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COLLEGE OF TECHNOLOGY AND BUILT ENVIRONMENT (CTBE)

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Effects of Hospital Waste Ash as a Partial Cement Replacement on the Properties of C-30 Concrete

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APPROVAL

This is to certify that the thesis prepared by Birtukan Dejene, entitled '**Effects of Hospital Waste Ash as a Partial Cement Replacement on the Properties of C-30 Concrete**' and submitted in partial fulfillment of the requirements for the Degree Master of Science in Civil Engineering (Specialization: Construction Technology and Management) complies with the regulation of the university and meets the accepted standards with respect to originality and quality.

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Declaration

I, the undersigned, declare that this thesis entitled: "Effects of Hospital Waste Ash as a Partial Cement Replacement on the Properties of C-30 Concrete" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of material used for this thesis have to be duly acknowledged.

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Effects of Hospital Waste Ash as a Partial Cement Replacement on the Properties of C- 30 Concrete

Abstract

In Ethiopia, rapid urbanization and new environmental regulations have led to rising construction costs and material shortages. As cement demand continues to grow, identifying sustainable alternatives has become essential. This study explores the utilization of hospital waste ash (HWA) as a cement partial replacement in the properties of C-30 concrete to reduce cost and improve mechanical properties.

The hospital waste ash was collected from Yekatit 12 Medical College Hospital. The aim of this research is to is to identify the optimum percentage of hospital waste ash (HWA) as a partial replacement for cement and to investigate its effect on the fresh and hardened properties of concrete. In addition, the research objectives to assess the cost-effectiveness of incorporating hospital waste ash as a sustainable alternative to conventional cement.. The properties of materials were identified to get information about the material for the next steps and these tests was conducted using ASTM standard. This hospital waste ash was replacing the cement at the percent of 0%, 5%, 10% and 15%. After identification of all properties of material design mix was prepared according to ACI method. Casting of concrete was made by using mechanical mixer and for compressive, flexural and split tensile strength test then cured for 3^{th}, 14^{th} and 28^{th} day for those percentage of replacement. In addition, mechanical property test permeability test performed for all percentage of replacement.

The setting time of concrete increases when hospital waste ash is added to the cement paste, a trend observed for both initial and final setting times across all replacement percentages. Similarly, workability decreases: the slump test showed lower slump values as the amount of hospital waste ash increased.

The experimental results revealed that replacing 5% of cement with hospital waste ash significantly increased compressive, tensile, and flexural strengths among all mixes. Overall, a 10% replacement level was identified as the optimum proportion, showing good performance compared to other samples. However, concrete strength significantly decreased at replacement of 15% Within.

In terms of durability, the 5% hospital waste ash mix showed low permeability, which means it is more resistant to water penetration, while the 15% mix showed high permeability. According to the results, a partial replacement of cement with hospital waste ash up to 10% improves the density and durability of concrete. On the other hand, there is an increase in higher replacement. porosity and decrease compactness. In addition to testing the mechanical properties, an analysis of the curing water was performed to check for heavy metals. The results showed that lead was present at 0.02 ml/g, while cadmium was not detected.

Key words: Partial replacement, hospital waste ash, heavy metals, incineration

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Lists of Abbreviations

AAiT- Addis Ababa Institute of Technology

ACI- American Concrete Institute

ASTM- American Society for Testing and Materials

BS- British Standard

CA- Coarse aggregate

C-S-H- Calcium Silicate Hydrate

FA- Fine Aggregate

HWA-Hospital Waste Ash

OPC- Ordinary Portland Cement

SCMs- Supplementary Cementitious Materials

HCFs- Health Care Facilities

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1 Introduction

1.1 General

The construction sector primary play's major role to environmental degradation, characterized by its heavy reduction of resources found in nature and produce a significant portion of global greenhouse gases emission. Cement is an essential ingredient in concrete, its most environmentally harmful of all construction materials. The manufacturing of cement is extremely energy-demanding process, and it generates close to 8% of the world's total carbon dioxide emissions [1–3]. To achieve sustainable low-carbon development it is important to focused on research and adopt supplementary cementitious materials (SCMs) as partial replacements for cement. Simultaneously, the safe handling of hospital waste, particularly the ash produced through high-temperature incineration, represents a major environmental and public health challenge. This incineration process generates considerable amounts of hospital waste ash (HWA), considered mainly as bottom ash or fly ash. Chemically, HWA contains oxides such as Al_2O_3, CaO, SiO_2, and Fe_2O_3, which are comparable to the primary compounds in ordinary Portland cement (OPC) [4]. Recent research indicates that these analogous chemical properties position hospital waste ash as a viable material used as supplementary for cement that uses in concrete manufacturing [5]

Among the different concrete grades that are used in the Ethiopian construction industry, C-30 concrete has a particular importance. C-30 concrete defines a medium-strength concrete, capable of bearing a characteristic compressive strength of 30 Mega Pascals (MPa) at the age of 28 days. It is one of the most common grades. In fact, it is the grade designated in the specification of all reinforced concrete structures throughout the country.[6]

It is well known that cement and aggregate are important components in concrete and highly demand within the construction industry. This continuous and increasing demand puts significant pressure on natural resource reserves. In response to rising environmental awareness, the conservation of resources and protection of ecosystems have become urgent priorities, driving interest in the use of substitute materials resulting from recycled or waste sources. Therefore, this research evaluates the feasibility of partial cement replacement with hospital waste ash in C-30 concrete production.

1.2 Statement of the problem

Ethiopia currently experiences a significant increase in the construction materials cost. This rise is also anticipated due to increased regulations regarding land use and environmental, which are related to the rapid urbanization that is causing these shortages. Finding alternative sources of cement that utilized in its place is crucial and can be very expedient for concrete production.

The Ethiopian construction sector is significantly challenged by increasing costs. Construction projects in Addis Ababa are incurring huge price increase in particular. This trend is recognized as a detriment to various facets of project performance and project results.[6-8]. Cement is expensive, making construction costly, but even worse is the rising carbon emissions from cement over time, which is a threat in the long run.

In recent year the construction sector has expanded considerably, resulting a sharp rise in the use of construction materials. The direct impacts of this problem are cement consumption, and cement. Plumbing is a crucial contribution towards almost all construction activities. Despite the economic difficulties, there is still an increase in the cement demand due to urbanization and infrastructure. Relying on one production source wouldn't be a sustainable long-term strategy. There could be supply shortages in the future without a sufficient linkage of demand to production[2].

Various alternative materials have been discovered by Addis Ababa University and several research entities, partly replacing cement in concrete. Regardless, hospital waste ash (HWA) might have potential use but has not been given much thought, especially as its environmental and logistical impact grows. In Ethiopia and similar developing countries, the final disposal and management system of hospital waste is often inadequate. Incineration generates large quantities of ash which are usually dumped in the open area or near the hospitals. This practice risks contaminating air, soil, and groundwater, potentially exposing nearby populations to hazardous substances like heavy metals and dioxins [10,11].

Based on these problems, this study will determine the extent to which hospital waste ash can be replaced for cement and the effect on strength and workability in order to produce normal strength concrete.

1.3 Objectives

1.3.1 General objective

The main objective of this study is to evaluate the effect of hospital waste ash as a partial cement replacement on the properties of C-30 concrete.

1.3.2 Specific objectives

- To examine the effects of hospital waste ash on the fresh properties of concrete, including workability and setting time
- To evaluate the influence of hospital waste ash on the mechanical properties of concrete, such as compressive, tensile, and flexural strengths.
- To determine the optimum percentage of hospital waste ash among the studied replacement levels that enhances the strength and durability of concrete

1.4 Research questions

The research attempts to answer the following questions

1. How does the partial replacement of cement with hospital waste ash affect the workability of concrete?
2. What is the influence of hospital waste ash on the mechanical properties of concrete, specifically compressive strength, split tensile strength, and flexural strength?
3. What is the optimum percentage of cement replacement with hospital waste ash that achieves desirable strength and performance without compromising concrete quality?

1.5 Significance of the study

Expectedly, this research is likely to play a significant role in understanding the use of hospital waste ash (HWA) as a partial substitute of cement in the properties of concrete after successful completion of the study. If strength testing and analysis are conducted in the study, it will prove HWA is feasible and effective for the production of non-structurally sound concrete.

Results are expected to generate important data on the physical and mechanical properties of concrete by utilizing hospital waste ash. This will be vital assistance to the local construction

industry, aiding the engineers and contractors to incorporate more affordable and sustainable methods in construction by establishing an optimal replacement percentage that maintains or enhances the required 30 MPa strength, this research will provide engineers with a technically validated alternative material.

Outcomes may lead to repurposing of incinerated hospital waste, thereby supporting improved waste management practices and pollution mitigation. The data produced will form a basis for subsequent research into the wider use of waste- derived materials in green construction. In this way, the study could validate HWA as a practical supplementary cementitious material, aligning with the dual aims of economic and environmental sustainability for Ethiopia's construction sector.

1.6 Scope of the study

This research is limited to studying the mechanical and selected durability properties of concrete where hospital waste ash (HWA) partially replaces cement. The laboratory testing is focused on C-30 grade concrete and assesses compressive, split tensile, flexural strength, and permeability.

The scope is limited to C-30 grade concrete due to time and resource limitations. However, further studies can extend the investigation to higher grades such as C-40 and above. Besides, the study not includes microstructural analysis, long-term durability tests like resistance to sulfate attack or carbonation, and an environmental effect assessment. The HWA used was obtained and processed from a single hospital; therefore, potential variations in ash composition from different healthcare facilities or incineration methods fall beyond this study boundary.

The study also limited to cadmium and lead to assess the leaching effects of concrete produced utilizing hospital waste ash based on their high risky for human and environment. Nevertheless, incinerator ash originating from hospitals is known to have a wider range of potentially toxic elements which include mercury (Hg), chromium (Cr), arsenic (As) among others so it is recommended for future researcher to conduct test on these heavy metals.

2. Literature review

2.1 Introduction

Numerous studies and journal publications have examined the replacement of different concrete making materials. The research regarding substitute construction materials is essentially decided. These would allow for greater economic integration and sustainable development, according their objectives. Presently, we are using a wide range of other supplementary cementitious materials and industrial by-products are being studied as potential replacements for conventional cement, aggregates and other components of concrete.

In keeping with the above, this literature review presents the studies focused on the replacement of cement by Hospital Waste Ash (HWA). The next section will discuss earlier investigations related to the characteristics, behavior and application potential of HWA in cement-based.

2.2 Concrete and concrete making materials

2.2.1 Cement

Cement is one of the most important building materials. Its production process, however, generate a lot of CO2, estimated at 5–8% of the total CO2 in the world.[12–14]. Such environmental footprint produces a demand for the development of alternative materials that can be used to partially replace cement in concrete production in order to reduce emission[15].

“The most popular type of concrete used worldwide is hydraulic-cement concrete. As defined by ASTM standards, hydraulic cement hardens through a chemical reaction with water, a process that can even occur underwater. It is manufactured by finely grinding Portland cement clinker primarily composed of hydraulic calcium silicates and typically blending it with small quantities of calcium sulfate to regulate its setting time. Additionally, supplementary cementitious substances such as fly ash, slag, silica fume, or calcined clay can be mixed with this cement”[16].

Ordinary Portland Cement is white powder or a finely ground grey composed of aluminates, calcium silicates and alumino ferrites. Its primary raw materials are: argillaceous (clayey), siliceous (silica-rich), calcareous (lime-based), and ferriferous (iron-bearing). These materials

undergo a combination of thermal treatment (pyrolysis) and mechanical processing to achieve a product with the precise chemical composition and targeted mechanical properties [17].

As shown in Table 2.1, Ordinary Portland Cement (OPC) consists primarily of four clinker compounds C_3S, C_2S, C_3A, and C_4AF along with gypsum and minor oxides. The elemental oxide composition of these compounds also provided in Table 2.2, which lists the main components as CaO, SiO_2, Al_2O_3, and Fe_2O_3.

No.	Compounds	Chemical Formula	Bogue formula	Amount by weight %)
1	Alite, or Tricalcium silicate	$Ca_3\ SiO_5$ $[3CaO \cdot SiO_2]$	C_3S	30-50
2	Belite, or Dicalcium silicate	$Ca_2\ SiO_4$ $[2CaO \cdot SiO_2]$	C_2S	20-45
3	Celite, or Tricalcium aluminate	$Ca_3\ Al_2O_6$ $[3CaO \cdot Al_2O_3]$	C_3A	8-12
4	Brownmillerite, or Tetra-calcium alumino ferrite	$Ca_4Al_2\ Fe\ 2O_{10}$ $[4CaO \cdot Al2O_3 \cdot Fe_2O_3]$	C_4AF	6-10
5	Gypsum, or Calcium sulphate dehydrated	$CaSO_4 \cdot 2H_2O$	-	4-8
6	Potassium oxide	K_2O	K	<2
7	Sodium oxide	Na_2O	N	<2

Table 2.1: Main components of OPC *[17]*

Table 2.2: Chemical composition of OPC *[17]*

No.	**Component**	**Amount (wt %)**
1	CaO	58-68
2	SiO_2	16-26
3	Al_2O_3	4-8
4	Fe_2O_3	2-5
5	MgO	1-4
6	SO_3	0.1-2.5

The performance of cement in concrete is significantly influenced by its physical properties . Key properties such as consistency and setting time are assessed to understand the paste's workability and initial hydration.

The amount of time that concrete may be processed and placed is determined by the cement's setting time, which is a basic physical characteristic. There are two components to this parameter: initial and final setting times. The final setting time is reached when the cement paste has fully hardened and acquired enough cohesiveness to withstand applied pressure, while the initial setting time is defined as the interval between the addition of water and the beginning of hardening[18,19].

Many variables affect the time that cement takes to set, such as proportion of water to cement, its chemical makeup, the amount of gypsum present, its particle size and the surrounding temperature [20]. Higher temperature and finer cement are often associated with accelerated hydration and shorter setting time. Additive inertness is crucial to prevent undesired effects in target compounds during the synthesis process. Similarly, deviations from ideal gypsum levels can influence overall setting characteristics by affecting tricalcium aluminate (C_3A) reactivity, leading to unintentional acceleration or retardation. [18,19].

As per ASTM C191, the setting periods of OPC have to be checked by the use of a Vicat apparatus and must have initial set of not less than 45 minutes and final set of not more than 375 minutes. Keeping the setting within this range is essential because it guarantees that the concrete hardens with the desired strength and durability while providing enough time for putting and working the concrete.

2.2.2 Water

Water cement ratio

The specifications for the performance of the concrete determine the choice of water-to-cement ratio. Ordinary construction (such as driveways and pavements) usually uses ratios of 0.6–0.7 to ensure workability, while high-strength structural applications usually use reduced ratios in the range of 0.35–0.45 to optimize compressive strength and long-term durability. In general, most concrete mixtures have a w/c ratio between 0.40 and 0.60.[19].

Table 2.3 explains the inverse relationship between concrete strength and the ratio of water-to-cement, a lower ratio yields higher 28-day compressive strength. For the same compressive strength, the water cement ratio decreases for air entrained concrete as compared with non-air entrained.

Table 2.3: Relationships between water-cement ratio and compressive strength of concrete*[19,20]*

Compressive strength at 28th day	**Water cement ratio, by mass**
	Non-air-entrained concrete
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69

2.3 Hospital waste ash

Solid waste is a natural byproduct of the diagnostic and treatment procedures at a healthcare facility. Formally known as "hospital waste," this waste stream is made up of all wasted biological and non-biological items that have no future use.

Ethiopia is the second largest population nation in Africa, following Nigeria. [21]. This quick population growth directly contributes to the growing need for healthcare and infrastructure development. [22] nation's cement consumption rises as a result of this growing need, which also increases the production amount of biomedical waste [23]. Using environmentally friendly construction methods for example, using certain hospital waste ash in place of cement is a promising way to simultaneously solve these issues, improving Ethiopia's environmental sustainability and advancing its growth [5]. Table 2.4 presents the composition of Ethiopia's healthcare infrastructure as of the end of 2018, information from the Federal Ministry of Health. The table categorizes healthcare facilities by type and operational phase listing those actively in service alongside those under construction.

Table 2.4: Health care institutions in Ethiopia as of 2018 [24]

Institution / Operational status	Service providing	Under construction
Hospital	338	218
Health centers	4063	68
Health posts	17154	438
Private hospitals	43	-
Private clinics	3867	-

Hospital waste is generally classified into three groups: medical, infectious, and domestic waste. Medical waste generated from diagnosis, treatment, or immunization of the patient. Infectious waste is a subset of medical waste contaminated by contact with infectious patients and poses a transmission risk. In practice, poor segregation often leads all medical waste or even the entire hospital waste stream when mixed to be treated as infectious. Domestic waste consists of non-hazardous, general refuse similar to household waste generated within the hospital [25].

2.3.1 Segregation, Collection, Transportation Storage of hospital waste

Segregation

A key component of effective healthcare management of waste is segregation. The amount of waste that requires sophisticated treatment is significantly decreased by the methodical separation of hazardous and non-hazardous waste. There are numerous crucial steps in the process: appropriate packing in approved containers, the application of labels and color-coding, unambiguous signs, and specified handling, transportation, and storage procedures [26].

Highly contagious waste must be immediately segregated at the time of creation and sterilized (for example, by autoclaving) before being disposed of. Examples of such waste include diagnostic laboratory samples and waste materials from isolated infectious patients. After being disinfected, the waste can be transported away from the clinical area in infectious healthcare waste containers that are already approved [27].

Collection

The frequency of collection should align with the trends in waste generation throughout time. Infectious waste, such as discarded dressings produced during morning medical rounds, should be collected in the middle of the morning to reduce the amount of time that potentially dangerous materials are held. conversely, after daily visiting hours are over, general and recyclable rubbish that accumulates from visitor items like newspapers and food packaging should be collected. [27].

The dedicated participation and coordination of the facility's whole workforce including maintenance, housekeeping, transportation, and all medical staff is important to the successful implementation of healthcare management of waste. To guarantee the effective and secure transfer of garbage from its point of origin to storage or treatment, waste collection and transportation procedures must be designed, with an emphasis on reducing occupational risk [26].

Transportation

The movement of waste from its point of generation to a central storage area within the facility called on-site transportation. Transporting hazardous and non-hazardous waste separately using dedicated system is strongly recommended. Typically, there are three distinct transport stream. General, non-hazardous waste should be collected in trolleys painted black and "General Waste" or "Non-Hazardous Waste" should be clearly labeled." Infectious waste, which may be carried with used sharps, must be kept separate from other hazardous categories and moved in yellow trolleys marked "Infectious Waste," adhering to the standard color code. Other hazardous wastes, such as chemical and pharmaceutical waste, require separate handling in appropriate, secure containers for direct transport to their designated central storage locations [27].

Storage

Infectious medical waste can be kept in a refrigerator between 3° and 8° C for seven days. Without refrigeration, storage times must be shortened based on the climate: in temperate areas, storage should not exceed 48 hours in the summer and 72 hours in the winter; in extreme

temperatures, storage should only last 48 hours in the cold season and 24 hours in the hot season [26].

Hospitals must utilize designated utility rooms typically used for cleaning equipment and soiled linen for the interim storage of hazardous waste generated in medical areas. This practice isolates the waste from patient zones, allowing for secure, consolidated collection before its transfer to a central storage facility. This stage is referred to as short-term or interim storage [26].

Treatment and disposal of heath care waste

Technologies for high-temperature processing (incineration)

Incineration is a thermal high-temperature oxidation method typically ranging from 200°C to over 1000°C To turn combustible, organic trash into non-combustible, inorganic residues. This method significantly reduces the original waste's volume and weight. The transformation occurs through high-heat chemical and physical reactions, including combustion, pyrolysis, and gasification, which break down the organic materials [24,26].

Loss of Ignition (LOI) means the mass reduction of a sample after heating in an air or oxygen atmosphere for a specified period and it is caused by heating materials to high temperatures during incineration. Several standardized LOI methods exist, each with specific heating temperatures and testing durations tailored to the material type and its field of application[28].

Encapsulation is a great method for disposing of healthcare waste. It is used in hospitals that have enough capabilities. The waste is placed in containers, which are then sealed after adding a solidifying or immobilizing agent. [26].

Cement-based stabilization/solidification (CST) refers to the treatment method where hazardous components are either physically enclosed in a solid cement matrix or chemically binds to form a stable insoluble material. The primary purpose of the method is to lower the leachability of contaminants and improve the physical treatment and structural properties of the waste treated.

Table 2.5 shows the chemical composition of hospital waste ash to differ significantly according to various studies indicating its inherent variability. Throughout the four references, we see

extensive value ranges for the key constituents. The reported SiO_2 content ranges from 14 wt% to 57.2 wt% and CaO between 19.34 wt% and 39 wt%

Table 2.5: chemical composition of hospital waste ash reviewed by different journals. [29].

No.	Component	Amount of chemical content (wt %)			
1	SiO_2	57.2	37.58–47	17-23	14
2	CaO	19.34	25–32.5	14–20	39
3	Al_2O_3	7.32	10.82–13.7	8–15	6
4	MgO	1.83	-	3	4
5	Fe_2O_3	1.18	-	1-3	3
6	NaO	6.5	4.39–12.24	8–16	13
References		[30]	[31]	[32]	[33]

2.3.3 Amount of biomedical waste ash generated in Ethiopia

The health care system in Addis Ababa, Ethiopia, comprising 48 hospitals, 88 health centres, and 847 clinics, generates a significant quantity of waste, about 31,223.2 kg per day. Da Nang's total amount of waste dropped was 10,806.265kg/day which is 39.04% higher than that of 2015 [34]. Unlike Addis Ababa, Da Nang has shown technological progress in 2024. Indeed, optimization of the waste collection route using the Dijkstra algorithm results in reducing the average length of the route by 9–42%. Certainly, this helps reduce the cost of operations significantly [35].

Ethiopia faces a significant challenge from biomedical waste. According to the 2018 annual report of the Ethiopian Public Health Institution, Ethiopia generates in excess of 93593 tons of medical waste every year. In the study most relevant to controlling this waste stream, Girma and Asteray (2022) researched the possibility of utilizing the ash from incinerated biomedical waste through assessment of its combined effects with bagasse ash on the fresh, mechanical, and microstructural properties of high-strength concrete. [5]. Assessment of healthcare institutions in Addis Ababa found that the generated waste is estimated as 14,700 kg/day or nearly equal to 5,360 metric per annum tones. About 50-60% of the content in this volume is hazardous waste

from hospitals and medical laboratories. Sustainable biomedical waste management solutions are urgently required in Ethiopia, based on the waste generation rates of hospitals, health centers and laboratories [36,37].

2.3.4 Application of hospital waste ash in construction

The incinerated ash of a hospital waste can be used for agricultural and construction purposes such as making concrete, cement and roads. According to research, adding some of this ash to concrete can increase its compressive strength. Yet to ensure efficient usage, it requires a pretreatment process to stabilize the ash, reduce its toxic property and improve reactivity [38].

2.4 Concrete mixing, casting and curing

A key methodological requirement that appears throughout the literature is to control the concrete mixing process as strict as possible. According to standard practices like ASTM C192/C192M [39] mixing should be carried out in a mechanical mixer or by hand. The sizes of batches should be made to give an approximate volume that is 10% more than the volume needed to mold specimens. This ensures a representative; homogenous sample is obtained for testing. However, a significant limitation is noted: as per ACI 211.1-91 hand-mixing is unsuitable for both air-entrained concrete, which requires mechanical action for proper air-void dispersion, and no-slump concrete, which is too stiff for effective manual homogenization. The use of improper mixing techniques for such mixtures can lead to non-uniform samples and mischaracterization of material properties, table 2.6 outlines the specified slump value ranges for various concrete construction applications according to the standard ACI 211.1-91. The recommended slump, measured in millimeters, varies based on the structural element.

Table 2.6: Recommended value for slump for various type construction as per ACI 211.1-91. [40].

No.	Types of construction	Slump value (mm)
1	Reinforced foundation walls and footings	20-80
2	Plain footing, substruction walls	20-80
3	Beams and reinforced walls	20-100
4	Building columns	20-100

5	Pavements and slab	20-80
6	Mass concrete	20-80

2.5 Hardened concrete test

Compressive strength

Table 2.7 presents the development of compressive strength in concrete over time, expressed as a percentage of its 28-day strength. The data illustrates a rapid initial gain, with concrete achieving approximately 16% of its ultimate strength after just one day and 40% after three days.

Table 2.7: Concrete compressive strength for different days

No.	Age	Strength Percent
1	1 day	16%
2	3 days	40%
3	7 days	65%
4	14 days	90%
5	28 days	99%

2.6 Related research using hospital waste ash to partially replace cement

Singh et al (2007) investigated the effects on the characteristics of both fresh and hardened concrete of partially replacing cement with biomedical waste ash. In their experimental work, they tested for percentages of replacement ranging from 0% to 15% in steps of 2.5%. The research showed that as the amount of ash increased, the workability and density of the concrete decreased. As regards hardened properties compressive strength analysis indicates that a replacement level of up to 10% would result in strength comparable to that of normal concrete [41].

Katare et al (2023) analyzed the concrete with cement partially replaced by biomedical waste ash 2.5%, 5%, 7.5%, 10%, 12.5% of replacement percentage. The optimal replacement was revealed at 7.5 % on tests of both fresh and hardened concrete Tests on both fresh and hardened concrete

revealed that a 7.5% replacement was optimal. When using this dosage, the compressive strength at 28 days in addition to split tensile and flexural strengths showed an increase of around 20% and 17%, and 14% respectively in comparison to control mix only. Consequently, the replacement percentage is recommended up to 7.5 % for better mechanical properties [42].

Sathvik et al. (2019) Research was conducted on replacing cement with biomedical waste ash at 5%, 10% and 15% effects. The test results show that workability and density decrease as the increase of ash content. The hardened properties indicate that the compressive and split tensile strengths of concrete with 5% and 10% replacement are comparable to the strength of a conventional concrete whereas the 15% replacement is a drop in strength. In light of these results, a 10% replacement percent is the ideal in their opinion [43].

Kumar U. et al. (2016) tested the effect of partial replacement of cement with biomedical waste ash by 2.5%, 5%, 7.5%, 10%, 12.5%, 15% respectively. After testing fresh concrete, a decrease in both the workability and density was recorded as the ash content increased. The compressive strength was evaluated on the 7th and 28th day. Results showed that the use of biomedical waste ash for concrete production was feasible and compressive strength results of all replacement percentages tested conformed with the requirements of normal concrete.[44].

Habeeb et al. (2019) the study examined concrete using biomedical waste ash to replace cement at 5% and 10%. After the characterization of materials fresh and hard concrete were tested. Results revealed that compressive strength at 5% and 10% replacement and split tensile strength at all replacement percents were greater than the conventional concrete. Only 5% replacement mixture had demonstrated high flexural strength as compared to the normal concrete [45].

Elinwa (2016) conducted material test on fresh and hardened concrete on combinations in which 10%, 20%, 30%, and 40% of the cement were replaced with hospital waste ash. Results indicated that, as replacement levels increased, so did the water absorption rate, with the ash exhibiting both retarding and pozzolanic characteristics. Regarding compressive strength, all the replacement ratios resulted in values that were lower than that of conventional concrete; with the 10% replacement mixture performing similarly [46].

A detailed review of six different investigations on the use of hospital waste ash (HWA) as a partial cement replacement in concrete, was performed by Krishna Priya and Devi in 2021.

Properties like Flexural strength, split tensile strength, and compressive strength are highlighted in their review. The comparative investigations showed that the inclusion of 3% to 5% HWA generally enhanced compressive strength compared to ordinary concrete. The findings reveal that with the addition of 5%, 10% and 15% percentages of ash, there was a noticeable improvement in the split tensile strength. Nevertheless, the mechanical strength decreased when the replacement level reached above the optimal. The most significant flexural benefit was achieved with 5% HWA replacement. After analyzing the overall results of the study, the researchers found that HWA substitution at 5% level is the optimum, since it achieves a functional strength for a sustainable concrete [47].

Memon et al. (2013) examined the potential of hospital waste ash (HWA) as a substitute for cement at various levels of 2%, 4%, 6% and 8%. They conducted the test for properties of concrete on fresh and hardened cases. The results revealed that as the percentage of HWA increased, the workability and water absorption of the concrete decreased along with its density. Tests conducted on the compressive strength at 3, 7 and 28 days were satisfactory for 2% replacement percent whereas 4%, 6%, and 8% replacement levels showed lower strengths than the control mix. Overall, the study concluded that using hospital waste ash as a partial cement replacement is suitable for producing low-cost concrete, provided that strength performance is not compromised [48].

Dambhare et al. (2024) investigated cement replacement with incinerated biomedical waste ash with a range of 0% to 22%. Morphology of the ash was examined using scanning electron microscopy. Specimens of concrete were cast, cured, and tested at 7, 14, 28, and 90 days. Their findings show that replacement percents up to 16% are viable, while exceeding 18% leads to a reduction in concrete strength [49].

Table 2.8: Summary of studies on the use of biomedical/hospital waste ash in concrete

Author (year)	Type of material	Cement replacement Ratio (%)	Effect on fresh properties	Effect on hardened properties (Compressive, split tensile, flexural)	Optimum replacement (%)	Remarks / key findings
Katare et al. (2023)	Biomedical Waste Ash	2.5, 5, 7.5, 10, 12.5	Fresh and hard concrete tested; workability decreased slightly with higher ash content	At 7.5%, compressive ↑ 20%, split tensile 17%, flexural 14% (after 28 days)	7.5	Up to 7.5% replacement is recommended for best overall strength.
Sathvik et al. (2019)	Biomedical Waste Ash	5, 10, 15	Workability and density decreased as ash increased	Compressive and tensile strengths improved at 5% & 10%; 15% caused strength reduction	10	10% replacement considered optimum; excessive ash lowers strength.
Habeeb et al. (2019)	Hospital Waste Ash	5, 10, 15	Fresh and hardened concrete tested	Compressive strength improved at 5% & 10%; split tensile improved at all levels; flexural best at 5%	5–10	Strength properties better than control up to 10%; flexural strongest at 5%.
Elinwa	Hospital	10, 20, 30, 40	Absorption increased;	Compressive strength below control but 10%	10	Has pozzolanic and retarding properties;

(2016)	Waste Ash		retardation effect observed	comparable		best performance at low levels.
Krishna Priya & Devi (2021)	Hospital Waste Ash	3, 5, 10, 15 (review of six studies)	—	Compressive best at 3–5%; split tensile best at 5–15%; flexural best at 5%	5	Review concluded 5% as optimum replacement for balanced performance.
Memon et al. (2013)	Hospital Waste Ash	2, 4, 6, 8	Workability, absorption, and density decreased	Compressive strength best at 2%; higher levels below control mix	2	Suitable for low-cost concrete; minor replacement beneficial.
Dambhare et al. (2024)	Incinerated Biomedical Waste Ash	0–22	—	Up to 16% replacement maintained good strength; >18% caused reduction; SEM showed favorable morphology	16	High potential as cement substitute up to 16%; excessive replacement weakens concrete.

2.7 Summary on literature

In summary, research indicates that the workability and density of fresh concrete are typically reduced when biomedical or hospital waste ash utilized as cement replacement material partially. The majority of research indicates that low replacement levels, usually between 5% and 10%, can produce compressive, tensile, and flexural strengths comparable to or greater than those of ordinary concrete. However, the effect on hardened strength varies with dosage. Although ideal dosages vary between studies (e.g., 7.5% or up to 16%), reflecting differences in ash properties or mix designs, strength usually decreases beyond 10–12.5% replacement. These results validate the material's potential as a sustainable cement replacement; nevertheless, more investigation is needed to develop standardized processing methods and consistent optimal replacement levels for various waste sources.

Although previous studies have demonstrated the potential of hospital waste ash as a supplementary cementitious material, the results remain inconsistent due to variations in ash composition, burning conditions, and replacement ratios. Different burning temperatures and conditions produce variable ash qualities, leading to inconsistent results, no studies have examined hospital waste ash from Ethiopian and its early stage leaching effects so, research is needed to evaluate the effects of locally generated hospital waste ash on the properties of concrete and to determine an appropriate replacement level for sustainable cement production.

3. Research methodology and materials

3.1 Introduction

This section demonstrates the ingredients, mixing ratios, and experimental methods used in the study. Every component material was quality checked to make sure it was suitable for making concrete. The experimental procedures, encompassing both material characterization and concrete preparation and testing, were conducted in the materials lab of the School of Civil and Environmental Engineering at the Addis Ababa Institute of Technology (AAiT).

3.2 Study design

This study conducted by combining qualitative data collecting with laboratory investigations. The experimental approach involved characterizing properties of materials and testing concrete, while qualitative approach was gathered through interviews and site visit at selected hospitals. Chemical analysis of the hospital waste ash was performed at the Geological Survey of Ethiopia. All other material tests, concrete preparation, and properties on concrete on fresh and hardened case were assessed in the materials lab of the Addis Ababa Institute of Technology (AAiT)

The experimental investigation followed for the study are listed in Figure 3.1. This study employed a matrix-based experimental design to assess influence of Hospital Waste Ash (HWA) as a cement substitute in concrete. Mechanical properties compressive, split tensile, and flexural strength were tested using replacement levels of 5%, 10%, and 15% by weight of cement. Additional assessments included water permeability of the concrete and heavy metal analysis of the curing water. In addition to the experimental work, qualitative data were gathered through interviews and site visits at four purposively selected hospitals to examine current waste management and disposal practices

Research design

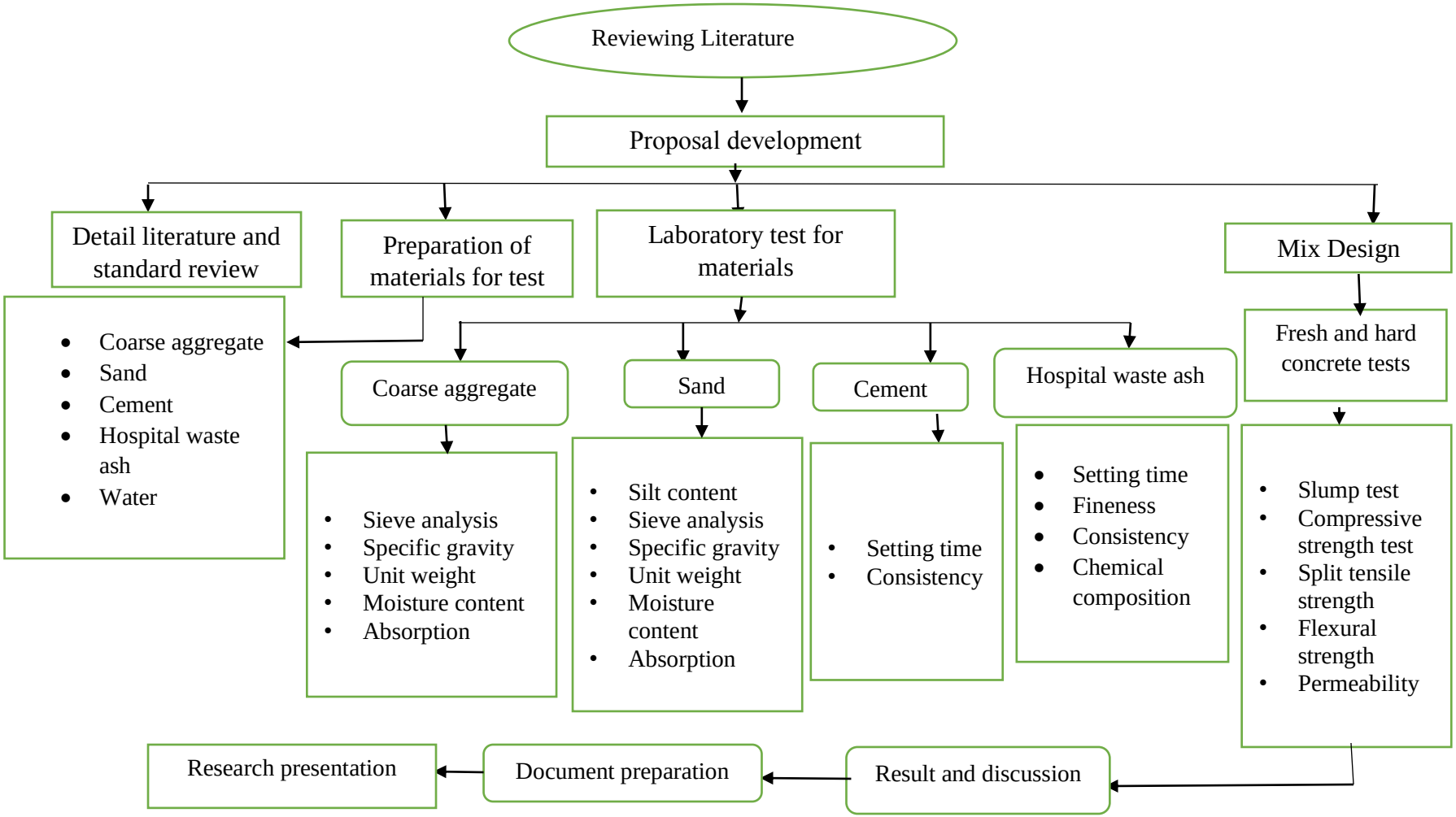


Figure 3.1 Research design chart

3.3 Materials

The concrete mixture was formulated specifically for this experimental investigation. Before being used, all of the component materials cement, water, Hospital Waste Ash (HWA), sand, and coarse aggregate were prepared and quality-tested in a lab.

3.3.1 Cement

The National Cement Factory supplied the cement used in this study, which was ordinary portland cement (OPC) with a strength grade of 42.5 N/mm². To prevent moisture, the cement was stored in a dry place to ensure consistent quality during the testing stage.

3.3.2 Fine aggregate/sand

The river sand used in this study is a naturally available local sand. The obtained material came from Metehara, Goro, and Addis Ababa, and it was screened using 4.75 mm. The laboratory experiment was carried out, and the material quality was evaluated based on the standards of ASTM C-128 and ASTM C-142 which assessed the properties such as silt content, moisture content, gradation, unit weight, specific gravity, and water absorption.

3.3.3 Coarse aggregate

The coarse aggregate used was purchased from Goro, which took place at a crusher in Koye Feche area. To achieve the nominal maximum size of 25 mm as per the specifications of ASTM C33, two different aggregates fractions were proportioned and blended. The designed process is to make a continuously graded aggregate that helps in giving suitable workability to concrete. The resulting particle size distribution was confirmed to comply with the standard limits, validating its suitability for concrete production.

3.3.4 Hospital waste ash

The incinerator at Yekatit 12 Hospital in Addis Ababa generated the hospital waste ash (HWA) used in this study. Samples were collected specifically from the final combustion chamber, where more complete combustion typically yields a finer and more uniform ash. In order to obtain a representative and sufficient quantity of material for the full experimental programme, the collection of ash was made with systematic sampling for two months. Every morning the ash

was collected which accumulated from the previous night's incineration activities then it was cooled to ambient temperature, and placed into clean, sealed storage bin (madaberia) before transport to the AAiT Materials Laboratory. After being oven-dried to remove any remaining moisture, a 75 µm sieve size screen was used to sieved it, to get a fineness suitable for replacing cement. The ash was not subjected to any further crushing or chemical processing. The hospital waste ash which is sieved using 75µm sieve size shown below in figure 3.2.



Figure 3.2 Hospital waste ash

3.3.5 Water

In this research, potable tap water was used for mixing and curing of concrete and sourced from the Addis Ababa University (AAU) campus network. Significant logistical convenience was provided by its nearness to the materials laboratory. More significantly, this water source is thought to be free of dangerous contaminants that could negatively impact cement hydration, strength development, or the concrete's long-term durability because it complies with regional regulations for human consumption.

3.4 Tests on constituent materials

3.4.1 Testes for cement

I. consistency: The standard consistency of the cementitious paste was determined following ASTM C187. Tests were performed on mixes in which Hospital Waste Ash (HWA) replaced for cement at weight percentages of 0%, 5%, 10%, and 15% using a Vicat apparatus. Water was gradually added to 500 g of total binder (cement + HWA) for each blend until the Vicat plunger reached a penetration depth of 10 ± 1 mm, which established the normal consistency.

.**II. Setting time:** The initial and final setting times of the cement paste were measured following ASTM C191 –The Vicat needle is used in the standard test procedure for hydraulic cement setting time. The Vicat apparatus was used in this test to evaluate the impact of partially substituting hospital waste ash (HWA) for cement on the paste's setting behavior [50]. Cement was substituted at weight percentages of 0%, 5%, 10%, and 15% for assessment of the impact of HWA on setting time. For every replacement level, a paste was prepared at its particular standard consistency and water content. A paste was mixed for each replacement level at its specific standard consistency water content. The paste was then located in a Vicat apparatus, and the setting time was conducted under standard laboratory conditions according to the penetration criteria of the Vicat needle.

3.4.2 Hospital waste ash

I. Physical properties of hospital waste ash

In table 3.1 shown the ash physical properties was demonstrated these physical properties include, shape, texture, size, and finesse of the particles. And most of the properties of hospital waste ash can be inspected using naked eyes. And figure 3.3 shows how size of particle of hospital waste ash is identified by sieving it using 75 µm sieve size.

Table 3.1 Physical properties of hospital waste ash

No.	Properties	Appearance
1	Color	Grey
2	Appearance	Fine
3	Shape	Irregular

4	Maximum Particle size after sieving	75µm



Figure 3.3 Sieving hospital waste ash

II. Chemical properties of hospital waste ash

Ability of materials to change into different substances through chemical reactions are referred to as its chemical properties. These properties are determined by the atomic structure and bonding of the material and define how it interacts with other substances, which is an essential component of its chemical identity. Table 3.2 shows the result obtained from the testing of chemical composition of the ash. To figure out the hospital waste ash chemical composition, an X-ray Fluorescence (XRF) analysis was conducted. This test was performed at the Geochemistry Laboratory of the Geological Institute under the Federal Democratic Republic of Ethiopia's Ministry of Mines. The resulting elemental data were then used to assess the ash's suitability as a partial cement replacement in concrete.

Table 3.2 Chemical properties of hospital waste ash

No.	Compound	Amount in %	ASTM C150Standard in %
1	Lime (CaO)	38.84	58-68
2	Silica (SiO_2)	8.1	16-26
3	Alumina (Al_2O_3)	4.84	4-8

4	Iron Oxide (Fe_2O_3)	1.26	2-5
5	Magnesia (MgO)	6.7	1-4

3.4.3 Test for fine aggregate

Evaluation on the physical properties of the sand were passes through a series of standard tests, including silt content, gradation, fineness modulus, specific gravity, moisture content, unit weight and absorption capacity, each conducted according to the procedures detailed in their respective sub-sections.

I. Silt content

The sand was naturally sourced and for this study it was purchased from Goro, and originated from often Matahara. To ensure concrete quality, the sand was washed prior to use to eliminate impurities like silt, clay, and organic materials. The resulting silt content, tested according to ASTM C117, is presented in Table 3.3.

Table 3.3 silt content of sand

No.	**Volume of Pure sand (ml)**	**Volume of silt (ml)**	**Silt content in %**
1	293	7	2.3

II. Sieve analysis

Using standard ASTM C136 a 500gm sieved sand sample was taken using a graded series of sieves from 9.5 mm down to 150 µm. The resulting fineness modulus was calculated as 2.94 (see Appendix A). The mechanical sieving procedure is depicted in Figure 3.4.



Figure 3.4 Sieve analysis of fine aggregate

Table 3.4: Gradation of fine aggregate

Sieve size (mm)	Actual result (%)	ASTM Upper boundary (%)	ASTM Lower Boundary (%)
9.5	100	100	100
4.75	99.42	100	95
2.36	91.5	100	85
1.18	78.88	85	50
0.6	25.82	60	25
0.3	5.06	30	5
0.15	0.08	10	0

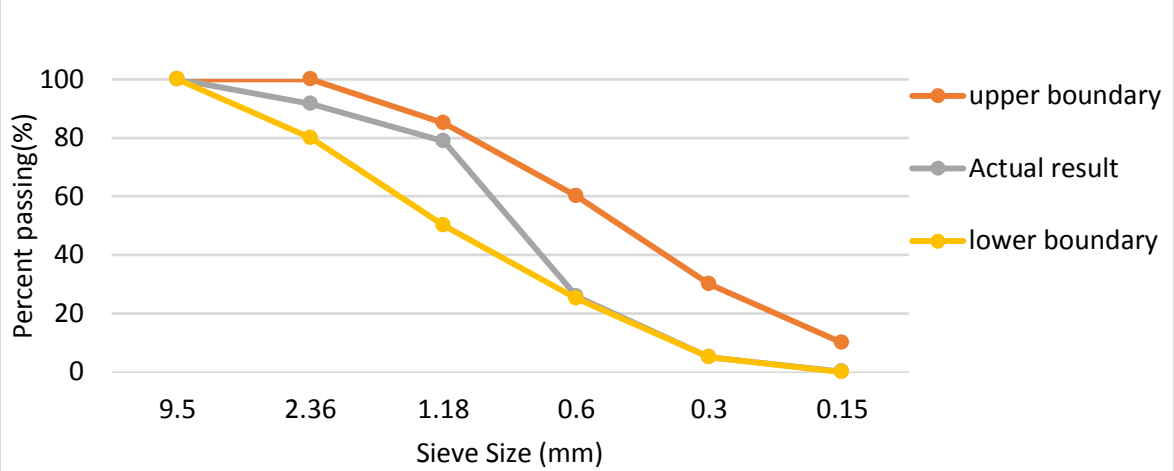


Figure 3.5 Graphical presentation of gradation of Fine aggregate

III. Specific gravity, absorption and moisture content

Table 3.5 presents the results of the specific gravity, water absorption, and moisture content tests conducted on the fine aggregate. These tests were carried out in compliance with accepted laboratory practices to determine the physical characteristics of the sand used in the concrete mixture. The results obtained from the laboratory analysis provide essential information for quality assessment and suitability of the sand for concrete production.

Table 3.5 Specific gravity, absorption and moisture content test result of fine aggregate

Bulk Specific gravity	Absorption	Moisture content
2.44	1.8 %	1.2%



Figure 3.6 Specific gravity of fine aggregate

IV. Unit weight of fine aggregate

According to ASTM C29 procedure fine aggregate bulk density was determined, as illustrated in Figure 3.7. The figure represents the standard laboratory balance and the specific metal measure (typically a cylindrical container of known volume) used for this test. This setup was important for obtaining an accurate unit weight, a critical parameter for concrete mix proportioning.



Figure 3.7 Balance for measuring unit weight of sand

3.4.3 Test for coarse aggregate

I. Sieve analysis

Table 3.6 presents gradation of coarse aggregate results, conducted according to standard of ASTM C 33. This standard was used in order to investigate the gradation of coarse aggregate and the fineness modulus of the aggregate calculated as 2.96.

Table 3.6 Gradation of coarse aggregate

Sieve size	Actual result	Upper limit	Lower limit
37.5	100	100	100
25	98.574	100	95
19	71.838	-	-
12.5	28.436	60	25
9.5	4.354	-	-
4.75	0	10	0

II. Specific gravity, absorption and moisture content

Table 3.5 demonstrated the coarse aggregate's specific gravity and water absorption conducted as per ASTM C127 and moisture content of ASTM C566 using this standard method the following test result are recorded.

Table 3.7 Specific gravity, Absorption and moisture content of coarse aggregate

Bulk Specific gravity	Bulk specific gravity (SSD)	Apparent Specific gravity	Absorption	Moisture content
2.79	2.85	2.96	2.07 %	0.99%

III. Unit weight

According to ASTM C29/C29M, method for bulk density test standard ("Unit Weight") and Voids in Aggregate the bulk density (unit weight) of the coarse aggregate was measured. This test used to assess the aggregate's packing and compactness, which influence the workability, strength, and overall economy of concrete mixtures. A clean, dry cylindrical container with a known volume was used for the procedure. Oven-dried coarse aggregate was placed using a container in three equal layers, with 25 tamping rod strokes used to each layer to achieve uniform packing and minimize voids. After the container was filled, the surface was prepared and, the aggregate and container's combined mass was noted. The calculation for bulk density was carried out by dividing the mass of the aggregate by the container volume. The test result showed that the unit weight of the coarse aggregate was 1668.53 kg/m^3

3.5 Physical properties of concrete ingredients

ASTM standards were used for the characterization of physical properties of the constituent materials cement, fine aggregate, and coarse aggregate, then batching followed. It is needed to predict the behavior of the material (during mixing, placement and curing) and design accurate mix proportion. The aggregate fineness modulus, moisture content, water absorption, specific gravity and bulk density were tested and slump test was performed on fresh concrete to measure the workability of the concrete. Table 3.8 summarizes the concrete ingredients physical

properties, including specific gravity, water absorption, moisture content, bulk density, and fineness modulus for the aggregates and cement, as well as the measured slump of the fresh concrete mix.

Table 3.8: Physical properties of concrete ingredients

No.	Types of material tests	Result
1	Cement specific gravity	3.15
2	Fine aggregate specific gravity	2.44
3	Coarse aggregate specific gravity	2.96
4	Slump	50mm
5	Fine aggregate fineness modulus	2.94
6	Fine aggregate water absorption	1.8%
7	Water absorption of coarse aggregate	2.07%
8	Fine aggregate moisture content	1.2%
9	Coarse aggregate moisture content	0.99%
10	Bulk density of fine aggregate	1502.12 kg/m^3
11	Bulk density of coarse aggregate	1668.53 kg/m^3

3.6 Mix design and mix proportioning

C-30 concrete mix was design using the American concrete institute (ACI) method in accordance to ACI 211.1-91-" standard practice for choosing proportion for mass, heavyweight and normal concrete". This method is a systematic and most acknowledged practice which assist in identification of a appropriate proportions of concrete making materials (cement, water, fine aggregate and coarse aggregate) to achieve the strength, workability, durability of concrete.

The concrete mix design was developed methodically, starting with the determination of the strength of target mean. This was calculated using the C-30 concrete specified properties of compressive strength, which is 30 MPa at 28 days. An appropriate water-cement (w/c) ratio was selected afterwards to fulfil the strength requirements as well as the necessary durability specifications. Subsequently, the necessary water content and expected air content were calculated based on the target slump (workability) and nominal maximum size of the coarse aggregate. With the establishment of the above parameters, the lastly step involved finding out the mass proportion of concrete ingredients to produce one cubic meter of concrete. Appendix B contains the detailed calculations and final mix proportions.

Table 3.9: Samples mix code

No.	Material	Description	Code
1	0% Hospital waste ash	Without addition of hospital waste ash	Co
2	5% Hospital waste ash	5% Cement replacement by Hospital waste ash	M-5
3	10% Hospital waste ash	10% Cement replacement by hospital waste ash	M-10
4	15% Hospital waste ash	15% Cement replacement by hospital waste ash	M-15

3.6.1 Mix proportion

Concrete mix proportioning is to select the constituent materials as well as their quantities to achieve specified characteristics such as strength, durability, workability, etc. The mix design developed using ACI method for C-30 grade concrete, whose proportions were adjusted on replacing a partial weight of cement with a Hospital Waste Ash (HWA) at 0%, 5%, 10%, and 15% by weight. The quantities of total materials required to manufacture 1m3 of concrete are given in Table 3.10.

Table 3.10 Mix proportion for 1m3 concrete production

No.	Code	Cement (kg/m^3)	Hospital waste ash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
1	Co	360	0	993.74	1102	197.67
2	M-5	342	18	993.74	1102	197.67
3	M-10	324	36	993.74	1102	197.67
4	M-15	306	54	993.74	1102	197.67

3.6 Concrete casting

3.6.1 Steps on casting concrete

The process of concrete casting requires crucial steps. Initially, the molds were oiled on the inner surfaces for easy demolding. The coarse aggregate, sand and finally cement were loaded into

mixer in sequence and mixed without any water. After that, the measured water was added, mixing continued for about one minute.

The freshly mixed concrete was placed in position to the prepared forms and was compacted to remove entrapped air. Compaction was done using a table vibrator by applying the load for a period of two minutes at the frequency of 12,000 to 14,000 vib/min. The uniform method ensured the samples remained consistent and dense throughout the samples. Figure 3.8 gives the overall process from batching to final compaction.



Figure 3.8 Casting of concrete

3.7 Curing of concrete

The cast concrete was cured by continuously soaking the specimen in water to maintain hydration. As shown in Figure 3.9, the specimens were removed from the moulds 24 hours after casting and placed in open plastic containers with water. The process of full immersion curing was carried out for a period of 28 days so that cement hydrates completely and achieves design strength. The curing under ambient laboratory conditions in Addis Ababa between April 24 and end of May 2025 showed a range of 14°C to 28°C. averaging around 20°C daily. The minimum temperatures were typically recorded in the early morning hours (13–15 °C), while the maximum daytime temperatures reached up to 28 °C.



Figure 3.9 Curing of concrete

3.8 Test on fresh concrete

3.8.1 Slump test

To assess workability a slump test was conducted at the time of mixing for every concrete mix proportion. The test was carried out using apparatus: a slump cone, a non-absorbent base plate, a tamping rod, and a tape measure for measurement. Figure 3.11 shows measuring of the slump of the prepared mix.



Figure 3.10 Slump test

3.9 Test on hardened concrete

3.9.1 Compressive strength

Compressive strength refers to the maximum compressive stress a concrete specimen can sustain prior to failure. The specimen in total 36 cube (150 mm × 150 mm × 150 mm) were prepared and tested at 3, 14, and 28 days. A Universal Testing Machine (UTM) was used to conduct the test in compliance with ASTM C39/C39M, applying a continuous, at uniform rate of load 0.28 MPa/s until failure. The prepared cube sample and the testing machine are shown in Figure 3. 11.

To determine an average compressive strength at each designated curing age three cube specimens (n=3) at every mix with 0%, 5%, 10%, and 15% of cement replaced by hospital waste ash were tested. The failure load was recorded and used to calculate the compressive strength for each mixture.



Figure 3.11 Compressive strength testing machine

3.9.2 Split tensile test

The split tensile strength of concrete was assessed using an indirect testing method as per ASTM C496, where diametrically opposing loads are applied to a cylindrical specimen until failure. This test provides a measure of the concrete's tensile resistance, which typically falls between its direct tensile and flexural strength values. For this study, 24 cylindrical specimens with diameter of 200 mm height × 100 mm, were used and for each mix proportion, three specimens (n = 3)

were prepared and tested at 14 and 28 days. The same Universal Testing Machine (UTM) used for compressive testing was employed, with appropriate adjustments to the loading configuration. The test setup is illustrated in Figure 3.12.



Figure 3.12: Split tensile strength test

3.9.3 Flexural strength test

Using ASTM C78 (third-point loading) and ASTM C293 (center-point loading) the modulus of rupture, which is a measure of flexural strength was tests. In the figure 3.13 the flexural strength was made using different metal which is prepared for flexural strength purpose and applying load to it. Prismatic beam specimens of 500 × 100 × 100 mm were used to determine the concrete's flexural strength. ASTM standard test was used to conduct flexural testing of concrete. For each mix proportion, specimens of three (n = 3) were prepared and tested at curing ages of 14 and 28

days to evaluate the development of flexural strength over time. The specimens were subjected to a third-point loading configuration until failure, and the maximum load was recorded to calculate the flexural strength. Reporting the number of specimens tested per batch (n = 3) ensures statistical reliability and allows the assessment of variability in the flexural performance of the concrete mixtures, including those incorporating hospital waste ash as a partial cement replacement.



Figure 3.13: Flexural strength test

3.10 Permeability of concrete

As per BS EN 12390-8 standard the water permeability of the hardened concrete was evaluated, which measures the depth of water penetration under pressure. In this test, water is applied under pressure to the surface of a concrete specimen. After removing the specimen from applied water pressure, the sample is split, and the maximum depth of the water front is measured[51]. Concrete's durability is significantly influenced by its permeability the ease with which liquids or gases can penetrate it. Lower permeability enhances resistance to deterioration, a property largely governed by the water-cement ratio and curing conditions. In this study, water permeability was evaluated for mixes containing 0%, 5%, 10%, and 15% cement replacement by hospital waste ash. Twelve samples in total were prepared and examined following a 28-day curing period.

The method utilized to measure water permeability of concrete specimens was the water penetration under pressure apparatus (depth of penetration method). The test was selected mainly

because of the availability of the apparatus in the Addis Ababa Institute of Technology (AAiT) Materials Laboratory.

The effective water penetration under pressure approach was part of this study owing to examining and practicality of the laboratory, though it is recommended for future researchers to use complementary permeability assessment methods where facilities allow. The equipment may include Sorptivity test apparatus, DIN water permeability apparatus, initial surface absorption test (ISAT) apparatus (measurement of capillary absorption). Employing various testing methods could give an improved assessment of permeation and durability properties of concrete using hospital waste ash.

3.11 Interview and site visiting in different hospital

A public hospital in Addis Ababa was purposefully chosen for this research. Given their role as major healthcare providers, public hospitals generally serve a significantly larger patient base than private institutions or small clinics. This higher volume of patients results in greater medical activity and, by extension, a larger and more consistent stream of hospital waste. This selection criterion ensures sufficient sample availability for comprehensive analysis and establishes a representative foundation for studying the waste's properties and its viability as a resource for construction materials.

To assess the incineration practice interview and site visit were conducted on purposively selected hospitals. The selected hospitals were Yekatit 12 hospital, St. Peter hospital, Zewditu memorial hospital, and black lion hospital. A set of structured questions was prepared for this purpose. In alignment with hospital waste management systems, the waste segregation, storage, and disposal practices of these hospitals were systematically evaluated through field observations and interviews with professionals responsible for waste management operations. The structured interview questions used in this assessment are presented in Appendix Table D1.1 of the research.

3.12 Estimation of material costs for concrete mixes

One cubic meter (1 m^3) of concrete's production cost, was estimated for each mix proportion using the material quantities and their current market prices. The unit costs for cement, fine

aggregate, and coarse aggregate were sourced from the local Addis Ababa market in 2025. For this analysis, Hospital Waste Ash (HWA) obtained as a by-product from hospital waste incineration was considered as zero cost.

$$\text{Material Price (Birr)} = \text{Quantity (Kg/m}^3\text{)} * \text{Unit Price (Birr/Kg)}$$

The material cost for one cubic meter of concrete was calculated to evaluate the economic viability of each mix design. This estimation used the exact proportions from the mix design combined with current 2025 Addis Ababa market rates for standard materials. Cement was priced at 17 ETB/kg, fine aggregate at 1.76 ETB/kg, and coarse aggregate at 1.75 ETB/kg.

Even though ash is a waste material and has no raw material cost, the collecting, transporting and preparing of it has a cost. These costs were established through a cost breakdown and incorporated into the production cost per cubic meter for accuracy.

For the purpose of costing, bulk density of 800 kg/m³ was assumed for hospital waste ash. This value was chosen based on published data for similar materials: fly ash from waste incineration has a bulk density reported between 540-860 kg/m³ for coal-derived fly ash,[52] while effective densities for the incinerator fly ash particles in the size range relevant to blending cement are reported around 700-800 kg/m³[53]. for this research 800kg/m^3 is taken as density of hospital waste ash.

3.13 Determination of heavy metal in wastewater

The water for curing of concrete was used to analyzed for heavy metal content in order to evaluate the risk of leaching contamination. A one-liter sample was collected from the curing tank containing specimens made with Hospital Waste Ash (HWA) at different replacement percents. The analysis was conducted at the JIJE Analytical Testing Service Laboratory. As the sample was categorized as wastewater, it underwent microwave-assisted acid digestion in a closed-vessel system to fully dissolve metallic elements. The digested sample was then analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP–OES) to quantify the concentrations of cadmium (Cd) and lead (Pb). The heavy metals were selected on the basis of their status as European Water Framework Directive priority pollutants, signifying that such substances represent a serious risk to human health and the aquatic environment.

4.Results and discussion

4.1 Introduction

This chapter presents and discusses the experimental results concerning the physical and mechanical properties of concrete in which hospital waste ash (HWA) used as partial cement replacement. The findings obtained from laboratory tests on fresh and hardened concrete, are systematically analyzed and interpreted. Key results are demonstrated by graphical representations that assist with an understand of the trends and relationships.

4.2 Consistency of cement paste

The consistency of the pastes with different percentage replacements by waste hospital ash were shown in figure 4.1 below. The pastes with 0%, 5%, 10%, and 15% replacement of cement by hospital waste ash had consistency values of 26%, 26.5%, 28.5%, and 30%, respectively. The consistency of cement increased as the amount of waste hospital waste ash replacement increased, as demonstrated by the graph. This is likely because of high water absorption of hospital waste ash than the cement because of high carbon and unburned residue content in the ash could attract and retain more water.

Table 4.1 Consistency of paste

No	Percentage of replacement by weight	Consistency	w/c	Penetration (mm)
1	0	26%	0.26	7
2	5	26.5%	0.27	8
3	10	28.5%	0.31	10
4	15	30%	0.35	12

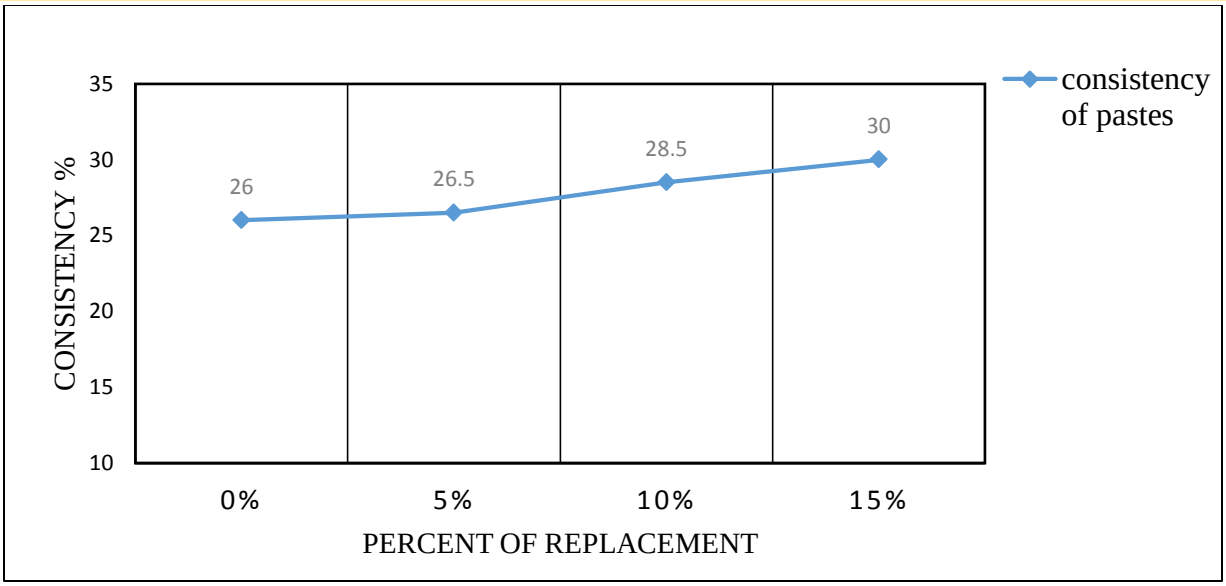


Figure 4.1 Consistency of cement paste

4.3 Setting time of cement paste

. The paste's initial and final setting times increased when the percentage replacement of hospital waste ash increased, as illustrated in figure 4.2.

According to the experimental result the percentage of Hospital Waste Ash (HWA) and the cementitious paste's setting time show a clear positive correlation. As the hospital waste ash content increased from 0% to 15%, both the initial and final setting times increased progressively. The initial setting time extended from 65 min for the control mix (0% HWA) to 151 min for the mix containing 5% HWA. Similarly, the final setting time lengthened from 598 min to 710 min for the mix with 15% HWA. This systematic delay indicates that hospital waste ash acts as a retarder, likely due to its lower calcium oxide content and the presence of unburnt carbon or other inert constituents, which slow down the normal hydration of cement. Consequently, higher replacement percents of hospital waste ash result in proportionally longer setting times.

The small quantity of residue (5% weight) is possibly filling the voids between cement particulates due to packing impact. That does not take a lot of water yet. The spaces in between the particles increase by 5 and 10 percent. Ash has a “sponge” effect as the hospital waste ash

has a lot of unburnt organic matter or cellular structure. It absorbs all the excess water which was formerly lubricating the mix.

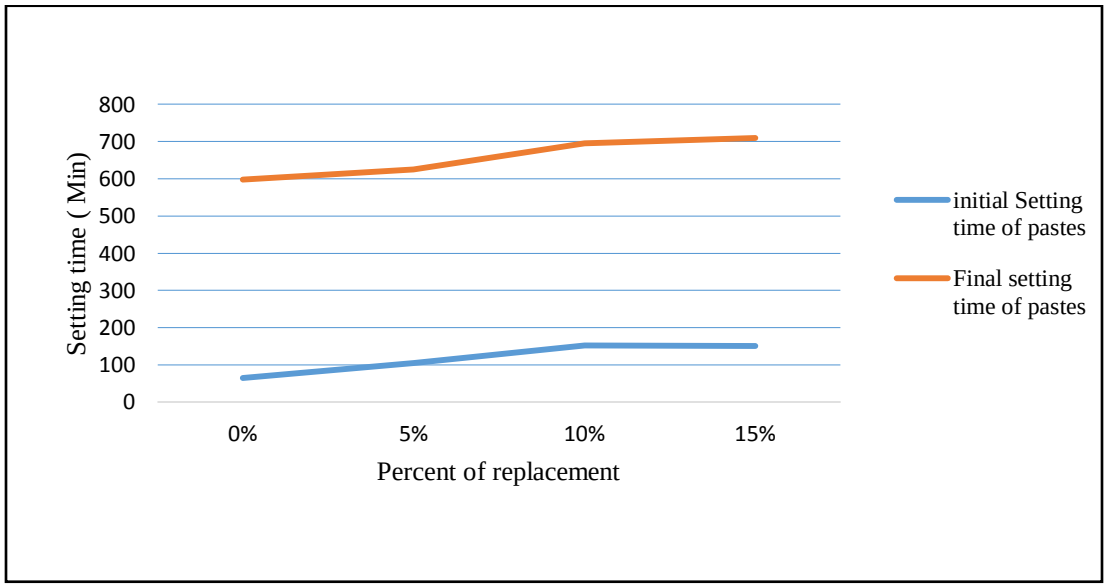


Figure 4.2 Setting time of cement paste

4.4 Properties of fresh concrete

4.4.1 Slump test

The test results on slump value indicate a consistent decrease in workability as the proportion of hospital waste ash (HWA) increases as illustrated in table 4.2. The slump height decreased from 60 mm for the control mix (0% HWA) to 39 mm at the 15% replacement level. This decrease is characteristic of concrete that contains supplementary materials with a high surface area or porous morphology, which absorb more mixing water and lessen the fluidity of the mixture [54]. The reduction in workability is because of the water-absorbing characteristics and irregular shape of hospital waste ash particles, which influence the effective ratio of water-to-cement. Other types of ash, such as biomass fly ash also exhibits this kind of phenomenon [55,56]. The decrease in fluidity when fine, pozzolanic materials are added is further corroborated by research on other supplementary cementitious materials, like rice husk ash. These studies also indicate a significant decreasing of workability, imputed to the greater fineness and specific surface area of the materials[57]. Thus, in accordance with broader studies on pozzolanic additives, increased HWA incorporation leads to less fluid concrete.

Table 4.2 Slump test results

No.	Mix code	Percent of replacement	Slump value (mm)
1	Co	0%	60
2	M-5	5%	55
3	M-10	10%	45
4	M-15	15%	39

4.5 Properties of hardened concrete

4.5.1 Compressive strength of concrete

compressive strength is one of the most significant properties of the material refers to the ability of concrete to endure a compressive load throughout its service life. Figure 4.3 illustrate the plotted compressive strengths of various concrete mixes at the 3rd, 14th, and 28th days of curing.

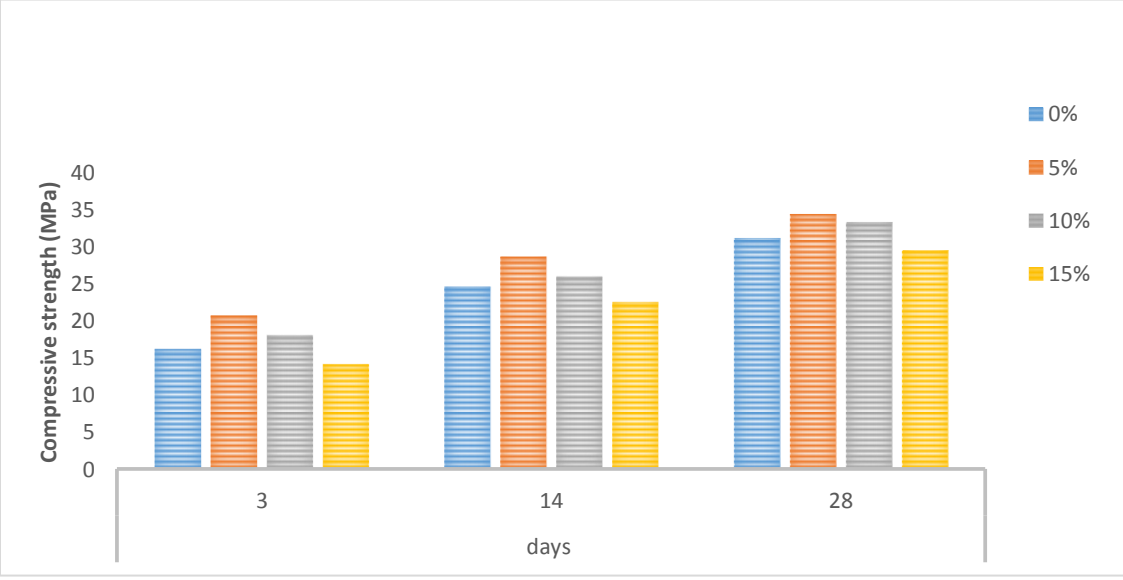


Figure 4.3: Compressive strength test results

Figure 4.3 illustrates how the concrete mixes' compressive strength increased when hospital waste ash (HWA) replaced for cement up to 10% (M-10), after which it decreased at 15% (M-15).

The mixes with 5% (M-5) and 10% (M-10) compared to control mix, its replacement demonstrated higher strength which indicates that cement replacement with hospital waste ash has the tendency to enhance compressive performance to a certain extent. Though the replacement intervals were relatively wide, the observed trend suggests that the optimal replacement level is approximately 10%. It is recommended to conduct further investigations with smaller incremental replacements to better define this optimal range.

4.5.2 Split tensile of concrete

Tensile strength refers to structural behavior of concrete to resist cracking and deformation under tensile forces. This property is fundamental to ensuring the safety, serviceability, and durability of concrete elements in construction.

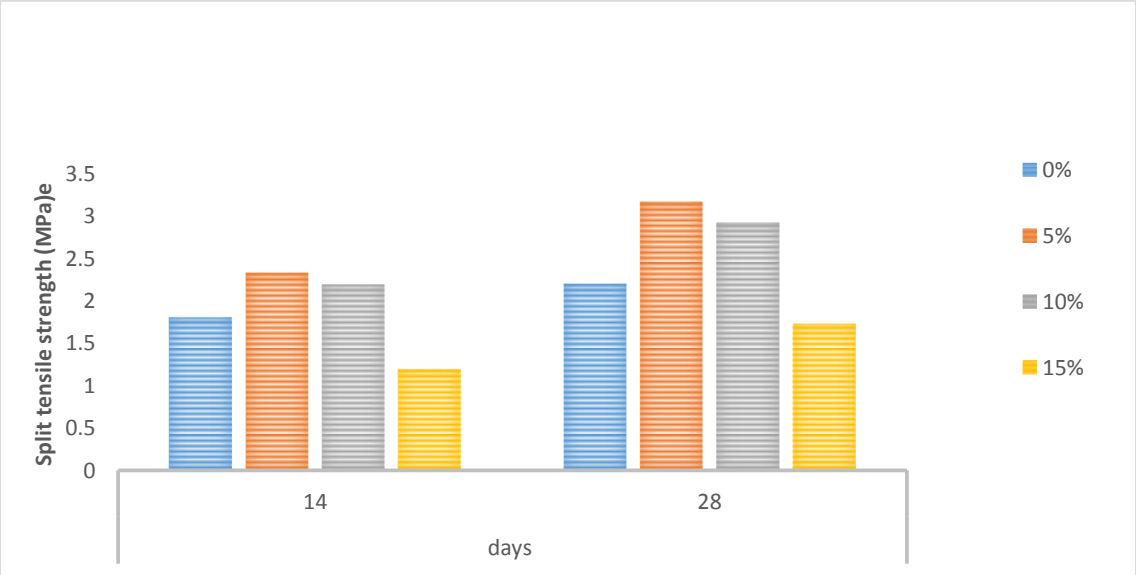


Figure 4.4 Split Tensile strength test results

Experimental result illustrated in figure 4.4 shows that the concrete split tensile strength mixes containing 5% (M-5) and 10% (M-10) hospital waste ash exceeded that of the control mix at both 14 and 28 days. This improvement proposes that using HWA as a partial cement

replacement enhances the paste-aggregate interfacial transition zone, a benefit likely attributed to the ash's fine particles acting as a filler.

However, when the replacement percent was increased to 15% (M-15), the concrete split tensile strength decline compared to the control mix. This decrease can be explained by replacing excessive cement, which lowers the amount of calcium silicate hydrate (C-S-H) gel that is available for strength development. Overall, the experimental results suggest that using hospital waste ash up to 10% replacement percent improves the concrete split tensile strength, with the 5% replacement mix (M-5) exhibiting the highest tensile strength among all mixes

4.5.3 Flexural strength of concrete

Flexural strength test results at 14 and 28 days are presented in Figure 4.5, illustrating strength development over time and compare the relationship of the control mix with mixes containing hospital waste ash.

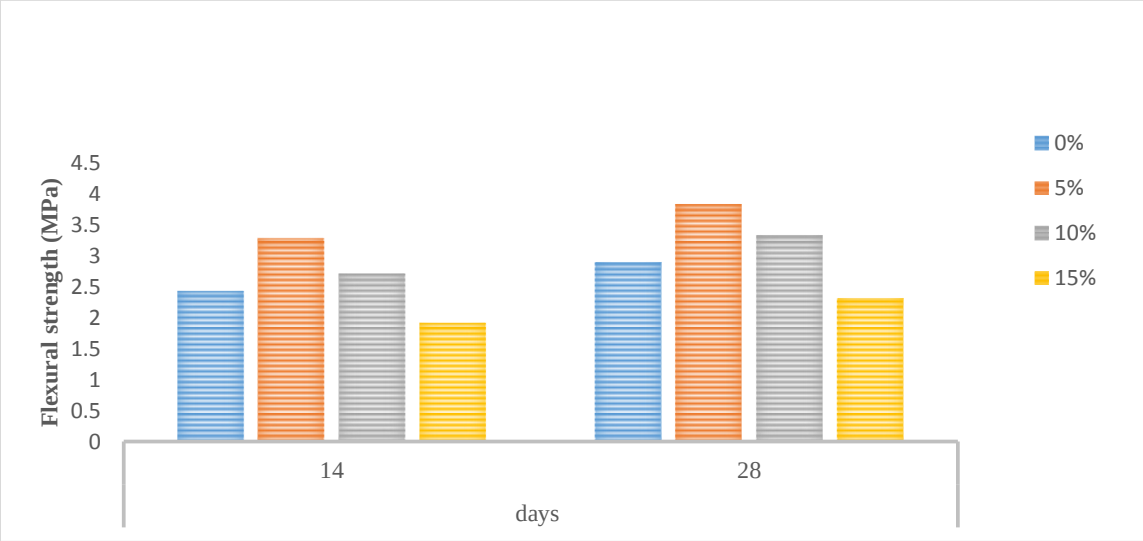


Figure 4.5: Flexural strength test results of concrete

When hospital waste ash (HWA) replacement exceeded a certain optimal point, the flexural strength of concrete generally decreased. Nevertheless, mixes containing 5% (M-5) and 10% (M-10) HWA showed higher flexural strength compared to the control mixture. This implies that the mechanical behavior of the concrete can be improved by a moderate amount of HWA, specifically its flexural capacity. The lower replacement percents improve the flexural strength,

is likely due to a pozzolanic reaction, where reactive silica in the ash interacts with hydration byproducts, producing additional binding gel that strengthens the internal structure of the concrete.

In summary, the flexural strength of concrete can be increased by replacing up to 10% of cement with hospital waste ash. Strength decreases after this point, probably as a result of increased porosity and cement dilution. Thus, for better flexural performance, about 10% replacement is optimal.

4.5.4 Water permeability test of concrete

According to the permeability test results in Figure 4.6, concrete containing 5% hospital waste ash had the least penetration of water while concrete with 15% replacement had the highest. This means that a rise in permeability ensures a rise in HWA content and vice versa. Specimens with 5% HWA and 10% HWA absorbed less water compared to the control mix, demonstrating enhanced resistance to water penetration and potentially improving durability.

The permeability classifications of EN 12390-8:2019 indicates that concrete with a water penetration depth under 30 mm (at 5-bar pressure) is classified as very low permeability, 30–50 mm as moderate, and above 50 mm as high. These criteria indicate that concrete with a 5% replacement of hospital waste ash is considered low-permeability, whereas concrete with a 15% replacement mix is considered high-permeability. This shows that concrete impermeability is improved by replacement levels up to 10%, while pore structure and compactness are compromised by greater proportions.

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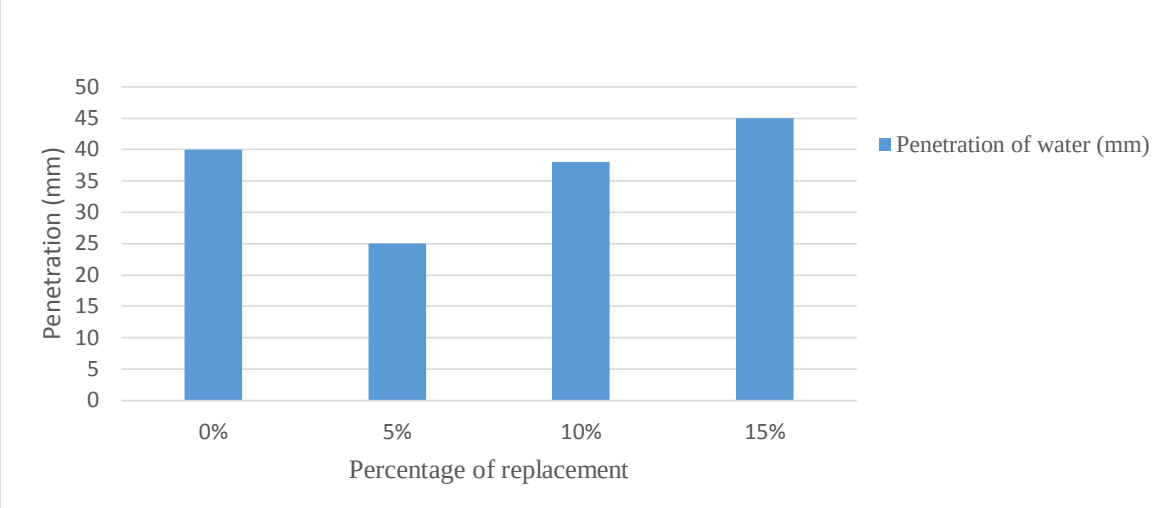


Figure 4.6 Water permeability of concrete test result

4.6 Material cost comparison of concrete (for 1m^3)

Material	Unit price (birr/kg)	Control mix		With hospital waste ash for 5%		With hospital waste ash for 10%		With hospital waste ash for 15%	
		Quantity (kg)	Price (birr)	Qty(kg)	Price (birr)	Qty(kg)	Price (birr)	Qty (kg)	Price (birr)
Cement	17	360	6120	342	5814	324	5508	306	5202
Hospital waste ash	1.04	-	-	18	18.72	36	37.44	54	56.16
Fine aggregate	1.76	993.74	1748	993.74	1748	993.74	1748	993.74	1748
Coarse aggregate	1.75	1102	1928.5	1102	1928.5	1102	1928.5	1102	1928.5
Total Price (birr)			**9796.5**		**9509.2**		**9221.9**		**8934.6**

Table 4.6 shows that when the percentage of Hospital Waste Ash (HWA) rises, the overall cost of concrete materials continuously declines. The control mix cost was calculated to be 9,796.5 birr based on current Addis Ababa market rates of approximately 1.76 birr/kg for sand and 1.75 birr/kg for coarse aggregate. The corresponding expenses per cubic meter for 5%, 10%, and 15% HWA replacement were 9509.2 birr, 9221.9 birr, and 8931.6 birr, respectively for the detailed calculation see appendix F, table F1. This translates to cost reductions of approximately 2.93%, 5.87%, and 8.80% compared to the control mix. The primary driver of these savings is the decreased use of cement, which is the costliest constituent in concrete. As hospital waste ash is

acquired at no cost as an incineration by-product but is has cost for collection, preparation and transportation, each incremental replacement of cement directly reduces the total material cost.

Higher replacement levels may simultaneously decrease the concrete mechanical properties beyond the optimal level, even if they continue to save costs. Mixes containing 5–10% HWA had similar or marginally better strength characteristics than the control concrete, as was observed in previous sections. Thus, the 10% replacement level appears to provide the optimal compromise between cost effectiveness and structural appropriateness from both an economic and performance perspective.

4.7 Result and discussion on the interview

Interview was prepared for four different hospitals regarding their waste management system and the incineration process up to its final output of the ashes.

Yekatit 12 medical college segregate their waste using a color-coded system: red for infectious waste, yellow for sharps, and blue for general waste. However observational results showed that this approach is not always followed, and waste types are occasionally mixed.

After segregation, trash is kept for 12 to 24 hours in specified on-site locations before being collected and treated This storage duration aligns with the national healthcare waste management guideline (Ministry of Health, 2021), which specifies proper segregation, handling, and temporary storage of medical waste. Furthermore, these procedures comply with broader national regulations, including the hazardous waste management and disposal control proclamation[58,59] which collectively mandate safe handling and disposal of hazardous and infectious wastes to protect human health and the environment.

After being temporarily stored, the separated waste is gathered in special designated and transported to the hospital on-site incineration using dedicated carts. A 200 kg/h electric incinerator with a combustion temperature range of 1000°C to 1800°C is operated by the facility It processes infectious waste, such as items contaminated with bodily fluids or blood, laboratory cultures, excreta, and isolation ward waste as well as sharps, such as needles, syringes, scalpels,

and broken glass. Non-infectious waste, including food waste, is managed separately through recycling channels and is not mixed with the infectious waste stream.

The hospital adheres to the Ministry of Health's guidelines for waste separation and collection. Upon visiting the site, it is noted shortfalls in the storage of waste on occasion, which could have safety and efficiency implications. The facility burns on average 300 kg of waste per day starting from usually 4 p.m. And continued for two hours or less.

The second facility studied was St. Peter's hospital which practices segregation of waste with the help of coloured bins. Waste that is segregated is kept for 24 hours before getting incinerated. The hospital is equipped with a single chamber incinerator. Medical waste management method at the hospital includes grouping or coding the waste further which includes infectious waste, non-infectious waste, and food waste. Waste such as you see contains infectious and sharps waste is incinerated.

The hospital generates approximately 1,500 and 2,000 kg waste daily on average. The incineration of this waste is done from 8:00 AM to 10:00 AM and 4:00 PM to 6:00 PM with an individual session lasting around three hours. The incinerator works at 600 to 800 degree C for thermal decomposition of hazardous material and their safe destruction.

The third site was Zewditu memorial hospital, follows a code bin color system. However, a clear separtion cannot always be done between recyclable and incinerable waste, leading to the combined disposal of recyclables and infectious waste The hospital has a manually-fed brick incinerator with no auxiliary combustion device. The fire is ignited with matches by the day laborers from 6 PM to 12 AM.

A manual incineration process is being used without temperature or quantitative controls. Every day about 50 kg of waste is burnt but the final ash weight is unmeasured. The ash cools down to a safe handling temperature after about three hours. The absence of automation will suggest the incompatibility of the treatment with a successful outcome and safety.

The fourth hospital was black lion hospital. In this hospital, waste segregation is carried out using color-coded bins, and the waste is temporarily stored for a maximum of 24 hours before collection. The collected waste is then transported to the on-site automatic incinerator using carts

and waste bags, allowing for onsite treatment and disposal. The incinerator operates at temperatures ranging from 1,000 °C to 1,200 °C.

Although the hospital separate food from recyclable waste (such as plastics) and infectious waste, the overall waste composition management is considered weak. The burning process begins at 12:00 PM and continues for approximately 6 hours. The hospital diesel fuel for incineration of wastes nevertheless, the temperature control system of the incinerator is not operational. The total volume of waste processed by the hospital is approximately 80kg per day.

4.8 Heavy metal content in curing wastewater

The concentrations of heavy metals, specifically cadmium (Cd) and lead (Pb), in the curing wastewater were analyzed to evaluate potential contamination resulting from the use of hospital waste ash (HWA) as a substitute for cement. The recorded levels of Cd and Pb are illustrated in Figure E1.27.

Laboratory analysis of the hospital waste ash detected lead at a concentration of 0.02 mg/L in a water leachate test, while cadmium was not detected. This indicates that lead present in the ash is capable of leaching into water, posing a potential risk of groundwater contamination.

According to WHO standards of drinking water quality, the suitable limit of cadmium is 0.003 mg/L and lead is 0.01 mg/L [56]. According to WHO, there is no allowable limit for lead concentration in hospital waste ash for concrete, although its measured concentration of 0.02 mg/L exceeds the limit for drinking water. The mix design establishes the danger that this entails for concrete production, HWA ratio, and concrete end-use. As lead tends to accumulate, its presence can become particularly significant for large structures or elements in contact with soil or water.

Although concrete can be intentionally mixed with lead to stop ionizing radiation and prevent corrosion, the toxic nature of lead and its risk to the environment limit its use. Lead from concrete can destroy soil and water and affect living beings. As a result, a stringent control system should be established while using the lead-containing ash of hospital waste in concrete, along with other safeguard measures to prevent contamination. In this research, HWA

(hazardous industrial waste) incorporation into C-30 concrete will require controlling lead levels and management of handling to protect environment and health.

Based on this research, the use of HWA for partial replacement cement in concrete can be beneficial if the use is controlled. For lightweight aggregates, non-structural applications such as partition blocks, masonry units, decorative, and pavements can safely use HWA at 5-10% (by weight of cement) where mechanical performance is similar to or above conventional concrete.

Nonetheless, this material is not recommended for use in foundations, columns, and slabs when placed in contact with soil or groundwater that may cause leaching of lead and thus contaminating the environment. The optimal mix design, curing and ash encapsulation shall be carried out to mitigate such risks. It will be necessary to collect and perform ongoing tests of leachate from HWA-containing concrete to ensure lead concentrations remain low enough for safety.

For this study the initial surface leaching test was conducted which is beneficial in understanding the short-term environmental performance of the material. Nonetheless, it might remember that this may not reflect long-term leaching behavior nor worst-case scenario contamination done on it by the environment. An assessment of the TCLP toxicity is recommended to obtain an ultimate prediction about the environmental toxicity and suitability of HWA blended cement for construction works.

5. Conclusions and Recommendations

5.1 Conclusions

Based on the mechanical and physical characteristics of hospital waste ash, the following conclusions were drawn about their potential as partial substitutes for cement.

- Increasing the proportion of HWA in concrete reduces workability of fresh concrete but extends both initial and final setting times, providing a retarding effect that is beneficial for concrete placement in hot weather conditions.
- A 5% replacement of cement with hospital waste ash (HWA) provided the best mechanical strength performance, improving compressive, flexural, and split tensile strengths compared to the control mix.
- Concrete containing 5–15% HWA can be classified as normal-strength concrete, with the 5% replacement mix exhibiting low water permeability, indicating resistance to water penetration and good durability.
- Using HWA in concrete reduces material costs, offering an economical and alternative for sustainable replacement of cement partially replace in construction projects.
- The presence of lead in curing water highlights the need for monitoring heavy metal content to ensure environmental safety when using HWA in concrete.

5.2 Recommendations

The findings of the research lead to the following recommendations for the appropriate authorities.

- HWA can be considered as a partial replacement for cement in non-structural concrete elements at low replacement levels (5–10%), which may help reduce cement costs and promote sustainable waste management.
- It is recommended to perform Scanning Electron Microscopy (SEM) analysis to study the microstructural hydration and distribution of products in concrete containing HWA. This will provide insight into durability, strength development, and interactions between ash components and the cement matrix.
- To minimize environmental and health risks, HWA should be used only in above-ground, non-structural concrete elements, such as walls, blocks, and decorative components, while adhering to proper mix design, curing, and encapsulation practices.

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Appendixes

Appendix A: Material properties

1. Sand

1.1 Silt content

A = 15ml

B = 280ml

Where:

A = amount of silt deposited above the sand

B = amount of clean sand

Calculation:

$$\text{Silt content (\%)} = \frac{A}{B} * 100$$

$$Silt\ Content = \frac{15}{280}\ X\ 100 = 5.35\% < 6\% \qquad OK$$

Table: A1.2 Sieve analysis

Sieve size (mm)	Weight of Sieve (gm)	Wt. of sieve and retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
9.5	460	0	0	0	0	100

4.75	430.2	432.9	2.9	0.58	0.58	99.42
2.36	373.3	390.5	17.2	3.44	4.02	91.5
1.18	396.9	482.4	85.5	17.1	21.12	78.88
0.6	315.6	580.9	265.3	53.06	74.18	25.82
0.3	309.9	413.7	103.8	20.76	94.94	5.06
0.15	278.8	303.7	24.9	4.98	99.92	0.08
Pan	416.9	416.5	0.4	0.48	100	**0**
Total					**294.76**	

Fineness modulus (FM) Calculation:

$$F.M = \frac{\sum cummulative\ coarser\ (\%)}{100}$$

$$= \frac{\sum 294.76}{100}$$

F.M= 2.94

1.2 Specific gravity test

W= pycnometer weight = 210g

A= oven dry sample in air weight = 491g

B= weight of pycnometer filled with water = 710g

C= weight of pycnometer with water and water to calibration mark = 1005.3g

Bulk specific Gravity

$$bulk\ specific\ gravity = \frac{A}{B + 500 - C}$$

$$= \frac{500}{710 + 500 - 1005.3}$$

$$bulk\ specific\ gravity\ of\ sand = 2.44$$

1.4 Absorption

$$Absorption\ (\%) = \frac{500 - A}{A} x100$$

$$Absorption\ (\%) = \frac{500 - 491}{491} x100 = 1.8\%$$

1.5 Moisture content

A = weight of original sample [g] =500g

B = oven dry sample weight [g]= 494g

$$w\ (\%) = \frac{A - B}{B} * 100$$

Where:

w = Moisture content (%)

$$w\ (\%) = \frac{500 - 494}{494} x100 = 1.2\%$$

1.6 **Unit weight**

Weight of the Measure = 4855g

Weight of sample + Measure = 26095g

Dimension of the Measure:

- Inside Diameter = 255 mm
- Inside Height of the measure = 277 mm

Volume of the measure:

$$V = \frac{\pi D^2 h}{4} = \frac{3.14x0.255^2x0.277}{4} = 0.01414m^3$$

$$Unit\ weight\ of\ sand\ = \frac{26.095 - 4.855}{0.01414} = 1502.12\frac{kg}{m^3}$$

2. Coarse aggregate tests

Table: A 2.1 Sieve analysis

Sieve size (mm)	Weight of Sieve	Wt. of sieve and	Weight Retained (gm)	Retained Percentage	Cumulative Retained	Passing percentage	ASTM C33 Standard range Nominal size

	(gm)	retained (gm)		(%)	(%)		25mm-4.75mm
37.5	1066	1066	0	0	0	100	100
25	1216.2	1287.5	71.3	1.426	1.426	98.574	95-100
19.5	1379.3	2716.1	1336.8	26.736	28.162	71.838	-
12.5	1175.2	3345.3	2170.1	43.402	71.564	28.436	25-60
9.5	1237.1	2441.2	1204.1	24.082	95.646	4.354	-
4.75	564.9	782.6	217.7	4.354	100	0	0-10
Pan	748.7	748.7	0	0			
Total					**296.798**		

Fineness modulus (FM) Calculation:

$$\text{F.M} = \frac{\sum cummulative\ coarser\ (\%)}{100}$$

$$= \frac{296.798}{100} = 2.96\%$$

Coarse aggregate specific gravity of

Where:

A = weight of oven-dry sample in air, [g]

B = weight of saturated – surface – dry sample in air, [g] and

C = weight of saturated sample in water, [g]

A= 1980.2

B= 2021.3

C=1312.5

$$Bulk\ sp\ gr = \frac{A}{B - C}$$

$$Bulk\ sp\ gr = \frac{1980.2}{2021.3 - 1312.5} = 2.79$$

Bulk Specific Gravity (Saturated – surface – basis):

$$Bulk\ sp\ gr\ (SSD\ basis) = \frac{B}{B - C}$$

$$Bulk\ sp\ gr\ (SSD\ basis) = \frac{2021.3}{2021.3 - 1312.5} = 2.85$$

Apparent Specific Gravity:

$$Apparent\ sp\ gr = \frac{A}{A - C}$$

$$Apparent\ sp\ gr = \frac{1980.2}{1980.2 - 1312.5} = 2.96$$

Absorption capacity

$$Absorption\ Capacity\ (\%) = \frac{B - A}{A} * 100$$

$$Absorption\ Capacity = \frac{2021.3 - 1980.2}{1980.2} x100 = 2.07\%$$

2.1 Moisture content

Where

A = weight of original sample [g]

B = weight of oven dry sample [g]

Calculation:

$$w\ (\%) = \frac{A - B}{B} * 100$$

$$w\ (\%) = \frac{2000 - 1980.2}{1980.2} x100 = 0.99\%$$

Unit weight

Weight of the measure = 4855g

Weight of sample + Measure = 28635g

Dimension of the Measure:

- Inside Diameter = 255 mm
- Inside Height of the measure = 277 mm

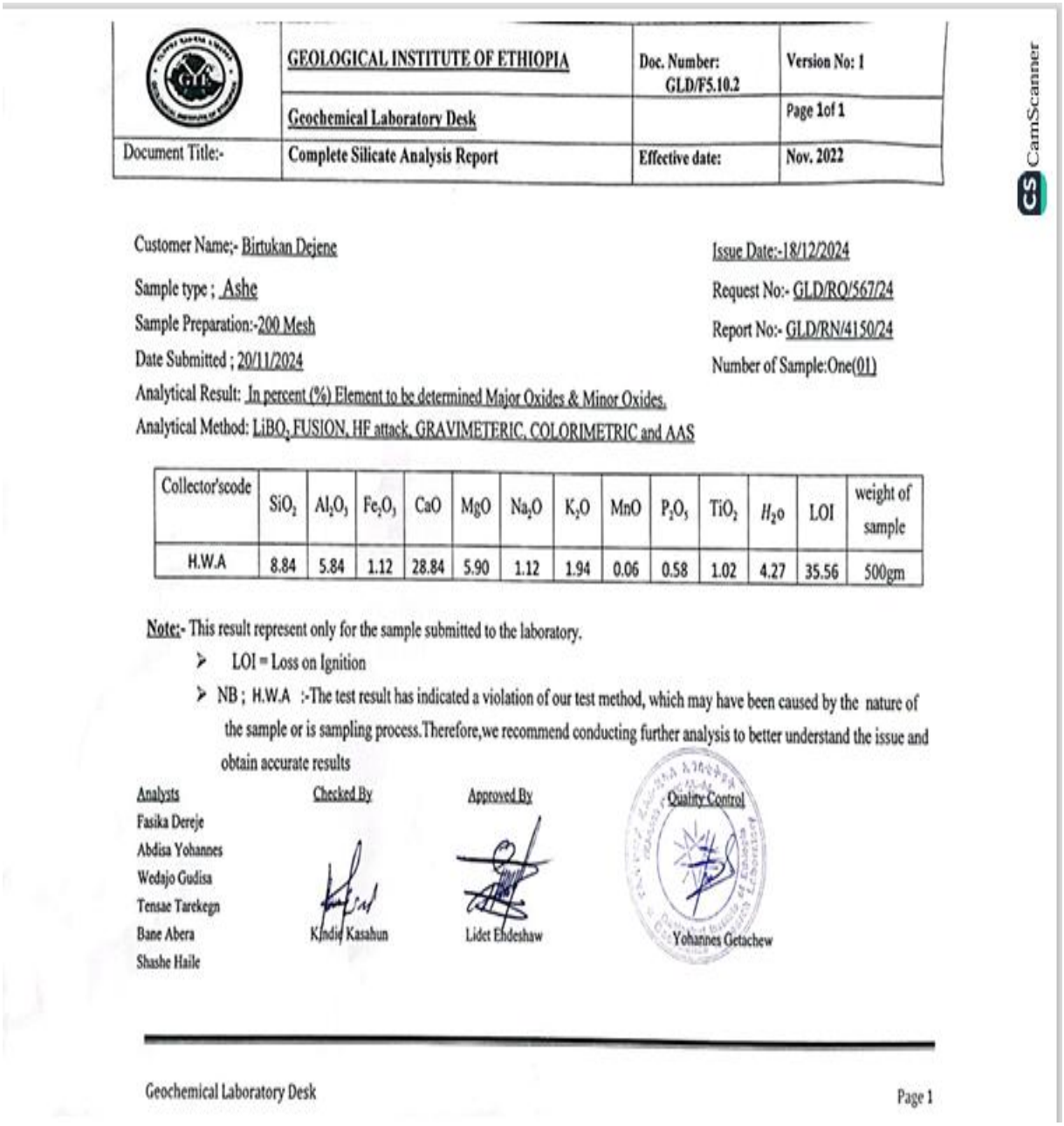
Calculation

Volume of the measure:

$$V = \frac{\pi D^2 h}{4} = \frac{3.14x0.255^2x0.277}{4} = 0.01414m^3$$

$$Unit\ weight\ of\ C-agg. = \frac{28.448 - 4.855}{0.01414} = 1668.53\frac{kg}{m^3}$$

3. Hospital waste ash chemical composition test results



	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name;- Birtukan Dejene

Issue Date:-18/12/2024

Sample type ; Ashe

Request No:- GLD/RQ/567/24

Sample Preparation:-200 Mesh

Report No:- GLD/RN/4150/24

Date Submitted ; 20/11/2024

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'scode	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2o	LOI	weight of sample
H.W.A	8.84	5.84	1.12	28.84	5.90	1.12	1.94	0.06	0.58	1.02	4.27	35.56	500gm

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

- LOI = Loss on Ignition
- NB ; H.W.A :-The test result has indicated a violation of our test method, which may have been caused by the nature of the sample or is sampling process.Therefore,we recommend conducting further analysis to better understand the issue and obtain accurate results

Analysts: Fasika Dereje, Abdisa Yohannes, Wedajo Gudisa, Tensae Tarekegn, Bane Abera, Shashe Haile

Checked By: Kindie Kasahun

Approved By: Lidet Endeshaw

Quality Control: Yohannes Getachew

Geochemical Laboratory Desk

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Figure A1.1 The first sample test result on chemical composition of hospital waste ash

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name;- Birtukan Dejene

Sample type ; Ash

Sample Preparation:-200 Mesh

Date Submitted ;12/30/2024

Issue Date:-21/01/2025

Request No:- GLD/RQ/754/25

Report No:- GLD/RN/4283/25

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'scode	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	weight of sample
HWA-2	8.10	4.84	1.26	38.84	6.70	0.72	3.47	0.04	1.30	1.30	1.14	24.17	700gm

503

765

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

- LOI = Loss on Ignition
- NB:- The sample code HWA-2 The test result has indicated a violation of our test method, which may have been caused by the nature of the sample or its sampling process. Therefore, we recommend conducting further analysis to better understand the issue and obtain accurate results.

Analysts
Fasika Dereje
Abdisa Yohannes
Wedajo Gudisa
Tensae Tarekegn
Bane Abera
Shashe Haile

Checked By
Kindie Kasahun

Approved By
Lidet Endeshaw

Quality Control
Yohannes Getachew

Geochemical Laboratory Desk

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Figure A1.2 The second test result of chemical composition of HWA

Appendix B: Mix design for C-30 concrete

Mix design –ACI method

Concrete trail mix design

1. Details for the mix design

- Desired strength = 30MPa
- Maximum aggregate size = 25mm
- Expected Slump = 50mm

1.1 Materials

- **Cement**

Specific Gravity $_{cement}$ = 3.15

- **Sand**

Absorption Capacity = 1.8% Moisture Content = 1.2%

Finess Modulus= 2.94

Dry Unit Weight $_{sand}$ = 1502.12kg/m^3

Dry bulk specific gravity = 2.44

- **Coarse Aggregate**

Dry unit weight = 1,668.53kg/m

Absorption Capacity = 2.07% Moisture Content = 0.99%

Fineness Modulus = 2.96

Dry bulk specific gravity = 2.96

Calculation

Step 1: Selecting a slump

A Slump of 50mm

Step 2: Choice of aggregate maximum size

The maximum size of aggregate is 25mm

Step 3: Water content and air content estimation

Using maximum aggregate size of 25mm and slump value of 50mm and, readings from table indicated under;

Water content

=180kg/m^3 Air content

= 1.5% = 15lit

Table A1.5.3.3- The required approximate mixing water for different slumps and maximum sizes of aggregates

Water kg/m^3 of concrete for indicated maximum sizes of aggregate in mm

Slump cm.	10	12.3	20	25	40	50^+	70^+	150^+
Non-air entrained concrete								
3 to 5	205	200	185	180	160	155	145	125
8 to 10	225	215	200	195	175	170	160	140
15 to 18	240	230	210	205	185	180	170	
Approximate amount of entrapped								
air in non-air entrained concrete								
%	3	2.5	2	1.5	1	0.5	0.3	0.2
Air entrained concrete								
3 to 5	180	175	165	160	145	140	135	120
8 to 10	200	190	180	175	160	155	150	135
15 to 18	215	205	190	185	170	165	160	
Average total air content recommendation, percentage	8	7	6	5	4.5	4	3.5	3

*These mixing water quantities are used to calculate the cement factor for experimental batches. They are maxima for angular coarse aggregates that are reasonably well-shaped and graded within a range of accepted specifications.

*The values of slump for concrete containing aggregate larger than 40mm are based on slump tests after removal of particles larger than 40 mm by wet-screening.

Step 4: Water cement ratio selection

From Table A1.5.3.4(a) the water cement ratio of compressive strength 30Mpa at the age of 28 days in non- air entrained is 0.55

Step 5: Cement content calculation

As per the Ethiopian building code standard, for C-30 Concrete with maximum aggregate size 25mm, the minimum cement content is 290kg/m^3. Reading from table is shown as follow;

Water to cement ratio of the non-air-entrained concrete = 0.55

Cement content = $(180 kg/m^3)/0.55$ = 327.27kg/m^3 > **290 kg/m^3 … OK!**

Table A1.5.3.4(a) Relationship between compressive strength of concrete and water-cement ratio

Water cement ratio, by weight

28 days of compressive strength kgf/cm^2	Non-air-entrained concrete	Air-entrained concrete
450	0.38	-
400	0.43	-
350	0.48	0.4
300	0.55	0.46
250	0.62	0.53
200	0.70	0.61
150	0.80	0.71

Step 6: Coarse aggregate estimation

From table, using the maximum aggregate size 25mm and the fineness modulus of sand which is 2.96, Using interpolation 0.654 m^3, the Bulk volume of coarse aggregate can be obtained.

Bulk volume of coarse aggregate = 0.654m^3 per m^3 of concrete

$Weight\ of\ dry\ coarse\ aggregate = 0.654m3 \times 1{,}668.53 kg/m3 = \mathbf{1091.2kg}$

For its convenience, the volume batching is used.

The absolute volume is calculated by using this formula

$$V = Va + \frac{W_w}{1000} + \frac{W_c}{1000} + \frac{W_{Fa}}{1000} + \frac{W_{ca}}{1000}$$

$$V = \frac{W}{1000(G)}$$

V= the absolute volume in cu.m.
W= the weight of the material in kg
G= the specific gravity of the material
1000 = the density or unit weight of fresh water in kg per cu.m.

Table A1.5.3.6 - Volume of coarse aggregate per unit of volume of concrete

Maximum size of aggregate mm	Dry rodded coarse aggregate volume per unit the volume of concrete for different fineness levels sand modulus			
	2.40	**2.60**	**2.80**	**3.00**
10	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
40	0.76	0.74	0.72	0.70
50	0.78	0.76	0.74	0.72
70	0.81	0.79	0.77	0.75
150	0.87	0.85	0.83	0.81

Step7: Fine aggregate content estimation

- Air absolute volume = 0.015
- Water absolute volume $= \frac{W_w}{1000} = \frac{180}{1000}$ = 0.180
- Cement absolute volume $= \frac{W_c}{1000\,(Gc)} = \frac{327.27}{1000\times3.15}$ = 0.103
- Absolute volume of Coarse aggregate $= \frac{W_{ca}}{1000\,(Gca)} = \frac{1091.2}{1000\times2.96}$ = 0.368
- Total Volume without Sand = 0.666cu m
- Absolute volume of sand $= 1.000 - 0.666 = 0.334cum$
- Weight of sand $= 0.334 \times 2.94 \times 1000$

$$= 981.96\,{}^{kg}/_{m^3}$$

Table B1.1: Total weight of concrete making material for 1m^3

	Absolute Volume (m^3)	**Weight (kg)**
Absolute volume of air	0.015	
Absolute volume of water	0.180	180
Absolute volume of cement	0.103	327.27
Absolute volume of coarse aggregate	0.368	1091.2
Absolute volume of fine aggregate	0.334	981.96

Adjustment

Increase weight of water by an amount equivalent to the weight of water demanded to saturate the fine and coarse aggregate.

- Adjusted water = 180 + 1091.2*0.0207 +981.96*0.018

  =180 + 22.58+17.67 = **220.25kg**

Increase the weight of sand and weight of coarse aggregates to consider the prevailing moisture content.

- Adjusted Sand = 981.96 + 981.96*0.012
  = 981.96+11.78

  = **993.74kg**

- Adjusted Coarse aggregate = 1091.2 +1091.2 * 0.0099
  =1091.2+10.8

  = 1102.0kg

Decrease the weight of water by the same amount the sand and aggregate increased.

- Adjusted water = 220.25 – 11.78 – 10.8 = **197.67kg**

Table B1.2: The modified mass of ingredients per cubic meter of concrete

No.	**Ingredients**	**Contents in Kg**
1	Cement	360
2	Water	197.67
3	Fine aggregate	993.74
4	Coarse aggregate	1102

Table B1.3: Quantity of concrete making materials for the mix

Mix code	Test	% of replacement	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Hospital waste ash (kg)
Co	Compressive	0	12.36	6.79	34.11	37.83	0
M-5		5	11.74	6.79	34.11	37.83	0.62
M-10		10	11.13	6.79	34.11	37.83	1.24
M-15		15	10.51	6.79	34.11	37.83	1.85
Co	Split tensile	0	3.84	2.11	10.59	11.74	0
M-5		5	3.65	2.11	10.59	11.74	0.19
M-10		10	3.45	2.11	10.59	11.74	0.38
M-15		15	3.26	2.11	10.59	11.74	0.58
Co	Flexural	0	12.20	6.71	33.70	37.36	0
M-5		5	11.59	6.71	33.70	37.36	0.61
M-10		10	10.98	6.71	33.70	37.36	1.22
M-15		15	10.37	6.71	33.70	37.36	1.83
Co	Permeability	0	1.92	1.05	5.29	5.87	0
M-5		5	1.82	1.05	5.29	5.87	0.10
M-10		10	1.73	1.05	5.29	5.87	0.19
M-15		15	1.63	1.05	5.29	5.87	0.29
Total quantity of materials			**110.29**	**66.68**	**334.77**	**371.19**	**9.10**

Appendix C: Test results on hardened concrete

C1: Compressive strength test result for 0%, 5% 10 % and 15%

Table C1.1: Compressive strength test result for 0% percentage of replacement on 3rd, 14th and 28th day

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	3rd	15	15	15	8142	3375	2.412	367.8	16.27
2		15	15	15	8154	3375	2.416	375.2	16.65
3		15	15	15	8110	3375	2.402	353.2	15.65
Mean					**8135**	**3375**	**2.41**	**365.4**	**16.19**
1	14th	15	15	15	8025	3375	2.377	549.1	24.4
2		15	15	15	8011	3375	2.373	554.7	24.65
3		15	15	15	8023	3375	2.377	560.3	24.9
Mean						**3375**	**2.375**	**554.7**	**24.65**
1	28th	15	15	15	7989	3375	2.367	719.8	31.93
2		15	15	15	7996	3375	2.369	701.3	31.17
3		15	15	15	7995	3375	2.368	682.9	30.33
Mean						**3375**	**2.368**	**701.3**	**31.14**

Table C1.2: Compressive strength test result for 5% percentage of replacement

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	3rd	15	15	15	8260	3372		471.2	20.94
2		15	15	15	8210	3375		467.3	20.76
3		15	15	15	8242	3375		463.5	20.60
Mean					**8248**	**3375**		**467.3**	**20.76**
1	14th	15	15	15	7979	3375		649	28.84
2		15	15	15	7995	3375		644.7	28.65
3		15	15	15	7951	3375		640.4	28.46
Mean						**3375**		**644.7**	**28.65**
1	28th	15	15	15	8222	3375		777.9	34.58
2		15	15	15	8235	3375		775.2	34.45
3		15	15	15	8248	3375		771	34.26
Mean					**8235**	**3375**		**774.7**	**34.43**

Table C1.3: Compressive strength test result for 10% percentage of replacement

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	3rd	15	15	15	8232	3375	2.439	399.5	17.68
2		15	15	15	8230	3375	2.438	408.5	18.12
3		15	15	15	8228	3375	2.437	417.6	18.56
Mean					**8230**	**3375**	**2.438**	**408.5**	**18.12**
1	14th	15	15	15	8210	3375	2.432	585.4	26.02
2		15	15	15	8216	3375	2.434	585.3	26.01
3		15	15	15	8222	3375	2.436	585.3	26.01
Mean					**8216**	**3375**	**2.434**	**585.3**	**26.01**
1	28th	15	15	15	8193	3375	2.427	745.2	33.12
2		15	15	15	8136	3375	2.410	754.0	33.49
3		15	15	15	8160	3375	2.417	749.3	33.30
Mean					**8163**	**3375**	**2.418**	**749.5**	**33.3**

Table C1.4: Compressive strength test result for 15% percentage of replacement

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	3rd	15	15	15	7992	3375	2.368	319.2	14.14
2		15	15	15	8010	3375	2.373	319.8	14.16
3		15	15	15	7998	3375	2.369	319.5	14.15
Mean					**8000**	**3375**	**2.370**	**319.5**	**14.15**
1	14th	15	15	15	8024	3375	2.377	522	23.2
2		15	15	15	7950	3375	2.355	505.3	22.46
3		15	15	15	7982	3375	2.365	488.6	21.72
Mean					**7985**	**3375**	**2.365**	**505.3**	**22.46**
1	28th	15	15	15	7960	3375	2.358	661.4	29.39
2		15	15	15	7979	3375	2.364	663.3	29.48
3		15	15	15	7988	3375	2.366	665.2	29.56
Mean					**7975**	**3375**	**2.362**	**663.3**	**29.48**

C2: Split tensile test results for 0%, 5% 10% and 15%

Table C2.1: Split tensile test result for 0% percentage of replacement on 14th and 28th day

Sample No.	Test age (days)	Dimensions (cm)		Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	Dia.					
1	14th	20	10	3810	1570.80	2.425	37.5	1.87
2		20	10	3796	1570.80	2.416	36	1.79
3		20	10	3799	1570.80	2.418	35.2	1.75
Mean				**3801**	**1570.80**	**2.419**	**36.23**	**1.8**
1	28th	20	10	3783	1570.80	2.408	44.1	2.2
2		20	10	3789	1570.80	2.412	40.3	2.01
3		20	10	3795	1570.80	2.415	47.8	2.39
Mean				**3789**	**1570.80**	**2.411**	**44.1**	**2.2**

Table C2.2: Split tensile test result for 5% percentage of replacement 14th and 28th day

Sample No.	Test age (days)	Dimensions (cm)		Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	Dia.					
1	14th	20	10	3799	1570.80	2.418	45.7	2.29
2		20	10	3786	1570.80	2.410	46	2.3
3		20	10	3810	1570.80	2.425	48.2	2.41
Mean				**3798**	**1570.80**	**2.417**	**46.6**	**2.33**
1	28th	20	10	3770	1570.80	2.400	64.0	3.17
2		20	10	3768	1570.80	2.398	65.9	3.24
3		20	10	3784	1570.80	2.408	62.2	3.10
Mean				**3774**	**1570.80**	**2.402**	**64.0**	**3.17**

Table C2.3: Split tensile test result for 10% percentage of replacement 14th and 28th day

Sample No.	Test age (days)	Dimensions (cm)		Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	Dia.					
1	14th	20	10	3798	1570.80	2.417	44.5	2.17
2		20	10	3792	1570.80	2.414	44.6	2.19
3		20	10	3749	1570.80	2.386	44.4	2.22
Mean				**3779**	**1570.80**	**2.405**	**44.6**	**2.19**
1	28th	20	10	3777	1570.80	2.404	61.4	3.04
2		20	10	3764	1570.80	2.396	58.7	2.92
3		20	10	3767	1570.80	2.398	56	2.8
Mean				**3769**	**1570.80**	**2.399**	**58.7**	**2.92**

Table C2.4: Split tensile test result for 15% percentage of replacement 14th and 28th day

Sample No.	Test age (days)	Dimensions (cm)		Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	Dia.					
1	14th	20	10	3780	1570.80	2.406	23.8	1.19
2		20	10	3784	1570.80	2.408	24.4	1.22
3		20	10	3786	1570.80	2.410	23.3	1.16
Mean				**3783**	**1570.80**	**2.408**	**23.8**	**1.19**
1	28th	20	10	3773	1570.80	2.401	34.2	1.7
2		20	10	3775	1570.80	2.403	34.7	1.73
3		20	10	3776	1570.80	2.404	35.2	1.75
Mean				**3774**	**1570.80**	**2.403**	**34.7**	**1.73**

C3: Flexural strength test results for 0%, 5%, 10% and 15%

Table C3.1: Flexural strength test result for 0% percentage of replacement 14th and 28th day

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	14th	50	10	10	12194	5000.0	2.438	5.5	2.41
2		50	10	10	12196	5000.0	2.439	5.4	2.43
3		50	10	10	12189	5000.0	2.437	5.4	2.44
Mean					**12193**	**5000.0**	**2.438**	**5.4**	**2.43**
1	28th	50	10	10	12122	5000.0	2.424	6.7	2.99
2		50	10	10	12125	5000.0	2.425	6.4	2.89
3		50	10	10	12130	5000.0	2.426	6.2	2.8
Mean					**12125**	**5000.0**	**2.425**	**6.4**	**2.89**

Table C3.2: Flexural strength test result for 5% percentage of replacement 14th and 28th day

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	14th	50	10	10	12358	5000.0	2.471	7.4	3.36
2		50	10	10	12355	5000.0	2.471	7.2	3.28
3		50	10	10	12341	5000.0	2.468	7.1	3.19
Mean					**12351**	**5000.0**	**2.470**	**7.2**	**3.28**

1	28^{th}	50	10	10	12229	5000.0	2.445	8.4	3.78
2		50	10	10	12218	5000.0	2.443	8.5	3.83
3		50	10	10	12220	5000.0	2.444	8.6	3.88
Mean					**12222**	**5000.0**	**2.444**	**8.5**	**3.83**

Table C3.3: Flexural strength test result for 10% percentage of replacement

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	14^{th}	50	10	10	12372	5000.0	2.474	6	2.69
2		50	10	10	12362	5000.0	2.472	6.3	2.71
3		50	10	10	12377	5000.0	2.475	6.6	2.74
Mean					**12370**	**5000.0**	**2.473**	**6.3**	**2.71**
1	28^{th}	50	10	10	12423	5000.0	2.484	7.3	3.27
2		50	10	10	12460	5000.0	2.492	7.4	3.33
3		50	10	10	12426	5000.0	2.485	7.5	3.39
Mean					**12436**	**5000.0**	**2.487**	**7.4**	**3.33**

Table C3.4: Flexural strength test result for 15% percentage of replacement

Sample No.	Test age (days)	Dimensions (cm)			Weight (gm)	Volume (cm3)	Unit weight (g/cm3)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H					
1	14^{th}	50	10	10	11789	5000.0	2.357	4.3	1.86
2		50	10	10	11932	5000.0	2.386	5.2	1.91
3		50	10	10	11740	5000.0	2.348	5.3	1.95
Mean					**11820**	**5000.0**	**2.363**	**4.9**	**1.91**
1	28^{th}	50	10	10	11990	5000.0	2.398	5.9	2.21
2		50	10	10	11986	5000.0	2.397	5.7	2.31
3		50	10	10	11981	5000.0	2.396	5.5	2.41
Mean					**11985**	**5000.0**	**2.397**	**5.7**	**2.31**

Table C4.1: Permeability of concrete test results

Percentage	Penetration of water (mm)	Percentage	Penetration of water (mm)
0%	43	**10%**	31
	45		48
	32		35
Mean	**40**	**Mean**	**38**
5%	29	**15%**	42
	25		45
	22		48
Mean	**25**	**Mean**	**45**

Appendix D: Interview and site visiting in different hospitals

Interview introduction

I would like to start by saying thank you for taking time to participate in my survey regarding title "Effects of Hospital Waste Ash as a Partial Cement Replacement on the Properties of C-30 Concrete". My name is Birtukan Dejene and I am conducting research at Addis Ababa Technology Institute. Your feedback is crucial in helping me to understand the hospital waste process and its disposal method. This Interview will address the overall waste production, incineration type, training and awareness about the incinerator and related environmental effects. I am conducting research on effects of hospital waste ash as a partial cement replacement on the properties of C-30 concrete. In my research the Hospital waste ash will be replaced cement with different percent i.e 5%, 10%, and 15% and the final output will be compared with the conventional concrete. The final goal of this research is to understand the performance of hospital waste ash to replace cement and to get the optimum percentage of replacement.

I. Personal information for the interviewee

Name of Hospital _____

Position _____

Work experience _____

Educational background _____

II. Questions related with hospital waste

1. Waste segregation system_____
2. The security level of storing system _____
3. Storage duration of the waste_____
4. How the waste is collected and transported_____
5. Waste treatment and disposal method _____
6. Is there staff training about the waste handling, segregation and disposal procedure_____

_____

III. General information about the waste and incinerator

Table D1.1 Interview question on hospital waste ash

No.	Name of hospitals	Questions						
		Types of Incinerators	Waste composition method	Types of waste to be incinerated	What is the daily volume processed	How long the waste is incinerated	At what time the burning process starts and ends	What is the expected temperature used for incineration process
1	Yekatit 12 medical college							
2	St. Peter hospital							
3	Zewditu memorial hospital							
4	Black Lion Hospital							

Appendix E: Pictures taken during conducting tests



Figure E1.1: Sieve analysis of sand



Figure E1.2: Specific gravity



Figure E1.3: Unit weight of sand

Coarse aggregate



Figure E1.4: sample taking



Figure E1.5: Sieve analysis of coarse aggregate



Figure E1.6: Unit weight



Figure E1.7: Weighting 2000g of aggregate



Figure E1.8: Measuring aggregate at SSD base and immersing it in water



Figure E1.9: Oven dry aggregate

Casting and mixing process



Figure E1.10: Measuring hospital waste ash



Figure E1.11: Preparing the ingredients for mix



Figure E1.12: Mixing and casting of concrete



Figure E1.13: Casted concrete



Figure E1.14: Dismantling the casted concrete



Figure E1.15: Curing



Figure E1.16: Compressive strength test



Figure E1.17: Tensile and flexural test



Figure E1.18: Samples in permeability testing machine



Figure E1.19: Measuring the penetrated water



Figure 1.20: Consistency and setting time test



Figure E1.21: Brick made incinerator at Zewditu memorial hospital



Figure E1.22: Recyclable waste and final output (ash) at Zewditu memorial hospital



Figure E1.23: Internal and external part of the incinerator at black lion hospital



Figure E1.24: Generated waste and final output (ash)



Figure E1.25: Incinerator at St.Peter hospital



Figure E1.26 : Incinerator and segregated waste at yekatit 12 hospital

Table E2.1:Hardened concrete test result (compressive strength)

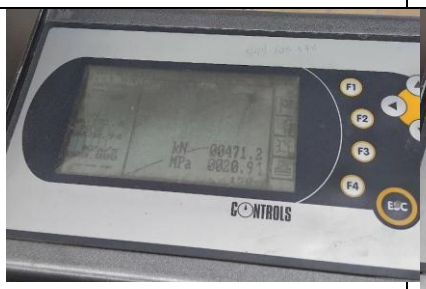
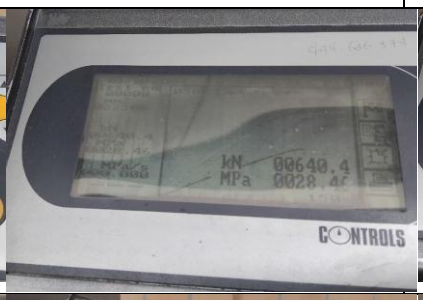
Percentage	3rd	14th	28th
0%			
5%			
10%			
15%			

Table E2.2: Split tensile strength test result sample

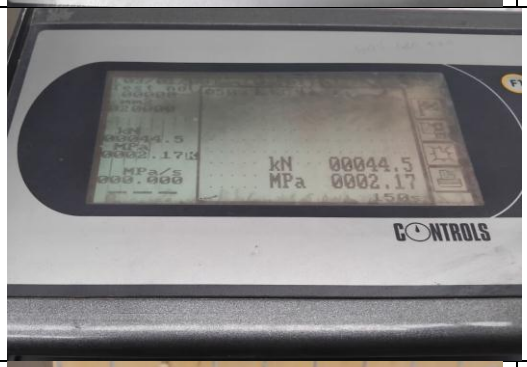
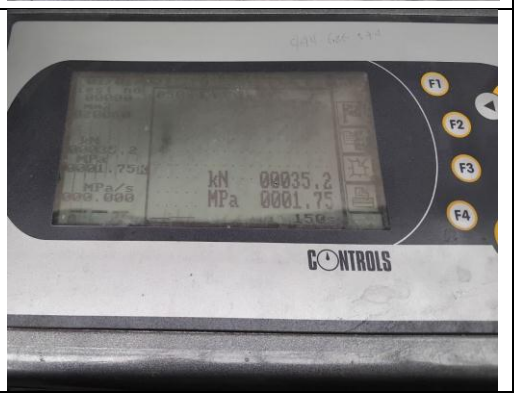
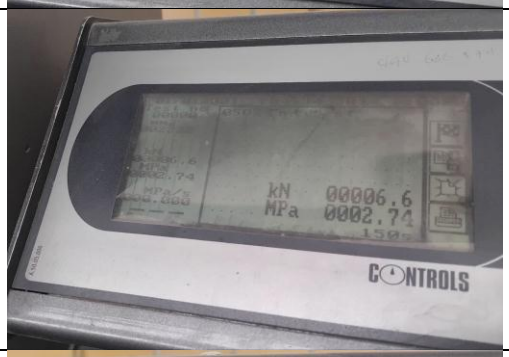
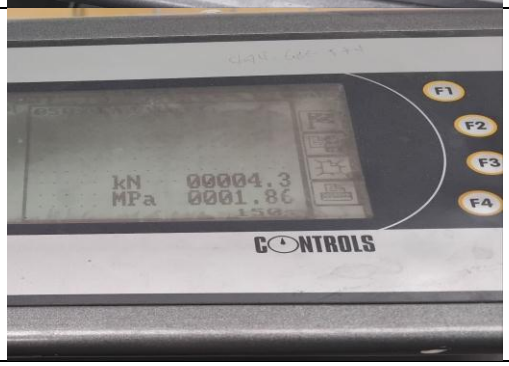
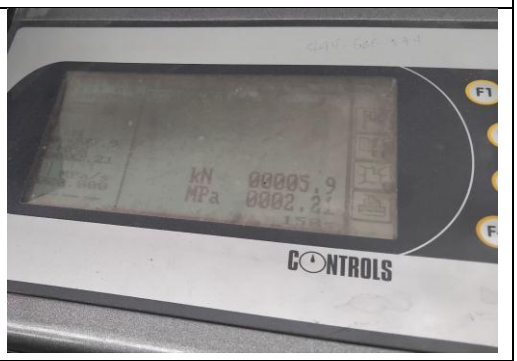
Percentage of replacement	14th day	28th day
0%		
5%		
10%		
15%		

Table E2.3: Flexural strength test result

Percentage of replacement	14th day	28th day
0%		
5%		
10%		
15%		

JIJE LABOGLASS	JIJE Analytical *Testing* Service Laboratory	Doc. No: JATSL/F5.10-3.1	Page 1 of 1	
			Ver. No: 04	Effective Date: July 08, 2017
	Analytical Test Report			
Customer Name:	Ms. Birtukan Dejene	Test Report No:	182	
Contact Person:	Ms. Birtukan Dejene	Report Date:	11/07/2025	
Sample Type:	Waste Water	Test Request No:	Not Specified	
Sample Source:	Water Used For Curing of Concrete	Tel (Mob):	+251921294471	
Sample Collected By:	Ms. Birtukan Dejene	Fax:	Not Specified	
Sample Collection Date:	26/06/25	E-mail:	Birtukandduu27@gmail.com	
Sample Receiving Date:	26/06/25	Tested By:	JATSL	
Sample Condition:	Normal	Dates Tested:	26/06/2025 to 10/07/25	

S/N	Lab No	Customer ID	Results (mg/L)	
			Pb	Cd
1	J-0745/2606/25	-	0.02	ND

S/N	Parameters Tests	Test Methods
1	Metals (Cd, Pb)	AAS-AES

Remark

1. This test report is only for specific sample(s) which has been tested by JIJE Analytical *Testing* Service Laboratory.
2. ND: Indicates Not Detected.

Verified by

Name: Melese Mulu — Signature — Date: 11/07/2025

Technical Signatory

Authorized by

Name: Muligeta Terefe — Signature — Date: 11/07/2025

Laboratory Manager

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Physical Address: Nifas Silk Lafto Sub City, Woreda 01, Lebu, Fozana Building 6th Floor, Infront of Varnero Real Estate, Addis Ababa, Ethiopia.

CamScanner

Figure E1.27: Heavy metal test result

Appendix F: Cost break down for hospital waste ash

Table F1: Hospital waste ash cost breakdown in birr/m^3

										LABOUR HOURLY OUTPUT:		3	m3/hr		
WORK ITEM: Production of hospital waste ash										EQUIPEMENT:		16	m3/hr		
			1	m3						RESULT:	831.78	Birr/m3			
Material Cost (1:01)					Labour Cost (1:02)					Equipment Cost (1:03)					
Type of Material	Unit	Qty	Rate	UF	Cost per Unit (birr)	Labour by Grade	No.	UF	** Indexed Hourly Cost	Hourly Cost (birr)	Type of Equipment	No.	Hourly Rental	Hourly Cost (birr)	
Water	li	12.5	0.2		2.5	Forman	1	0.5	75	37.5	Dump Truck	1	1000	1000	
Diesel Fuel	li	2.5	120		300	DL	2	1	56	112	Water Tanker	1	20	20	
Helmet	pcs	1	300	0.3	90					0	Wheelbarrows	2	10	20	
Gloves	pcs	2	150	0.2	60					0	Shovels & Hand Tools	4	10	40	
Boots	pcs	1	2000	0.01	20										
Face mask	pcs	5	10	1	50										
	Total (1:01)			522.5	**Total (1:02)**					**149.5**	**Total (1:03)**			**1080**	
A= Materials Unit Cost	522.5	Birr/m3		B= Manpower Unit Cost				49.83	Birr/m3	C= Equipment Unit Cost		67.50	Birr/m3		
				Total of (1:02)						Total of (1:03)					
				Hourly Output: _____						Hourly output: _____					
				Direct Cost of Work Item = A+B+C =						639.83	Birr/m3				
						Over head cost :			10%	95.98	"				
						Profit Cost:			15%	95.98	"				
						Total Unit Cost :				831.78	Birr/m3				
Remark _____															

Calculation for HWA in birr/kg

Density of HWA= 800kg/m^3

Cost of HWA per m3= 831.78 birr/m^3

Formula:

Cost per Kg= $\frac{cost\ per\ m^3}{density\ (^{kg}/_{m^3})}$

Calculation:

Cost per Kg= $\frac{831.78/\ m^3}{800\ (^{kg}/_{m^3})}$

Cost per kg = 1.04 **Birr/kg**