INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND ASH FROM WASTE INCINERATION TO STABILIZE EXPANSIVE SUBGRADE SOIL.

BY

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A FINAL YEAR PROGRESS RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELORS OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING AT UGANDA CHRISTIAN UNIVERSITY

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ABSTRACT.

Expansive soils pose significant challenges in civil engineering projects due to their high plasticity index (PI) and low California Bearing Ratio (CBR) values, often failing to meet standard requirements. This study investigates the effectiveness of locally available materials, crushed granite stone (CGS), and waste incineration ash (WIA), in stabilizing expansive soils in Kawanda Town Council, Wakiso District.

Initial soil tests revealed unsatisfactory CBR and PI values. Subsequent addition of 30% CGS resulted in a notable increase in CBR values, meeting Ministry of Works and Transport (MoWT) standards. However, the PI value remained above the permissible limit at 26.2%.

To further enhance soil stabilization, varying percentages of WIA (0%, 2%, 4%, 6%, and 8%) were introduced while maintaining the 30% CGS ratio. The results demonstrated a decrease in PI values with increasing WIA content, reaching a minimum of 22.3% at 8% WIA.

Optimization analysis revealed that a combination of 30% CGS and 8% WIA yielded the most favourable outcomes, achieving optimal values for CBR, Maximum Dry Density (MDD) and Optimum Moisture Content (OMC), Plasticity Index (PI), and Liquid Limit (LL). This finding underscores the efficacy of using locally available materials for stabilizing expansive soils, offering a sustainable solution for civil engineering projects in the region.

DECLARATION

I, **ASHABA PETER**, so affirm that the information in this report is entirely my own and where I may have acquired information from other sources, I have cited and referenced.

………………………………

ASHABA PETER.

APPROVAL.

This report has been presented with the endorsement of my supervisor as indicated.

MR. SEJJEMBA HENRY

………………………………

DEDICATION

I dedicate this report to my parents and all my loved ones.

ACKNOWLEDGEMENT

I am deeply delighted to have reached this stage of academic accomplishment in life. Great thanks go to the Almighty Lord for the spiritual, physical, mental and social providence He has provided all throughout my life and academic journey, it has really been a struggle. I am greatly thankful for the gift in my life, that is my dear parents for all the tremendous financial, moral, spiritual, physical, and parental guidance and support that they have given me and everyone they have impacted positively in this life. I am truly grateful and will forever be indebted to them.

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ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials.
ASTM	American Society for Testing and Materials
BS	British Standards
CBR	California Bearing Ratio
CGS	Crushed Granite Stone
MWIA	Municipal Waste Incinerated Ash
PCDDs	Polychlorinated Dibenzo-p-Dioxins
PSD	Particle Size Distribution
RCRA	Resource Conservation and Recovery Act
USCS	Unified Soil Classification System.
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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CHAPTER ONE: INTRODUCTION

1.1. Background

Expansive clay soils have significant volumetric variations in moisture content. The CBR of the pavement layers is adversely influenced by their periodic swelling and shrinking, which causes them to expand during the rainy season and shrink upon evaporation during the dry season. (Adeniji, 2011).

Expansive soils are mainly comprised of minerals such as montmorillonite that are prone to expansion or shrinkage depending on the variation of the water content in a particular season (Saadeh, & John T, 2019). These soils are comprised of fine particles and hence are intensely viscous which makes it hard to drain.

The unfavourable characteristics of these soils, such as substantial volume fluctuations and unwanted settlements, result in a variety of construction-related damages to the buildings. Owing to the increased demand for land, these soils' engineering qualities must be improved in order to make them appropriate for building (Hossain & Tucker, 2011). The purpose of this procedure, known as "soil stabilisation," is to modify the natural soil's chemical and physical characteristics.

Expansive clay soils can be found in semi-arid and arid regions of Uganda, in the Albertine region, on the eastern slopes of Mount Elgon, and in certain sections of northern Uganda (Mugisha, Kisira & Muwanga, 2022). Based on the kind of foundation, engineering features, and soil characteristics, the extent of issues related to the presence of these expansive soils may vary depending on the location.

1.2. Problem statement

A study done by (Niyomukiza J.B., 2023) showed that town roads of Kawanda town council in Wakiso District, pass through low-lying areas with expansive soil deposits. This has hindered upgrading of these town roads to paved standard due to the behaviour of these soils in different weather conditions. The study was carried out on the soils and the CBR value obtained was below standards. The expansive soils are problematic to the engineering works due to their low strength and high plasticity and hence cause the earth to heave and settle, resulting in cracks and other damages to the road (Nartey, Nanor & Klake, 2012).

1.3 Objectives

1.3.1 Main objective

To investigate the use of Waste Incinerated Ash and Crushed Granite Stone (CGS) in the stabilizing of expansive soils.

1.3.2 Specific objective

- To determine the engineering properties of neat expansive soils.
- To characterize the waste used for incineration.
- To determine the engineering properties of WIA and Crushed Granite Stone.
- To determine the engineering properties of the stabilised soil.

1.4 Scope

Geographical scope

The expansive soils are to be obtained from Kawanda town council, Wakiso district. The waste ash is to be obtained from BioHaz waste solutions located in Bombo which burns the inorganic waste at temperatures above 500^0C providing the residue with a calcified nature.

The Granite stone is to be obtained from a stone crushing site in Mbalala along Mukono-Jinja highway.

Time scope

This study will have a running period starting from September 2023 to April 2024.

Content scope

The research will focus on assessing the use of MWIA and CGS to stabilize expansive soils.

1.5 Justification

Expansive soil raises the initial cost of construction for subgrade and foundation preparation, especially in the road building industry, due to the requirement to strengthen its strength as the base for pavement structure (Abubekir, Elmer & Anteneh, 2019). For weak soil deposits, crushed granite stone is one of the widely used and affordable ground repair techniques. They perform the essential roles of drainage and reinforcing, enhancing the characteristics of deformation and strength in weak soil deposits (Onyewole, F., & D.,2012). CGS exhibits excellent shear strength according to (Soosan, Sridharan, Babu, & Abraham, 2005), which is advantageous for its application as a geotechnical material. A previous scholar named (Wobudeya, 2023) carried out research on using granite stone and the results showed and increase in CBR values by 13% but the PI barely reduced and it was still above the 25% which is beyond standards. Therefore, we added ash from municipal waste incineration to significantly lower the soil's PI.

CHAPTER TWO: LITERATURE REVIEW.

2.1. Introduction.

In civil engineering, roads are classified according to several aspects such as topography, location and function, traffic type, stiffness, economy, and building materials. A road is a paved or smoothed-over path that is used for travel to get from one location to another. The most dependable and affordable mode of transportation for individuals is road travel, which is also the oldest. District roads, community roads, and private roads—the majority of which are low traffic roads—are only a few of the categories into which roads are divided.

2.2. Pavement design for a road.

Since the design of a pavement is a crucial aspect of road construction, it should be done with great attention. There are two varieties of pavement: rigid and flexible. The components of flexible pavements, which are widely utilised in Uganda, are listed below.

2.2.1. SURFACE COURSE.

The amount of traffic and the kind of material utilised determine the thickness of the surface course. Gravel roads should have more thickness added to them since traffic activity wears down the thickness. Bituminous wearing courses must be built using high-quality aggregate whose aggregate impact value does not exceed 30% in order to reduce aggregate deterioration due to crushing.

2.2.2. BASE LAYER.

Base layer is to withstand high stress concentrations which develop due to traffic under the wearing surface.

2.2.3. SUBBASE LAYER.

The subbase dissipates the loads exerted by traffic across a large portion of the subgrade.

2.2.4. SUBGRADE.

The subgrade is the foundation of a road. It is described as the "roadbed portion on which pavement, surfacing, base, subbase, or a layer of any other material is placed" in the Standard Specifications of the California Department of Transportation (Calitrans). The type and thickness of pavement structure, as well as the way it is planned, are greatly influenced by the subgrade characteristics since pavements are engineered to distribute traffic-generated stresses to the subgrade. (Jones, Rahim, Saadeh, & John T, 2011).

2.3. Expansive Soils

Because of their poor strength and low bearing capacity, expansive soils remain among the hardest soils to work with during construction. They are extremely dangerous since they are prone to drying and wetting cycles.

This tendency causes the subsurface of the road pavement to shrink and swell, which causes fractures to form in both structural and non-structural components. Their unfavourable physical and mechanical characteristics, which include, among other things, extremely fine montmorillonite mineral particles, elevated levels of natural moisture content that causes significant volume changes, high void ratio, high OMC, low CBR, and low compressive strength, are also a major source of problems. Their microstructure's main minerals tend to draw monovalent cations, making them unsaturated. Scholars have experimented with a variety of strategies to address these issues, including granular piles, chemical stabilisation, and the sand cushion technique. The most prevalent and effective way to enhance the mechanical and physical characteristics of these troublesome soils is by chemical stabilisation of clay soils. With this technology, engineering properties are said to improve significantly.

Thus far, the most widely utilised chemical stabilisers in soil modification have been lime and cement. These substances have strong binding and pozzolanic qualities. The two primary ways that the chemical stabilisation occurs are through stabilisation or modification, which results from the lime losing its calcium hydroxide or oxide cations in an extremely alkaline media. The primary cause of stabilization's lengthy duration is the pozzolanic reaction.

Studies on conventional cement stabilisers have demonstrated an increase in the unconfined compressive strength (UCS) of clays under various cement surcharges, such as in; a decrease in shrinkage in, a rise in the soil's dry density, and a decrease in OMC, as demonstrated in. However, lime, or lime slurry, has garnered the majority of attention as a soil stabiliser mostly because of its abundance in $Ca(OH)_2$ and CaO cations. Calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) are formed when the minerals in the clay, namely SiO_2 and Al_2O_3, dissolve and react with the calcium produced by the lime. Expansive clays under lime stabilisation are believed to gain strength due to this pozzolanic reaction(Brueckner, 2008).

Soils categorised as CL, CI, and CH are often expansive soils. These soils can also be found in the ML, MI, and MH classes. In certain situations, even soils designated as SC may be expansive. According to index characteristics such potential swell, clay content, linear shrinkage, shrinkage limit, and plasticity index, among others, several researchers have classified expansive soils(Jones *et al.*, 2021).

2.3. Soil

Earth's soil is a complex mixture of minerals, organic materials, gases, liquids, and many microorganisms that work together to support life. The weathering process and associated erosion are two examples of the many physical, chemical, and biological processes that cause soil to change continuously. To obtain desired engineering attributes, stabilisation is typically required in soft soils (silty, clayey peat, or organic soils)(Afrin, 2017).

2.4. Soil stabilization.

Soil stabilization is a mechanical or chemical alteration of one or more soil properties to create an improved soil material possessing the desired engineering properties (Mekonnen *et al.*, 2020)

It is the technique of increasing the soil's bearing capacity by enhancing the shear strength characteristics. When the soil that is ideal for construction cannot support the structural load, it is necessary. In earth structures, soil stabilisation is used to improve the shear strength of the soil mass and decrease its permeability and compressibility. In order to lessen the settling of buildings. Stabilising agents, also known as binder materials, are employed when attempting to improve the geotechnical properties of poor soils (Afrin, 2017).

2.4.1. Soil stabilization methods.

Stabilization of soil is classified in majorly two ways; mechanical and chemical.

2.4.1.1. Mechanical stabilization

The method of increasing the soil's qualities by altering its gradation is known as mechanical stabilisation. This procedure involves applying mechanical energy to the soil through the use of rammers, rollers, vibration techniques, and occasionally blasting. This approach depends on the intrinsic qualities of the soil material to maintain soil stability. To create a composite material that is better than any of its constituent parts, two or more different types of natural soils are combined. To create a material that satisfies the necessary specifications, soils of two or more gradations are mixed or blended to achieve mechanical stabilisation.

2.4.1.2. Chemical stabilization.

This is the remediation technique most frequently employed for expansive soil. The goal of chemical stabilisation of soils is to increase soil stability through cementation, lowering the plasticity index, raising the swelling-shrinking potential, and increasing the grain size of the soil material. A specific number of chemical compounds are introduced into the expanding soils in order to stabilise the soil.

Chemical stabilizers include:

a) Traditional stabilizers (chemical additives) such as; Lime, Cement, Fly ash

b) Non-traditional stabilizers (other additives); Granulated blast furnace slag, dust from cement and lime kiln dust, Bitumen emulsion, calcium-based stabiliser, gypsum, silica fume, and bottom ash (Fondjo, Theron, and Ray, 2021).

2.4.2. Criteria for choosing a suitable stabilizer.

There may be more than one possible stabiliser for a specific type of soil, but there are some broad guidelines that indicate which stabilisers are preferable depending on the characteristics of the soil, such as its texture, granularity, or fluidity (Guyer and PE, 2018). Traditionally, the 2 mostly used chemical stabilizers are cement and lime. To determine which of the 2 is most suitable for a stabilization of a given soil, the MoWT General specifications for reads and bridges series 3000 guide as follows;

Table 1 Criteria for choosing a suitable stabilizer

% passing the 0.075mm sieve BS 1377-2	**Plasticity index (%)** **BS1377: Part 2**	**Best suited stabilizer**
Less than 25%	PI less than 6 or PI x (% passing 0.075mm) is less than 60	Cement only
	6-10	Cement preferred
	More than 10	Cement and/ or lime
More than 25%	Less than 10	Cement preferred
	10 - 20	Cement and/ or lime
	More than 20	Lime preferred

(EAC, 2014)

From the table, it is concluded that cement is generally suitable for soils with a PI less than 20. For a PI above 20, then lime is more suitable.

Additionally, when the PI of the soil is between 10 and 20, then both cement and lime can be used.

Lime is applied to soil with a high PI because it needs clay particles to react in order to be effective. A high PI suggests that the soil can swell to a significant extent. This demonstrates that clay-like soil particles exist.

High PI soils can be stabilised with cement, though lime is typically recommended in these situations. If cement is still required, the material can be pre-treated by adding 2% lime before cement stabilisation to increase the soil's workability.

2.4.3. Factors that affect the strength of stabilized soils.

a) Organic matter

Most soils include a significant amount of organic matter in their top layers. However, in well-drained soil, organic matter can sink up to 1.5 metres. Organic matter in the soil reacts with hydration products, including calcium hydroxide (Ca (OH)2), to produce low PH. As a result, the resulting low pH may impede the 10-hydration process and interfere with the ability of stabilised soils to solidify, making the process of compacting them difficult or impossible.

b) Sulphates

When calcium-based stabilisers are applied to sulphate-rich soils, the stabilised sulphate-rich soil reacts with excess moisture to form calcium sulpho-aluminate (ettringite) and/or thamausite, the product that occupies a larger volume than the total volume of reactants. However, in order for the reaction to proceed, excess water to one that was initially present during the time of mixing may be needed to dissolve sulphate.

c) Sulphides

Sulphides in the form of iron pyrites (FeS2) can be found in a variety of waste materials and industrial byproducts. FeS2 oxidation results in sulfuric acid, which can combine with calcium carbonate to make gypsum, or hydrated calcium sulphate, as shown by the reactions below.

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$$

$$CaCO_3 + H_2SO_4 + H_2O = CaSO_4.2\,H_2O + CO_2$$

When too much water is present, the hydrated sulphate that has formed may attack the stabilised material in a manner similar to that of sulphate. Nevertheless, natural soil contains gypsum as well(Elzahaby, 2019).

d) Compaction

The impact of adding binder to soil density is really significant. For a given level of compaction, the maximum dry density of the stabilised mixture is lower than that of the un-stabilized soil. As the number of binders grows, so does the ideal moisture content. In soils stabilised with cement, the hydration process begins as soon as the cement comes into contact with water. Because the soil mix will be hardened throughout this process, it must be compacted as quickly as feasible. Any delay in compaction may cause the stabilised soil mass to harden, necessitating additional compaction work to achieve the same result. That could result in a severe bond breaking and a subsequent loss of strength. Delays in compaction for soils stabilised with lime may offer benefits not found with cement. For the maximum impacts on plasticity, lime stabilised soil needs to be allowed to flow through the soil during a mellowing period. Following this time, soil stabilised with lime can be mixed again and given a final compaction, giving it an exceptional strength that would not otherwise be possible.

e) Moisture content

Sufficient moisture content in stabilised soils is necessary for effective compaction as well as the continuation of the hydration process. In contrast to quicklime (CaO), which absorbs approximately 32% of its own weight in water from the environment, fully hydrated cement absorbs just 20% of the water in its surroundings. Binders will compete with soils to obtain these levels of moisture if the moisture content is insufficient. The hydration process may be slowed down in soils with high soil-water affinity (such as clay, peat, and organic soils) because of insufficient moisture content, which will ultimately impair the final strength.

f) Temperature

Temperature variations can affect the pozzolanic reaction. The temperature in the field changes all day long. Low temperatures cause pozzolanic reactions between binders and soil particles to slow down, which reduces the strength of stabilised mass. It might be a good idea to stabilise the soil in colder climates during the warm season. (Afrin, 2017).

2.5. Crushed Granite Stone.

Granite is an igneous rock comprised mostly of Quartz, feldspar, micas, amphiboles, and a variety of other trace minerals. The amount and modification of these minerals determine the variety of colours and textures found in granite. For instance, granite containing between 10 and 50% quartz will typically appear semitransparent white, while granite containing between 65 and 90% feldspar will appear pinkish with a white hue. It has been used in construction as an aggregate in the production of concrete, as well as, a decoration as kitchen countertops. Chemically, the primary constituents of granite are SiO_2 (65%-70%), a trace amount of AL_2O_3, CaO, MgO, and Fe_2O_3, making granite an acidic rock (haimei, 2011). Depending on the location, minerals, or contaminants, present in the granite during crystallization, the chemical composition of granite varies substantially.

Affordability of granite stone.

Granite is quite affordable in Uganda for example a tonne of granite goes for about Uganda Shillings 70,000 only and that is at the Stone Quarry in Mbalala, Mukono district from where we got our sample.

This can, thus, support commercial production hence enhancing road construction.

2.6. Municipal Waste Incinerated Ash.

The local hauling company, the city council, and the residents who produced the waste had little to no concern about the chemical, physical, and biological characteristics of the municipal solid waste stream as recently as three to four decades ago. Similar to this, the overall amounts of waste generated received little consideration. Because so few measurements were taken, waste quantities may have seemed to be roughly constant from year to year. For easy final disposal, wastes were hauled to the town dump next to the river or maybe the nearby landfill. At the time, the main issues with trash management were aesthetic and financial, meaning that the materials that were unpleasant needed to be removed from the curb or bin as soon as possible, conveniently, and for the least amount of money(Hill, 2002).

Categories of wastes.

Wastes from industries, manufacturers, utilities, and consumers have a wide range of chemical and physical characteristics. It is practical to classify wastes in order to execute cost-effective management techniques that are advantageous to the environment and public health. Wastes can be categorized, for instance, according to the type of generator—that is, the industry or source that produces the waste stream. Municipal, hazardous, industrial, medical, universal, construction and demolition, radioactive, mining, and agricultural waste are some of the main categories of garbage (Majerova & Martin, 2022).

Physical Composition of Municipal Solid Waste

Chemical Class	General Composition	
Organic	Paper products	Office paper, computer printout, newsprint, wrappings
		Corrugated cardboard
	Plastics	Polyethylene terephthalate (1)[a]
		High-density polyethylene (2)
		Polyvinyl chloride (3)
		Low-density polyethylene (4)
		Polypropylene (5)
		Polystyrene (6)
		Multi-layer plastics (7)
		Other plastics including aseptic packaging
	Food	Food (putrescible)
	Yard waste	Grass clippings, garden trimmings, leaves, wood, branches
	Textiles/rubber	Cloth, fabric
		Carpet
		Rubber
		Leather
Inorganic	Glass	Clear ("flint")
		Amber, green, brown
	Metals	Ferrous
		Aluminum
		Other non-ferrous (copper, zinc, chromium)
	Dirt	Dirt
		Stones
		Ash
	Bulky wastes	Furniture, refrigerators, stoves, etc. ("white goods")

[a] Plastics coding system, Society of the Plastics Industry, Inc.

Figure 2. 1 Physical Composition of Municipal Solid Waste.

HAZARDOUS WASTE

Hazardous wastes are produced by most, if not all, of the sources listed. However, both the generator and the trash must comply with federal and state standards when the monthly quantity created surpasses a predetermined threshold. As per 40 CFR 240.101, hazardous waste is defined by RCRA as any waste or combination of wastes that present a significant risk to human health or living organisms due to their non-biodegradable or persistent nature, their ability to be biologically amplified, their potential for lethality, or their potential to cause adverse cumulative effects. Alternatively said, an RCRA hazardous waste is a solid waste that has the potential to increase death, serious illness, or incapacitation due to its quantity, concentration, or physical, chemical, or infectious features.

According to the RCRA laws, solid wastes that display any one or more of the following traits are considered hazardous: toxicity, ignitability, corrosivity, and reactivity(Dewling and Pikul, 2006).

Remainders from the production of solvents, electroplating, metal treatment, wood preservation, and petroleum refining are a few examples of hazardous wastes. Compared to regular MSW, regulations mandate much stricter management of these wastes. For instance, a comprehensive "paper trail" detailing the waste's condition from the site of generation to the points of interim storage, transportation, treatment (if any), and final disposal is necessary. Strict regulations apply to waste-generating establishments, carriers, and facilities for treatment, storage, and disposal. The "cradle to grave" method of managing hazardous wastes has been essential in encouraging good management practices(Dewling and Pikul, 2006).

INDUSTRIAL WASTE

Every year, industrial establishments generate and manage billions of tonnes of industrial solid waste on-site; this number is almost four times more than the MSW produced (Tammemagi, 1999). Industrial wastes are byproducts of manufacturing and other activities and are produced by a wide range of facilities. Most of these wastes—though not all of them—are produced in sizable amounts by a single generator and have modest toxicity levels. Coal combustion solids, such as bottom ash, fly ash, and flue gas desulfurization sludge, are examples of an industrial waste stream. The chemical, iron and steel, and pulp and paper industries are other frequent contributors of industrial trash. Waste Management Techniques: Federal and state laws typically do not explicitly classify municipal, hazardous, or industrial waste as either of those categories. If laboratory tests and an understanding of the relevant processes lead to the designation of an industrial waste stream as hazardous waste, the waste needs to be treated as such and transported to a licenced facility for treatment, storage, and disposal. Nonhazardous wastes are either burned or dumped at landfills or land application units, which are usually situated on business property. Wastewater is a major component of industrial waste and is either treated or held in surface impoundments. Eventually, treated wastewaters end up discharged into surface waterways through the National Pollutant Discharge Elimination System (NPDES) with licences granted by state governments under the Clean Water Act. It is the regulatory duty of state and some local governments to guarantee proper handling of industrial waste. As a result, regulatory programmes will differ greatly.

UNIVERSAL WASTE

These include:

- batteries used in electronic devices, cell phones, and portable computers, such as nickel-cadmium and tiny lead-acid batteries
- agricultural pesticides that have been recalled or banned from use, or are obsolete;
- thermostats that contain liquid mercury; and
- lamps that contain mercury or lead.

Both large and small enterprises subject to RCRA regulations produce universal wastes, and they were obliged to categorise the aforementioned materials as hazardous wastes. To lessen the regulatory burden on companies that produce these wastes, the Universal Waste Rule was initially published in the Federal Register in May in the year 1995. In particular, the Rule streamlines notice, labelling, marking, prohibitions, accumulation time restrictions, staff training, off-site shipments, exports, tracking, and transportation requirements. Households also generate universal wastes, which are allowed to be disposed of in the garbage since they are not subject to RCRA regulations. Because the Universal Waste Rule makes it easier for businesses to set up collection programmes and take part in manufacturer take-back initiatives mandated by certain states, it is highly supported by a wide range of industries. Industry is also drawn to the significant cost advantages that result from not having to handle the aforementioned wastes as hazardous. State-by-state variations exist in the way universal waste programmes are implemented; for instance, some states have added their own universal wastes to the list provided by federal regulations.

Source Reduction

The design, production, acquisition, or usage of materials—such as products and packaging—in a way that minimises their quantity or toxicity prior to their entry into the waste management system is known as source reduction or waste prevention. To put it another way, the issues of responsibility, storage, collection, and disposal costs are eliminated when the waste is not produced. Source reduction initiatives include, for example (U.S. EPA, 2001):

- Creating products that minimises the toxicity of the materials used or facilitates their reusage.
- Recycling already-existing goods, such as reusable pallets, refillable bottles, and reconditioned barrels and drums.
- Extending the lifespan of goods to delay disposal, such as tyres.
- Making use of packaging that minimises product deterioration.

Incineration

The controlled burning of wastes that are solid, liquid, or gaseous is known as incineration. "Controlled" circumstances could involve using an oxygen-enriched combustion chamber at high temperatures, using supplementary fuel, agitating the incoming waste vigorously, and using a forced air system the entire time. Incineration is used to dispose of about 15% of the MSW that is generated. The primary goal of incineration is volume reduction, which ultimately prolongs the life of a facility used for land disposal. Heat energy recovery from combustion for the purpose of heating water or space or generating power has been dubbed "waste to energy." Detoxification, or the elimination of microorganisms and other harmful species from the trash, is the third advantage of burning garbage.

The word "controlled" is stressed here in the description of incineration to set the technology apart from open burning or other equally flawed methods. Although reductions of 50 to 60% are more realistic, it has been reported that incineration can reduce the volume of MSW by 80 to 90%. There have been reports of reductions of up to 95–99% of the combustible portion, which includes paper goods, plastics, food trash, and yard garbage. Additional volume reduction will come from compacting the ash residue, and volume reduction will increase as metals are recovered from the residue. Consequently, only 25% of the MSW that is first processed in a municipal incinerator and then compacted in a landfill may remain after processing. It is expected that a disposal facility's lifespan can be doubled by combining sanitary landfilling with incineration. "Waste to energy" refers to the second goal of incineration, which is the recovery of thermal energy from burning for the production of electricity or water heating. Detoxification of the waste, or the elimination of microorganisms and other harmful organisms, is a third, albeit unintentional, advantage of burning trash. Because MSW has such a varied composition, it produces a wide range of wastes that will need further processing and disposal.

The substances that remain are Acidic gases (such as SO2, NO2, and HCl), trace gases that are dangerous at very low quantities, such as chlorinated dibenzodioxins, Particulate matter (which is sometimes referred to as "fly ash," dust, and soot, bottom ash from incinerators) carried by the gas stream might be liquids or solids suspended in the air stream (NAS, 2000).

THE MASS-BURN INCINERATOR

Without a doubt, the simplest incineration process is mass burning, which involves burning MSW immediately off of the collecting truck. Simple trash blending and the removal of big, bulky objects like appliances (including stoves and washing machines), huge, combustible furniture, beds, and other things, as well as hazardous materials, are the only processing steps needed. In the garbage storage pit, the removal is frequently completed by the crane operator. Therefore, the avoidance of capital and operating costs associated with considerable waste handling is a major benefit of mass-burn systems, even beyond their relative simplicity. Certain incinerators might make use of shredding machinery to break down large objects into manageable pieces. The ease of mass burning is matched by several serious health and environmental issues, as will become clear.

According to (Hickman, 1984) There are four main categories into which a mass-burning incineration can be divided:

• Burning without recovering energy

• Utilising modular furnaces for incineration

• Burning with heat recovery boilers in refractory furnaces

• Burning in water wall furnaces

MSW is emptied into a pit for storage. The pit needs to be big enough to hold enough garbage to run consistently and steadily for 24 hours a day, seven days a week. The MSW charge is subsequently moved by crane into loading hoppers, where it descends naturally into the furnace. Depending on the type of boiler, the combustion zone temperature varies, although it is typically kept between 615 and 9050 C. This temperature range maximises combustion and reduces the generation of odorous chemicals. These temperatures are also sufficient to safeguard the combustion chamber's refractory linings. Through a series of agitating grates, the waste is transported through the combustion chamber. There are just a few different kinds of grates that are used, and they are all designed to move trash through the firebox, stir things up, and move under-fire air upward. The MSW is stirred for more thorough combustion by the grate's rocking or spinning motion. The grates have holes through which ash can drop and land in a collection bin. This leftover material is known as "bottom ash." More unburned residue is transported to the grates' end, where it is gathered and mixed with additional bottom ash. The charge is dispersed across the grate surface several inches thick during the bulk burn of MSW. Waste and air mix during agitation, forcing the air over the grates (overfire air). The fuel gas, any gases produced by the MSW, and any particulate matter coming from the grates are all partially burned by the overfire air. Moreover, air is diverted beneath the grates. This under fire air, which makes up between 40 and 60 percent of the air that enters the furnace overall, cools the grates and fuels the combustion process. Insufficient under-fire air flow can raise grate temperatures and cause ash to become softer and clog the grates, leading to grate damage and subpar combustion. Boilers and water walls receive heat from the combustion gases. The main function of boilers, which are enclosed systems with controlled combustion, is to collect and export usable thermal energy as steam, or hot water (U.S. EPA, 2002).

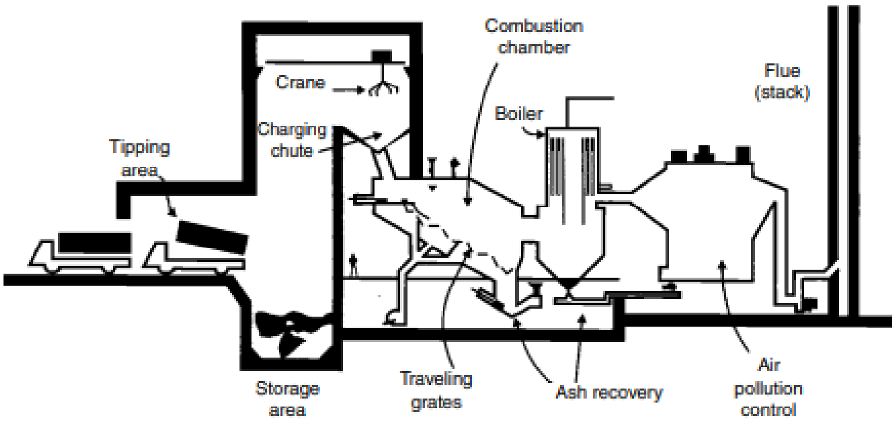

Figure 2. 2 Illustration of a cross section of a typical boiler.

(From Holmes, J.R., Refuse Recycling and Recovery, Wiley, New York, 1981. Copyright John Wiley and Sons Limited.)

MASS BURN ENVIRONMENTAL CONSIDERATIONS.

Mass burning is a straightforward and rudimentary technique for destroying garbage. Many unwanted and dangerous byproducts are so unavoidably produced.

Mass incineration of waste to attain ash, while it can offer benefits such as reducing landfill use and generating energy, also poses significant environmental considerations. Here are some key points to consider:

- **Air Pollution**: Incineration releases various pollutants into the air, including particulate matter, heavy metals, dioxins, and furans. These pollutants can have detrimental effects on both human health and the environment.

Particulate matter, for instance, can cause respiratory problems, and dioxins and furans are highly toxic and can bioaccumulate in the food chain.

- **Greenhouse Gas Emissions**: Incineration generates carbon dioxide (CO2), a greenhouse gas that contributes to climate change. While waste-to-energy plants may produce less CO2 compared to fossil fuel-based energy sources, they still emit CO2 and other greenhouse gases. Moreover, incinerating certain materials, like plastics, can release additional greenhouse gases if not managed properly.
- **Ash Disposal**: The ash produced from incineration contains concentrated amounts of heavy metals and other pollutants from the burned waste. Proper disposal of this ash is critical to prevent contamination of soil and water sources. If not managed carefully, leaching of contaminants from the ash can pollute groundwater and harm ecosystems.
- **Resource Consumption**: Incineration requires energy for the combustion process, as well as for the operation of pollution control systems. This energy consumption contributes to overall resource depletion and may offset some of the environmental benefits of waste reduction and energy generation.
- **Impact on Recycling and Waste Reduction Efforts**: Mass incineration can potentially discourage recycling and waste reduction efforts. If communities rely too heavily on incineration as a waste management solution, there may be less incentive to prioritize recycling, composting, and other methods of waste diversion, which are generally more environmentally sustainable in the long term.

- **Health Concerns for Workers**: Workers in incineration facilities may face health risks due to exposure to pollutants and hazardous materials. Proper safety measures and monitoring systems must be in place to protect workers from these risks.
- **Community Concerns**: Incineration facilities often face opposition from nearby communities due to concerns about air pollution, odors, and potential health impacts. Addressing these concerns through transparent communication, rigorous emissions control, and community engagement is essential for gaining public acceptance and trust.

In summary, while mass incineration of waste can offer certain benefits, it also poses significant environmental challenges that must be carefully managed through effective regulation, technology, and public engagement to minimize negative impacts on human health and the environment. Additionally, prioritizing waste reduction, recycling, and other sustainable waste management practices can help reduce the need for incineration and its associated environmental burdens.

GAS WASHING

Gas washing, also known as wet scrubbing or gas scrubbing, is a method used to remove pollutants from industrial gas streams. It involves passing the gas through a liquid, typically water or a chemical solution, to capture and neutralize contaminants.

Because wet scrubbers can successfully remove both particle and gaseous contaminants, they have gained popularity for cleaning contaminated gas streams. In wet scrubbing, a liquid that is added to the scrubbing apparatus as a finely atomized mist is brought into close contact with a polluted gas stream.

Here are some of its advantages and disadvantages:

Advantages.

1. Pollutant Removal: Gas washing is effective in removing various pollutants from gas streams, including particulate matter, acidic gases (such as sulfur dioxide and hydrogen chloride), and certain volatile organic compounds (VOCs). This helps to reduce air pollution and minimize the release of harmful substances into the atmosphere(Lam *et al.*, 2010).
2. Versatility: Gas washing can be tailored to remove specific pollutants by selecting the appropriate scrubbing solution and adjusting operating parameters such as temperature, pH, and contact time. This versatility allows for the treatment of a wide range of industrial emissions.
3. Relatively Low Cost: Compared to some other air pollution control technologies, gas washing can be relatively cost-effective to implement and operate, particularly for smaller-scale applications or when treating gas streams with lower pollutant concentrations.
4. Energy Recovery: In some cases, heat or energy can be recovered from the scrubbing process, such as by using waste heat to preheat the scrubbing solution or by generating steam for other industrial processes. This can improve the overall energy efficiency of the system.
5. Reduced Environmental Impact: Gas washing can help industries comply with environmental regulations and reduce their environmental footprint by minimizing emissions of pollutants that contribute to smog, acid rain, and other forms of pollution.

Disadvantages.

1. Waste Generation: Gas washing generates liquid waste, known as scrubber liquor or effluent, which may contain dissolved pollutants, excess scrubbing chemicals, and other contaminants. Proper treatment and disposal of this waste are necessary to prevent environmental harm.
2. Chemical Usage: Some gas washing systems require the use of chemicals, such as alkalis or oxidizing agents, to neutralize acidic gases or react with specific pollutants. The handling, storage, and disposal of these chemicals can pose environmental and health risks if not managed properly.
3. Water Consumption: Gas washing consumes water as the scrubbing medium, and large-scale scrubbing systems can require significant amounts of water. In water-scarce regions or during drought conditions, this water usage may be a concern and could compete with other water-intensive activities.
4. Maintenance Requirements: Gas washing systems require regular maintenance to ensure optimal performance, including monitoring and replenishing scrubbing solutions, inspecting and cleaning equipment, and addressing corrosion and fouling issues. Neglecting maintenance can lead to decreased efficiency and increased operating costs.
5. Space and Infrastructure Requirements: Gas washing equipment can be bulky and require significant space for installation, particularly for large industrial-scale applications. Additionally, infrastructure such as pumps, tanks, and piping may be necessary to support the scrubbing system, adding to the overall cost and complexity of implementation.

One of the most prevalent gaseous pollutants from the burning of MSW and other materials, including coal, is sulphur dioxide. The main method for removing sulphur dioxide from stack gas has been the condensation of SO2 to sulfuric acid for many years by coal-burning utilities and other large-scale SO2 emitters. Since SO2 dissolves fairly easily in water, the acidic liquid that results is collected and prepared for disposal. The following reactions for SO2 capture are the same as those previously mentioned for the creation of acid rain: $SO_2 + O_2 \rightarrow SO_3$

$SO_3 + H_2O \rightarrow H_2SO_4$ (aq)

To absorb the SO2, a solution of quicklime or limestone can also be prepared. When quicklime is used, the result is

$SO2 + CaO \rightarrow CaSO_3$ (s)

The reaction with limestone is

$SO2 + CaCO_3 \rightarrow CaSO_4$ (s) + CO2

Lime materials can be added to the combustion chamber or sprayed straight into the scrubber. Quicklime is created when limestone is fed into the furnace and reacts quickly:

$CaCO_3 \rightarrow CaO + CO_2$

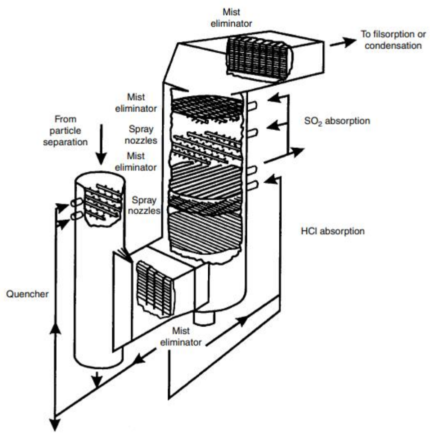

Figure 2. 3 Scrubber (packed tower) for washing acid gases (U.S. EPA, EPA/625/6-829/024, 1990).

METALS

Ash may have large quantities of some relatively less dangerous metals including Cu, Zn, Fe, and Al as well as other more toxic metals like Cd, Pb, As, Be, V, and Hg. Lead and cadmium concentrations in fly ash are thousands of times higher than those in bottom ash, but they are still far higher than those in uncontaminated soils. By removing the matrix elements like paper and plastic that held the metals and had limited their escape into the biosphere, the burning process concentrates these metals in the ash. Metals become much more accessible once they are in the form of ash. For instance, metals like lead and cadmium are easily leachable from ash at amounts that often surpass government criteria for being classified as hazardous waste. Toxic metals are a common component of many consumer goods that end up in municipal garbage.

ASH MANAGEMENT

The rate at which a particular metal will dissolve from ash and find its way into groundwater supplies or other environmental receptors is known as the leachability of heavy metals in ash. It has been the focus of concerns over ash mobility and toxicity (Qili & Xuguang, 2016). However, others have criticised the "leachability methods" for being insufficient for determining toxicity. In addition to contaminated groundwater, there are other ways that ash can expose people and the environment, therefore it is important to take into account the overall amounts of both metals and PCDDs when evaluating the toxicity of ash. For instance, ash particles can be inhaled by humans, and the poisons on the particles then enter the bloodstream or tissue directly. Furthermore, ash particles could be consumed directly or through contaminated food or drink. Data on the entire chemical makeup of ash must be included in a comprehensive evaluation of the risks it poses because these exposure routes can be quite important. Several steps must be taken to lessen the risk associated with metals and other pollutants in ash (Denison and Rustin, 1990):

- Preventing dangerous metals from getting into products that could end up in the waste stream;
- Preventing metal-containing items from going into incinerators;
- Preparing ash for disposal by chemically or physically treating it (mixing it with Portland cement, for example, and letting it set).

The density of noncompacted MSW ash can reach 900 kg/m3. The density can reach 1980 kg/m3 if the ash is compacted. The ash is extremely impermeable at this density; permeability could be as low as 1 x 10 - 9 cm/sec (Vesilind et al., 2002). Other uses for ash are being studied, such as pavement material, structural fill, ditches for gravel drainage, mines for capping strip and adding to cement to make construction blocks, as ash production increases and landfill space becomes increasingly scarce.

Additionally, recyclable metals, particularly steel and aluminium, can be recovered from the ash left over after MSW is burned.

Because of its pozzolanic properties, fly ash has been recycled for many years as an engineering material (Ghosh and Subbarao 1998). Regulatory bodies are pushing for the more advantageous use of fly ash due to the higher expense and possible environmental effects of landfilling (Ghodrati et al. 1995). Nevertheless, not many studies have looked into the idea of using fly ash from municipal trash incineration instead of mineral filler for pavement, particularly in Uganda. The goal of this research is to determine whether fly ash from municipal trash incineration can be used as a mineral filler in asphalt mixtures by examining the mixes' leaching characteristics and performance.

Incinerating municipal garbage Fly ash is a type of residue from municipal waste burning that includes a wide range of items, such as glass, paper, plastics, metals, and food waste (Liu et al. 2018). The most extensively utilised technique for managing municipal trash is the dumping of the leftover ash from incineration into a landfill (Xie et al. 2009). According to research by Hong et al. (2000), burning solid waste reduces waste overall by 90% in volume and 75% in weight. The production of municipal waste has grown dramatically during the past few decades on a global scale (Rajor et al. 2012). Uganda produces 93,075 tonnes of urban garbage annually, averaging 0.8-1.67 kg/bed/day (Syed et al. 2012; MOHFW, 2011).

Fly ash is typically disposed of in regulated landfills in order to minimise the contaminating impacts of the ash. These days, especially in densely populated cities, the lack of sufficient disposal sites, high costs, stringent regulations, and regular public opposition to the creation of new landfills are causing problems on a daily basis (Cangialosi et al. 2006; Anamul et al. 2012).

As a result, treating burnt fly ash prior to disposal becomes crucial (Akter 2000; Dermatas 2001). There are now a number of traditional techniques for treating fly ash. These methods are classified into three categories, such as; separation, solidification/stabilization (S/S), and thermal (melting, roasting, sintering, and low temperature treatment (Quina et al. 2008; Zhou et al. 2017). These methods either remove heavy metals from fly ash or stabilize heavy metals in an insoluble form.

Nonetheless, the most common technique for handling toxic waste is stabilisation, which entails combining the trash with a binding substance and decreasing both its toxicity and the mobility of heavy metals from the waste before disposing of it. According to Dermatas (2001), it transforms hazardous waste into a waste form that is appropriate for the environment for building or land disposal. Particularly suitable for wastes containing heavy metals is stabilization/solidification, a pre-landfill waste treatment technique (Malviya and Chaudhary 2006). Fly ash stabilisation in building materials is discussed by Agamuthu and Chitra (2009) as a safe and efficient disposal method. The process of stabilization/solidification has made significant developments in environmental technology possible. S/S has been extensively utilised for the cleanup of contaminated areas as well as the disposal of mixed and low-level hazardous wastes. The US Environmental Protection Agency (USEPA) states that for 57 wastes, S/S is the best proven available technology (BDAT). In order to handle hazardous and other waste kinds from industry, municipalities, and government sources, numerous S/S systems are being advocated and supplied.

The term "solidification" refers to a process that reduces waste to a single, highly structurally intact monolithic solid without requiring the waste and the reagents to react chemically excessively. Pollutant movement will be controlled by enormously reducing the surface area exposed to leaching or detaching the waste within an impermeable shell.

(Conner 1990) described that solidification/stabilization is an economical process for disposing of many waste types. The method involves mixing liquid or semi-solid wastes with binders to produce a solid, structurally sound, and impermeable solid.

The following list includes a few studies on the stabilisation and solidification of ash from municipal trash incineration.

Singh et al. (2016) used experiments to study the impact of partial replacement of cement with waste ash. The workability declined at a constant superplasticizer dose of 0.6% as the replacement level increased, according to the results. Additionally, research demonstrated that when replacement level increased, the density of fresh concrete somewhat dropped. Furthermore, the concrete produced using waste ash has a compressive strength that is higher up to a 7.5% replacement level and comparable to conventional concrete up to a 10% replacement level.

Al-Rawas et al. (2005) prepared two sets of mixes to investigate the potential substitution of incinerator ash for sand and cement in cement mortars. There were two samples ready. The amounts of cement and water were maintained constant, but the weight percentages for sand in the first set were used to replace the incinerator ash at0%,10%,20%,30%, and 40%. In the second set, cement, sand, and water quantities were fixed, and incinerator ash was substituted at weight ratios of 0%, 10%, 20%, and 30%. The study employed a mixing ratio of 1:3:0.7 for cement, sand, and water, respectively. The findings showed that when incinerator ash was substituted for sand, the slump values decreased, but when cement was substituted, the slump values increased. For the majority of the curing times, the mix made with 40% incinerator ash instead of sand had a higher compressive strength value than the mix made without incinerator ash. After 28 days of curing, the sample containing 20% incinerator ash reached its maximum compressive strength of 36.4 MPa. After a 28-day curing period, specimens set with 20% incinerator ash substituted for cement had a higher compressive strength (27.4 MPa) than the control mix.

Reijnders et al. (2005) studied the use of 50% of the ash produced from burned garbage to make sound-absorbing walls for German national highways. In the Netherlands, asphalt and a sublayer of roads were built using about 60% of the bottom ash. In Denmark, more than 72% of the ash is recycled to build parking lots, bike lanes, and other roads.

Al-Mutairi et al. (2004) compared the compressive strengths of mixtures made from bottom and fly hospital ash with micro silica and conventional concretes in order to assess the efficacy of reusing hospital incinerator ash. At 25°C, 150°C, 250°C, 500°C, 600°C, and 800°C, the impact of different percentages of micro silica, fly ash, and bottom ash on the compressive strength was also assessed. The results demonstrated that the cubes' compressive strength increased greatly when fly ash and micro silica were added at 5%. However, when fly ash, bottom ash, and micro silica were substituted for cement at 15%, 20%, and 25% of the cement, the cubes' compressive strength decreased and their workability decreased. It is evident that a substitution of 5% silica and fly ash is ideal. Bottom ash and micro silica had nearly identical compressive strengths with 25% cement replacement over 250°C.

The various mixes made by mixing regular Portland cement with bottom ash from hospital waste incineration in various ratios and water dosages were examined by Filipponi et al. (2003). Bottom ash showed poor pozzolanic properties when the curing durations exceeded 28 days and the waste dosages above 50%.

CHAPTER THREE: METHODOLOGY

3.1. Introduction.

This chapter is to provide a detailed explanation for the laboratory tests and procedures that are to be carried out in this research.

3.2. Materials and methods.

- To determine the engineering properties of the neat soil, a sample of this soil will be obtained by using 3 trial pits and collecting samples from 3 different points in the trial pits. The following tests will then be carried out on the soil.

Table 2 Tests carried out for objective one

TEST	**STANDARD**
Particle size distribution through sieve analysis Atterberg to obtain liquid limit, shrinkage limit and plastic limit Dry density of soil corresponding to optimum moisture content through Maximum dry density test. (MDD) CBR test	**BS1377: Part 2: 1990 BS1377: Part 2: 1990** **BS1377: Part 4: 1990** **BS1377: Part 2: 1990**

- To categorize the waste used for incineration

PROCEDURE	STANDARD
Identify the source/origin of the waste. Determine the constituents/composition of the waste. Classify the waste according to the standards	National Environment Management Authority (2020).

Table 3 Methodology for objective 3

- To determine the engineering properties of Crushed Granite Stone and MWIA;

Table 4 Tests carried out for objective two

TEST	**STANDARD**
X-Ray fluorescence (XRF) to obtain chemical composition of MWIA and CGS PSD of the MWIA and CGS	**ASTM D5381-93 (2021)** **BS1377: Part 2: 1990**

- To determine the variation of strength values with the different percentages of MWIA and CGS when added to the soil.

Table 5 Tests carried out for objective three

TEST	**STANDARD**
Proctor test	**BS1377: Part 4: 1990**
CBR test	**BS1377: Part 4: 1990**
Unconfined Compressive Strength (UCS)	**BS1377: Part 2: 1990**

On the plot of dry densities against comparable moisture contents, a curve of best fit should be generated. The maxima of the curve should yield the MDD and the OMC for each type of soil.

CHAPTER FOUR: RESULTS AND DISCUSSIONS.

4.1. Introduction

The laboratory results from the tests conducted for this study are shown in this chapter. The data is analysed and discussed from the results of the tests carried out. So far, the tests carried out were to determine the engineering properties of expansive soils and these tests included sieve analysis, Atterberg limits, California bearing ratio and Proctor test. Other tests were carried out to determine the engineering properties of Crushed granite and Ash from waste incineration and these were sieve analysis and X-Ray Fluorescence test respectively.

4.2. Classification tests.

4.2.1. Neat soil

The neat soil used in this study was greyish-black. The soil was classified using USCS as CH fat clay from grading.

4.2.1.1. Sieve analysis

Table 6 Results from sieve analysis of neat sample.

Sieve Size (mm)	Passing (%)	Grading Limits (G60 & 80)	
63.0	**100**	100	100
37.5	**100**	80	100
20.0	**100**	60	95
5.0	**100**	30	65
2.00	**99**	20	50
0.425	**90**	10	30

0.075	**69**	5	15
Grading Modulus	**0.42**		

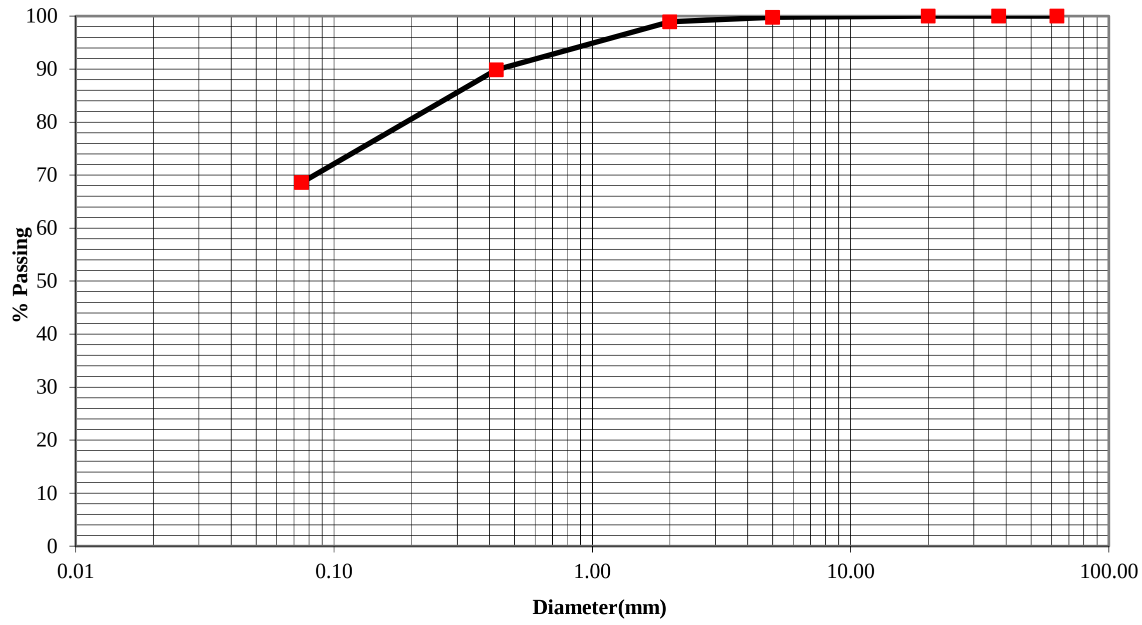

Figure 4. 1 Particle Size Distribution Chart for neat soil sample.

From the graph, the neat soil had 1.28% gravel, 29.57% sand and 69.15% fines. The high percentage of fines contributes to the high plasticity of the soil. The behaviour of the particles size distribution curve for the neat soil sample shows a significant number of fine-grained particles, a wide range of particle sizes, and a lack of well-defined particle size peaks.

According to AASHTO, when more than 35% of the soil is passing through 0.075mm sieve, it is denoted as fine-grained soil and this implied that is has a higher ability to retain water hence a higher moisture content which can affect the strength of subgrade as the water weakens materials.

In summary, the soil sample has a fine particle size distribution and is poorly graded.

4.2.1.2. Atterberg limit tests.

Atterberg limits are a basic measure of the critical water contents of fine-grained soils such as silt and clay as they transition from solid to liquid. They can also be referred to as consistency characteristics of the soil. A summary of Atterberg limits test results of the neat soil sample is summarized in table

Table 7. Consistency characteristics of neat soil sample.

Consistency characteristics	
Liquid Limit (%)	57.5
Plastic Limit (%)	27.5
Plasticity Index (%)	30
Linear shrinkage (%)	15.0

The soil had a high liquid limit of 57.5% which implied high compressibility as well as a high shrinkage or swelling potential. Having a high liquid limit directly implied a plasticity index. This indicated an excess of clay material in the neat soil.

Table 8 Rating of linear shrinkage

Category	**Linear shrinkage (%)**	**Expansive rating**
Low	0-12	Non-Critical
Medium	12-17	Marginal
High	17-22	Critical
Very High	>22	Very Critical

Linear shrinkage is used to estimate the swell and shrink behaviour of the soils. A shrinkage of 15.0% lies within the range of critical chance for cracking due to swelling and shrinking.

4.2.1.3. California Bearing Ratio.

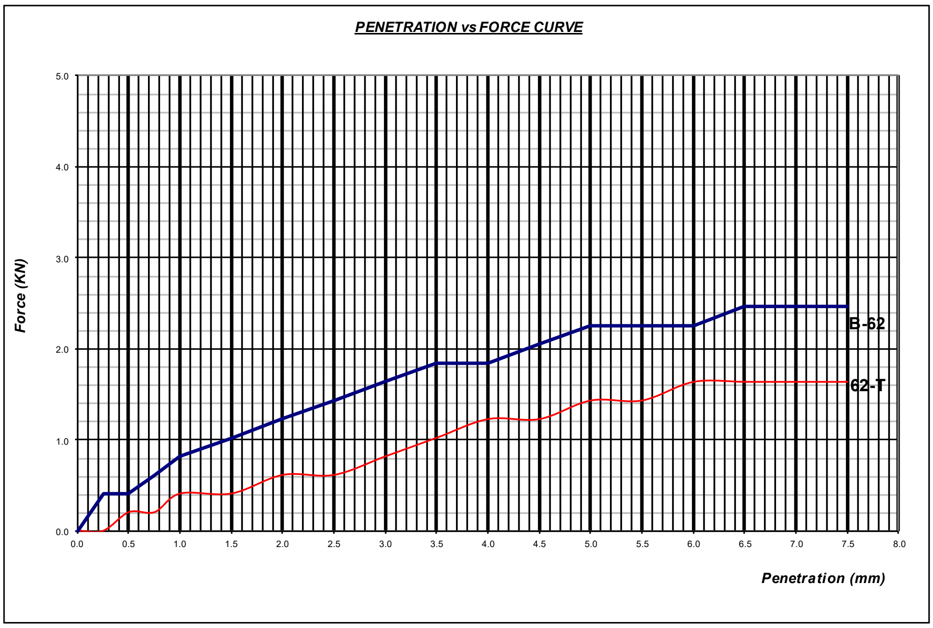

Figure 4. 2 Graph of penetration against force

Based on MoWT (2005), the minimum standard required CBR after 4 days of soaking is 15 for subgrade but the neat soil sample had a CBR of 11.1% days after 4 days soaking, hence it is weak material for subgrade construction thus required stabilization order to achieve the required strength according to the standard.

Furthermore, in the research, one-point method was used since the material would not be enough for three-point method and the material was compacted to 100% of MDD for BS light compaction.

4.2.1.4. Proctor test.

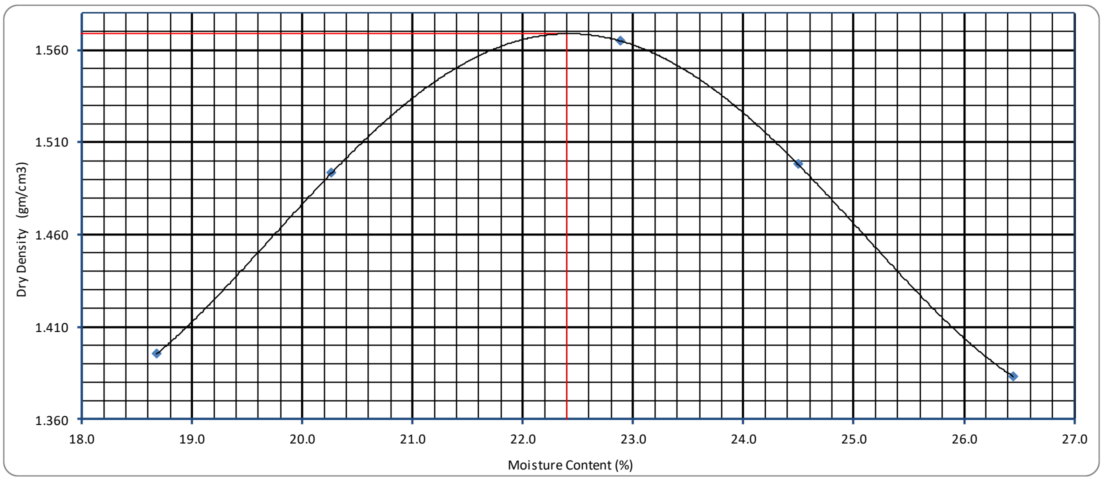

Figure 4. 3 Graph of dry density against moisture content.

The soil sample had a maximum dry density of 1.569gm/cm3 and an optimum moisture content of 22.4%. These parameters show the compaction levels of the soil.

4.2.2. Properties of waste incinerated ash

The ash was a dark-coloured material passed through sieve size 300 micro-meter to remove excess unwanted material.

4.2.2.1. X-Ray Fluorescence Test

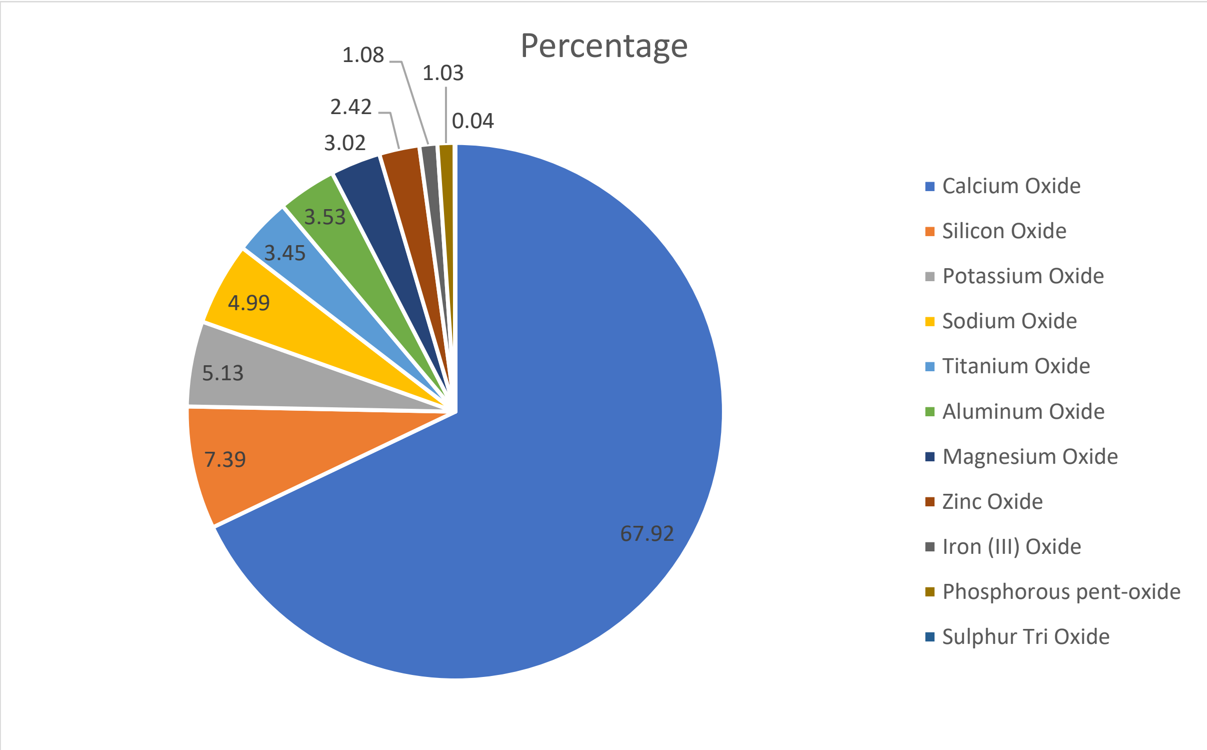

Figure 4. 4 Chemical composition of waste incinerated ash

From the test results above, a Calcium Oxide (CaO) value of 67.92% will contribute greatly to this stabilization process through the formation of hydration products, enhancing soil strength and durability. The minimum percentage of CaO required in a stabilizing agent is 60% so this material qualifies as one.

4.2.3. Properties of Crushed Granite Stone.

The crushed granite stone was greyish in colour and it was majorly gravel.

Figure 4. 5 Crushed Granite stone

4.2.3.1. Sieve Analysis

Table 9 Results from sieve analysis of crushed granite stone.

MAXIMUM SIEVE SIZE (mm)	Cumulative passing (%)	SPECIFIED LIMITS *(spec table 3902/2)*(%)
37.5	100	100
28.0	95	87—97
20.0	88	75 - 90
10.0	63	52 - 68
5.0	43	38 - 55
2.0	31	23 - 40
1.18	24	18 - 33
0.425	16	11 - 24
0.075	7	4 - 12

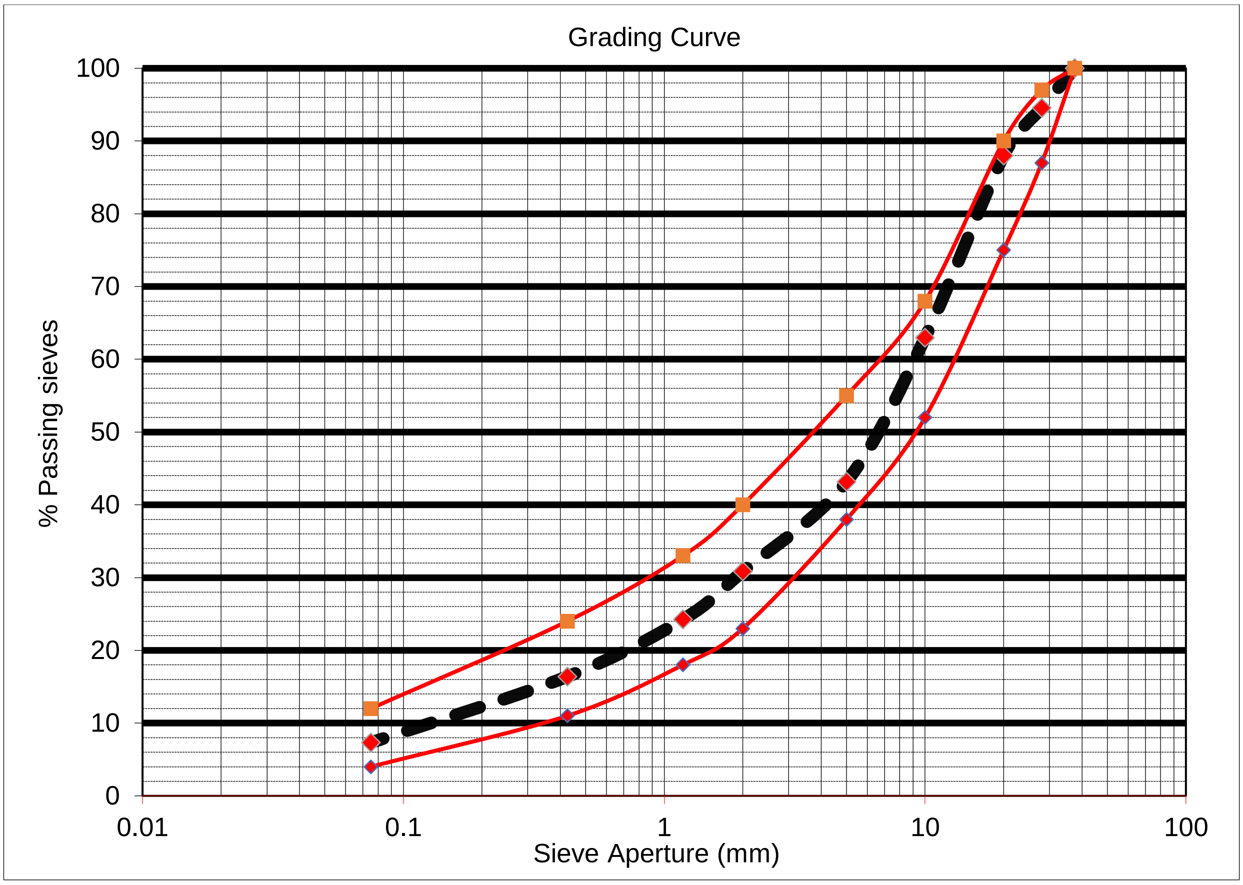

Figure 4. 6 Grading Curve for crushed granite stone.

The crushed granite stone was sieved and it was noted to have 74.46% gravel, 25.33% sand and 0.21% fines. The high percentage of gravel will enable in the interlocking of granite particles with soil particles hence filling voids present in the expansive soils, which will increase the Maximum Dry Density of the soil whilst reducing its Optimum Moisture Content.

4.2.4. The effect of the stabilizers in the soil.

4.2.4.1. Proctor test.

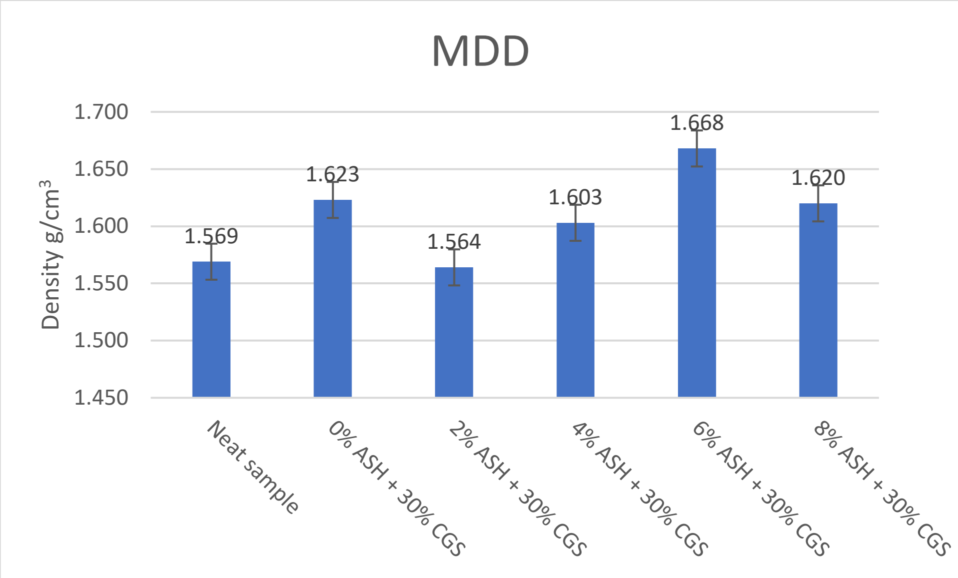

Figure 4. 7 MDD graph for the different percentages of the stabilizers

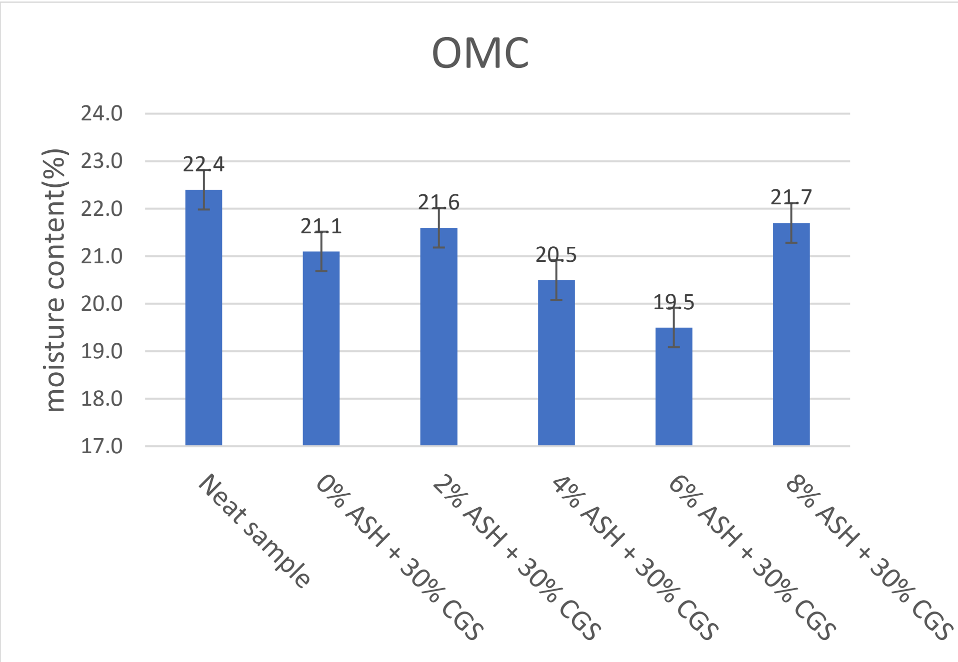

Figure 4. 8 Moisture Content graph for the different percentages of the stabilizers.

30% CGS improves soil's density and reduces the moisture content due to interlocking properties of the CGS.

There is an increase in density of the soil and a corresponding decrease in moisture content with increase in ash from 2% to 6% because the reaction between ash and the clay properties of the soil creates a strong bond and reduces water intake of the soil.

However, beyond the threshold (6% ash content), the MDD starts to decrease due to excessive addition of ash, which might lead to overcrowding of particles, hindering proper compaction and resulting in reduced density.

4.2.4.2. California Bearing Ratio test.

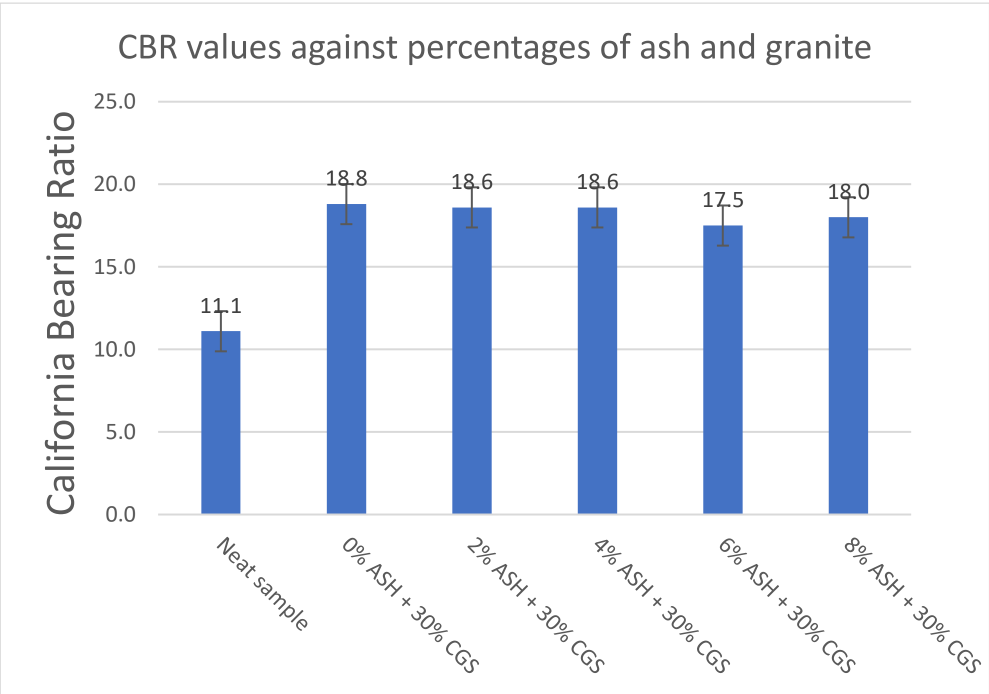

Figure 4. 9 CBR graph for the different percentages of the stabilizers.

Explanation.

Replacement of 30% of the soil with CGS leads to increase in CBR value of about 7.7%. This is due to the interlocking properties of the CGS that fills the voids within the soil hence increasing the particle density of the soil which increases the resistance to loading.

However, introduction of 2% ash at each stage leads to decrease in the CBR value and this is attributed to the fact that the neat soil sample is replaced with more fine particles that may not be able to withstand imposed loads.

4.2.4.3. Atterberg limits test

a) Plastic Limit.

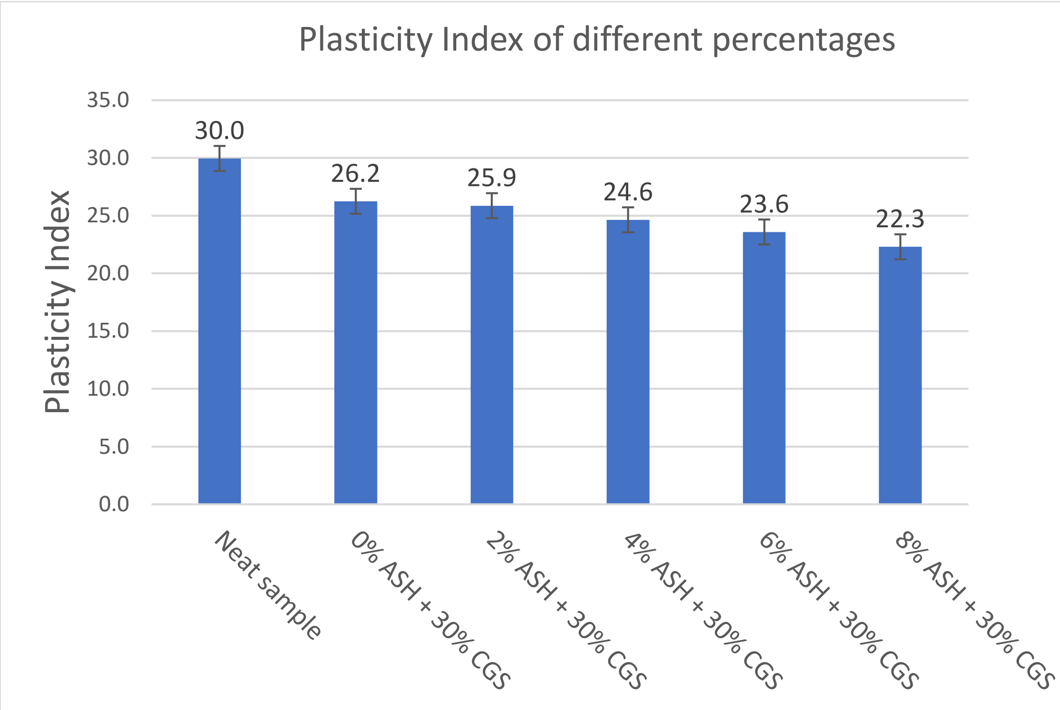

Figure 4. 10 Plasticity Index graph for the different percentages of the stabilizers.

The plasticity index (PI) is a measure of the plasticity of a soil, which is the ability of the soil to change its shape without cracking or breaking.

Introduction of 30% CGS causes a sharp fall in the PI values and this is because the clay content is replaced with granite stone which is non plastic.

From the graph, as the percentage of ash in the mixture increases, the plastic index decreases. This can be explained by the fact that the addition of ash to soil reduces the clay content and increases the ash content, resulting in a less plastic soil.

This is as a result of the components that support plasticity being present in less amounts. Consequently, as the ash-clay particle bond increases, the number of bonds between the clay particles decreases. Furthermore, the granite stone particles have a more angular shape compared to smoother clay particles, which can create interlocking structure that increases the soils strength and reduces its plasticity.

b) Linear shrinkage.

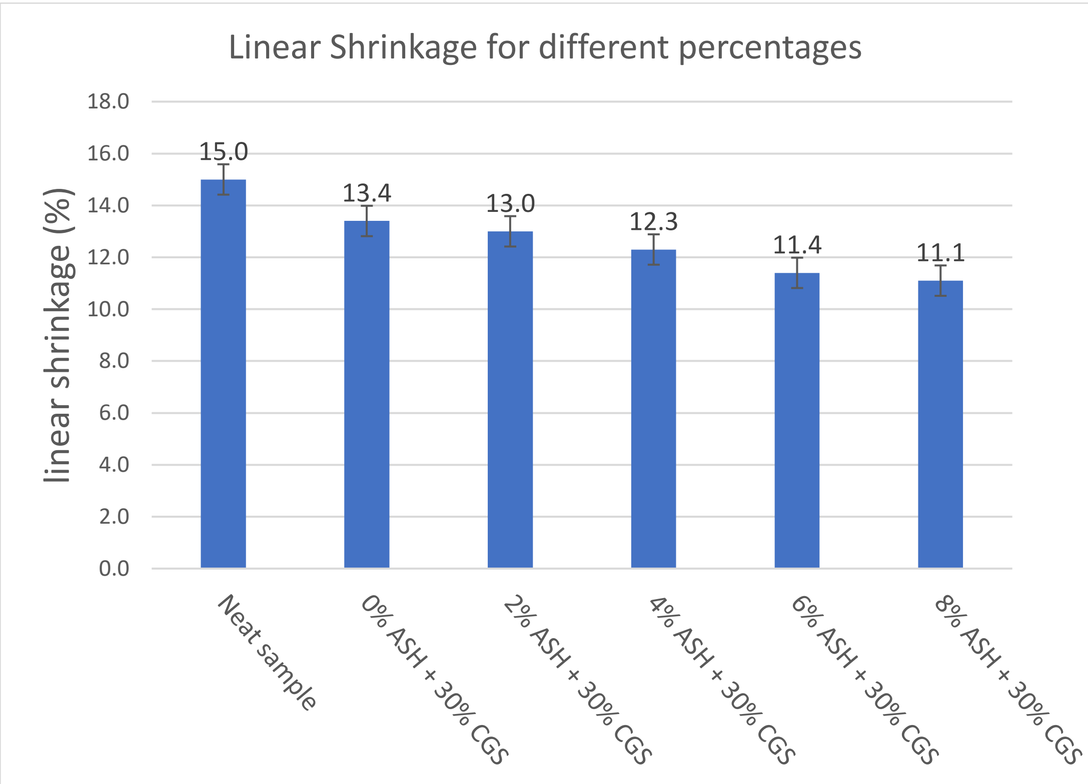

Figure 4. 11 Linear shrinkage graph for the different percentages of the stabilizers.

As observed, the linear shrinkage decreased with introduction of 30% CGS and continued to decrease with 2% addition of Ash at every stage.

Reason: When added to soil, the ash binds soil particles together, reducing their ability to move and settle. This binding effect reduces the tendency of the soil to shrink linearly, meaning it will maintain its volume more effectively.

4.2.5. Categorization of the waste.

Source: The waste used in the incineration process to obtain the ash is got from some hospitals and drug shops within central region of Uganda. These hospitals include Mukwaya General Hospital (MGH) along Ggaba road, Marie stopes Uganda, Bethesda medical centre along Makerere hill road among others. It also treats waste from waste collection companies like Bin it services limited.

Composition: The waste comprised of items such as expired pharmaceuticals (such as drugs), food products, sharps (such as needles and syringes), personal protective equipment (like hand gloves and masks), general waste (non hazardous waste such as box packaging, paper documents and other office supplies) plastic bottles, plaster, bandages among others.

Category: Medical waste.

Meaning of colour codes used in packaging:

- Black represents waste that is non-infectious waste such as paper, packaging materials or empty containers.
- Red represents biohazardous waste indicating that the contents may be contaminated with potentially infectious materials such as blood, bodily fluids or items used in patient care that have been in contact with those substances.

- Yellow represents hazardous waste that requires treatment before disposal. These include; sharps like needles, syringes or materials contaminated with hazardous materials and often signify high level of risk

Figure 4. 12 Packaged waste.

CHAPTER 5: CONCLUSION AND RECOMMENDATION.

5.1. Introduction

This chapter includes conclusions and recommendations made basing on the findings in the lab.

5.2. Conclusion

The study focused on the use of crushed granite stone and ash from waste incineration to stabilize expansive subgrade soils and the following conclusions were made based on the test results and discussions.

It was found that the soil collected from Wakiso district, in Kawanda town council was expansive with a plasticity index of 30% with 1.28% gravel, 29.57% sand and 69.15% fines. The soil was classified with USCS as CH fat clays. In its natural state, it does not meet the minimum requirement for subgrade construction as per the MoWT (2005) summarized.

Ash from incinerated waste contains about 67% Calcium Oxide which when introduced to expansive soils, reacts with the clay minerals forming a cementing agent known as Calcium Aluminate Silicate Hydrate (C-A-S-H) hence this ash is a good calcium rich stabilizer hence a perfect substitute for conventional lime.

The different percentages of waste incinerated ash at 0%, 2%, 4%, 6% and 8% were able to increase the reduce Plasticity index and at granite stone of 30% and Ash percentage of 8, we observed the best soil strength properties exhibited meeting minimum requirements as required by MoWT (2005).

30% Crushed Granite Stone and 6% MWIA gave the best results of **PI (23.6), LS (11.4)**, and a **CBR value of 17.5** which are within above MoWT standards. And I considered these to be the Optimum percentages.

Therefore, addition of waste ash and granite dust in expansive soils greatly improves their engineering properties hence making the soils suitable for use as subgrade materials.

5.3. Recommendations for future study.

As discussed earlier that granite stone greatly improves CBR value and the ash from waste incineration reduced the plasticity of the soil.

I recommend further studies in the use of the additives in the research for stabilization of expansive soils for subgrade.

Further study should be under taken in the use of natural calcium rich stabilizer besides waste incinerated ash such rice husk ash, bagasse ash alongside the crushed granite stone to see how it reacts with this granite and clay properties of the expansive soil.

REFERENCES

3dJATwMc%0Ahttps://www.cedengineering.com/userfiles/An Introduction to Soil Stabilization for Pavements R1.pdf.

Afrin, H. (2017) 'A Review on Different Types Soil Stabilization Techniques', *International Journal of Transportation Engineering and Technology*, 3(2), p. 19. Available at: https://doi.org/10.11648/j.ijtet.20170302.12.

Agamuthu, P., and Chitra, S. (2009). Solidification/stabilization disposal of municipal waste incinerator flyash using cement. Malaysian Journal of Science, 28(3), 241-255.

Agamuthu, P., and Chitra, S. (2009). Solidification/stabilization disposal of municipal waste incinerator flyash using cement. Malaysian Journal of Science, 28(3), 241-255.

Al-Mutairi, N., Terro, M., and Al-Khaleefi, A.L. (2004). Effect of recycling hospital ash on the compressive properties of concrete: statistical assessment and predicting model. Building and Environment, 39(5), 557-566.

Al-Rawas, A.A., Hago, A.W., Taha, R., and Al-Kharousi, K. (2005). Use of incinerator ash as a replacement for cement and sand in cement mortars. Building and Environment, 40(9), 1261-1266.

Al-Rawas, A.A., Hago, A.W., Taha, R., and Al-Kharousi, K. (2005). Use of incinerator ash as a replacement for cement and sand in cement mortars. Building and Environment, 40(9), 1261-1266.

Anamul, H.M., Rahman, J., and Tanvir, M. (2012). Zn and Ni of bottom ash as a potential diffuse pollutant and their application as 'Fine Aggregate'. Journal of Civil Engineering Research, 2(6), 64-72.

Anastasiadou, K., Christopoulos, K., Mousios, E., and Gidarakos, E. (2012). Solidification/stabilization of fly and bottom ash from municipal waste incineration facility. Journal of hazardous materials, 207, 165-170.

Anastasiadou, K., Christopoulos, K., Mousios, E., and Gidarakos, E. (2012). Solidification/stabilization of fly and bottom ash from municipal waste incineration facility. Journal of hazardous materials, 207, 165-170.

Androjic, I., Kaludjer, G., and Komljen, M. (2013). Usage of the fly ash in hot mix asphalt mixes. In Proceedings of the XXVIII International Baltic Road Conference.

Aubert, J.E., Husson, B., and Vaquier, A. (2004). Use of municipal solid waste incineration fly ash in concrete. Cement and Concrete Research, 34(6), 957-963.

Azni, I., Katayon, S., Ratnasamy, M., and Johari, M.M.N.M. (2005). Stabilization and utilization of hospital waste as road and asphalt aggregate. Journal of Material Cycles and Waste Management, 7(1), 33-37.

Baur, I., Ludwig, C., and Johnson, C. A. (2001). The leaching behavior of cement stabilized air pollution control residues: a comparison of field and laboratory investigations. Environmental science and technology, 35(13), 2817-2822.

Bone, B.D., Barnard, L.H., Boardman, D.I., Carey, P.J., Hills, C.D., Jones, H.M., MacLeod, C.L., and Tyrer, M. (2004). Review of scientific literature on the use of stabilisation/solidification for the treatment of contaminated soil, solid waste and sludges (SC980003/SR2). The Environment Agency, Bristol, 1-375.

Cangialosi, F., Intini, G., Liberti, L., Notarnicola, M., Pastore, T., and Tazzoli, F. (2006). Clean up of contaminated sediments of the Taranto harbour by stabilization/solidification treatment Transaction: Ecology and the Environment 88.

Červinková, M., Blaha, A., and Meegoda, J.N. (2007). Leaching of heavy metals stabilized in asphalt matrix. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 11(2), 106-113.

Donald, I.W., Metcalfe, B.L., and Taylor, R.J. (1997). The immobilization of high-level radioactive wastes using ceramics and glasses. Journal of materials science, 32(22), 5851-5887.

Environmental Agency (2005). EA NEN 7375:2004, Leaching Characteristics of moulded or monolithic building and waste materials, Determination of leaching of inorganic components with the diffusion test, "The Tank Test" Netherlands Normalisation Institute Standard.

Filipponi, P., Polettini, A., Pomi, R., and Sirini, P. (2003). Physical and mechanical properties of cement-based products containing incineration bottom ash. Waste Management, 23(2), 145-156.

Fondjo, A.A., Theron, E. and Ray, R.P. (2021) ‘Stabilization of Expansive Soils

Ghodrati, M., Sims, J.T., and Vasilas, B.L. (1995). Evaluation of fly ash as a soil amendment for the Atlantic Coastal Plain: I. Soil hydraulic properties and elemental leaching. Water, Air, and Soil Pollution, 81(3-4), 349-361.

Guyer, J. P., 2018. *An introduction to construction methods for soil stabilized pavements.* s.l.: s.n.

Guyer, J.P. and PE, R.A. (2018) *An Introduction to Construction Methods for Soil*

Halim, C.E., Amal, R., Beydoun, D., Scott, J.A., and Low, G. (2003). Evaluating the applicability of a modified toxicity characteristic leaching procedure (TCLP) for the classification of cementitious wastes containing lead and cadmium. Journal of hazardous materials, 103(1-2), 125-140.

Hong, K.J., Tokunaga, S., and Kajiuchi, T. (2000). Extraction of heavy metals from MSW incinerator fly ashes by chelating agents. Journal of Hazardous materials, 75(1), 57-73.

https://books.google.com/books?hl=en&lr=&id=nGVLDwAAQBAJ&oi=fnd&pg=PA1&dq=tank+truck+stability&ots=Tl-l5R-HhW&sig=HIv3VkZCZsnLUaM9j--

Huang, Y., Bird, R.N., and Heidrich, O. (2007). A review of the use of recycled solid waste materials in asphalt pavements. Resources, conservation and recycling, 52(1), 58-

International Journal of Engineering Research and Technology, 8(5), 71-75.

Juel, M.A.I., Mizan, A., and Ahmed, T. (2017). Sustainable use of tannery sludge in brick manufacturing in Uganda. Waste Management, 60, 259-269.

Jung, C.H., Matsuto, T., Tanaka, N., and Okada, T. (2004). Metal distribution in incineration residues of municipal solid waste (MSW) in Japan. Waste management, 24(4), 381-391.

Kar, D., Panda, M., and Giri, J.P. (2014). Influence of fly-ash as a filler in bituminous mixes. ARPN Journal of Engineering and Applied Sciences, 9(6), 895-900.

Kim, J., An, J., Nam, B.H., and Tasneem, K.M. (2016). Investigation on the side effects of municipal solid waste incineration ashes when used as mineral addition in cementbased material. Road Materials and Pavement Design, 17(2), 345-364.

Kimani, N. G. (2007). Environmental pollution and impact to public health.Implication of the Dandora Environment Program (UNEP), Nairobi, Kenya.

Kosson, D.S., van der Sloot, H.A., Sanchez, F., and Garrabrants, A.C. (2002). An integrated framework for evaluating leaching in waste management and utilization of secondary materials. Environmental engineering science, 19(3), 159-204.

Laugesen, J. (2007). Behaviour of solidified/stabilised contaminated sediments in confined disposal facilities (CDFs). Doctoral Thesis, Faculty of Engineering Science and Technology - Department of Civil and Transport Engineering, Norwegian University of Science and Technology, Trondheim. 113.

Lee, W.J., Liow, M.C., Tsai, P.J., and Hsieh, L.T. (2002). Emission of polycyclic aromatic hydrocarbons from municipal waste incinerators. Atmospheric

Liu, F., Liu, H.Q., Wei, G.X., Zhang, R., Zeng, T.T., Liu, G.S., and Zhou, J.H. (2018). Characteristics and treatment methods of municipal waste incinerator fly ash: A review. Processes, 6(10), 173.

Mahzuz, H.M.A., Alam, R., Alam, M.N., Basak, R., and Islam, M.S. (2009). Use of arsenic contaminated sludge in making ornamental bricks, International Journal of Materials. Envi. Engineering Science, 19(3), 159-203.

Malviya, R., and Chaudhary, R. (2006). Evaluation of leaching characteristics and environmental compatibility of solidified/stabilized industrial waste. Journal of material cycles and waste management, 8(1), 78-87.

Mekonnen, E. *et al.* (2020) 'Application of Microbial Bioenzymes in Soil

MOHFW (2011). Environmental Assessment and Action Plan for the Health, Population and Nutrition Sector Development Program (HPNSDP), 2011-2016. Environment Management Plan - Government of the People's Republic of Uganda.

Quina, M.J., Bordado, J.C., and Quinta-Ferreira, R.M. (2008). Treatment and use of air pollution control residues from MSW incineration: an overview. Waste Management, 28(11), 2097-2121.

Rahman, A., Ali, S.A., Adhikary, S.K., and Hossain, Q.S. (2012). Effect of fillers on bituminous paving mixes: an experimental study. Journal of Engineering Science, 3(1), 121-127.

Rajor, A., Xaxa, M., and Mehta, R. (2012). An overview on characterization, utilization and leachate analysis of biomunicipal waste incinerator ash. Journal of environmental management, 108, 36-41.

Reijnders, L. (2005). Disposal, uses and treatments of combustion ashes: a review. Resources, Conservation and Recycling, 43(3), 313-336.

Singh, A.K., Srivastav, V., and Kumar, U. (2016). Biomunicipal waste ash in concrete: an experimental investigation. International Journal of Innovative Research in Science, Engineering and Technology, 5(6), 2347-6710.

Stabilized Pavements. Available at:

Syed, E.H., Mutahara, M., and Rahman, M. (2012). Municipal waste management (MWM): it is a review. Home Health Care Management and Practice, 24(3), 140-145.

Tang, Q., Liu, Y., Gu, F., and Zhou, T. (2016). Solidification/stabilization of fly ash from a municipal solid waste incineration facility using Portland cement. Advances in Materials Science and Engineering, 2016.

tps://doi.org/10.1155/2020/1725482.

Using Mechanical and Chemical Methods: A Comprehensive Review', *Civil Engineering and Architecture*, 9(5), pp. 1289–1294. Available at: https://doi.org/10.13189/cea.2021.090503.

Wobudeya, V., 2023. *Investigating the use of granite stone dust to stabilize subgrade expansive soils,* s.l.: s.n.

APPENDIX A

Figure 14. Incinerator where waste is burnt

Figure 15. Sample preparation for Atterberg limits test

Figure 16. Air drying of granite sample

APPENDIX B

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND MUNICIPAL WASTE FLY ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF NEAT SAMPLE

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) | Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC		62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	NEAT SAMPLE	11/29/2023	100	100	100	100	99	90	69	0.42	57.5	27.5	30.0	15.0	1.569	22.4	11	1.01	1.01
			100	100	100	100	99	90	69	0.43	57.4	27.4	29.9	15.0	-	-	- - -	-	
			100	**100**	**100**	**99.68**	**98.83**	**89.98**	**68.87**	**0.42**	**57.4**	**27.5**	**30.0**	**15.0**	**1.569**	**22.4**	**11.1**	**1.01**	**1.01**
	AVERAGE		100	100	100	100	99	90	69	0.423	57.4	27.4	30.0	15.0	1.569	22.4	11.1	1.01	1.01

FOR LAB

Lab Technician

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In any Correspondence on this subject please quote No............ GE 057/2024

02nd February 2024

MR. TUSUBIRA ANDREW AND MR ASHABA PETER
REG NO. S20B32/036 & S20B32/217
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-778-051449

REPORT OF ANALYSIS

Description of the Samples

One sample in a black polythene bag containing Municipal waste ash sample was submitted by Mr. Tusubira Andrew, on 25th January 2024, and analysed on 31st January 2024. A summary of the sample received is shown in table below

S/N	Description	Quantity	Assigned Lab ID
1	Municipal waste Ash sample packed in a black polythene bag.	01	**Sample "A"** **GE 057/2024**

Analysis Requested

Elemental analysis

Method of Analysis

Elemental analysis was done using the XRF Method.

Results of Analysis

The above sample has been analyzed with the following results as below,

Parameter	Units	Results
		Municipal waste Ash sample **GE 057/2024**
Calcium Oxide	% m/m	67.92
Silicon dioxide	% m/m	7.39
Potassium Oxide	% m/m	5.13
Sodium Oxide	% m/m	4.99
Titanium di oxide	% m/m	3.45
Aluminum oxide	% m/m	3.53
Magnesium Oxide	% m/m	3.02
Zinc oxide	% m/m	2.11
Iron (III) Oxide	% m/m	1.08
Phosphorous pent-oxide	% m/m	1.03
Sulphur trioxide	% m/m	0.04

Remarks

1. Results relate to sample analyzed and are reported as on received basis.

02/02/2024

Semalago Fredrick
Government Analyst

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF ALL THE TEST RESULTS

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC	62Blows	62
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL	11/29/2023	100	100	100	100	99	90	69	0.42	57.5	27.5	30.0	15.0	1.569	22.4	11.1	1.01
			100	100	100	100	99	90	69	0.43	57.4	27.4	29.9	15.0	-	-	- - -	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR		100	100	90	75	68	53	31	1.479	51.5	25.4	26.1	13.4	1.623	21.1	18.8	0.91
			100	100	93	76	69	55	34	1.413	52.0	25.6	26.4	13.4	-	-	- - -	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 2% ASH		100	100	94	76	69	53	34	1.441	49.0	23.1	25.9	13.0	1.564	21.6	18.6	0.9
			100	100	90	76	68	53	32	1.460	48.9	23.0	25.9	13.0	-	-	- - -	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 4% ASH		100.0	100.0	94.1	79.2	72.7	58.8	37.5	1.310	47.0	22.4	24.6	12.3	1.603	20.5	18.6	0.8
			100.0	100.0	93.1	77.6	70.2	55.9	35.8	1.380	46.7	22.1	24.6	12.3	-	-	- - -	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 6% ASH		100.0	100.0	93.1	77.3	70.7	56.6	37.0	1.357	46.2	22.7	23.5	11.4	1.668	19.5	17.5	0.6
			100.0	100.0	95.0	77.5	71.5	58.1	36.0	1.344	46.4	22.7	23.7	11.4	-	-	- - -	-
	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 8% ASH		100.0	100.0	96.1	84.3	78.1	66.0	48.0	1.080	45.4	23.1	22.3	11.1	1.620	21.7	18.0	0.7
			100.0	100.0	95.5	81.9	75.1	59.8	37.1	1.280	45.4	23.1	22.3	11.1	-	-	- - -	-

FOR LAB

Lab Technician

Materials Engineer

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INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIED WITH 30%CRR

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC		62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIED WITH 30%CRR	11/29/2023	100	100	90	75	68	53	31	1.48	51.5	25.4	26.1	13.4	1.623	21.1	18.8	0.91	0.91
			100	100	93	76	69	55	34	1.41	52.0	25.6	26.4	13.4	-	-	- - -	-	
			100	**100**	**91.09**	**75.53**	**68.81**	**54.02**	**32.59**	**1.45**	**51.8**	**25.5**	**26.2**	**13.4**	**1.623**	**21.1**	**18.8**	**0.91**	**0.91**
	AVERAGE		100	100	91	76	69	54	33	1.446	51.8	25.6	26.2	13.4	1.623	21.1	18.8	0.91	0.91

FOR LAB

Lab Technician

Materials Engineer

STIRLING CIVIL ENGINEERING LTD
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STUDENTS

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PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIED WITH 30%CRR & 2% ASH

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR	CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC		62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 2% ASH	11/29/2023	100	100	94	76	69	53	34	1.44	49	23.1	25.9	13.0	1.564	21.6	18.6	0.85	0.85
			100	100	90	76	68	53	32	1.46	48.9	23.0	25.9	13.0	-	-	- - -	-	
			100	**100**	**91.95**	**76.03**	**68.49**	**53.28**	**33.16**	**1.45**	**49.0**	**23.1**	**25.9**	**13.0**	**1.564**	**21.6**	**18.6**	**0.85**	**0.85**
	AVERAGE		100	100	92	76	68	53	33	1.451	49.0	23.0	25.9	13.0	1.564	21.6	18.6	0.85	0.85

FOR LAB

Lab Technician

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STUDENTS

INSTITUTION	STUDENTS	TESTING LAB
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PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIED WITH 30%CRR & 6% ASH

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR			CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC				62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 6% ASH	11/29/2023	100	100	93	77	71	57	37	1.36	46.2	22.7	23.5	11.4	1.668	19.5	18			0.62	0.62
			100	100	95	78	71	58	36	1.34	46.4	22.7	23.7	11.4	-	-	-	-	-	-	
			100	**100**	**94.05**	**77.41**	**71.11**	**57.38**	**36.48**	**1.35**	**46.3**	**22.7**	**23.6**	**11.4**	**1.668**	**19.5**	**17.5**			**0.62**	**0.62**
	AVERAGE		100	100	94	77	71	57	36	1.350	46.3	22.7	23.6	11.4	1.668	19.5	17.5			0.62	0.62

FOR LAB

Lab Technician

Materials Engineer

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STUDENTS

INSTITUTION	STUDENTS	TESTING LAB
UGANDA CHRISTIAN UNIVERSITY A Centre of Excellence in the Heart of Africa	ASHABA PETER S20B32/217 & TUSUBIRA ANDREW S20B32/036	Stirling

PROJECT: INVESTIGATING THE USE OF CRUSHED GRANITE STONE AND INCINERATED WASTE ASH IN STABILIZING OF SUBGRADE EXPANSIVE SOILS

SUMMARY OF TEST RESULTS FOR EXPANSIVE MATERIAL OF EXPANSIVE SOIL MODIFIED WITH 30%CRR & 8% ASH

LOCATION: KAWANDA TOWN COUNCIL (WAKISO DISTRICT) Depth: 0.5m

LOCATION	BLENDED %	SAMPLING DATE	GRADING								ATTERBERG LIMITS				MDD		CBR			CBR SWELL	
			63	37.5	20	5	2	0.425	0.075	GM	LL	PL	PI	LS	MDD	OMC				62	AVERAGE
KAWANDA TOWN COUNCIL (WAKISO DISTRICT)	EXPANSIVE SOIL MODIFIED WITH 30%CRR & 8% ASH	11/29/2023	100	100	96	84	78	66	48	1.08	45.4	23.1	22.3	11.1	1.620	21.7	18.0			0.65	0.65
			100	100	95	82	75	60	37	1.28	45.4	23.1	22.3	11.1	-	-	-	-	-	-	
			100	100	95.8	83.1	76.63	62.87	42.53	1.18	45.4	23.1	22.3	11.1	1.620	21.7	18.0			0.65	0.65
	AVERAGE		100	100	96	83	77	63	43	1.180	45.4	23.1	22.3	11.1	1.620	21.7	18.0			0.65	0.65

FOR LAB

Lab Technician

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Materials Engineer

STUDENTS