= $\frac{32.8}{(32.8-(90.9275-78.624))}$

= **1.60**

c) Water absorption

Water absorption =100 $\frac{(A-D)}{d}$

A= weight in gram of SSD sample=532.8g

D= Weight in gram of oven dried sample= 500g

Water absorption =100 $\frac{(515.8-500)}{500}$

= **3.16%**

Appendix II. Physical properties of fine and coarse Aggregate

i) Physical properties of fine Aggregate

a. Moisture content of fine aggregate

A = Weight of Original sample = 500 g

B = Weight of dry sample @ 105 ºC for 24 hrs = 480 g

MC % = $\frac{A-B}{B}$ *100

= $\frac{500g-480g}{500g}$ *100

= **2.4%**

a. Specific gravity and absorption capacity of fine aggregate

Bulk specific gravity

Bulk sp.gr =$\frac{D}{(C-(A-C))}$

Where

A= weight in g of pycnometer sample and filled with distilled water= 1822.4g

B= Weight in g of pycnometer and filled with distilled water=1512.6g

C= Weight in g of saturated surface dry aggregate=500g

D= Weight in g of oven dried sample=495.4g

Bulk sp.gr = $\frac{D}{(C-(A-C))}$

= $\frac{495.4}{(500-(1822.4-1512.6))}$

= **2.6**

Apparent specific gravity= $\frac{D}{(D-(A-B))}$

$= \frac{495.4g}{(495.4g-(1822.4g-1512.6g))}$

=**2.67**

Water absorption =$\frac{C-D}{D} * 100$

$= \frac{500-495.4}{495.4} * 100$

= **0.93**

ii) Physical properties of coarse Aggregate

a. Moisture content of the coarse aggregate

The moisture content of the coarse aggregate was determined by using the formula

M=$\frac{A-B}{B}$*100

Where:

M= moisture content of the aggregate sample, in %

A= mass of original aggregate, in g=2000g

B= mass of oven dried sample, in g= 1969g

M=$\frac{A-B}{B}$*100

= $\frac{2000g-B1969}{1969}$*100

= 1.57%

b. Specific gravity and absorption capacity of coarse aggregate

The bulk specific gravity, apparent specific gravity and the water absorption of the the aggregate sample were determined by the following formulas

Bulk specific gravity = $\frac{D}{C-(A-B)}$

Apparent specific gravity= $\frac{D}{D-(A-B)}$

Water absorption = $\frac{C-D}{D}$* 100

Where:

A= weight of sample + vessel + water=3377.1g

B= weight of vessel + water= 2757.2g

C= weight of saturated surface dry sample= 1000g

D= weight of oven dried sample= 985g

Bulk sp.gr = $\frac{985g}{1000g-(3377.1g-2757.2g)}$

= **2.61**

Apparent sp.gr = $\frac{985g}{985g-(3377.1g-2757.2g)}$

= **2.71**

Water absorption= $\frac{1000g-985g}{985g}$* 100

= **1.52%**

Appendix III. Pictures taken during the research work

Figure 1. Determining the particle size distribution of the Repie MSWI bottom ash.

Fig.2 preparation of concrete cube samples

Fig. 3 measuring the compressive strength of the concrete cube samples using Automatic compressive strength measuring machine