INVESTIGATING THE PHYSICAL, MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE HAVING CEMENT PARTIALLY REPLACED WITH RICE STRAW AND EGG SHELL ASHES

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Investigating the Physical, Mechanical and Durability Properties of Concrete having Cement Partially Replaced with Rice Straw and Egg Shell Ashes

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This work is dedicated to my wife Sophy and Children Abigael, Aaron, Adelyn, Adriel and the late Adrian.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASTM	American Society for Testing and Materials
BRE	Building Research Establishment
BS	British Standard
°C	Degree Centigrade
CSH	Calcium Silicate Hydrates
CV	Constant Velocity
CWA	Cassava Waste Ash
EN	European Norm
ESA	Egg Shell Ash
FA	Fly ash
GHA	Ground Nut husk ash
GNP	Gross National Product
Ha	Hectares
Hr	Hour
Hz	Hertz
Hp	Horse Power
Kg	Kilogramme
KN	Kilo Newton

KNBS	Kenya National Bureau of Statistics
KS	Kenyan Standard
LOI	Loss on Ignition
MM	Millimetre
μm	Micro metre
OPC	Ordinary Portland Cement
RSA	Rice Straw Ash
RPR	Residue to Produce Ratio
RHA	Rice Husk Ash
S	Seconds
SCM	Supplementary Cementitious Material
SCBA	Sugar Cane Bagasse Ash
SDA	Saw Dust Ash
SR	Silica Ratio
WA	Wood Ash

ABSTRACT

Provision of adequate housing has become a challenge especially in developing countries. This has been occasioned by both high cost of building materials such as cement and low incomes of the populations. At the same time cement production has adverse effects to the environment. This has necessitated research into alternative supplementary materials that are abundant and renewable in nature that can be used to partially substitute cement in concrete thereby reducing the cost of construction making construction of housing affordable. Similarly by reducing cement consumption the adverse effect of cement production to the environment will be mitigated. Incorporating egg shells and rice straw ashes will mitigate their disposal problem. This research presents the properties of concrete made with cement partially replaced with rice straw ash and egg shell ash. Rice straw and egg shells were first incinerated, sieved and ground. The physical and chemical properties of the resultant ashes as well as other materials incorporated in the concrete mixes were also determined. A concrete mix with a compressive strength of 35 N/mm^2 and a water cement/ ratio of 0.5 was designed to British Research Establishment method. The control was the concrete neat cement. Cement in concrete mix was partially replaced with rice straw ash at 5, 10, 15, 20, 25 & 30%. Compressive and splitting tensile strength of the concrete with cement partially replaced as indicated above was determined at 7, 14, 28, 56 and 90 days of curing age. Durability, resistance to acid attack as well as fresh properties of the concrete were also determined. An increase in compressive strength was observed for concrete with 5% & 10% partial replacement of cement with rice straw ash. The 7, 14, 28, 56 and 90 day strengths were found to be 32.7, 36.7, 38.8, 40.3, 41.3 N/mm^2 and 33.7, 37.1, 40.2, 41.8, and 42.7 N/mm^{2,} respectively. The control was found to have compressive strength of 27.9, 33.0, 35.9, 36.6 and 38.7 N/mm^2 for 7,14,28,56 & 90 days of testing. When egg shell ash was added at 10% by weight of cement to concrete mixes made with cement partially replaced with rice straw ash at 15% and 20%, the 28, 56 & 90 days compressive strengths were found to increase by 25.3, 26.7 and 29.2% and 5.3, 3.26 and 3.9%, respectively. It was concluded that rice straw ash can be used to partially replace cement in concrete at an optimum of 10% by weight of cement while rice straw and egg shell ash can simultaneously be used to partially replace cement at 15% and 10% by weight of cement, respectively, in concrete and result in a concrete whose properties compare favourably with the control. These results can be applied in the construction industry to reduce the cement content hence cost of concrete material, cement being the most expensive ingredient in concrete. Authorities can also adapt this as an avenue of disposing agro-waste that is produced in bulk and poses disposal challenges. The blended concrete can be used for construct in regions where soils are acidic or to construct facilities exposed to acidic substances since they have better resistance to acid. The challenges include the scattered nature of the sources of the agro-waste, lack of a facility to incinerate, sieve and grind the agro-waste ashes and in sufficient quantities. The study findings are limited to Type 1 Ordinary Portland cement and not any other cement found in the market.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The provision of adequate housing for man has become a challenge around the world especially for developing countries. This is a consequence of ever increasing population, low gross national product (GNP) and the general lack of purchasing power. Development and ownership of houses is also constrained by the high-cost of building materials. The progressive deterioration of the limited existing buildings necessitates the development of alternative building materials from locally available raw materials for low cost housing. These raw materials should be abundantly available and renewable in nature (Ugwiushwu et al., 2013). Improvement of the housing situation in developing countries has been greatly hampered by the unavailability of affordable building materials to the general populations in urban and rural areas (Jimoh et al., 2013). The world's population has been projected to reach between 9.5 and 12.9 billion by the year 2100 from the current 6.6 billion. With it will come huge demand for housing and other infrastructure (Biernacki et al., 2017).

Cement is an important material in the infrastructure sector since it is the most fundamental ingredient in concrete. Ordinary Portland cement concrete is considered to be the most used synthetic material globally owing to its versatility and sheer abundance of its raw materials (Biernacki et al., 2017). The global cement production in the year 2020 was estimated to be 4.4 billion metric tons (Chaeyeon et al., 2020). The global demand for cement is expected to increase to between 6 - 13.5 Giga tones per annum (Wolfram et al., 2020). Cement utilization in Kenya has increased from 5,705.8 thousand tons in 2016 to 5,933.3 thousand tons in 2019 (KNBS, 2020). That means that the demand for cement is unlikely to reduce in the near future. The housing sector is the dominant user of cement in the urban world (Manning et al., 2019).

With cement usage, comes concerns with regard to the effect cement manufacture to the environment. As it stands today, the cement production sector is the third largest energy consumer, behind aluminium and steel. Furthermore it emits approximately one ton of Carbondioxide (CO_2) into the atmosphere for every ton of cement produced. There is concern about the high amount of CO_2 released to the atmosphere which is a green house gas (Andreola et al., 2018). Between 1920 and 2018, cement industry released 1,500 metric tons of CO_2 to the environment. The CO_2 green house gas has led to climate change which is a severe threat to human existence (Chaeyeon et al., 2020).

Climate change is a major concern of the world today. The link between CO_2 emissions and climate change has caught the attention of scientists, politicians and the general public, and as such many countries have agreed to reduce CO_2 and other green house gases emissions to limit global temperature rise to two degrees centigrade, (Thomas et al., 2016). The two aspects of cement production that lead to CO_2 emission are the chemical reaction that leads to production of klinker and the combustion of fossil fuels to generate energy for the energy intensive cement making process (Robbie, 2019).

Further since cement industry is highly extractive there are environmental concerns due to excessive usage of natural resources to produce cement. Emissions form cement industries have various adverse effects on human beings and plants within the surroundings of cement making plants. Various diseases including cancer and psychasthenia have been associated with cement plant emissions (Adeyanju & Chukwieloka, 2019).

The air pollutants from cement industries contain alkaline particulates that have had an impact on the ecosystem thus affecting physiochemical and biological activity of soils. While deposits of cement particulates on plant surfaces affect their productivity through inhibiting photosynthesis (Olayinka et al., 2016).

Consequently the growing concern about green house gases has led researchers to try to find ways of reducing consumption of cement in the construction industry.

On the other hand the agro processing industry has been producing tones of agro residues that pose a challenge of disposal to the authorities. The depositing in landfills can lead to generation of other by products that are toxic. It is estimated that by 2050 demand for food will grow by 70% and this will demand sustainable food production and management of associated waste products (Sagrario et al., 2019).

To avoid environmental challenges, solid waste should be managed in consideration of the principles of prevention, reuse and recycling (Santiago et al., 2020). Due to their sheer volumes, post harvest solid wastes are normally improperly managed. Therefore there is interest in converting these by products for use in concrete industry (Balagopal et al., 2017). This will reduce the threat they pose to sustainability and aesthetic environment (Narain et al, 2020). Incorporating industrial waste as a substitute material can be an avenue to help to save large quantities of natural resources as well as protect the environment (Senani et al., 2018). Furthermore, biomass waste in the form of straw, fruit shells, cobs, pod seeds, shells, bagasse when properly selected and treated has been used as supplementary cementitious materials. These materials can be considered as a CO_2 neutral or quasy neutral, since the CO_2 released from their combustion can be considered to have been already absorbed by the plant during photosynthesis processes (Samantha et al., 2021).

The avenues through which green house gas emissions can be minimized in the cement industry include energy efficiency measures in manufacturing process, emissions efficiency, carbon capture and storage during clinker production, enhanced re-carbonation, alternative energy sources, grid re-carbonation and material substitution.

Material substitution could be partial or full and includes alternative binders, cementitious substitution for example the use of fly ash, pozzolans and the use of alternative materials such as timber (Pamenter & Meyers, 2021).

In constructions that use concrete material, the main route is by reduction of the cement content of concrete by inclusion of mineral admixtures like fly ash, silica fume, rice husk ash or metakaolin to partially replace ordinary portland cement helps in this effort (Kanchan et al., 2012). Apart from reducing the cost of binder there are potential technological benefits that arise from the use of pozzolanic material which include increased workability, reduced permeability, resistance to thermal cracking and increased ultimate strength and durability (Alp et al., 2009).

Pozzolanas are materials with silica content which by themselves are not cementitious in nature but in processed forms and finely divided form react with water to form cementitious compounds in the presence of water with lime (Manasseh, 2010). Pozzolans may therefore be classified into two: naturally occurring ones such as silica fume, pumice, shale tuffs, trass and the artificially occurring ones such as fly ash, bagasse ash, and ground nut husk ash. The pozzolans can be put to use in lime-pozzolana mixture to substitute cement in a wide range of building applications that is not confined to block making and low strength concrete and by incorporating them in cement to make blended cement by inter-grinding them with cement in cement clinker in suitable proportions or using them as cement replacement materials (this is economical since pozzolans are less costly compared to cement).

In this regard a lot of focus has been drawn to agricultural based pozzolanic materials for their environmental friendliness and sustainability (Jimoh et al., 2013). In developing countries the most readily available material that can be used to partially replace cement and still maintain economy are agro based wastes (Manasseh, 2010).

One of the products of hydration of Portland cement is calcium hydroxide ($Ca(OH)_2$). It greatly contributes to the deterioration of concrete. Blending a pozzolan with cement makes the lime react with some oxides in the pozzolan to not only reduce the quantity and therefore harmful effects of calcium hydroxide but also increases the quantity of calcium silicate hydrates that are responsible for strength hence increasing the concrete strength (Ettu et al., 2013).

Previous studies on partial substitution of cement in concrete have been done by researchers Srinivisan and Sathiya (2010) used Sugar Cane Bagasse Ash alone SCBA reported increase in compressive strength above control at 5-10% for all ages of testing but strength declined for 10% replacement and above.

Chirag et al, (2013) replaced cement in concrete with Rice husk ash alone at 5, 10, 15, 20%. They reported a strength increase above the control at 7&28 days up to 15% replacement. Beyond 15% cement replacement, there was a strength decrease.

Abalaka (2013) used Rice Husk Ash (RHA) alone to partially replace cement in concrete at 5, 10, 15, 20, 25% Water/Binder ratio of 0.45 & 0.5. He reported increase in Compressive strength above the control at 7, 14, 28, 56 days for replacements of up to 15%. For replacements beyond 15%, strength decreased.

Nuru Asman et al. (2017) partially replaced cement in concrete with Rice Husk Ash(RHA) and Egg Shell Ash at randomly selected ratios of 2 %:8 %,4 %:6 %,6 %;4 % . They reported a compressive strength reduction for all the ratios except for 6%ESA;4 % RHA.

Nurrudeen and Musa, 2020 partially replaced cement with egg shell ash alone in concrete at 0, 5, 10, 15, 20 and 25 %. Compressive strength increased above the control at 7, 14, 28, 56 days up to 5 %. They reported strength decrease beyond 5% replacement.

Majority of previous researches have focused on rice husk ash yet the rice straw is equally rich in silica. Rice straw ash was chosen due to it having a higher residue to produce ratio than the rice husk and is available in plenty. It can also be obtained from rice cultivation areas unlike the rice husk ash that can only be obtained from rice mills.

Paddy rice production rose by 42.6 % from 112.6 thousand tons in 2018 to 160.6 thousand tons in 2019. All other schemes registered an increase in paddy production except Bunyala (Source: KNBS, Economic Survey, 2020). Using a residue to produce ratio (RPR) of 2.185, the annual rice straw production was 160,584x2.185= 350,876.04 tons. With an ash yield of 19.2%, approximately (350,876.04 tons x 19.2% = 67,368.19 tons) of rice straw ash is available in Kenya from irrigation schemes alone.

The annual egg production in Kenya is about 1.3 billion eggs worth Ksh 9.7 billion (ANAW, 2020). Using an average egg weight of 62.5 grams (Crosara et al., 2018) gives approximately 81,250 tons of calcium carbonate in form of egg shells is available in Kenya for lime production. Production of both rice straw and egg shells is renewable and sustainable in nature. The egg shells were chosen owing their availability in plenty and ease of collection at a minimal cost from hatcheries, fast food processors, and homes. Since disposal of rice straw and egg shells is not controlled, use of their ashes will reduce solid waste disposal problem.

In this research, two agro wastes; rice straw ash and chicken egg shell ashes will be evaluated for use as supplementary materials in concrete for structural elements of buildings. The rice straw which is considered as having no economic value will be used in ash form as a supplementary material to partially replace cement in concrete. Chicken egg shells another agro waste will be added to the blended mix in ash form to reduce the effect of removal of cement from the concrete system during partial replacement with rice straw ash and remedy the strength decline reported by majority of researchers at higher replacements of cement by agrowastes in concrete. The objective being to achieve a concrete material that is less costly using cement that is blended with agro-wastes but which meets the requirements for use in construction of houses. This will make housing affordable to the large population that lives under the monetary poverty line.

1.2 Problem statement

With the global population estimated to reach 10.9 billion by 2050, this population will increase demand for housing and other infrastructure (Marijana et al., 2019).The growing populations exert a demand for socio-economic infrastructure that is aimed at meeting the needs of emerging affluent societies. This in turn leads to gradual increase in the demand for cement (Ash et al., 2019). The increase in cement production is projected to reach between 8.3-10.9 billion metric tons by 2050 and as such the cement production alone will be contributing to 24% of the global CO_2 emissions. Such a high share of CO_2 by one industry alone will not be tolerated. Any improvement will have significant impact in reducing global CO_2 emissions (Marijana *et al.,* 2019).

On the basis of the above; there is need to cut down cement production and usage by partially substituting cement in concrete. Developing countries are heavily dependent on agricultural production and with it comes large volumes of agro-waste that pose a challenge to dispose. Rice is produced in large quantities irrigation schemes in Kenya. In the process rice straw, a by-product is available in plenty. Chicken egg shells as are also produced in plenty by day old chick producing hatcheries as well as the food industry. Incorporating these two agro wastes in concrete is an attractive method of disposing them in order to safeguard the environment. There has been a lot of research on partial substitution of cement with agro-waste ashes in concrete. Researchers Srinivisan and Sathiya (2010), Chirag et al, (2013), Abalaka (2013), Nuru Asman et al. (2017), Nurrudeen and Musa, (2020) among others reported a decline in compressive strength with increase in percentage partial replacement of cement beyond the optimum replacement. However, there is limited information on how to remedy the decline in strength that occurs beyond the optimum partial replacement of cement with the ashes. This research will attempt to remedy this decline in strength by introducing another agro-waste, egg shell ash in addition to the pozzolanic agro-waste ash in the blended concrete. Since the ashes are cheaper than cement, further reduction in cement will result in savings in construction.

1.3 Objectives

1.3.1 General objective

To investigate the properties of concrete with cement partially replaced with rice straw ash and egg shell ash.

1.3.2 Specific objectives

1. To assess the physical and chemical properties of cement, rice straw ash, egg shell ash and physical properties of coarse and fine aggregate.

2. To determine physical and mechanical properties of concrete having cement partially replaced with rice straw ash.

3. To assess the mechanical properties and durability of concrete having cement partially replaced with rice straw ash and egg shell ash.

1.4 Research Questions

1. What are the physical and chemical properties of rice straw ash and egg shell ash?

2. What are the physical and mechanical properties of concrete having cement partially replaced with rice straw ash?

3. What are the mechanical and durability mechanical properties and durability of concrete having cement partially replaced with rice straw ash and egg shell ash?

1.5 Justification of the study

There is need for decent and affordable housing in the up-coming urban areas of Kenya given that housing or shelter is one of the three basic needs for human beings. There is need to lower cement content in concrete as a construction material since its production is harmful to the environment owing to both extraction of limestone and release of particulates to the atmosphere by cement factories.

Rice straw is available in Kenya in large quantities from both paddy rice irrigation and non paddy sources in various parts of the country with little competing use. While egg shells are available in large quantities both from large and small scale hatcheries that produce day old chick, hotels and food processing industries. The successful utilization of agro wastes namely rice straw ash and egg shell ash as partial replacements of cement in concrete industry for housing will reduce the cement consumption, leading to reduction in energy and raw material use for cement manufacture. It will also cut down the release pollutants and green house gases. This will in turn reduce the harmful environmental effects associated with cement, resulting in a sustainable and economic concrete material.

The cost reduction will make construction of decent housing affordable to 36% (or 15.9 million) of the Kenyan population who live below the monetary poverty line (KNBS Poverty report, 2020). The successful use of egg shell ash in cement may be adapted by cement manufacturers as a cost cutting measure in terms of energy and raw material. The incorporation of egg shell ash in concrete will provide a safe and economical method of disposing solid egg shell waste.

1.6 Scope and Limitation

1.6.1 Scope

This research evaluated the effect of rice straw ash as sourced from Bunyala Rice Irrigation scheme alone, located in Busia County, Kenya and not any other scheme. Chicken egg shells used in concrete were sourced from Busia and Bondo towns within Busia and Siaya Counties, in Kenya. They were obtained from small scale hatcheries and food processors. The fine aggregate used was river sand as obtained from the Malaba river. The coarse aggregate used was graded crushed stones obtained from Sirikwa area in the outskirts of Eldoret town in Uasin Gishu County. The incineration of agro-waste was done in open the open air environment at prevailing environmental temperature and pressure and not under controlled conditions. The characterization of agro waste ashes was confined to physical properties and chemical oxide analysis, while tests done on concrete were physical and mechanical alone. The methodology used was as indicated in the relevant standards and the equipment manuals supplied by the manufacturers.

1.6.2 Limitations

1. There was limited access to technologically advanced equipment for exhaustive study of the properties of the blended concrete. Non destructive tests, micro-structure, morphology and Ultrasonic Pulse velocity tests were not conducted in this study.

2. The cement used in this study was Type I Ordinary Portland Cement only and not any other type of cement available in the Kenyan market.
3. The water/cement ratio used for all the concrete mixes in this study was 0.5
4. The incinerator available was small in volume, thus incineration of rice straw had to be done in small batches.
5. The sieves available are small in volume. To sieve enough rice straw ash for a large batch of mix took a long time and had to be done in small portions at a time.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical review

2.1.1 Concrete

Concrete is a material that is used in buildings both for substructures and superstructures. It is composed of a mixture of different materials and the granular sizes of these different materials affect its properties. Both fresh and hardened properties are determined by the distribution of these particle sizes (Campo & Geyer, 2019) as well as water/cement/aggregate ratio, age of curing, temperature and additives among others (BRE, 1988).

A typical concrete mix is made up of coarse aggregates, fine aggregates, water and a binder which is the principal constituent. The most common binding medium is cement. A number of factors affect compressive strength of cement that include water/cement ratio, compaction, cement to aggregate ratio aggregate grading, physiomechanical and mineralogical properties of aggregate. The basic function of aggregate is to provide bulk to concrete as a mineral filler that is cheaper than cement because cement is the most expensive ingredient. They also provide stability of volume of concrete (Teye et al., 2018). The quality of concrete is derived from its constituent materials. Concrete may be classified as normal and high strength concrete; Compressive strength being the most significant attribute that differentiates normal and high strength concrete. Compressive strength is defined as the maximum resistance a concrete can offer to an applied pressure. American concrete institute defines high strength concrete as a concrete with compressive strength greater than 41MPa. High performance concrete is superior to normal concrete in terms of modulus of elasticity, lower creep and drying shrinkage, freeze thaw resistance, low permeability, and chemical resistance. It is normally prescribed where situations demand a small member to carry a large load (Obi, 2017).

The most commonly used construction material in the world is concrete. There are environmental concerns in terms of the damage caused by raw material extraction as well as green house gas emissions during cement manufacture (Muhamad *et al.*, 2013). These environmental concerns necessitate the research into alternative materials so as to mitigate damage to environment. Many modifications have been done to it to achieve desired characteristics of concrete, mainly high strength and durability. To meet this requirement blended concretes have been introduced. Cementitious materials known as pozzolans are being used with normal cement as replacement materials. Originally, the term pozzolan was restricted to calcined earth and volcanic ashes; nowadays this term covers all aluminous/siliceous materials which in powder form react with calcium hydroxide in presence of water to form cementitious compounds (Muhamad *et al.*, 2013).

The strength that the concrete possesses is contributed by each of these constituents. Hence the overall cost of the concrete depends largely on both the availability of these constituents and their costs. Because cement remains the most expensive of these ingredients there is need to find a means of economizing the use of cement in concrete production (Mijedu, Adebara & Lamidi, 2014).

Characteristics demanded by concrete construction may not be met by concrete made from these materials only; it is this condition that makes admixtures useful. Most widely used concrete admixtures are those that control setting time and/or reduce water. The main categories of admixtures are accelerators, retarders, plasticizers, cementitious and pozzolanic materials, water proofing agents and alkali-silica reaction inhibitors (Otunyo, 2011).

The durability properties of adequately produced concrete are generally good and as such do not need to be improved by the addition of other poisonous substances to increase the lifespan as some of the competing building materials. Further, admixture ingredients in concrete comprise only a tiny percentage of the total concrete weight and even then they remain bound into hydration products (Vesa, 1997).

Where characteristics such as strength, durability, impermeability, fire resistance and absorption resistance are desired, concrete is the material of choice (Sathish, 2012). However with the advancement of technology and increased scope of application of cement and mortars, the use of recycled wastes as well as agricultural wastes and industrial products has come into use (Mahesh and Satome, 2012).

The long term results of rapid industrialization are disposal problems of waste materials, depleting energy sources, scarcity of raw materials and global warming due to release of green house gases. Every industry therefore tries its best to minimize and combat these global problems. In concrete construction industry the primary route is the reduction of the content of ordinary Portland cement in concrete through the inclusion of admixtures as partial replacements of Portland cement.

To fulfill the demands for both sustainable construction and incorporating waste materials, concrete made with multi-blended cement system of ordinary Portland cement and different mineral admixtures remains the judicious choice (Kanchan *et al.*, 2013). Considerable efforts are being done worldwide to make use of natural waste and by-products as supplementary materials to improve properties of cement concrete (Khusbu & Sharma, 2014).

An environmental problem continues to be created by the generation of industrial and agricultural wastes creating numerous environmental problems both in terms of their treatment and disposal. This has led to the construction industry being identified as one to absorb majority of the waste as fillers in concrete. And where these fillers have pozzolanic properties, they not only impart technical advantages but also enable larger quantities of cement to be replaced (Raheem *et al.*, 2012).

For third world countries, the most common and readily available material that can be used for partial replacement of cement without economic implications are agro-based wastes notable ones being bagasse ash, rice husk ash, acha husk ash and periwinkle shell ash. The advantage of using agro wastes over others includes the low capital cost per ton production, waste management promotion, increased farmers' economy base through sale of agro waste, conservation of limestone deposits as well as reduction in carbon dioxide emissions (Manaseh, 2010).

Ways of reducing the cost of portland cement production and improving the quality of cement are continually being sought by researchers in order to provide accommodation for the increasing populace in many parts of Africa. In technologically disadvantaged communities, industrial and agricultural waste products could be harnessed towards this effort (Ettu *et al.*, 2013).

Efforts have been channeled towards the exploitation of agricultural and industrial waste products including foundry waste, fly ash and natural fibres. For developing countries supplementary cementitious materials (SCM's) are vital in achieving lower cost of construction for the production of sufficient shelter, the main benefits being saving in energy, conservation of natural resources and reducing the carbon footprint of cement plants (Agbenyeku & Aneke, 2014).

2.1.1.1 Concrete making materials

a) Aggregates

Aggregates are normally occupy 70-80% of the volume of concrete and are normally regarded as inert fillers. Though deemed to be inert they control concretes thermal as well as elastic properties. They give concrete a skeletal body, reduce shrinkage and afford concrete dimensional stability and economy. Normal weight aggregates are divided into two; natural aggretates which include sand, gravel, crushed rock such as quartzite, basalt, sandstone and artificial aggregates which include broken brick, air cooled slag sintered fly ash and bloated clay (Obi, 2017). Concrete compressive strength is partly determined by aggregates. On the basis of particle size, aggregates are also broadly divided into two. Fine aggregate are those with particle size retained on 0.075mm sieve size and passing through 4.75mm sieve size. Their function in the concrete matrix is to fill the voids left by coarse aggregates. They also reduce the cost of concrete and increase the workability of the concrete. The main characteristic of fine aggregate that affects the concrete properties is bulking which is the increase in volume of fine aggregates with variation in moisture content. The percentage of bulking is inversely proportional to the size of the fine aggregate. On the other hand particles that are retained in sieve size 4.75mm are called coarse aggregates. Use of large sized aggregates allows a reduction in cement and water requirements. The main property of coarse aggregates that affect concrete is the aggregate crushing strength which is an indication of its resistance to compressive load. An aggregate crushing value of less than 10 indicates a strong aggregate while a value of 35 and above is considered a weak aggregate (Masud et al., 2020). The quality and type of parent rock from which the aggregates were made determine various properties of concrete such as workability, durability. Most igneous rocks have been found to produce satisfactory aggregates for concrete use. They have massive structure which is hard and dense and is either wholly crystalline or wholly glassy (Obi, 2017). The size of the aggregates is controlled by the final use of the concrete. Larger aggregate sizes lead to a reduction in cement and water quantities required. Aggregates thus play a major role in concrete since they occupy approximately 80-85% of a typical concrete mixture (Maria et al., 2020).

Aggregates form the skeletal body of concrete. They help in shrinkage reduction and make concrete an economical material. Good gradation is one of the most important factors in the production of workable concrete (Amitkumar et al., 2013). Aggregates are inert fillers in the concrete matrix and they constitute approximately 70-75% by volume of the whole mixture (Faseyemi, 2012).

The flakiness index and elongation index for coarse aggregates need to be maintained below 15 % (Amitkumar *et al.*, 2013). Crushed stone is normally used in order to ensure good mechanical performance so that any differences in mechanical properties of the mixtures are easily detected (Sumit & Raut, 2011).

The most common fine aggregate is river sand that conforms to the grading requirements of the American Society for Testing Materials (ASTM) or any other approved standard (Amitkumar et al., 2013). Its content should be as permitted for various sizes in the specifications (Faseyemi, 2012). Sand is a naturally occurring granular material made of finely divided rock and mineral particles. The composition varies greatly depending on the local rock sources. In inland continental settings the most common constituent of sand is silica, usually in the form of quartz which is resistant to weathering owing to its chemical inertness and considerable hardness. Silica sand has a variety of applications throughout the world ranging from water filtration, to blasting, to adding texture to roads, to producing concrete (Chirag et al., 2013). Locally available river bed sand that is free from debris may be used as a fine aggregate, the particle size distribution should be such that it gives minimum voids ratio, in order to reduce the amount of mixing water required (Srinivasan & Sathiya, 2010).

b) Water

Water is an important ingredient because it triggers the chemical reaction of cement upon contact to form the strength giving gel. Without water, concrete cannot be produced. As a general rule water which is acceptable for drinking is suitable for making concrete. The chemical reactions in cement cannot begin without water. The water to cement ratio used in a concrete should take into account the aggregate content and whether the aggregates are fully saturated (Masud et al., 2020). Water has an impact on the workability of concrete. Whereas a low water/cement ratio gives better strength and durability, it may result in an unworkable concrete that is difficult to handle. The quality of water used should be pure and free from chlorides and salts that can attack the concrete (Ash et al., 2019). Complete compaction of concrete is a critical factor for achieving maximum strength. For maximum compaction to be achieved a higher water/cement ratio is required than the theoretically calculated one, thus the role of water is to lubricate the concrete for achievement of desired compaction (Obi, 2017).

The quantity and quality of water need careful consideration (Amitkumar et al., 2013). The quality should be such that the water is free from acids, organic matter, suspended solids, alkalis and other impurities that may have adverse effect on the concrete strength (Faseyemi, 2012).

c) Admixtures

Concrete is typically made up of cement, fine aggregate, coarse aggregate and water. Outside these, any ingredient added either before or during mixing to alter specific properties of the concrete is termed as an admixture (Akoba et al., 2020). The use of admixtures imparts positive effects to concrete like improving workability, acceleration or retardation of setting times, reduction in water/cement ratio among others. (Abdullah et al., 2012).

Conventional admixtures primarily fall into the following categories; accelerators, retarders, plasticizers, water proofers, cementitious, pozzolanic materials and chemicals that inhibit alkali-silica reaction (Otunyo, 2011). Other than conventional admixtures, there has been an increase in the use of Agro-based admixtures in order to reduce cement content in concrete.

(i)Conventional admixtures

Include accelerating , Water reducing, Retarding admixtures, Air- entraining , Super plasticizing admixtures (Surender & Upasana, 2017), Corrosion inhibitors ,damp proofing admixtures, Gas forming admixtures and Colouring admixtures (Tomas, 2013).

Reasons for use of admixtures vary depending on the specific needs (Akoba et al., 2020).

(ii) Mineral admixtures

These are materials that are finely divided and added to concrete in relatively large amounts, in the order of 20-40% by weight of Portland cement. Their origin may be from raw or calcined natural minerals or from industrial by products. ASTM C 618 classifies mineral admixtures as class N, class F and class C (Surender & Upasana, 2017). Though admixtures have become an essential part of the modern concrete mix providing middle ground for the conflict between water/cement ratio and workability, they are not and cannot be a remedy for poor concrete mix design due to incorrect proportioning of ingredients, poor mixing or low quality materials (Legeto et al., 2016).

(iii) Agro-based admixtures

The versatility of cement has impacted its demand and production leading to negative environmental effect. Apart from the negative effects of cement production, it is also not sustainable (Soumyan & Aswathi, 2016). For this reason, many researchers have developed green concrete by incorporating different materials of agricultural origin as pozzolans to replace cement in concrete and mortar and hence come up with sustainable construction solutions. One of the strategies is to use materials that are available in abundance to create supplementary cementitious materials (Devinder & Jaspal, 2016). This opens up a window for formulation of concretes that would utilize the abundant and untapped resources that present characteristics similar to conventional concrete. Senani et al. (2017) reviewed studies of the effect of coconut shell ash, ground nut ash, rice husk ash and sugar cane bagasse ash on concrete properties workability and concrete strength. They concluded that cement could be advantageously replaced with agro-based ashes in concrete without losing compressive strength up to an optimum amount percentage that was specific to each researcher and each agro-waste ash. They also concluded that the workability of the concrete decreased with the increase in percentage partial cement replacement with agro-waste ashes.

Muhamad et al. (2019) studied the properties of concrete made with cement partially replaced with wheat straw ash as an admixture. They found out that for partial replacement of cement with 15, 20, 25 & 30% rice straw ash, the compressive strength of concrete and mortar decreased with increase in percentage partial replacement except those containing 15% wheat straw ash. Further the concrete with 15% partial replacement of cement showed improved ductility, stiffness and toughness at 91 days.

Egbe-Ngu and Solomon (2014) investigated use of saw dust ash as an admixture in attempt to improve mechanical and durability of cement pastes. They reported that normal consistency increased with increase in saw dust ash, setting time of concrete increased with increase in saw dust ash, drying shrinkage decreased with increase in saw dust ash, the workability decreased with increase in saw dust ash content, compressive strength increased with partial substitution of cement with saw dust ash up to 2%, and the resistance to acid attack increased with increase in saw dust ash content in concrete.

Mohamed and Taher (2006) conducted research on the effect of rice straw ash on the properties of different cement types namely ordinary Portland, high slag and sulphate resisting cement. The results reported showed that initial and final setting times increased with increase in percentage partial replacement of cement with rice straw ash for all the cement types.

Bagcal and Baccay (2019) researched on the influence of corn cob ash on the properties of mortar when used to partially replace cement in mixes. The results indicated that the corn cob ash exerted a delay in setting times of the mortar; the addition of corn cob ash reduced the fluidity and plasticity of cement mortar paste. The compressive strength was found to decrease with increase in percentage partial replacement of corn cob ash.

From the foregoing it can be observed that other than conventional additives, agro-based additives can equally be used to alter specific desired properties of cement and mortars and they can be used to partially substitute cement up to a specific optimum percentage replacement.

d) Binder

Another ingredient of concrete is the binder which on mixing with water can set, harden and bind aggregate materials together. The binding material should have adhesive and cohesive properties. The most common binding material used in concrete is Portland cement (Masud et al., 2020). Many types of Ordinary Portland cement are available in the market even though there is limited combination of materials that can be used to produce cement. Therefore there is potential in research on the use of numerous other materials to partially or fully replace cement and therefore come up with numerous other that can be made available to the market. The list of possible alternative binders to OPC cement is growing by the day with continued research and included but is not limited to High volume supplementary cementitious materials (SCM), limestone calcined clay cement (LCC), Alkali activated materials (AAM), and Calcium Sulphoaluminate Cement(CSA), metakaolin and fly ash based geo-polymers (Marijana et al., 2019).

a) Cement

The patent for Portland cement was given to Joseph Aspdin in 1924. The modern cement is an improvement of Joseph Aspdin's cement by his son William in the latter half of the 19th century. The chemical composition of OPC has remained unchanged for the last 100 years (Biernacki et al., 2017). Portland cement is the most common binder used in concrete making (Masud et al., 2020). Cement binds together solid bodies/aggregates by transforming from plastic to a solid state (Ash et al., 2019). It reacts with an activator-normally water to form a solid and durable matrix. (Pamenter & Myers, 2021). Worldwide, cement is an important material for use in construction of socio-economic infrastructure (Symala et al, 2017). The projected global cement production for the year 2020 was estimated to be 4.4 billion metric tons and the demand for cement is continuously growing (Chaeyeon et al., 2020). According to European standard specification EN 197, five categories of cement are available in Europe;

Cement Type I (CEM I), Cement Type II (CEM II), Cement Type III, (CEM III) , Cement Type IV (CEM IV) and Cement Type V, (CEM V) (Ash Ahmed et al., 2019).

(i) Basics of cement usage

The cement properties must lie within a certain range of standards for the engineer to have confidence that it will perform satisfactorily (Ul Amin, 2010). Cement is mainly used to bind hard and coarse aggregates together in concrete (Al-Khateeb, 2013). Currently there are many varieties of concrete such as pumpable, ultra-high strength, self compacting, sprayable (shotcrete) and early- age strength development concrete (Biernacki et al., 2017).

(ii)Basic Chemistry of Portland cement

Raw materials for production of cement are limestone, shale, chalk, clay and sand (Ash et al., 2019). The materials undergo calcinations, whose product, calcium oxide, is mixed together with silica, ferrous oxide and alumina and burnt at high temperatures to form clinker. Clinker is ground and milled with other additives such as gypsum & slag etc to the required fineness form cement (Kuruva, 2018).

The main components of Portland cement are dicalcium silicates (Ca_2SiO_4), tri-calcium silicates (Ca_3SiO_5), tricalcium aluminates ($Ca_3Al_2O_6$), and tetracalcium alumino ferrite ($Ca_4Al_2Fe_2O_{10}$). The dicalcium silicate, tri-calcium silicate, tricalcium aluminates and tetracalcium alumino ferrite are denoted as C_2S, C_3S, C_3A and C_4AF respectively in cement chemist's notation. The silicates, C_3S and C_2S, are the most important compounds, which are responsible for the strength of hydrated cement paste (Ash et al., 2019). In Kenya, cement is manufactured according to Kenyan STANDARD KS-EAS- 18-1 2001 which is an adaptation of European Norm EN 197 Cement Standards (Okumu et al., 2017). The European standard specification for the percentages of the various oxide compositions in cement are as tabulated in Table 2.1;

Table 2.1: Chemical oxide composition of OPC to European standard EN 196-2

Oxides	European Standard Concentration (% by weight)
Calcium oxide CaO	61-67
Iron oxide Fe_2O_3	0-6
Silica SiO_2	19-23
Aluminum oxide Al_2O_3	2-6
sulphur trioxide SO_3	1.5-2.5
Magnesium oxide MgO	less than 5%

(Source: Sam *et al,* 2013).

The chemical analysis of composition of cement is significant since it will be used as the control while conducting experiments during this research. Also it could give guidance on what and how much to add to improve the cement's performance.

The quantity of the cement compounds may be calculated from the oxide concentrations using the Bogue's formulae as follows:

$$C_3S = [(4.071CaO) - (7.6SiO_2) - (6.178Al_2O_3)] - (1.43Fe_2O_3) - (2.852SO_3) \quad (2.1)$$

$$C_2S = [(2.867SiO_2) - (0.7544C_3S)] \tag{2.2}$$

$$C_3A = [(2.65Al_2O_3) - (1.692 * Fe_2O_3)] \tag{2.3}$$

$$C_4AF = [3.403Fe_2O_3] \tag{2.4}$$

(Sam *et al.,* 2013).

b) Lime

Lime may be argued as the first true green and versatile building material. The use of lime in construction however declined in the nineteenth century with the introduction of cement. Lime is versatile and possesses several advantages over cement: These include allowing water to escape preventing risk of dampness and erosion, flexibility to allow minor movements without cracking and low cost of production compared to cement. Further, it consumes less energy during production and emits 20% less CO_2 compared to cement.It also re-absorbs CO_2 during setting when used in mortar (Thirumalini & Sekar, 2013). Use of lime is therefore a good opportunity towards achieving eco-friendly and sustainable development in construction.

2.1.1.2 Pozzolans and agro-waste ashes as cement replacement materials in concrete

Many materials have been used to partially replace cement in concrete. These include industrial by products such as silica fume, fly ash, blast furnace slag and metakaolin. However scarcity of natural resources has seen a shift towards research and use of agro-industrial wastes whose accumulation could generate environmental and social problems (Moises et al., 2012). This research focuses on the use of with agro-waste namely rice straw and egg shell ashes as partial replacements of cement in concrete.

According to American Society for Testing Materials (ASTM) specification C618-78, pozzolans are siliceous or siliceous and aluminous material which itself possesses no cementitious value but in finely divided from and moisture present react with calcium hydroxide to from cementitious compounds (Otoko, 2014).

Pozzolans which are also called supplementary cementitious materials (SCM'S) are used in concrete to partially replace ordinary portland cement. Pozzolans were originally associated with calcined earth and volcanic ashes. However today the term pozzolan includes all aluminous/siliceous materials on powder form that in the presence of water react to form cementitious compounds. Experimental and research in concrete has led to several cement replacement materials that may be naturally occurring or by products of industrial processes (Muhamad et al., 2013). Research has revealed that pozzolans can produce concrete with characteristics close to normal concrete at 28 days and beyond. Application of various ashes as potential replacement of cements has attracted researchers due to it's potential to reduce cost of concrete and also eliminate classification of ashes as waste materials (Agbenyeku & Aneke, 2014). The primary focus is currently on the prospects of using the various suitable agricultural ashes commercially as partial replacement for ordinary portland cement composites (Ettu et al., 2013).

Agro-wastes cannot be used directly to replace cement; they require to be treated by heat, a process known as pyroprocessing **(**a process in which materials are subjected to high temperatures in order to bring about a chemical or physical change). There are two important factors to be considered before using an agro-residue to replace cement. First is the chemical composition and second, the ash content (Parande etal., 2011). Under chemical composition, silica content is the most important factor because it will react with the lime to form calcium silicate hydrates for both strength and other microstructural properties.

2.1.1.2.1 Cement hydration, pozzolanic reactions and Ca $(OH)_2$ consumption

Cement hydration produces calcium silicate hydrates (CSH) gels that give strength and cohesion to concrete. Though there are other solid hydration products in the cement paste, the CSH constitutes 60% of the hydrated cement volume (Abalaka, 2013).The other compounds formed in clinker are tetra calcium aluminoferrite (C_4AF) and tri calcium aluminate (C_3A). The C_4AF and C_3A control setting time and heat evolved during hydration. Addition of gypsum is sometimes done to adjust setting time of cement (Sam et al., 2013). Upon wetting of cement the following reactions occur:

$$2(3CaSiO_2) + 6H_2O \rightarrow 3CaO.SiO_2.3H_2O + 3Ca(OH)_2 \quad (2.5)$$

$$2(2CaO.SiO_2) + 4H_2O \rightarrow 3CaO.SiO_2.3H_2O + Ca(OH)_2 \quad (2.6)$$

$$3CaOAl_2O_3 + 31H_2O + 3CaSO_4 \rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O \quad (2.7)$$

$$4CaOAl_2O_3Fe_2O_3 + 10H_2O + 2Ca(OH)_2 \rightarrow 6CaO.Al_2O_3.Fe_2O_3.12H_2O \quad (2.8)$$

The main strengthening compounds are the CSH produced in Equation 2.5 and Equation 2.6.Further during the hydration process of the two main components of cement namely tricalcium silicate and dicalcium silicate, calcium hydroxide is produced. The calcium hydroxide and ettringite

($3CaO_. Al_2O_3.3CaSO_4.32H_2O$) in Equation 2.7 that are crystalline in nature form the frame of the gel like products. Hydration of C_4AF consumes $Ca(OH)_2$ to form gel like products (Ettu *et al.*, 2013).

During hydration of Portland cement, one of the products obtained is calcium hydroxide. It is responsible for concrete deterioration through leaching (Ettu et al., 2013). Excess $Ca(OH)_2$ in concrete can be detrimental to concrete strength owing to the tendency of crystal growth in one direction (Villar et al., 2003).

The calcium hydroxide formed has no cementitious properties. Further, when calcium hydroxide reacts with carbondioxide, it results in formation of a soluble salt which is capable of leaching out of concrete leading to a common architectural problem of efflorescence. High amounts of calcium hydroxide in concrete also render it vulnerable to sulphate attack and adverse alkali aggregate reactions (Verna et al., 2012). When a pozzolanic material is added to Portland cement it reacts with the $Ca(OH)_2$ to produce additional calcium silicate hydrates thus reducing the quantity of harmful $Ca(OH)_2$ and increasing the amount of beneficial C-S-H thus improving cementitious properties (Ettu et al., 2013).

Pozzolanic reaction occurs when a siliceous or aluminous materials in the pozzolan chemically reacts with calcium hydroxide in the presence of humidity to form compounds exhibiting cementitous properties. By adding pozzolanic material to mortar or concrete mix, the pozzolanic reaction will only start upon release of calcium hydroxide (Villar et al., 2003). The pozzolanic reaction involves the reaction of hydroxyl ions (OH^-) and calcium (Ca^{2+}) ions from sodium hydroxide and the SiO_2 or $Al_2O_3.SiO_2$ framework to form calcium silicate hydrates(C-S-H), calcium aluminate hydrates(C-A-H) and calcium aluminate-ferrite hydrate. Tobermorite gel

$$SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaO.SiO_2.H_2O \tag{2.9}$$

Calcium silicate hydrate

$$Ca(OH)_2 + H_2O + Al_2O_3 \rightarrow Al_2O_3.Ca(OH)_2.H_2O \tag{2.10}$$

Calcium aluminate ferrite hydrate

$$Ca(OH)_2 + Fe_2O_3 + Al_2O_3 + H_2O \rightarrow Ca(OH)_2.Al_2O_3.Fe_2O_3.H_2O \tag{2.11}$$

The C-S-H and C-A-H harden with age to form a continuous binding matrix which is responsible for cement paste strength (Kassim & Chern, 2004). Pozzolana-lime reactions are slow starting as late as one week after hydration of cement. This consequently makes concrete more permeable in the early ages and gradually gaining density with time.

The slow rate pozzolanic-lime reaction behavior can be attributed to two reasons; first, pozzolan particles act as precipitation sites for early hydration C-S-H and Calcium hydroxide hinders pozzolanic reaction. Second is the dependence of breaking down of the glass phase on the alkalinity of pore water which requires several days of hydration to attain alkalinity. The advantage brought about by pozzolanic reaction through formation of additional cement gel namely C-S-H and C-A-H include denser cement by blocking capillary pores and hence making the concrete denser and durable (Yu et al., 1999).

The calcium silicate hydrates and calcium hydroxide have been described as the dominant products of hydration produced at the early stages of hydration that result from the selective hydration of dicalcium silicate and tricalcium silicates. Between the latter two, tricalcium silicate reacts faster and dominates the early days of hydration. In order to take care of the huge amount of calcium hydroxide produced by hydration reaction, which might be disadvantageous to the quality of concrete since it can be a source of instability, any cheap agricultural material rich in silica may be used. The silica in these materials reacts with the excess amounts of calcium hydroxide to further produce additional calcium silicate hydrates which is significant for strength development. The amount of additional calcium silicate hydrates will be dictated by the amount of calcium hydroxide produced by the hydration reaction of cement (Okonkwo et al., 2012). Therefore the cementing quality is enhanced when a good pozzolanic material is blended with Portland cement in suitable proportion (Ettu et al., 2013). The pozzolans also improve the rate of strength gain and can also reduce the heat of hydration thus minimizing cracking in mass concrete (Agbenyeku, 2014).

The presence of pozzolans influences both the hydration process and the resultant compounds. It in fact complicates the hydration process since both the pozzolanic and hydration reactions take place simultaneously within the same matrix. Nevertheless they follow different processes and occur at different rates. Hydration reaction proceeds much faster than the pozzolanic reaction that becomes effective between 3-14 days (Ozlem et al., 2006).

Ordinary Portland cement is polymineralic in nature. The polymineralic nature makes the hydration process difficult to completely understand. Hydration of cement to date is not satisfactorily understood, and since complex reactions are involved it is difficult to realistically present stoichiometrically. It is worth noting that in addition to the main compounds C_2S, C_3S and C_4AF, there are minor oxides such as sodium oxide (Na_2O), potassium oxide (K_2O), Manganese III Oxide Mn_2O_3, Tin oxide (TiO_2), and Magnesiun Oxide (MgO); though they are minor by virtue of their quantities, they are also vital to the hydration of cement (Mtallib & Rabiu, 2009).

2.1.1.2.2 Rice straw agro-wastes

Globally, the area under rice cultivation is approximately 150 million hectares and the global rice production is estimated to be 500 million metric tons annually (Atera et al., 2018). In Kenya rice is mainly cultivated by small scale farmers in Central (Mwea), Western (Bunyala), Coast (Tana Delta, Msambweni) and Nyanza (Ahero, West Kano, Migori and Kuria) (Obura et al., 2017). Presently, 78% of the total area under rice cultivation is under irrigable land in national rice schemes managed by the National Irrigation Board (NIB) (Atera et al., 2018). There are about 18 medium to large size and 11 small size rice mills in Kenya (Ndirangu & Oyange, 2019).

Common rice production estimates are those of Ministry of Agriculture (MOA) for all milled rice production and the National Irrigation Board (NIB) for all paddy rice produced in its irrigation schemes (Short et al., 2012). Cropped rice area rose by 17.9 % to 32.3 thousand acres in the last five years (KNBS Economic Survey, 2020). Most households use family labour to undertake rice field operations (Cheserek et al., 2012). Rice straw has a high ash content of 19.2% (Chardust, 2004). Every kilogram of rice paddy harvested produces straw weighing between 0.41 and 3.96(giving an average of 2.185) kilogrammes (Jeng et al., 2012). In the year 2018/2019, paddy rice production by NIB schemes in Kenya was 160,584 tons. Since Rice straw is highly lignified material with low nutritive value, it has a low potential value as feed for ruminants (Sarnklong et al., 2010). Thus a large quantity of rice straw is basically left in the farms with little competing use and is available in sufficient quantity for utilization in partial substitution of cement. Feeding rice straw on ruminants is limited due to its high lignin, high silica content, low palatability and slow digestion of structural carbohydrates.

Most previous research works on rice by-products as pozzolans have concentrated on rice husk ash. Thus making Rice husk ash is one of the most studied biomass ash as a pozzolan. The use of rice straw ash as a pozzolan in concrete mixes is limited. Rice straw ash has been less explored by researchers despite the fact that according to the United Nations Food and Agriculture Organization (FAO), rice straw production is estimated to be 600 million tons per year. This therefore provides an opportunity for characterizing the properties of RSA and assessing its potential for use as a pozzolan (Samantha et al., 2021).

Rice husk ash is a by-product of paddy rice and forms highly reactive pozzolanic ash (Pravin, 2012). Rice husk is the outer covering of the grain of rice plant with high concentration of silica content ranging between 80-85%. The rice plant is among the plants that also absorbs silica from the soil during growth and assimilates it into its structure (Alireza et al., 2010).

Mohamad and Taher (2006) conducted chemical analysis on rice straw ash incinerated at 550º centigrade for one hour and found it to contain 65.92% silica(SiO_2), 1.78% Alumunium Oxide(Al_2O_3), 0.2% Ferric Oxide (Fe_2O_3) , 2.4% Calcium Oxide(CaO), 3.11% Magnesium Oxide(MgO), 0.69% sulphur trioxide(SO_3), and 9.71% Loss on ignition. Researchers Dabai and Muhammad (2017) found out that incinerating rice straw at 1,100 degrees centigrade for two hours, resultant rice straw ash were found to be composed of 61.50% silica (SiO_2), 4.67% Alumunium Oxide (Al_2O_3), 3.08% Ferric Oxide (Fe_2O_3), 15.45% Calcium Oxide (CaO), 1.89% Magnesium Oxide (MgO), 2.18% sulphur trioxide (SO_3), 1.07% potassium oxide (K_2O), 9.79% Loss on ignition and 1.55 free lime. Samantha et al., (2020) evaluated rice straw ash to as a pozzolanic material in cementitious mixes. Rice straw was burnt rapidly and energetically at 500ºC. The rice straw ash was then milled for 15 minutes using a ball mill with 50 large and 60 small alumina balls. Chemical composition results indicated silica ($SiO_{2)}$ was 52.4, alumina (Al_2O_3) was 0.47, ferric oxide (Fe_2O_3) was 0.71, and calcium oxide (CaO) was 8.01% among others. The loss on ignition was 14.6%. This research will evaluate suitability of rice straw ash as a cement partial cement replacement material in concrete.

2.1.1.2.3 Chicken egg shells

The chemical composition of egg shell and its similarity to cement is what makes them worthy pursing as a possible supplementary material for replacing cement. Egg shell is typically composed of calcium carbonate with some researchers reporting 94-97% calcium carbonate, 3-4.5% organic matter and 0.83% magnesium oxide (Owuanaman & Cree, 2020). It can be observed that calcium carbonate is the predominant composition of egg shells; similarly calcium carbonate is the primary raw material for cement production (Afolayan, 2017). Their main component is calcium carbonate ($CaCO_3$) which is about 95% with the remainder including magnesium, potassium, sodium, phosphorus, aluminum, zinc copper (Chirag et al.,2013). During incineration to ash, there is decomposition of egg shell ($CaCO_3$) to calcium oxide (CaO)/lime and carbon (IV) oxide.

$$CaCO_3 \rightarrow CaO + CO_2 \tag{2.12}$$

The CO_2 escapes as gas while the CaO / lime remains in the ash (Mtallib and Rabiu, 2009). Hen Egg shells could be used as a source of lime. They are known to be very rich in calcium carbonate. The ash yield of the calcinations process of egg shells is 65 % (Beck et al., 2010).

As it stands today Kenya has an estimated 28 million birds of which 76% are free ranging indigenous and 22% are commercial layers and broilers. About 2.2% are other poultry species such as ostrich, guinea fowl, pigeon, and quail. The weekly production of chicks by the commercial poultry sector is over one million. There are four main hatcheries in Kenya namely Kenchic with an annual day old chick production of 13.0 million based in Athi River, Kajiado, Kisumu and Nairobi Industrial area, Sigma with an annual chick production of 1.0 million day old chicks based in Nairobi, Kenbird with annual production of 1.092 million day old chicks based in Naivasha and Muguku with an annual day old chick production of 1.152 million day old chicks based in Kikuyu (ANAW, 2020). Production of chicken egg shells at an industrial level leads to considerable quantity of egg shells residue that is considered to have no economic value despite the fact that they are rich in minerals and amino acids that could be of beneficial use in other industries (Soumyan & Aswathi, 2016).

The disposal of the egg shells is a problem to the authorities (Sathish & Kumar, 2017). Chicken egg shells are part of agro-wastes that are normally thrown as litter to the environment (Afolayan, 2017). The chicken egg shells when left in the environment for long they create some allergies and undesirable smell that can cause irritation (Ashfaque et al., 2019).

From the above figures, there are a lot of egg shells available from production of day old chicks by hatcheries other than those emanating from small scale hatcheries, domestic, hotel and confectionery uses of hen eggs. These are generally considered waste and may be a challenge to dispose them off. The use of lime in construction should be encouraged since it offers a number of advantages compared to cement with regard to both environment and economy. The quantity of egg shells available in Kenya is an enormous source of lime that can be exploited by incorporating it into concrete production by the construction industry. It is a sustainable and eco-friendly alternative to quarry limestone.

2.1.1.3 Properties of concrete

The concrete produced by partially replacing cement with rice straw ash and egg shell ash is expected to have similar properties as the conventional concrete. Therefore it will be tested for properties similar to those of concrete made with conventional cement as a binder.

2.1.1.3.1 Properties of fresh concrete

Fresh concrete properties include setting time, heat of hydration, and workability. Setting time can be categorized into two. Initial set which is the duration that elapses between the instance of adding water and when the cement ceases to behave like a paste or plastic fluid and final set which is when the cement paste reaches a state of hardness capable of sustaining some load. It is tested using the Vicat apparatus. Heat of hydration refers to the heat generated during the reaction of cement and water. It is determined by the water-cement ratio, fineness of cement, curing temperature and the amount of tricalcium silicate and dicalcium silicates present (Al-Khateb, 2013).

Workability is the property of freshly mixed concrete that determines how easy it can be placed, consolidated and finished without segregation. The workability is usually measured by means of conventional slump test apparatus, the slump value being determined by the slump cone. This is usually done before the fresh concrete is cast (Vijaykumar et al., 2013). A concrete that has acceptable workability is a high quality concrete (around 65 mm slump height). Bigger height of slump means better workability (Srinivasan & Sathiya, 2010).

2.1.1.3.2 Properties of hardened concrete

Hardened concrete properties include compressive strength, splitting tensile strength and flexural strength. The compressive strength of cement varies with time and therefore is generally reported at 7 days, 14 days 28 days or even 90 days (Al-Khateb, 2013). The strength of concrete is related to the workability and can only be maximized if the concrete has adequate degree of workability because of self compacting ability (Srinivasan & Sathiya, 2010).

Determination of compressive strength is very important, since compressive strength is a criterion for concrete quality. It is this strength that help in the determination of optimum replacement level of cement (Lavanya et al., 2012). Compressive strength test provides the breaking strength of the cubes made purposely for determination of the compressed concrete strength. The compressive strength is obtained by dividing the maximum load carried by the specimen during the test by the average cross sectional area:

Compressive strength = Maximum load/Cross sectional area (2.13)

Splitting tensile strength is a measure of the splitting tensile strength of concrete by application of diametral compressive force on a cylindrical concrete specimen with its axis horizontal between plates of a testing machine.

Splitting tensile strength T, then is given by

$$T = \frac{2P}{\pi d l} \qquad (2.14)$$

Where

P is maximum load at failure of concrete

d is average diameter of cylinder

l is the average length of the concrete specimen

The flexural strength on a simple beam is used to determine the modulus of rapture (f_b) of concrete and it can be calculated as follows

$$f_b = \frac{PL}{\left(bd^2\right)} \tag{2.15}$$

Where

P is the maximum applied load

b is the average width of the specimen at point of fracture

d is the average depth of the specimen at point of fracture (Sooraj, 2013).

L = span of the beam between supports

2.2 Empirical Review

Amitkumar et al. (2013) studied the properties of concrete with cement partially replaced with ceramic ash at 10, 20, 30, 40 and 50% by weight and a water binder ratio of 0.48. The ceramic was found to contain 63.29% silica, followed by 18.29% Al_2O_3 as the main components (Amitkumar et al., 2013).

None of the blended concretes achieved higher compressive strength than the control. 10% partial cement replacement with ceramic ash yielded the closest strength to the control at 28 days, no tests were done after 28 days.

Chirag et al., (2013) studied the properties of concrete with cement partially replaced with rice husk ash (RHA) at 5, 10, 15 & 20% by weight using concrete grade 30 and

60 RHA was found to contain 87.2% SiO_2, 1.12% Sodium Oxide and 0.55% Calcium oxide. Compressive strength was found to increase by 4.23% to 10.93% for 7 days for 5% and 10% replacement and 6.74 to 13.48% for 10 and 15% replacement levels at 28 days respectively. Further increase in cement substitution to 20% led to strength reduction of 17.97% compared to the control. While the M60 grade concrete yielded 7 day strength increase of 4.23% at10% replacement level and 28 days strength increase of 6.5% for 10% replacement level. They concluded that addition of RHA at 5-10% will increase the compressive strength, whereas addition 15-25% RHA would cause a strength reduction. From these findings, it can be concluded that the strength gain during partial replacement is less affected by the concrete classes since the order of strength gain for M30 and M60 concrete was the same.

Muhammad et al. (2013) examined effect of metakaolin, silica fume and brick powder as partial cement replacements in concrete. Cement was replaced at 5, 10 and 15% with water binder ratios of 0.63, 0.54 and 0.47. The compressive strength was tested at 28 and 90 days while sulphate attack test also performed. The silica fume, metakaolin and brick powder was found to compose of 92%, 67% and 23.12% silica, respectively. The compressive test for concrete with 15% silica fume replacement was higher than that of the control and other pozzolans for all ages. The brick powder recorded very little pozzolanic behavior with slight compressive strength increase at 5% replacement level. The increase in strength caused by silica fume and metakaolin was attributed to both their fineness and pozzolanic action that reduced calcium hydroxide as well as total voids in concrete. The replacement materials with high silica lead to more strength gain upon replacing cement partially than those with low silica content.

Khusbu and Sharma (2014) partially replaced cement with strength fly ash (FA) and rice husk ash (RHA) in concrete. The strength for the control mix was 31 N/mm^2 with a water binder ratio of 0.45. The replacements of cement with RHA and FA respectively and combined were at 6, 12, 18 and 24%. The compressive strength was found to increase above the control for FA and RHA up to 12% replacement level, beyond which it registered decrease in strength. Split tensile strength increased marginally for fly ash replacement of up to 12%. RHA did not register increase in tensile strength above the control. Replacement of cement with combined RHA and FA registered lower strength than singly replacing cement with RHA. These findings are similar to those of Muhammad et al., (2013). Thus there is a limiting percentage that cement can be partially replaced by pozzolans in concrete, beyond which strength decrease is recorded. Further combining of pozzolans to simultaneously replace cement partially offered no advantage in terms of strength gain. This can be attributed to similarity in chemical composition of pozzolans, RHA had 92.99% silica and 1.03% CaO while FA had 60.6% silica and 2.19% CaO.

Kanchan et al. (2013) investigated the effect of fly ash (FA) and silica fume (SF) admixtures on strength and slump of concrete blend. The superplasticizer dosage required for slump of 100 $\pm$ 20mm was higher for concrete using binary blend of OPC+silica fume compared to control mix, but was significantly reduced in binary blended concrete using OPC + fly ash. They attributed this to spherical particles of FA that act as small bearings and compensate for higher super plasticizer demand arising from inclusion of silica fume with very high specific area (Goyal et al., 2008). These findings agree with those of Muhammad et al. (2013), that the shape of pozzolan particles and fineness are of significance. In this study compressive strength was found to increase up to a certain limiting percentage of OPC replacement level for all water/binder (w/b) ratios. Low water binder ratio of 0.3 recorded higher strength gain above the control than of concrete with w/b ratio of 0.4 and 0.45. The synergic effect of OPC, Fly Ash and Silica was found to result in higher strength than binary blend of OPC and Fly Ash at both lower and higher replacement levels. These findings differ with those of Khusbu and Sharma (2014) who reported lower strength using ternary cements of OPC, Fly ash and RHA. It was also found that lower water binder ratios recorded higher strengths than higher w/b ratios for the same partial replacement levels of cement with pozzolans.

Manasseh (2010) reviewed partial replacement of cement with Acha Husk Ash (AHA), Bambara Groundnut Shell Ash (BGSA), Bone Powder Ash (BPA), Ground nut Husk Ash (GHA), Rice Husk Ash (RHA), Wood Ash (WA). None of them satisfied the cement criteria CaO: SiO_2 ratio of 3.13, silica ratio (SR) and Alumina ratio of 1.7-3.5 and 2.44, respectively, and a calcium oxide composition of 60-67%.

This implies that the agro wastes cannot serve as substitutes for cement but only as partial replacements. The decrease in strength with increase partial replacement of cement was attributed to two factors. Firstly, the reduction in CaO component in the mix because the contribution of CaO by the agro-waste materials is not commensurate with the reduction of CaO occasioned by replacing cement with the agro-waste. Secondly the high SiO_2 component in the agro-wastes resulted in the blended mixes having excess SiO_2 that remains unreacted. The decrease in strength is therefore an indication that more lime (CaO) is required. The lime liberated during the hydration of cement blended with agro-wastes is insufficient to completely react with silica in the cement + pozzolan combinations to form cementitious materials C_3S.Thus, it can be said that partial replacement of cement with agro-wastes beyond the optimum caused a deficit in CaO in relation to the silica content. The CaO ought to be present in proportions that ensure maximum conversion of the silica content from the pozzolanic cement replacement material to cementitious materials to ensure strength gain of concrete. This CaO may come from calcium oxide rich material.

Ettu et al.**,** (2013) partially replaced cement with cassava waste ash (CWA) at 5, 10, 15, 20 and 25% replacement levels. The compressive strength was tested at 3, 7, 14, 21, 28, 50 and 90 days using a concrete mix of 1:2:4 and a water/cement ratio of 0.6.The 3-21 day strength was found to be lower than the control values for all percentages of replacement. They attributed this to the low rate of pozzolanic reaction at those ages. At 50 days of curing the strength of the binary blended concrete was close to that of the control while the 90 day strength of 5-15% replacement of OPC with CWA was higher than of the control. They concluded that OPC-CWA binary blended concrete may be used for high strength cements at curing ages greater than 50 days. No attempt was made to use other water/binder ratios as Kanchan et al., (2013) found out, lower water/cement ratios result in higher strength.

Agbenyeku and Aneke (2014) incorporated domestically derived cassava peels ash (DDCPA) and laterite in concrete production at 0 to 30% partial replacement ratios. The compressive strengths were measured at 56, 90,120 and 150 days and observed a progressive drop in compressive strength with increase in cement substitution over the different prolonged periods of curing. They attributed this to excess content of silica and/or alumina from DDCPA and the laterite not used up in the reaction. They attributed the significant drop in compressive strength to excess silica and alumina content that were not utilized in the pozzolanic reaction. These findings agree with those of Manaseh (2010). In order to get maximum gains when substituting cement with agro waste ashes, there is need to convert the excess silica into cementitious materials (calcium silicate hydrates) as illustrated by Equations 2.5, 2.6 and 2.7 by availing sufficient calcium oxide (CaO).

Parande et al. (2011) studied the utilization of Rice Husk Ash and bagasse ash in concrete. The RHA was found to contain more than 80% silica and a bit of alumina. The replacement levels ranged from 5-35% in OPC. They found that higher replacement of cement with RHA in concrete led to lower strength of concrete and increased water absorption. This was attributed to the excess silica in RHA that did not combine with lime liberated by the hydration of cement. Strength loss was caused by the leaching out of excess silica from the concrete while increase in water absorption was reportedly caused by the fineness and micro-structure of RHA that gives it the tendency to absorb and retain water. Thus, an excess in silica content in concrete resulting from partial substitution of cement with agro waste was harmful to concrete. No proposals were made on how to address this.

Raheem et al. (2012) investigated physical properties of concrete with partial replacement of cement with saw dust ash (SDA) at 5,10,15,20 and 25% by weight replacement levels. Compressive strength at was tested at ages 3, 7, 28, 56 and 90 days. Water binder (w/b) ratio of 0.5 was used up to 15% replacement levels while w/b ratio of 0.65 was used for 20 and 25% replacement levels. The compaction factor was also found to decrease with increase in SDA content. This was attributed to the increased amount of silica. The silica-lime reaction required more water in addition to the water needed for cement hydration as demonstrated by chemical Equations 2.1, 2.2, 2.3 and 2.7and the findings of Raheem (2012).Compressive strength results recorded general increase with curing period and decrease with increase in amount of SDA. At all replacement levels and all ages the compressive strength of the control with no SDA replacement was the highest. The slow (Ettu et al., 2013) found out, this strength gains manifest at curing ages beyond 28 days. It was also found out that water is needed for two purposes, first for cement and second, during pozzolanic reaction.

Ustev and Taku (2012) partially replaced cement with coconut shell ash (CSA) in concrete production at levels ranging from 0, 10, 15, 20, 25 and 30%. They used a water/binder ratio of 0.5 in their concrete mixes. The concrete was tested at 7, 14 and 28 days curing ages. The optimal 28 day strength recorded was 31.78 N/mm^2 at 10% replacement while the control which recorded 34.22 N/mm^2 at the same age. These findings differ from those of Raheem et al. (2012) who reported strength close to the control at 56 days curing age. The 28 day strength at 10% replacement reported was 20.52 N/mm^2 for the control and14.8 N/mm^2 for 10% replacement. It was found out that by improving the fineness of the pozzolans through sieving, the age at which blended cement show strength close to the control may be reduced. This means that the cementing efficiency of the pozzolan is increased. However there was a possibility of achieving the similar results at a curing age of 56 days.

The use of Silica fume as a partial replacement of cement in concrete was investigated by Faseyemi (2012) at replacement levels of 5-25% by weight at 5% increments and Class 30 concrete mix. There was an increase in compressive strength attributed to both the high pozzolanic nature of micro-silica and also its capacity to fill voids. The optimum partial replacement was found to be 10%. These findings are similar to those of Muhammad et al. (2013) that fineness of pozzolan particles allows tight packing of particles that improves the concrete matrix density.

Otunyo **(**2011) used palm kernel husk ash (PKHA) in concrete as an accelerator and for partial replacement of cement. Setting time of concrete was found to decrease with increase in PKHA content while strength indicated decrease in strength with increase in PKHA content. From these results, it was found out that PKHA reduced setting time at the expense of strength.

Olutoge et al. (2012) used palm kernel shell ash (PKSA) to partially replace Portland cement at 10 and 30% PKHA in concrete and a water/binder ratio of 0.5. For the two cement replacement levels, the found to be lower than the control at 7, 14, 21 and 28 days. Strength gained beyond 28 days due to the slow pozzolanic reactions. PKHA was found to have the chemical oxides found in Portland but in different quantities. These varying quantities alter the chemical composition and content of oxides responsible for hydration is responsible for strength loss in the resulting blended mix.

Abalaka (2013) partially replaced cement with Rice Husk Ash in concrete with water/binder ratios of 0.35, 0.4, 0.45, 0.5 and 0.55. The results showed that as the water binder ratio increased, the amount of maximum RHA replacement also increased. The increase in maximum RHA as the w/b ratio increased was attributed to the hygroscopic nature of and microstructure of RHA. Lower water/binder ratio resulted in lower maximum RHA replacements as less water was available for absorption by RHA particles, in high w/b ratio mixes there was adequate water available for absorption by the rice husk ash resulting in higher replacement levels. The cement replacement with 5% RHA progressively gained strength with age however they did not record strength higher that of the control at all test ages for w/b ratio of 0.35. With a water binder ratio of 0.4 and 0.45 compressive strength increases above the control were recorded at test age of 180 days. At 15% replacement levels and water binder ratio of 0.5 all the test ages recorded compressive strength higher than that of the control. At water/binder ratio of 0.55 the compressive strength higher than the control was recorded at all ages at 5% RHA content. Thus it can be concluded that water plays a crucial role in pozzolanic reactivity within concrete. A low water binder ratio of 0.35 recorded no strength increase, comparing it with the results of water binder ratio of 0.55 suggests that optimum free water is needed for activation of pozzolanic activity, where free water is low, no reactivity was recorded conversely where it was high no strength gains were recorded. These findings agree with those of Raheem (2012). That for a given percentage partial replacement of portland cement with pozzolan in concrete, there is an optimum water binder ratio that allows both maximum reactivity of pozzolan and cement hydration for strength development. Equations 2.1 to 2.7 require water to proceed.

Akihonbare (2013) evaluated use of agro-waste namely bambara ground nut shell ash(BGSA), acha husk ash(AHA), groundnut husk ash(GHA), wood ash(WA), palm oil shell ash(POSA), bone powder ash(BPA) and periwinkle shell ash as partial replacements of cement in concrete at 10,20,30,40 and 50% by weight. The highest 28 day compressive strength was achieved at 10% partial cement replacement with bone powder ash. 20% cement replacement with Acha husk ash attained optimum compressive strength. BGSA, BPA, RHA and WA all exhibited reduced compressive strength with increase in cement replacement levels and their strength did not match that of the control at all replacement levels. The rice husk ash was found to have the highest silica content of the agro wastes used yet it recorded the lowest strength at all replacements levels compared to all other agro wastes. This could be attributed to the structure of silica which is affected by burning temperature, controlled burning is required to get rice husk ash that is reactive to lime. These findings differ from those of Faseyemi (2012), Khusbu and Sharma (2014) where high silica content in the agro-waste proved to be advantageous in terms of strength gain during partial replacement of cement. However in the methodology they used 212 micron sieve for RHA, 75 micron sieve for BGSA and hammer mill for grinding BPA. This gave the pozzolans different fineness with RHA having the coarsest particles hence low surface area. This may explain why it recorded lowest strength gain though it had highest silica. The methodology was bias and comparison of the pozzolans faulty.

Srinivasan and Sathiya (2010) studied sugar cane bagasse ash (SCBA) as partial replacement of cement in concrete with a water binder ratio of 0.48. The chemical analysis results found it to contain 78.34% silica, 8.55% Al_2O_3 and 3.61% Fe_2O among others. The slump of the concrete was found to increase with increase in SCBA; this was attributed to increase in surface area of the blended cement after adding SCBA that needs less water compared to wetting the cement particles. The compressive, tensile flexural strength increased above the control up to 10% replacement, beyond which the strength decreased. The use of 20% replacement of cement with SCBA showed a decrease in strength. This was explained by availability of excess silica in the cement- SCBA mix at that resulted in higher amount of silica than what is adequate to combine with lime liberated by the hydration process. The excess silica is leached out of the concrete matrix causing deficiency in strength since it occupies volume but does not contribute to strength. These findings are similar to those of Manaseh (2010) and Faseyemi (2012). Failure to achieve strength close to the control could also be attributed to the fixed water –binder ratio of 0.48, as Abalaka (2013) found out that higher cement replacement levels were achieved by varying the water – binder ratio.

Lavanya et al. (2012) also examined the compressive strength properties of concrete with partial replacement of cement with sugar cane bagasse ash in proportions of 0, 10,15,10,25 and 30% for water/binder ratios of 0.35, 0.4 and 0.45. Strength tests on cubes were done at 7, 14 and 28 days. At 15% partial replacement and 0.35 water/binder ratio, there was an increase in compressive strength above the control. The rest of the replacement levels and water binder ratios recorded lower strength than the control. Comparing these findings it can be observed that a higher optimum replacement level (15%) was achieved at a water/binder ratio of 0.35 whereas Srinivasan and Sathiya (2010) using a water binder ratio of 0.48 could only achieve an optimum replacement level of 10%. This can be attributed to the concrete mix designs, source and treatment of the bagasse ash used.

Ettu et al. (2013) used rice husk ash (RHA) as a replacement of cement at 0, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50% and a water/binder ratio of 0.6. Compressive strength tests were done at 3, 7, 14, 21, 28, 50 and 90 days. Particle size analysis found RHA particles to be coarser than cement particles, since RHA was not milled. The concrete compressive strength of blended concrete was lower than that of the control at 3-21 days. While a 50-90 days the strength increased was comparable and even greater than that of the control. 5% replacement level yielded strengths higher that cement. Other replacement levels yielded lower compressive strength than the control except at curing ages of 50 days and above. This was explained by the low rate of the pozzolanic reaction at early ages of hydration. Rate of chemical reaction and strength gain can be improved by crushing the RHA to make its particle size finer.

Ettu et al. (2013) also partially replaced OPC with rice husk ash (RHA) and saw dust ash (SDA) at 0, 10, 15 and 20%. For all the percentage replacement of OPC with RHA and SDA blended concrete the compressive strength increased to with leanness of mix to an optimum level beyond which the strength reduced. 10% partial replacement of cement at a mix proportion of 1:3:5 at a water binder ratio of 0.7 was reported to be ideal for OPC-RHA-SDA binary blended cement mix. Its 50 day strength was found to be 85-101% that of 100% OPC concrete. The study found that the strength of the OPC-RHA-SDA blended concrete is not determined much by the ratio of the coarse to fine aggregate as the proportion of the total aggregate. These findings are similar to those of Chiraget al. (2013), that strength of blended concrete is less affected by concrete mix ratios. Further the findings agree with those of Khusbu and Sharma (2014), Muhammad *et al.*, (2013) that partial replacement cement to a concrete with more than one pozzolanic material offers no advantage in terms of strength development. Chemical similarity of pozzolans is responsible for this. Similar findings were reported by (Khusbu & Sharma, 2014).

Pravin (2012) partially replaced cement with rice husk ash (RHA) and coir fibre in concrete. The 7 and 14 days age compressive strength of bended concrete was below that of the control, but nearly matched the control at 28 days. At 90 days age compressive strength exceeded that of the control. The addition of coir fibres increased the compressive strength compared to the control by up to 15%. The optimum replacement of cement with RHA was found to be 15% with 3% coir fibres.

Sooraj (2013) used palm oil fuel ash (POFA) to partially replace cement in concrete at 10, 20, 30 and 40% and a water/cement ratio of 0.45. A concrete class 30 was used. Save for 10% replacement of cement with POFA at 7 days age, the rest of the replacement levels recorded results lower than the control for both 7 and 28 days. The compressive strength was found to decrease with increase in cement replacement levels. It was concluded that up to 20% replacement level, targeted 28 days strength of 30N/mm^2 can be achieved. Splitting tensile strength was found to increase with increase in cement replacement levels up to 10%, for 20% replacement the tensile strength equaled that of the control while beyond 30% tensile strength decreased. 20% partial replacement of cement was optimum for flexural strength with a value of 6.12N/mm^2. Thus it is seen that partial cement replacement with pozzolans shows the same trend for compressive, tensile and flexural strength. The POFA comprised of 28.81% silica which is similar to typical OPC, making it a have less impact on strength when used to partially replace cement.

Olusola and Akaninyene (2012) examined the effect of periwinkle shell ash (PSA) blended concrete at 0, 10, 20, 30 and 40% replacement and 25N/mm^2 design strength. PSA recorded silica (SiO_2) content of 33.84%. The compressive strength increased with increased PSA content up to an optimum, beyond which there was a drop in strength. For ages of up to 28 days, the control recorded higher strength than the blended concrete while the 90 days and above results indicated that there was increase in strength attributed to continuous hydration and pozzolanic reactions. The compressive strength of the blended concrete was found to be lower than the control at early age but increased continually with curing age compared to the control.

2.3 Summary of literature review and research gap

From literature reviewed, as the percentage of partial of replacement cement in concrete with pozzolans increased, a decrease in strength below the control was observed by majority of the researchers: Chirag et al., (2013); Khusbu and Sharma (2014); Muhammad et al., (2013); Ettu et al., (2013); Agbenyeku and Aneke (2014); Parande et al. (2011); Raheem et al, (2012); Olutoge et al.,(2012); Srinivisa and Sathiya (2012); Olusola and Akinyene(2012) and Sooraj (2013). This limits the cost reduction anticipated from partial replacement of cement. Partial replacement of cement with agro waste ashes alters the calcium oxide and silica composition of cement (Manasseh, 2010). Since most pozzolans are rich in silica (Parande et al., 2011), this results in silica content that is higher than that of un-blended cement. With continued partial replacement of cement with pozzolans and on examining Equations 2.5, 2.6, 2.7, 2.8 it can be observed that the silica from the pozzolan will be consumed by the pozzolanic reaction (Equation 2.9, 2.10 and 2.11) up to optimum partial replacement of cement. Thus with the correct proportioning of cement and pozzolan, it is possible for the competing reactions presented by Equations 2.5, 2.6 and 2.7 to end up with an equilibrium mineral assemblage that contains no $Ca(OH)_2$. Eliminating all the $Ca(OH)_2$ through formation of additional calcium silicate hydrates increases the amount of binder and hence strength. (Richard & Walairat, 2005) This point where all calcium hydroxide from cement hydration is consumed fully by pozzolanic reaction is the optimum partial replacement of cement with pozzolan and it results in highest strength of the blended concrete. Beyond the optimum, addition of any agrowaste ash to the mineral assemblage will only result in the material playing a role of fine aggregate and filler material (Pekmezci & Akyuz, 2004) and will not contribute to strength gain. Higher cement replacement with pozzolan results in excess silicon dioxide, more than the optimum required to combine with the calcium oxide content in the blended cement to form calcium silicate hydrates. The excess silica if not remedied is harmful to concrete and may be leached out of the concrete leading to decrease in strength. Partial replacement of cement with pozzolan also leads to reduced reaction opportunity leading to lesser CSH, lesser bonds and ultimately lower strength. Decrease in CaO is occasioned by the partial replacement of cement since the contribution of CaO by agro-waste is not commensurate with that of cement which the agro waste partially replaces. The excess silica brought about by blending cement with pozzolans can be converted to calcium silicate hydrates which are responsible for strength.

The purpose of this research is to optimize partial replacement of ordinary Portland cement with rice straw ash in concrete. Thereafter, the optimum percentage of egg shell ash that can be added to OPC-RSA blended concrete will also be determined. The egg shell ash was expected to react with the excess silica from the pozzolan and form additional cementitious materials. This would mitigate the strength reduction reported by most researchers at higher partial cement replacement level with pozzolanic materials. From literature reviewed the optimum partial replacement of cement was reported to range between 5 – 15% by weight of cement. Optimum amount of egg shell ash was anticipated to fall within the same range. Although there are many researches on the use of agro based pozzolans as partial replacements of cement, there is limited information on a proposed a measure to either overcome the CaO deficit resulting from partial replacement of cement with agro-wastes and take advantage of the excess silica in the pozzolanic materials or to achieve higher replacement levels of cement. This research remedied the problem of CaO deficit by adding egg shell ash which is rich in CaO (Beck et al., 2010) in addition to the pozzolan. From the foregoing literature there is a good agreement that pozzolans can be used to partially replace cement; however at higher percentage of replacement, the compressive strengths decrease. This is due to high silica content and low calcium oxide content (Chirag et al., 2013; Amitkumar et al., 2013). When agro wastes ashes are used to partially replace cement, their contribution of CaO is not commensurate with the reduction in CaO occasioned by the partial replacement of cement with the pozzolan. This deficit in calcium oxide affects strength development since it is required to react with silica to form calcium silicate hydrates that are responsible for strength development. Addition of egg shell ash was expected to reduce the strength loss at higher replacement levels of ordinary Portland cement with agro based pozzolanic materials. Since the overall objective is to reduce cement content in concrete by incorporating agro-wastes, the calcium oxide will be provided in form of another agro-waste: incinerated egg-shell ash.

2.4 Conceptual framework

A conceptual framework is presented in Figure 2.1. It gives the organization and relationship between the variables that will be studied to achieve the research objectives

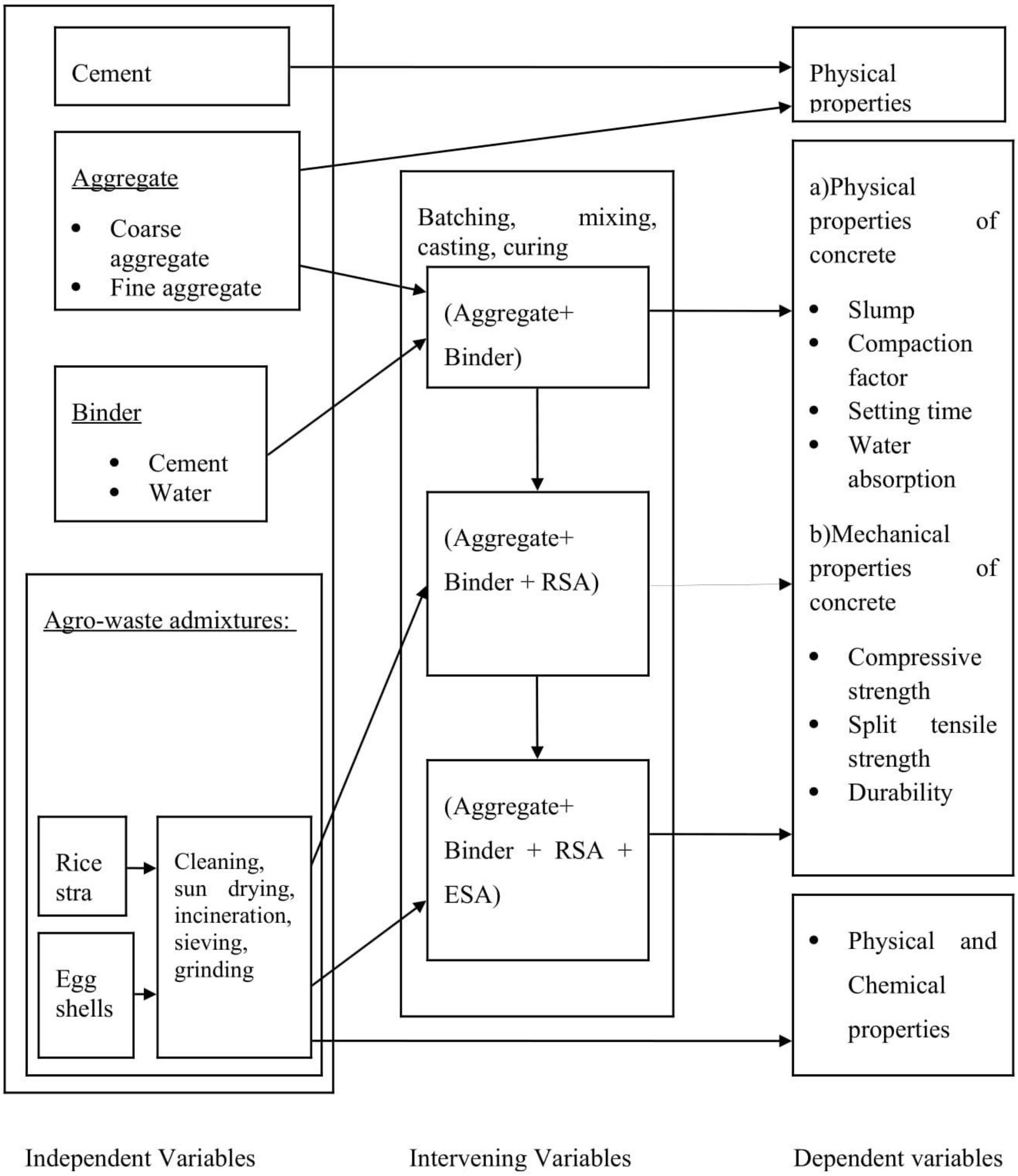

Figure 2.1: Conceptual framework

CHAPTER THREE

MATERIALS AND METHODS

This section confines itself to the materials and methods used in the study. Concrete tests were conducted at Bungoma County Government Materials Testing Laboratory located at Webuye Town, Bungoma County, Kenya. Chemical Tests were conducted at Ministry of Mines and Geology laboratories while hydrometer and density tests were done at Ministry of Transport and Infrastructure laboratories located along Machakos Road in Nairobi, Kenya.

3.1 Assessing physical properties of coarse and fine aggregates, and chemical properties of rice straw, egg shell ash and ordinary Portland cement

3.1.1 Material acquisition and preparation

Rice straw used was of *Oryza Sativa* (Basmati) species and was obtained from rice irrigation scheme in Bunyala (Busia County) in Kenya which is one of the main large scale rice growing areas in Western Kenya. The egg shells used were obtained from private hatcheries that produce day old chicks within Busia and Bondo Towns and from the selected hotels and food processors.

Coarse aggregate

Coarse aggregates used were obtained from graded crushed stones, with fractions sizes ranging from 5 mm to 20 mm. The required quantity was purchased from reputable quarries with crushing plants in Sirikwa area within Eldoret town.

Fine aggregate

Fine aggregate used was river sand obtained from Malaba River that originates from the slopes of Mt. Elgon, runs through Bungoma before entering Busia County. The sand was sieved through sieve size 4.75mm to eliminate oversize particles. It was then washed by running water to eliminate clay particles. Thereafter, the sand was drained and sun dried on a steel tray to saturated and surface dry condition.

Cement

Cement used was CEM 1- class 42.5 N Ordinary Portland cement formulated from Portland clinker

Water

The water used in this research was clean potable piped water as supplied by the Lake Victoria North water services board.

3.1.2 Physical properties

The physical properties tested on the various materials include particle size distribution, relative density, and setting time.

3.1.2.1 Particle size distribution of coarse aggregate

a) Data collection procedure

Particle size distribution was done to BS 812-103-1. The sampling was done according to the procedure described in clause 5 of BS 812-102 and reduced using a riffle box. The aggregates were washed through a fine sieve to eliminate clay and other materials that are likely to cause agglomeration of particles and dried in the sun to surface dry condition. The test portions again dried by heating at a temperature of105± 5 °C to achieve a dry mass which is constant to within 0.1% before determining particle size distribution. They were allowed to cool and then weighed. The weight was recorded as M_1. Clean dry sieves were nested in a fitting receiver in order of increasing aperture size from bottom to top. The dried sample was placed on the top coarsest sieve and covered with a fitting lid. The assembly was shaken by mechanical shaker for sufficient time to separate the sample into size fractions by sieve aperture size.

b) Data analysis

The mass retained on each sieve size M_2 was expressed as a percentage of the original dry mass, M_1. Mass passing each sieve was calculated as a cumulative percentage of the total sample. The cumulative percentage of the mass of the total sample passing each of the sieves versus nominal aperture size was plotted on a semi-log chart and compared with the grading envelope specified.

3.1.2.1 Particle size distribution of fine aggregate

a) Data collection procedure

Particle size distribution of fine aggregate was done according to section 3.1.2.1(a).

b) Data analysis

Data analysis was done according to section 3.1.2.1(b).

3.1.2.2 Particle size distribution of rice straw ash

(a) Data collection procedure

This test was done to BS 1377-2(1990) to determine the sizes of the rice straw particles and to group them into separate ranges of sizes and so determine the relative proportion by weight of each size. It involved sieving and sedimentation of the ash/water/dispersant suspension to separate the particles. Sedimentation is based on application of Stoke's law and periodic measurement of the density of the suspension. The sample was mechanically crushed in a ball mill and 50 grams of sample was placed in a shaking bottle, then 200ml of de-ionized water added. The 20ml of sodium hexametaphosphate added. The suspension was placed in an end-to-end shaker and shaken for 16 hr at 15 rpm. The suspension was transferred to 1 litre capacity measuring jar and filled to the 1 litre mark by de-ionized water. The hydrometer was placed in the suspension for 20 s before each reading. The hydrometer readings of the ash in suspension solution were recorded as H. A blank solution was prepared by adding 20 ml de-ionized water to 25% sodium hexametaphosphate solution. Hydrometer and temperature readings were taken simultaneously for both the suspension and the blank solution. The hydrometer readings of the blank solution were recorded as B.

(b) Data Analysis

For each hydrometer reading the summation percentage P was calculated as in Equation 3.1 below

$$P(\%) = \frac{(H - B) * 100}{W} \qquad (3.1)$$

Where

H = Hydrometer reading ash in suspension (g/L)

B = Hydrometer reading ash in blank solution (g/L)

W = Weight of Dry sample taken for testing (g)

Whereas particle size D at different times was calculated from Equation 3.2

$$D(mm) = 0.3315 * K * \sqrt{\left(\frac{L}{T}\right)} \qquad (3.2)$$

Where

K = Sedimentation constant, which varies with temperature and particle density

L = Tabulated effective length of hydrometer reading, mm

T = Time (minutes)

A plot of cumulative percentage (P) versus particle size diameter (D) was done on a semi-logarithmic graph and compared with that of Portland cement.

3.1.2.3 Loss on Ignition (LOI) for rice straw ash

a) Data collection procedure

The rice straw ash was dried in an oven at 100 ºC for 24 hours. Loss on ignition test was done to ASTM D 7438-08. A sample of dry rice straw ash was placed on a crucible and its mass determined as M_0.The loss on ignition test was done by placing on a crucible a mass of dried rice straw ash in a furnace and igniting at 900 ºC for 60 minutes to achieve a constant mass. After ignition, the mass of the rice straw ash was determined as M_1.

(b)Data analysis

The loss on ignition was calculated as mass percentage using the Equation 3.3:

$$LOI = \frac{(M_0 - M_1)}{M_0} * 100\% \qquad 3.3$$

Where

M_0 is the mass of the starting sample

M_1 is the mass of the sample after ignition

3.1.2.4 Relative density of rice straw ash

a) Data collection procedure

This test was done to determine the density of rice straw ash using Le Chatelier's flask to ASTM C 188. It is based on the measurement of the displaced volume of a liquid by the addition of a powder specimen. A sample of 64g of ash was placed in a flask filled with kerosene. Care was taken to avoid the ash sticking to the inside of the flask or the neck by using a funnel. The flask was placed in a constant temperature water bath to avoid temperature fluctuations. The meniscus readings of the two levels (before and after addition) of ash were taken to determine the volume of liquid displaced by the ash. Care was taken to avoid meniscus reading errors arising from parallax.

b) Data analysis

Density was calculated using the Equation 3.4

$$D = \frac{M}{V} \qquad (3.4)$$

Where

D = Density (Kg/m^3)

M = mass of sample in Kg

V = volume of kerosene displaced after adding of material (M^3)

Relative density was then calculated using the Equation 3.5

$$RD = \frac{\rho_{sample}}{\rho_{water}} \qquad (3.5)$$

Where

RD = relative density

ρ_{sample} =density of ash (kg/m^3)

ρ_{water} = density of water (kg/m^3)

The relative density was compared with that of Portland cement that the ash was used to partially replace in concrete mixes.

3.1.2.5 Particle size distribution of egg shell ash

a) Data collection procedure

Particle size distribution of egg shell ash was done as described in section 3.1.2.2(a).

b) Data analysis

Data analysis of particle size distribution of egg shell ash was done as described in section 3.1.2.2(b).

3.1.2.6 Relative density of egg shell ash

a) Data collection procedure

Relative density of egg shell ash was done as described in section 3.1.2.4(a).

b) Data analysis

Data analysis for relative density of egg shell ash was done as described in section 3.1.2.4(b).

3.1.2.7 Relative density of Portland cement

a) Data collection procedure

Relative density of cement was determined as described in section 3.1.2.4 (a)

b) Data analysis

Data collection and analysis was determined as described in section 3.1.2.4 (b)

3.1.2.8 Particle size distribution of Portland cement

a) Data collection procedure

Was conducted as described in section 3.1.2.2 (a) to determine the particle size distribution of Portland cement.

b) Data analysis

The particle size data was collected and analyzed as described in 3.1.2.2 (b)

3.1.2.9 Setting time of cement pastes

a) Data collection procedure

This test was conducted to determine the initial and final setting time of cement paste using Vicat apparatus to BS 4550 Part 3.5-1978. 400 g of the cement was placed in a tray and to it was added 25% water by weight then mixed thoroughly to a consistent cement paste within 4 to 5 seconds. The paste was filled on a Vicat mould sitting on a glass plate and made level with the surface of the mould. The assembly was placed under a rod bearing a plunger, the plunger was lowered gently to touch the surface and lowered to touch the surface and quickly released to sink into the paste. The depth of penetration was measured and recorded. Trial mixes of varying water content were prepared until a penetration depth of 33 to 35mm was achieved. The percentage of water by dry weight of cement required to prepare a cement paste of standard consistency was calculated by Equation 3.6

$$P = \frac{W}{C} * 100 \qquad (3.6)$$

Where

W = Quantity of water added

C = quantity of cement used

Samples were prepared by taking 400 g of cement and mixing with water equivalent to 0.85P above by weight of cement. This formed the control cement paste. Another series of samples were prepared having the 400g cement partially replaced with rice straw ash at 5, 10, 15, 20, 25 and 30% by weight of cement. The Gauge time was 3-5 minutes. A stop watch was started immediately water was added to the sample and the time recorded at t_1.The Vicat mould was filled with cement paste and smoothened on the surface to form a test block. Initial setting time was determined by lowering a plunger with a needle and recording the penetration of the needle into the test block. This was repeated every 2 minutes until the needle failed to pierce the test block for about 5 mm. This time was recorded as t_2.

Final setting time was determined by replacing the needle of the Vicat apparatus with an annular attachment. Final setting time t_3 was determined as the time at which the needle makes an impression and the annular attachment fails to make an impression on the surface of the test block. The setting times were determined for unblended cement paste and also for cement paste with cement partially replaced with various percentages of rice straw ash.

(b) Data Analysis

Initial setting time was calculated as determined by Equation 3.7:

$$\text{Initial Setting Time} = t_2 - t_1 \tag{3.7}$$

Final setting time was calculated as determined by Equation 3.8

$$\text{Final Setting Time} = t_3 - t_1 \tag{3.8}$$

Where:

t_1 = time at which water is first added to cement

t_2 = time when needle fails to penetrate 5-7 mm from bottom of mould

t_3 = time when needle makes an impression and annular attachment fails to do so

3.1.3 Chemical properties

The chemical properties tested on the various materials were chemical composition.

3.1.3.1 Chemical properties of rice straw ash

(a) Data collection procedure

The test was done to determine the chemical composition of incinerated rice straw ash. The straw was sun dried and incinerated in an incinerator made of two concentric cylinders made of expanded metal at a temperature of 650 ºC for $1^1/_2$ hours (Ettu et al., 2013). The resultant ashes were sieved through 600µm BS sieve size to eliminate coarse particles, and then followed by sieving through 425 µm BS sieve size and finally sieving through 75µm BS sieve size. Thereafter, the resultant ash was placed in a ball mill made of a cylinder of 300 mm diameter and 400 mm length with a grinding media of steel ball bearings of 20mm diameter powered by a 5.5 Hp mortar rotating at 1,400 revolutions per minute for four minutes. The particles retained on these sieves were discarded while a sample of those passing were subjected to chemical analysis by X-ray diffractometer and the rest used for partial replacement of cement (Abalaka, 2013). X ray diffraction analysis technique was used to determine crystallographic structure of material by irradiating the sample material with incident rays and measuring the intensities and scattering angles of the x rays that leave the material. The scattering was observed by applying Bragg' law and a suitably placed detector, and the crystalline structure of the material was determined at an atomic level.

(b) Data Analysis

A print out of the percentages of the chemical composition by weight of the material was obtained from the X-ray diffractometer machine. The composition of the combined percentages of silica (SiO_2), Alumina (Al_2O_3) and ferric oxide (Fe_2O_3) was compared with ASTM C 618 specifications for pozzolans.

3.1.3.2 Chemical properties of egg shell ash

a) Data collection procedure

The test was done to determine the chemical composition of incinerated and ground egg shells. The egg shells were incinerated at 900 ºC for 2hr to produce egg shell ash which is rich in calcium oxide (Beck *et al.*, 2010). The resulting ash was sieved using 600µm sieve (Mtallib & Raibu, 2009). The resultant ashes were further ground in fabricated steel grinding ball mill with a drum diameter of 300mm and length of 400mm, powered by a 240 Volts/50Hz, 5.5 Hp electric motor with a capacity of 70uF and rotating at 1,400 rpm for 4 minutes per batch. The grinding medium was steel ball bearings of 20.0mm diameter. A sample of the ash was taken to the X ray diffractometer for chemical analysis as described in section 3.1.3.1(a).

b) Data Analysis

X ray diffraction data on chemical composition was obtained as described in 3.1.3.1 (b). The percentage composition of CaO by weight in egg shell ash was compared with that of Portland cement

3.1.3.3 Chemical properties of Portland cement

a) Data collection procedure

Cement sample was subjected to analysis by X-ray diffractometer as described in section 3.1.3.1(a)

b) Data Analysis

X ray diffraction data on chemical composition was obtained as described in 3.1.3.1 (b).

3.2 Determining physical and mechanical properties of concrete having cement partially replaced with rice straw ash

The physical and mechanical properties of concrete tested were slump, compaction factor, water absorption, compressive strength, split tensile strength and durability.

3.2.1 Mix design

The mix design was done according to Building Research Establishment (BRE, 1988) method with a target characteristic strength of 35 N/mm^2 at 28 days. The choice of class concrete strength was informed by compressive strengths used by previous researchers: Khusbu and Sharma (2014) used a concrete strength of 32 N/mm^2, Faseyemi (2012) used a concrete strength of 30 N/mm^2, Olutoge et al. (2012) used a concrete strength of 34 N/mm^2, Lavanya and Taku (2012) used a concrete strength of 34 N/mm^2, Razak *et al.* (2022) used a concrete strength of 50 N/mm^2 , Sharma and Charlotra used a concrete strength of 44.5N/mm^2 while Dey and Sharna (2013) used a concrete strength of 28 N/mm^2 . Cement type 1 (42.5) was selected as opposed to blended Portland cement because Victoria (2018) while studying suitability of Kenyan blended Portland cement for production of structural concrete reported that none of the Kenyan blended cements is suitable for production of class 25 and above concrete. Secondly the blended Portland cements already contain a pozzolan in the form of silica fume, blast furnace slag or fly ash. This makes them unsuitable for use in concretes having cement partially replaced with pozzolans (Victoria, 2018). Batching was by weight. It was also chosen to cover the range of strength that can be used for in situ, pre-cast and four dimensional design and construction. The latter two methods have been reported to lower the cost of construction significantly. The BRE method of design involved the selection of correct proportions of cement, fine aggregate and water to produce concrete having specified properties namely: workability of fresh concrete, compressive strength at specified age and durability by specifying minimum cement content and/or maximum free water/cement ratio.

Table 3.1: Mix proportions for one cubic metre of concrete

Mix Code	Coarse Aggregate (Kg)	Fine Aggregate (Kg)	Water(Kg)	Cement(Kg)
Control M-35	1,010	700	238	476

The mix design using this method is attached in Appendix I. The control specimens for concrete were cast using the designed mix ratio. The first series had Ordinary Portland cement replaced with rice straw ash at 5, 10, 15, 20, 25 and 30% by weight of cement and a water-binder ratio of 0.5 was used during mix design.

3.2.1.1 Slump Test

a) Data collection procedure

Slump test was conducted to determine the workability or consistency of concrete from a freshly mixed batch. The concrete mix was placed in a frustrum slump cone with a bottom diameter of 200 mm and top diameter of 100 mm placed on a smooth horizontal non-porous flat plate. The concrete was placed in four equal layers and each layer tamped evenly with 25 strokes steel rod of 16 mm diameter. Excess concrete was removed and the surface leveled with a trowel. The mould was raised slowly in vertical direction. Slump was measured as the difference between height of the mould and the height of concrete specimen.

b) Data analysis

The slump readings were read directly from a steel rule and recorded in millimeters of subsidence of the specimen. The readings were plotted on a graph for the various mixes for comparison.

Plate 3.1: slump test

3.2.1.2 Compaction factor test

a) **Data collection procedure**

Compaction factor test was done to determine the consistency for concretes where workability was low and therefore were insensitive to slump test. The concrete was placed in the upper hopper of the compaction factor apparatus that consisted of three hoppers at three different heights. The hoper was filled to the brim and the trap door was opened so that the concrete falls into the lower hopper. When concrete came to rest the lower hopper was opened and concrete allowed to fall into the cylinder. Excess concrete was cut off the cylinder by a trowel and outside of the cylinder wiped clean. This was weighed on an electronic balance and recorded as weight of partially compacted concrete.

The cylinder was refilled with concrete in layers of 50 mm approximately and heavily rammed to full compaction. The top surface of fully compacted concrete was struck level and weight of fully compacted concrete determined using an electronic balance.

b) Data analysis

Compaction factor for the various concrete mixes was determined as in Equation 3.9 as follows

$$Compaction factor = \frac{W_P}{W_F} = \frac{(W_2 - W_1)}{(W_3 - W_1)} \tag{3.9}$$

Where

W_F = weight of fully compacted concrete

W_P = weight of partially compacted concrete

W_1 = weight of empty cylinder

W_2 = weight of empty cylinder + free fall concrete

W_3 = weight of empty cylinder + hand compacted concrete

Plate 3.2: compaction factor

3.2.1.3 Water Absorption

a) Data collection procedure

This test was used to determine the water absorption properties of hardened concrete specimens as a measure of the durability of the concrete that is blended with rice straw ash and egg shell ash. The test was carried out to BS 1881 Part 114 (1983) and BS 1881 Part 122 (1983) respectively. Concrete cube specimens were cast and cured for 90 days in water, then oven dried for 24 hours at 110^{o}C until mass became constant. The dry weight was noted (W_1). The specimens were then immersed in hot water at 85^{o}C for 3.5 hr. The weight of the specimens immersed in hot water was recorded determined and as (W_2).

b) Data analysis

The percentage water absorption was determined from the specimen weights recorded using Equation 3.10:

$$\%\,Water\,absorption = \left[\frac{(W_2 - W_1)}{W_1}\right] * 100 \qquad (3.10)$$

Where

W_1= oven dry weight in grams

W_2= weight in grams after 3.5 hours of immersion

3.2.1.4 Compressive strength test

a) Data collection procedure

This test was done on hardened concrete cube specimens measuring 150x150x150 mm. For each mix code, the concrete was cast in cubes, vibrated and de-moulded after 24 hours. A total of 21 cubes were cast for each of the 7 mix codes, making a total of 105 cubes for the five ages of testing. They were then immersed in curing tanks. After 7, 14, 28 and 90 days before the test, the cubes were taken out of the curing tank and allowed to drip off excess water for 20 minutes. The cubes were then be subjected to the compression testing machine with maximum capacity of 1,000KN according to BS 1881 Part 116 (1983)-Reprinted 1991 including Amendments No.1 & No. 2. The load was applied slowly to failure without causing any shock.

b) Data analysis

The compressive strength was obtained from readings recorded during the tests using Equation 3.11 below by dividing the maximum load carried by the specimen recorded during the test by the average cross sectional area

Compressive strength = Maximum load/Cross sectional area (3.11)

The compressive strength for the control and the concrete mixes with cement partially replaced with various proportions of rice straw ash were plotted on line graphs and bar charts for comparison and trend analysis.

Plate 3.3: Casting cubes for compressive strength test

3.2.1.5 Splitting Tensile strength test

a) Data collection procedure

This test was done to determine the tensile strength of hardened concrete specimens. For each concrete mix series, concrete cylinders measuring 150mm diameter and 300mm height were cast, de-moulded after 24 hours and placed in a curing tank for 6, 13, 27, 55 and 89 days. A total of 21 cylinders were cast for each of the 7 mix codes, making a total of 105 cylinders for the five ages of testing. They were subjected to diametral load on a compressive strength testing machine to failure. The test was done to BS 1881 Part 117 (1983) at the ages of 7, 14, 28, 56 and 90 days.

Splitting tensile strength is a measure of the splitting tensile strength of concrete by application of diametral compressive force on a cylindrical concrete specimen with its axis horizontal between plates of a testing machine.

b) Data analysis

Splitting tensile strength T, was then calculated using Equation (3.12):

$$T = \frac{2P}{(\pi d l)} \qquad (3.12)$$

Where

P is maximum load at failure of concrete

d is average diameter of cylinder

l is the average length of the concrete specimen

The splitting tensile strength for the control and the concrete mixes with cement partially replaced with various proportions of rice straw ash were plotted on graphs for comparison.

Tensile strength of concrete can be determined from three different types of tests: direct pull test on briquettes, modulus of rapture on test on beams and splitting tensile strength test. Technical difficulties in executing true tensile strength test are numerous. Flexural strength calculates tensile strength from bending stress at failure, assuming Hooke's law and straight line stress-strain distribution. This is not entirely true; the calculated flexural strength may be about twice as high as the true tensile strength. Among the three testing methods (direct tensile, splitting tensile, and flexural tests), researchers have pointed that the splitting tensile test gives the most accurate measurement of the true tensile strength of concrete like materials (Fanlu *et al.*, 2014). Therefore splitting tensile strength test will be considered in this research.

3.2.1.7 Durability test

a) Data collection procedure

This test was done to evaluate the resistance to deterioration. Concrete cube specimens made with both the unblended cement and with cement partially replaced with agro-waste ashes were cast and cured for 56 days in water. They were removed from water, oven dried at 105^{o}C for 2 hours and their weights determined. They were then immersed in testing baths containing 0.5% dilute sulphuric acid solution for 30 days. Thereafter, they were removed from the solution, had their surfaces cleaned and both their weights and dimensions measured. Further the compressive strengths of the cubes were also determined

b) Data analysis

Compression testing machine under uniform load was used to determine the compressive strengths of the specimens while an electronic balance was used to measure their weights. Both the percentage loss in mass and loss in strength were determined using Equations 3.13 and 3.14 respectively (Vysvaril et al., 2014).

$$\% mass loss = \frac{(M_1 - M_2)}{M_1} * M_1 * 100 \qquad (3.13)$$

Where

M_1 = mass of specimen before immersion in acid solution

M_2 = mass of specimen after immersion in acid solution

$$\% \; Loss \; in \; Strength = \frac{(S_1 - S_2)}{S_1} * 100 \qquad (3.14)$$

Where

S_1 = Compressive strength of specimen not immersed in acid solution

S_2 = Compressive strength of specimen immersed in acid solution

3.3 Assessing the mechanical properties and durability of concrete having cement partially replaced with rice straw and egg shell ash

The mechanical and durability properties of concrete tested were compressive strength, compaction factor and accelerated durability.

3.3.1 Mix Design

The physical and mechanical properties of concrete made with cement partially replaced with rice straw were determined. From the compressive and tensile strength concrete tests, the optimum percentage replacement of cement with rice straw ash/pozzolana was determined as the percentage replacement that produced the highest strength gain above the control. The trend of compressive strength results was observed for partial replacements of cement beyond the optimum.

The cement-pozzolan concrete mixes that exhibited a reduction in compressive strength below that of the control were deemed to be the ones containing excess silica from the pozzolan that did not have opportunity to react with CaO from ordinary Portland cement. Mixes that exhibited compressive strength reduction were prepared, and to them CaO oxide being the main component that forms cementitious compounds in cement was increased, This was achieved by addition of egg shell ash in percentage increments by weight of cement. This was done to compensate for the amount of CaO lost through partial replacement of cement with rice straw ash and to ensure that CaO is available to react with excess silica from the pozzolan to form additional cementitious materials. The CaO from egg shell was expected to react with the excess silica (SiO_2) contributed by pozzolanic material in the blended mix and form additional cementitious materials. The amount of egg shell ash added to each mix that exhibited strength reduction were 2.5, 5, 10 and 15% by weight of cement. The compressive strength of the resulting blended concrete mixes was determined at various ages of curing and compared with those of the first series.

3.3.2 Compressive strength test

a) Data collection procedure

The compressive strength of the concrete mix with cement partially replaced with rice straw and egg shell ash were determined as described in section 3.2.1.4 (a).

b) Data analysis

Data on compressive strength was analyzed as described in section 3.2.1.4(b).

3.3.3 Compaction factor Test

a) Data collection procedure

Compaction factor test was done as described in section 3.2.1.2 (a).

b) Data analysis

Data on compaction factor for the optimum mix was collected and analyzed as described in section 3.2.1.2 (b).

3.3.4 Accelerated durability test

a) Data collection procedure

Accelerated durability test was done as described in section 3.2.1.7 (a).

b) Data analysis

Data on accelerated durability test for the optimum mix was collected and analyzed as described in section 3.2.1.7 (b).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical and chemical properties of materials used in the study

4.1.1 Physical properties of materials used in the study

4.1.1.1 Particle size distribution of coarse aggregate

The results of sieve analysis of coarse aggregate in form semi-log graph of cumulative % passing versus sieve size is illustrated in Figure 4.1 and from the results as shown in Appendix VII.

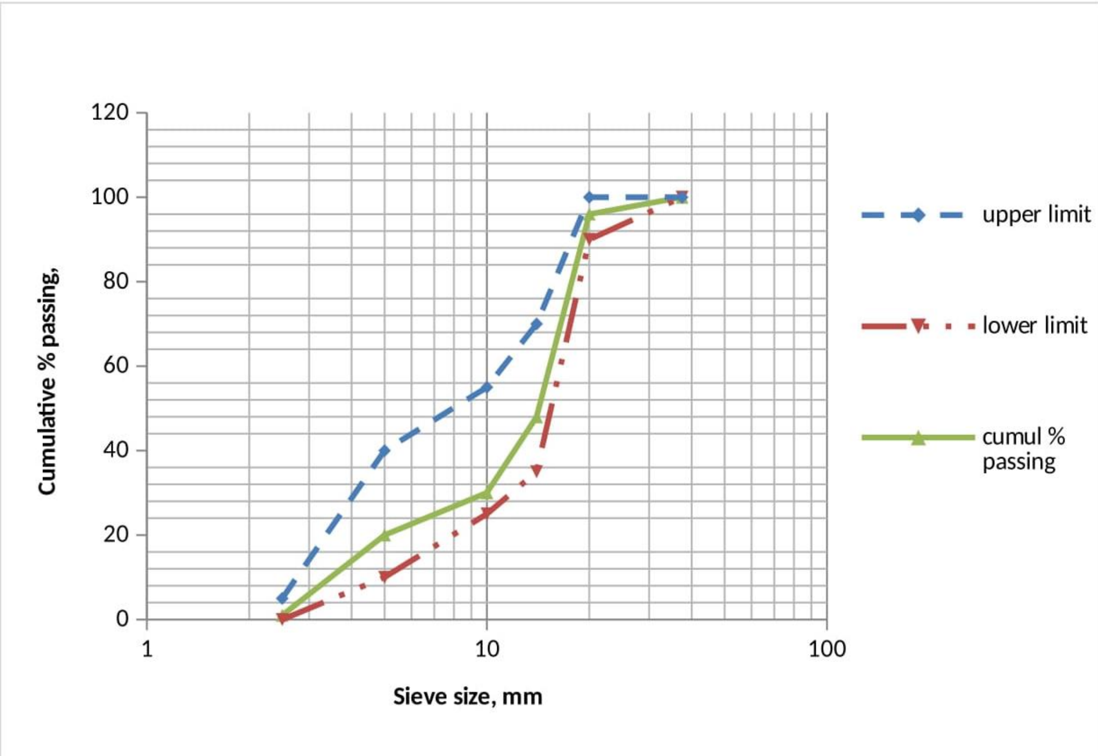

Figure 4.1: Grading curve for coarse aggregates

Particle size distribution was done by sieve analysis from a sample of aggregate. The grading of aggregates influences the extent to which the aggregates will pack or packing density during preparation of concrete mixes. From Appendix II, it can be observed that for every sieve size there was a proportion of aggregate retained. The proportions retained were 99, 80, 70, 52, and 4% for nominal sieve size 2.5, 5, 10, 14 and 20mm respectively. Results show that the grading curve was found to fit within the grading envelope specified. The aggregate did not have gap in gradation of particle size. The grading curve was found to fall within the specified grading envelope. The availability of various particle sizes ensured good particle interlock in the cement matrix with smaller sized particles fitting into voids left between larger sized particles. This ensured a dense concrete matrix without many voids hence maximized load bearing capacity of the concrete (Buertey et al., 2018).

4.1.1.2 Particle size distribution of fine aggregate

Results for fine aggregate sieve analysis and the semi-log graph of cumulative % passing versus sieve size is illustrated in Figure 4.2 and from the results as shown in Appendix III.

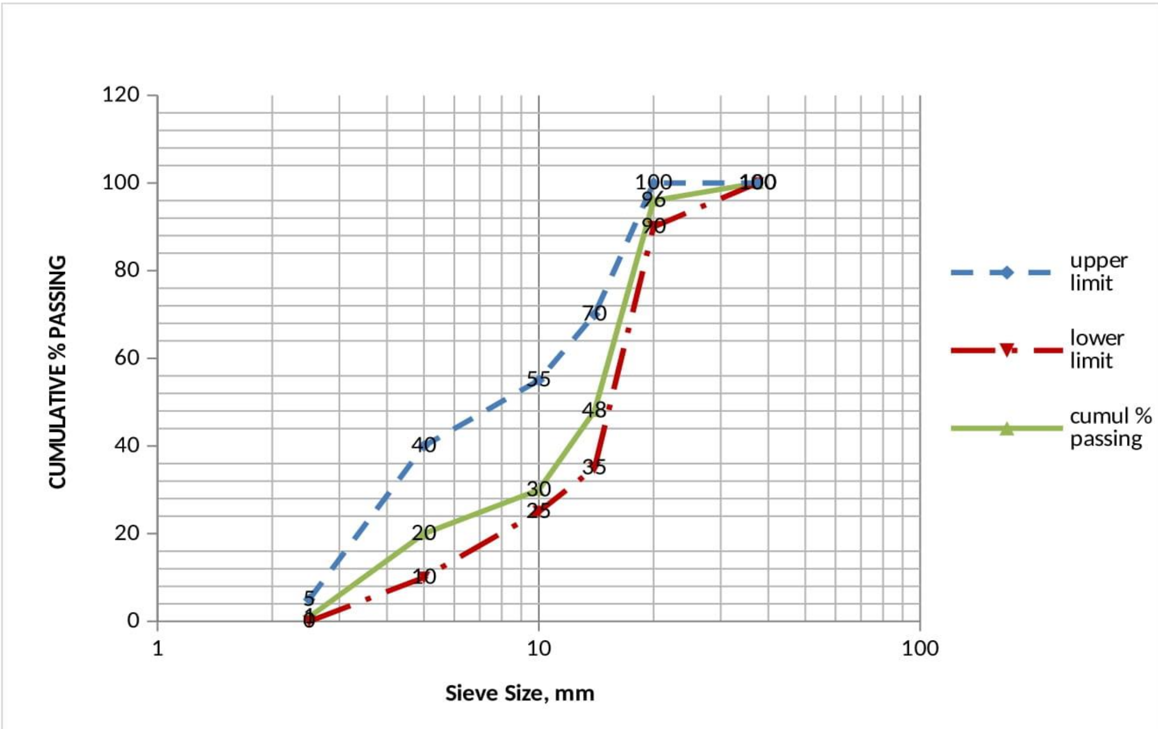

Figure 4.2: Grading curve for fine aggregates

Figure 4.2 shows the grading of fine aggregates. It was observed that the grading curve fell within the grading envelope specified. This implies that the particle sizes within the fine aggregate range were available in recommended percentage ranges. This ensured that the resultant concrete was neither susceptible to bleeding nor exerted high water demand owing to the large surface area of fine aggregate particles.

4.1.1.3. Particle size distribution of rice straw ash

Particle size distribution of rice straw ash was conducted by hydrometer analysis and the results are illustrated in Figure 4.3 and presented in Appendix IV.

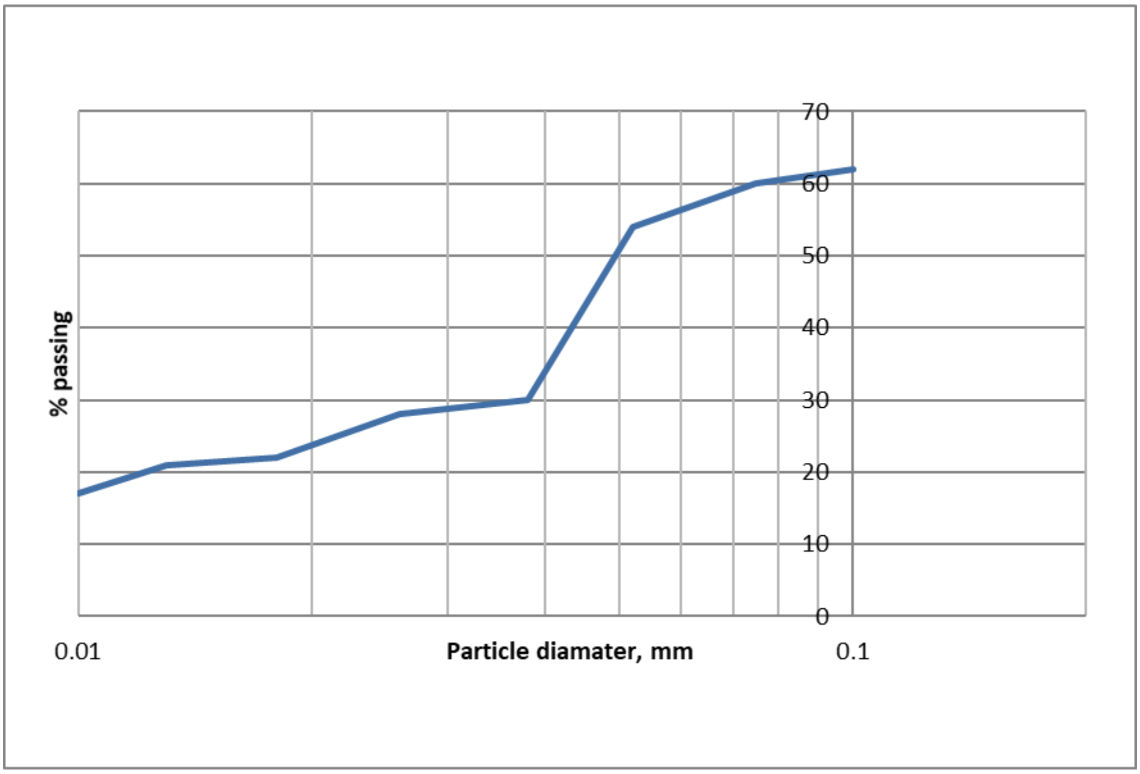

Figure 4.3: Particle size distribution of rice straw ash

From Figure 4.3 and appendix IV, comparison of the results of particle size distribution shows that for sieve size 0.01 the percentage passing was found to be 17% for rice ash. While for sieve size 0.026 mm the percentage passing was found to be 28%. Further for sieve size 0.038 mm the percentage passing was found to be 30%, finally for sieve size 0.1 mm the percentage passing was found to be 62%.

4.1.1.4 Loss on ignition of rice straw ash

Weight loss on ignition for rice straw ash is indicated in Table 4.1.

Table 4.1: Weight loss on ignition for rice straw ash

Description of sample	Wt of sample + crucible, kg	Wt of crucible, kg	Weight of rice straw sample alone , kg
Before ignition	0.624	0.489	0.135
After ignition	0.518	0.489	0.029

Weight loss on ignition = 0.135 – 0.029 = 0.106

Percentage Weight loss on ignition = (0.135 – 0.029)/0.135 x 100% = 78.5%

The percentage weight loss on ignition was found to be 78.5%. This is close to but higher than 71.99 and 76% reported on three samples by Surajit and Sharma (2018) who tested rice straw samples incinerated in a muffle furnace at 400 and 600ºC controlled temperatures respectively. The disparity could be due to different method of preparation of the ash. An incinerating temperature of 650ºC and open air burning was used in this research. Loss on ignition (LOI) is generally used as an indicator of residual carbon content in pozzolans. It was found that the ash yield of the rice straw was 21.5%. This is in agreement withs with Arunabh and Kumar (2016) who reported ash yield of 22.96%. Rice agro-wastes have been reported to produce higher ash yields than other agro-wastes by Nguyen et al. (2019), which makes them a better choice for partial replacement of cement compared to other agro wastes.

The combustion of carbon is therefore a major contributing component in ignition loss. Carbon content and fineness are properties of most concern in the pozzolans used for partial replacement of cement and they are interdependent since carbon particles tend to be coarser and porous. The presence of coarser carbon in a pozzolan leads to low fineness which in turn decreases surface area for the pozzolanic reaction. Further when residual carbon particles are present in a pozzolan, they may absorb water meant for hydration reactions owing to their porous nature which is detrimental to strength development. The absorption of water by carbon particles may also lower the workability of concrete mix (Chen et al., 2019). A higher loss on ignition as obtained above indicates that there was only a small percentage of residual carbon content in the rice straw ash (Morsy & Rashwan, 2015). This was favourable for the strength development of concrete as well as the workability of concrete made with cement partially replaced with rice straw ash up to the optimum percentage replacement. There were fewer carbon particles that are normally coarser and porous whose presence in a mix would have reduced the workability by absorbing water meant for hydration and increased friction in the concrete matrix due to their shape.

4.1.1.5 Relative density of ordinary Portland cement

The relative density of cement was found to be 2.908. Comparison was made with the relative density of rice straw ash which was found to have a lower relative density than that of cement. Therefore, a larger volume of rice straw ash was required to replace the same mass of cement in concrete.

4.1.1.6 Relative density of rice straw ash

The relative density of rice straw ash was found to be 2.099. This was 2.39% lower than that of cement which was found to have a relative density of 2.908. Morsy and Rashwan (2018), reported a relative density of 2.13, however they used a helium pycnometer which is more accurate than the LeChatelier’s flask apparatus used in this study. Apart from the burning temperature range of 600-700ºC, the difference could be attributed to geographical differences and species variation in the rice straw used. This means that for partial replacement of cement in concrete with rice straw ash, the volume of rice straw replacing the same mass of cement will be slightly larger. A larger volume means more particles which in turn meant an increase in specific surface area. This increase in surface area led to increase in water demand for concrete mixes having cement partially replaced with rice straw ash. The water demand led to reduced workability with increase in percentage replacement of cement with rice straw ash hence more compaction effort. On the other hand a larger surface area increased potential for chemical reaction within the cement matrix.

4.1.1.7 Particle size distribution of egg shell ash

Particle size distribution of egg shell ash was conducted by hydrometer analysis and the results are illustrated in Figure 4.4 and presented in Appendix V.

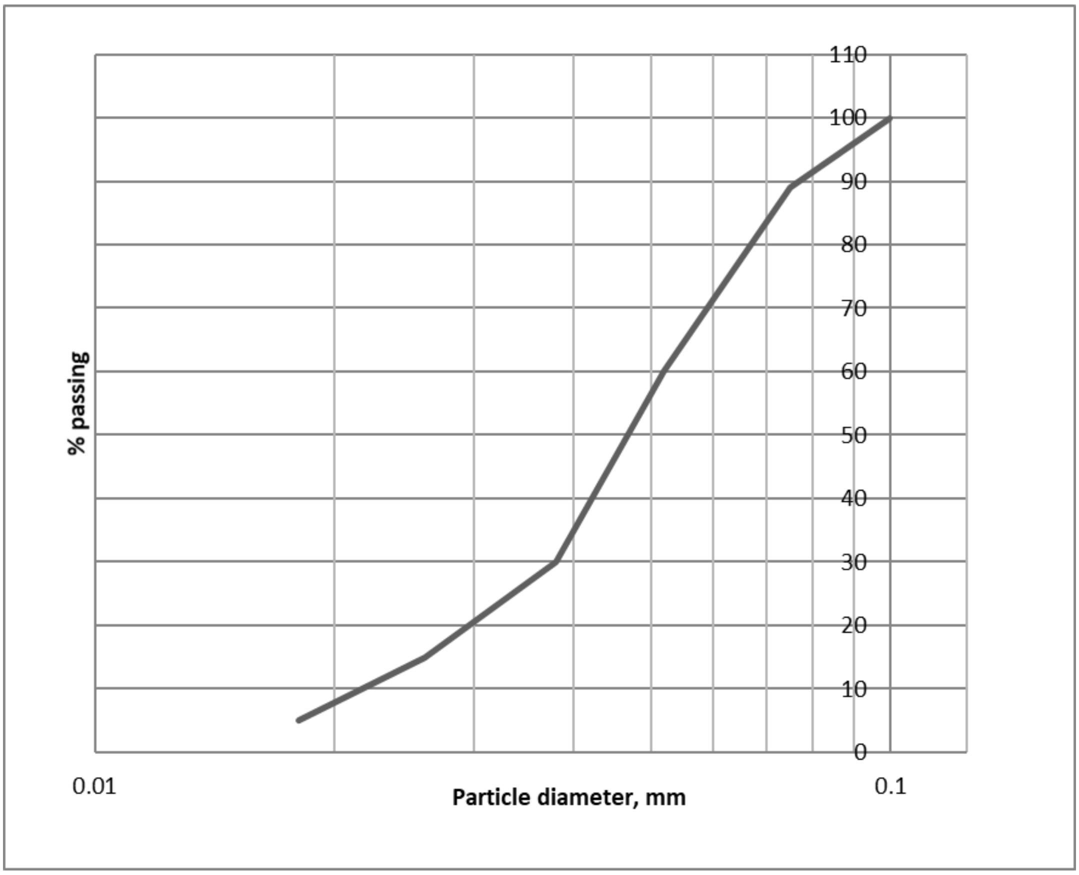

Figure 4.4: Particle size distribution of egg shell ash

From Figure 4.4 and Appendix 4, the results of particle size distribution show that for sieve size 0.01 the percentage passing was found to be 3.8% for egg shell ash and 4% for cement. While for sieve size 0.026 mm the percentage passing was found to be 20.43%. Further for sieve size 0.038 mm the percentage passing was found to be 25.95%, finally for sieve size 0.15 mm the percentage passing was found to be 59.04%. Thus for all the above sieve sizes it follows that the egg shell ash particles were smaller in size compared to those of cement. These results imply that, for the same mass, they had a larger surface area for chemical reaction than cement and had the effect of filling the voids and increasing the density of the concrete matrix when used to partially replace cement in concrete. Hence it improved the density and strength of the blended concrete mix.

4.1.1.8 Relative density of egg shell ash

The relative density of egg shell was ash found to be 2.59. In comparison with the relative density of cement, the relative density of cement was found to be higher at 2.908. Therefore for replacement by mass, a larger volume of egg shell ash was required to replace the same mass of cement in concrete.

4.1.1.9 Particle size distribution of Portland cement

Particle size distribution of cement was analyzed by hydrometer analysis and the grading curve for the particle size distribution of cement is illustrated by Figure 4.5 and results presented in Appendix VI. Analysis of compliance with the standard for particle size distribution of cement ASTM C 115 could not be done due to its limitation in scope. ASTM C 115 has a lower detection limit of 7.5 micrometers while the results in Appendix 6 recorded smaller sizes than the 7.5 micrometer limit.

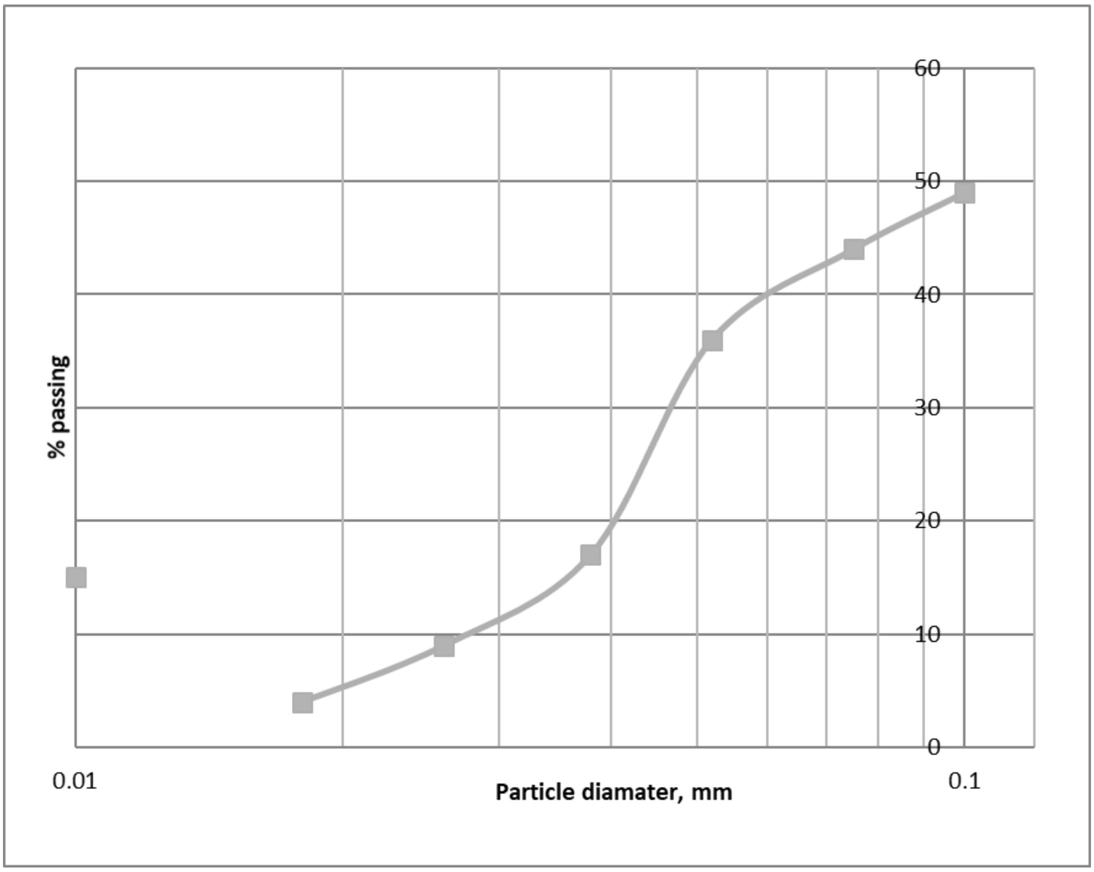

Figure 4.5: Particle size distribution of ordinary Portland cement

From Figure 4.5 and Appendix VI, the results of particle size distribution shows that for sieve size 0.01 the percentage passing was found to be 4% While for sieve size 0.026 mm the percentage passing was found to be 9%. Further for sieve size 0.038 mm the percentage passing was found to be 17%, finally for sieve size 0.1 mm the percentage passing was found to be 49%.

4.1.2 Chemical properties

4.1.2.1 Chemical properties of rice straw ash

The findings of chemical analysis of rice straw ashes are illustrated by Figure 4.6

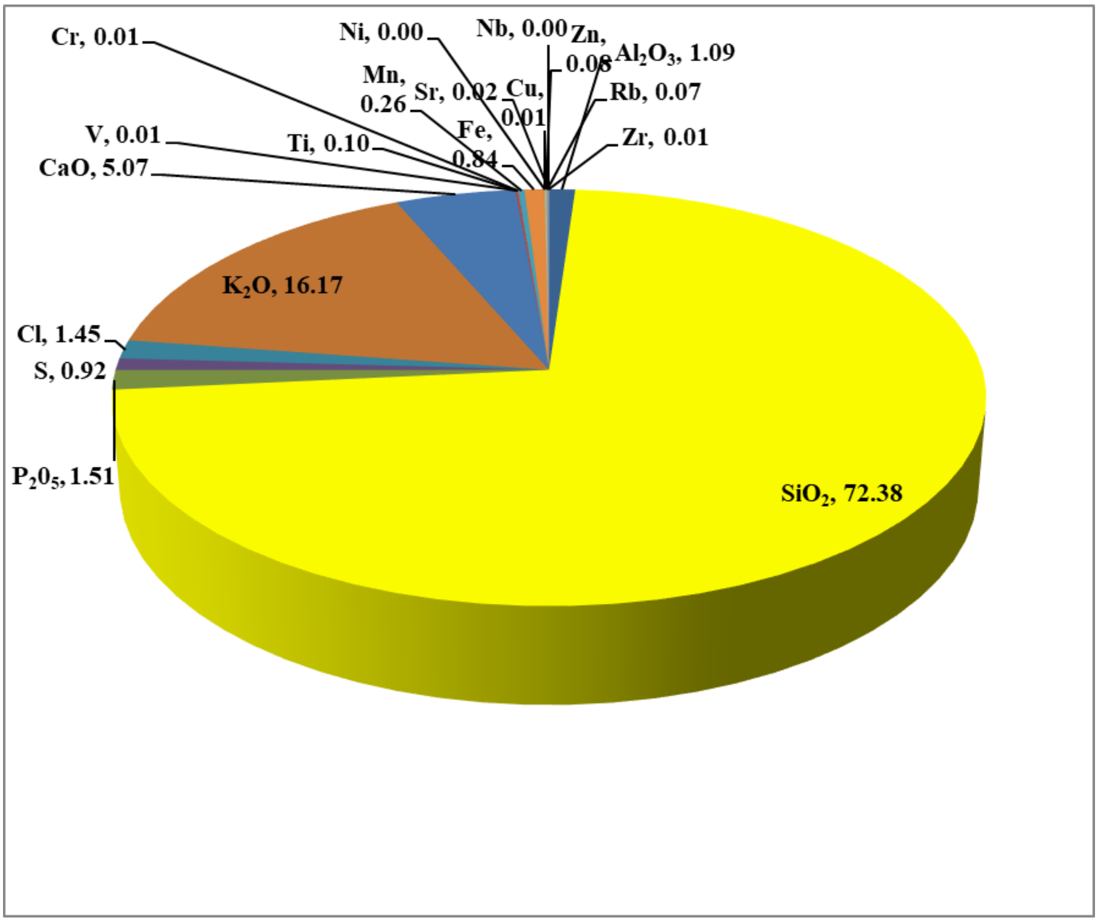

Figure 4.6: Chemical properties of rice straw ash

From the results in Figure 4.6, it is observed that the rice straw ash was composed of 72.38% SiO_2 (silica) followed by 16.17% K_2O by weight. The data is also presented in Appendix VII. ASTM C 618 specifications combined percentages of silica (SiO_2), Alumina (Al_2O_3) and ferric oxide (Fe_2O_3) should be greater than 70%. From Figure 4.1, the combined percentage of silica and alumina is 74.34% .This satisfies the 70% minimum specified by ASTM C 618. The RSA was found to be of class F pozzolan.

Class F pozzolan is one that requires a cementing agent in order to react and produce cementitious compounds. Previous researches Arunabh and Kumar (2016) reported 79.82% SiO_2 (silica) followed by 7.54% Mg followed by phosphorus pentoxide (P_2O) by weight as the pre-dominant chemicals. Morsy and Rashwan (2015) reported 69.2% SiO_2 followed by 6.4 % K_2O and 5.3% Al_2O_3 as the pre-dominant chemicals in rice straw ash. Thus there is a consensus among researchers that Silica is the predominant compound in rice straw ash. The differences are can attributed to differences in treatment procedures and equipment used for chemical analysis by the different researchers.

4.1.2.2 Chemical properties of egg shell ash

The results of the chemical oxide analysis of egg shell ash are presented in Table 4.2.

Table 4.2: Chemical analysis of egg shell ash

Analyte	Result	Standard Deviation
CaO	96.755%	(0.173)
K_2O	2.523%	(0.116)
SrO	0.606%	(0.006)
SO_3	0.116%	(0.006)
Total	100.0%	

From the results in Table 4.2, egg shell ash comprised of 96.76 % CaO (Calcium Oxide). Portland cement was found to be composed of 72.0% CaO. It can be observed that there are similarities in terms of the pre-dominant chemical oxide between Portland cement composition in Appendix 6 and egg shell ash as in Table 4.2. On the basis of this, the addition of egg shell ash to cement-rice straw ash blended concrete mixes had an effect of minimizing the CaO deficit arising from partial replacement of cement with rice straw ash. Calcium oxide content in egg shell ash has been reported to be 50.7%, 49.02% and 50.7% by Soumyam and Aswathi (2016), Afolayan(2017), and 63.8% Ashfaque et.al.,(2019), respectively. The disparity can be attributed to differences in pre-treatment method, genotype, age, ratio of egg shell to the protenous egg membrane and nutrition regimes of the breeders (Crosara et. al., 2018). Afolayan (2017). The presence of CaO from egg shell ash facilitated the formation of additional Calcium Silicate Hydrates which are cementitious products related to strength development by reacting with silica from the pozzolan as presented in Equation 2.9.

4.1.2.3 Chemical properties of Portland cement

The cement used was Ordinary Portland CEM 1- class 42.5 N. The results of the chemical analysis are illustrated by Figure 4.7 and tabulated in Appendix VIII.

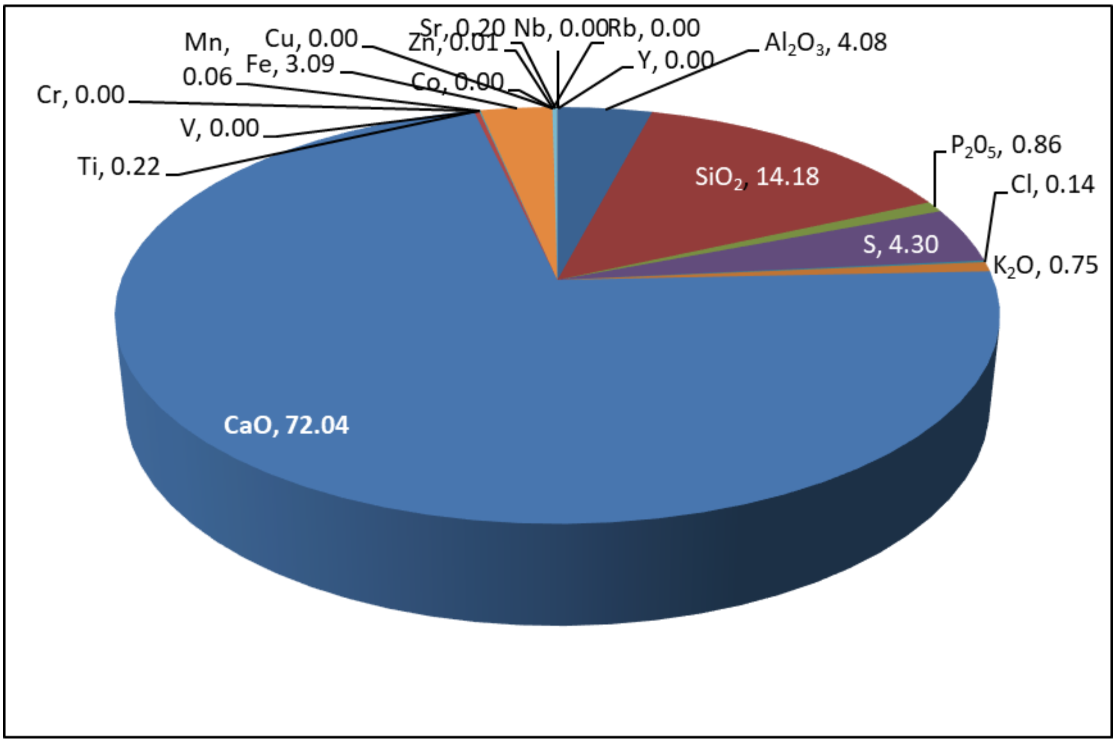

Figure 4.7: Chemical properties of ordinary Portland cement

It was observed that the main chemical oxide compositions for cement were found to be within the tolerances specified by Kenyan standard for cement KS EAS 18-1:2001. The cement therefore met the specifications for cement in Kenya and was therefore suitable for use in concrete.

4.2 Physical and mechanical properties of concrete having cement partially replaced with rice straw ash

4.2.1 Physical properties

4.2.1.1 Setting time of Portland cement and OPC-ESA cement pastes

The results for initial and final setting time of Ordinary Portland cement paste and rice straw ash-cement pastes for the various percentage partial replacements of cement are illustrated in bar chart form by Figure 4.8 and presented in Appendix VI.

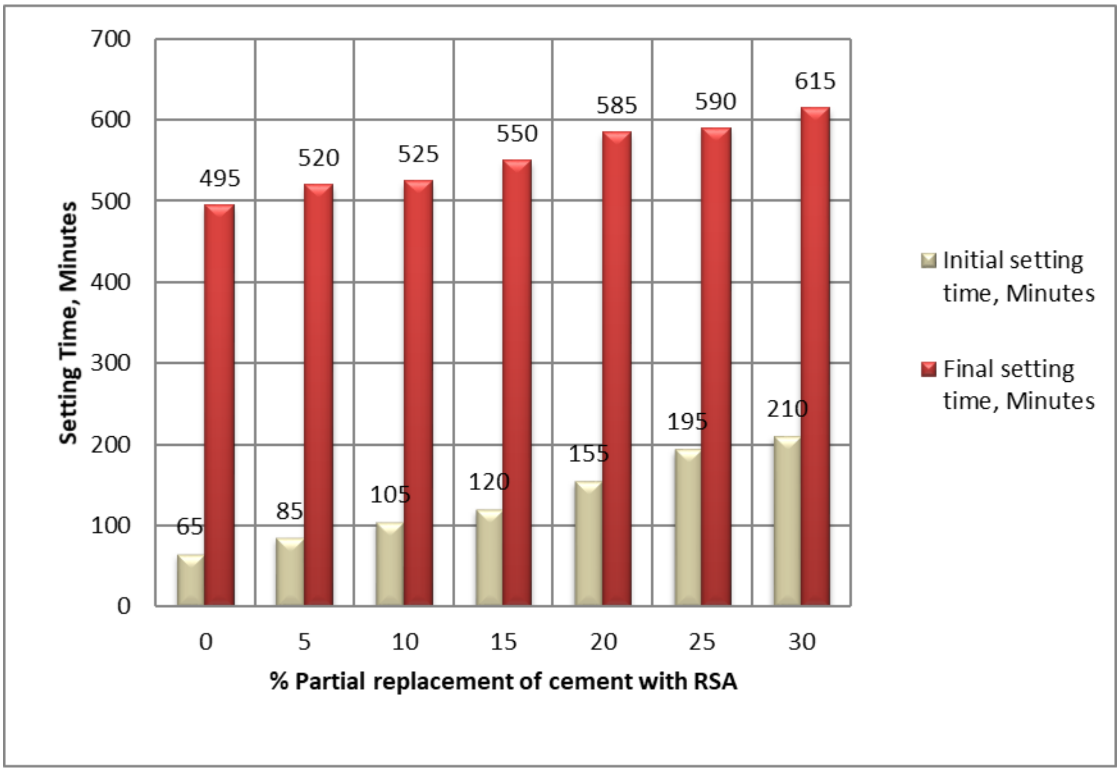

Figure 4.8: Initial and final setting time of cement pastes having cement replaced with RSA

The initial and final setting time of cement with 5 – 30 % partial replacement of cement with rice straw ash was found to range between 85 minutes to 615 minutes compared to the control which recorded an initial and final setting time of 65 and 495 minutes respectively.

Two main factors that affect setting time of cement are chemical composition of cement and fineness. From the results above, it can be observed that as the partial replacement of cement with rice straw ash increased, the initial and final setting time increased. Initial and final setting time of cement depends on chemical reactions that take place in cement. Al_2O_3 present in cement is responsible for formation of tricalcium aluminate which aids the quick setting of cement. From the chemical analysis of cement in Appendix 6, it can be observed that Cement was found to contain 4.076% Al_2O_3, while the chemical oxide analysis of rice straw ash in Appendix 2, rice straw ash was found to contain 1.094% Al_2O_3. Hence partially replacing cement with an equal mass of rice straw ash leads to reduction cement content and hence the amount of Al_2O_3 available for formation of tricalcium aluminate which is responsible for setting time of cement in concrete leading to increased setting times for cement pastes with cement partially replaced with rice straw ash.

These findings agree with those of Morsy and Rashwan (2015) and Dey and Sharma (2013) who reported an increase in both initial and final setting time with increase in rice straw ash content in cement pastes.

4.2.1.2 Slump test for concrete having cement partially replaced with rice straw ash

Upon mixing the concrete with various percentages of cement replacement levels, the results of slump test are illustrated by Figure 4.9.

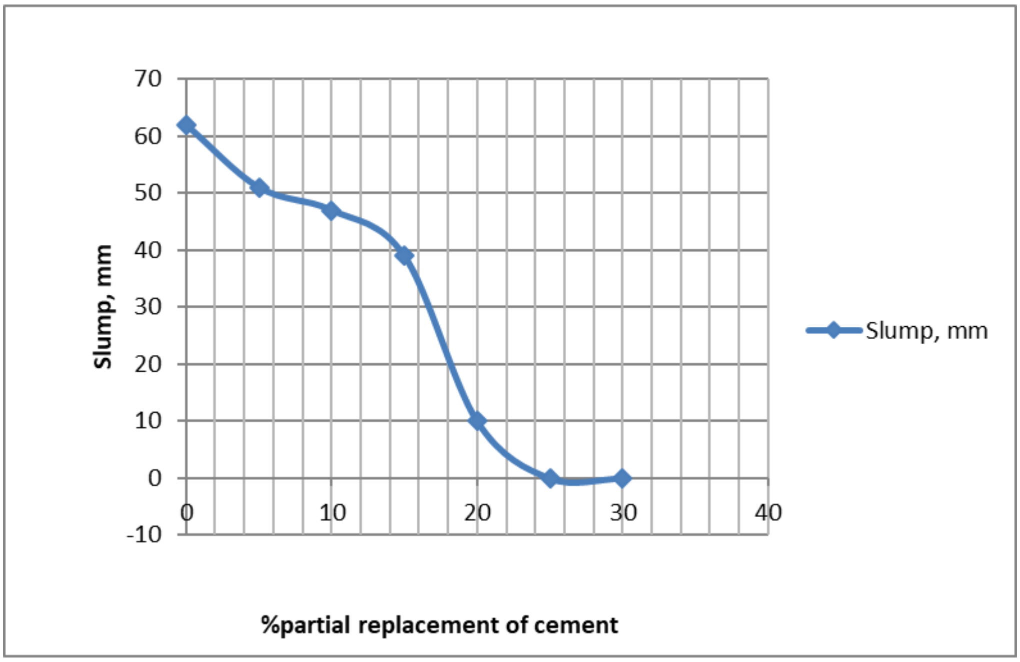

Figure 4.9: Slump versus percentage partial replacement of cement with RSA

The results indicate a steady decline in slump value recorded for various level of partial cement replacement. The control mix had the highest slump of 62.0 mm while concrete mixes with 25 & 30% partial cement replacement were found to have zero slump. This means that the concrete became less workable with increase in rice straw ash. These findings are consistent with those of Raheem *et al.* (2012). The reduction in consistency can be attributed to additional water requirement occasioned by smaller particle sizes of rice straw ash (particle size ranging from 0.01 – 0.1 from sieve analysis in Appendix 10) hence increased specific surface area compared to cement particles with particle size ranging between 0.1 and 0.019 presented in Appendix XI. The implication of this is that the concrete mixes became less workable with increase in the percentage of partial replacement of cement with rice straw ash hence required more compaction effort to achieve the same density as the control.

4.2.1.3 Water absorption of concrete having cement partially replaced with rice straw ash

The percentages of water absorption for the various mix codes after curing for 90 days and subjecting them to water absorption test are illustrated in Figure 4.10.

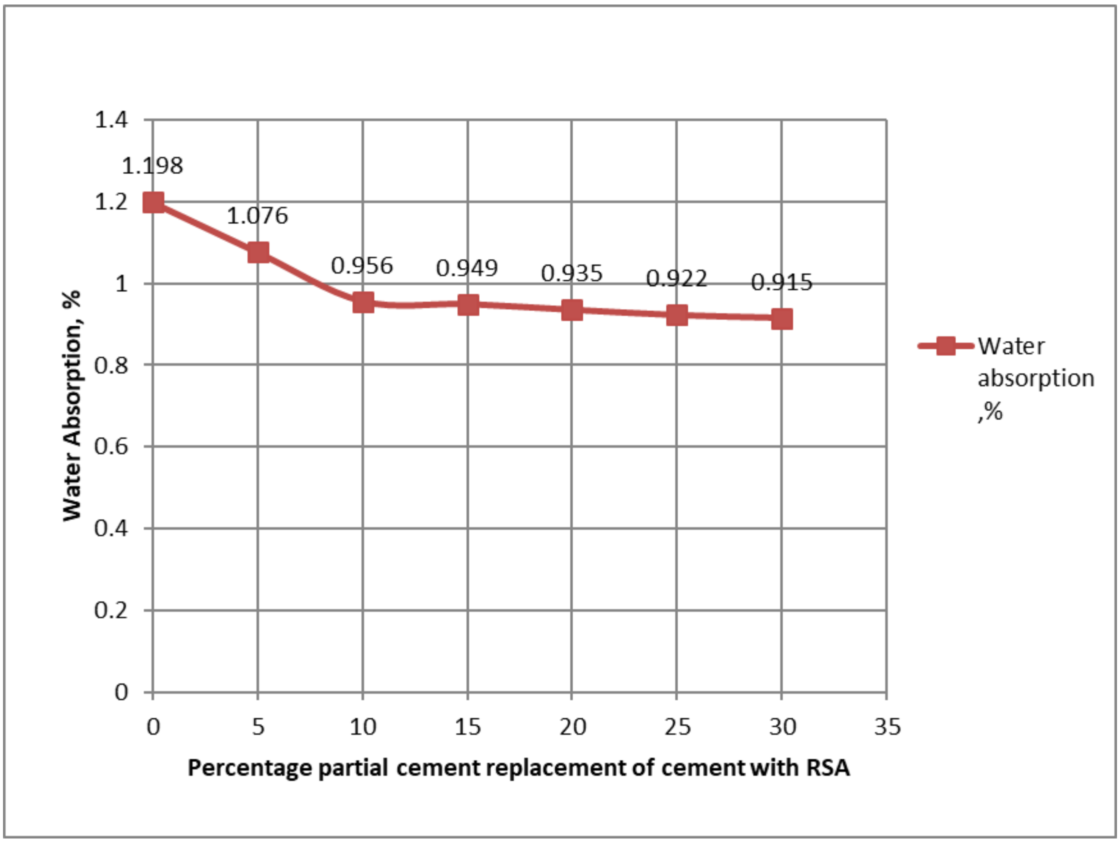

Figure 4.10: Percentage water absorption for concrete having cement replaced with rice straw ash

From Figure 4.10, it can be observed that there was a general reduction in water absorption with increase in percentage partial replacement of cement. The control recorded the higher capillary water absorption of 1.198% while the concrete with 10 % (optimum) partial cement replacement with rice straw ash was found to have a lower percentage water absorption of 0.956%. The reduction in percentage water absorption observed in samples with partial replacement of cement with rice straw ash can be attributed to both the micro-filler effect of the rice straw ash particles owing to their smaller size and the formation of calcium silicate hydrate gel from secondary pozzolanic reaction between silica in rice straw ash and calcium hydroxide from cement hydration that filled the voids of the concrete matrix causing it to be less porous to drawing of fluid by capillarity (Jawad et al., 2022).

4.2.2 Mechanical properties

4.2.2.1 Compressive strength

The variation of compressive strength with percentage partial replacement of cement with rice straw ash is illustrated by Figure 4.11 and presented in Appendix VIII.

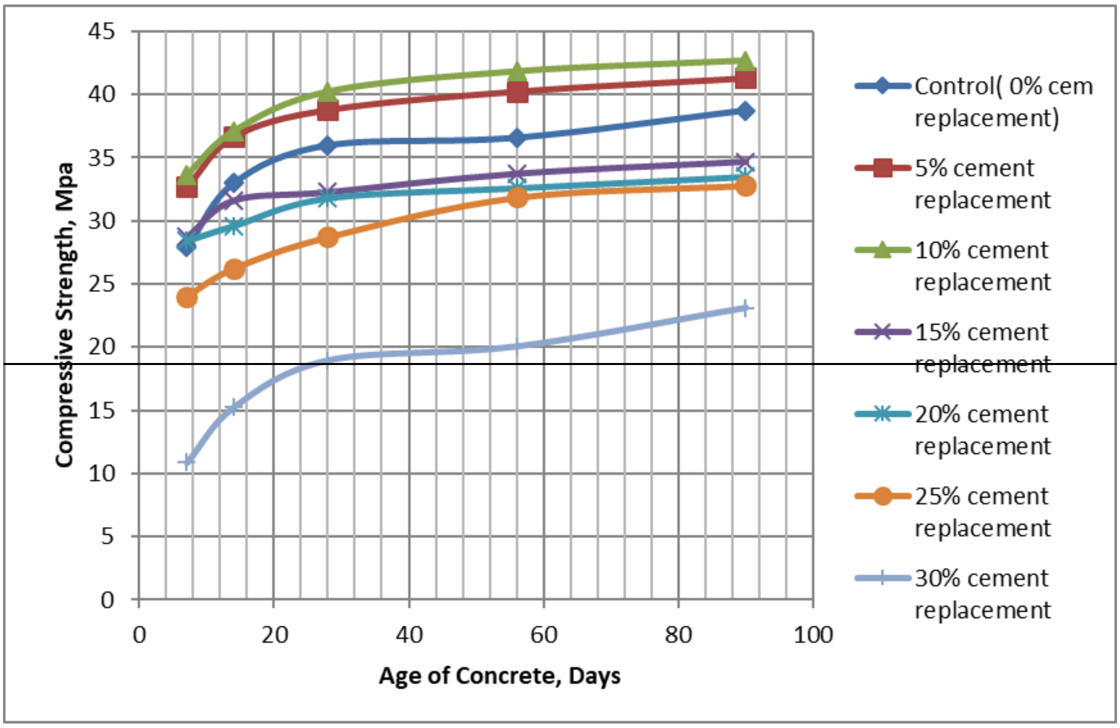

Figure 4.11: Compressive strength versus age of concrete for concrete having cement replaced with rice straw ash

An increase in compressive strength above the control was observed for concrete mixes with 5 and 10% partial cement replacement for all the ages of testing. The 7, 14, 28, 56 and 90 days compressive strength was found to be 27.9, 33.0, 35.95, 36.55 and 38.7 N/mm^2 for the control mix while the compressive strengths were found to be 32.70, 36.7, 38.8, 40.25 and 41.3 N/mm^2 representing, 17.2, 11.2, 7.9, 10.1 and 6.7% increase above the control respectively for 5% partial cement replacement. For 10% partial replacement of cement the strength was found to be 33.65, 37.10, 40.20, 41.80 and 42.65 N/mm^2 for 7, 14, 28, 56 and 90 days representing 20.6, 12.42, 11.8, 14.3, and 10.2% increase above the control respectively. The increase in concrete strength can be attributed to two factors. First, the filler effect of pozzolanic material which from the particle size distribution results were found to be smaller than those of cement. This resulted in denser packing of particles within the concrete matrix and at the aggregate/concrete interface. The second reason is the pozzolanic reaction between the silica in the rice straw ash and $Ca(OH)_2$ produced by cement hydration as illustrated in Equation 2.5 to from additional calcium silicate hydrates that are responsible for strength in concrete (Razal et. al., 2022). This reaction occurs after the hydration reaction and is responsible for strength gain during later days of concrete curing. Further the smaller sized, irregular, and porous particles of rice straw ash meant there was increased surface area for chemical reaction leading to faster pozzolanic reaction (Surajit & Sharma, 2018).

For mixes with partial cement replacement of 15, 20, 25 and 30%, a drop in compressive strength below the control was observed. The 7, 14, 28, 56 and 90 day compressive strengths were found to be 28.7, 31.6, 32.3, 33.7 and 34.7 N/mm^2 respectively, for 15% partial cement replacement and 28.4, 29.6, 31.8, 32.6 and 33.5 N/mm^2 respectively, for 20% partial cement replacement. Further, for 25% partial cement replacement the strengths were found to be 24, 26.2, 28.7, 31.9 and 32.8 N/mm^2 while for 30% partial cement replacement the compressive strength was found to be 10.9, 15.3, 18.9, 20.0 and 23.1 N/mm^2 for 7, 14, 28, 56 and 90 days curing age, respectively. Since the rice straw ash was found to have a CaO: Silica ratio of 1:14.3 instead of the recommended 3:13 and a CaO content of 5.1% instead of the recommended 61-67% as in Table 2.2, partial replacement of cement with the same mass of rice straw ash results into a surplus in silica content. At low percentages of cement replacement, the silica in pozzolana reacts with the $Ca(OH)_2$ released by hydration of cement to form cementitious materials. At higher replacement levels of cement, there is an increase in the amount of pozzolana in the concrete mix. However, the replacement of cement with pozzolan has an effect of reducing the cement content in the concrete which in turn reduces the quantity of $Ca(OH)_2$ released by hydration of Portland cement. This reduction in $Ca(OH)_2$ production leads to reduced production of cementitious product (C-S-H) that is responsible for strength development in concrete as was illustrated by Equations 2.1 and 2.2 (Ash *et al*., 2019; Marangu *et al*., 2018).

Eldin et al. (2013) reported that 10% was the optimum partial replacement of cement with RSA in concrete similar to this research. On the other hand, Sharma and Chalotra (2022), and Razak et al., (2022), reported 15% as the optimum replacement of cement with RSA in concrete at 28 days. The difference in the optimum percentage partial replacement of cement with RSA in concrete reported by these researchers can be explained by the following. Sharma and Chalotra (2022), replaced normal sand with foundry sand in concrete (in addition to RSA) which is cleaner, more uniform-sized, finer and with higher silica content than normal sand. Foundry sand enhanced pozzolanic activity and densified the concrete matrix. While Razal *et al.*, (2022) used a low water/cement ratio of 0.35 and superplasticizer than the 0.5 used in this research. The lower the water/cement ratio, the higher the compressive strength. Nevertheless there was consensus among the researchers that strength decreased with partial cement replacement above the optimum cement replacement reported. Afolayan (2017) reported a general increase in compressive strength with increase in percentage partial replacement of cement with egg shell ash in concrete.

In order to consume the excess silica and form additional cementitious materials requires the addition of a substance rich in CaO. The CaO in the substance will react with the silica (SiO_2) to form additional cementitious materials. These additional cementitious materials contribute to strength of concrete. In an unreacted form, the SiO_2 has no cementitious properties and does not contribute to strength of concrete. It only acts as a mineral filler. The compressive strength was also observed to increase gradually with age of concrete for both the control concrete and the blended concretes with various percentage partial replacements of cement. For the control, the curve flattened after 28 days. This was attributed to little strength gain beyond 28 days owing to lack of pozzolanic reactions in the mix.

Further, concretes with 5 and 10% partial replacement of cement with rice straw ash recorded a compressive strength above the control for all ages of testing while the concretes with 15, 20, 25 and 30% partial replacement recorded strength below the control for all ages of testing.

The concrete with 10% partial replacement of cement with rice straw ash recorded the highest strength at all ages while the concrete with 30% partial replacement of cement with rice straw ash recorded the lowest strength at all ages.

From the foregoing, it can be concluded that 10% partial replacement of cement with rice straw ash is the optimum. Further, the concrete mixes with partial replacement of cement showed significant gain in compressive strength beyond 28 days compared to the control. This can be attributed to pozzolanic reactions that take place in later curing ages that form additional cementitious materials that are responsible for increase in strength beyond 28 days age of curing.

4.2.2.2 Splitting Tensile Strength

The results of the splitting tensile strength tests are illustrated in Figure 4.12 and presented in Appendix IX.

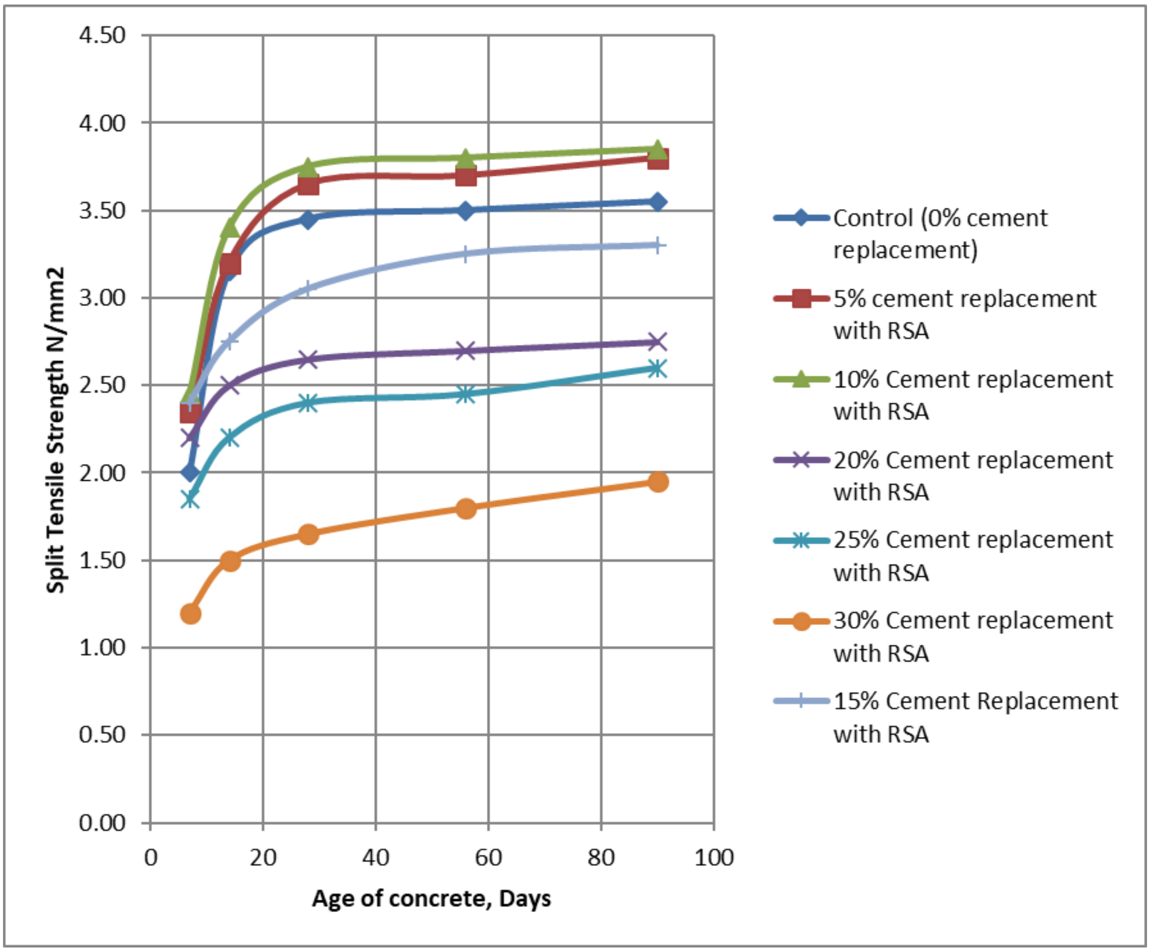

Figure 4.12: Splitting tensile versus age for concrete having cement replaced with rice straw ash

Splitting tensile strength was found to range between 1.2 N/mm^2 and 3.85 N/mm^2. Test results showed an increase in strength above the control for partial cement replacement of 5 and 10%. The 7, 14, 28, 56 and 90 days splitting tensile strength for the control mix was found to be 2.0, 3.1, 3.4, 3.5 and 3.6 N/mm^2, respectively while that of 5% partial cement replacement was found to be 2.3, 3.2, 3.6, 3.7 and 3.8 N/mm^2 at ages of 7, 14, 28, 56 and 90 days, respectively, representing splitting tensile strength increase of 13.0, 1.9, 5.5, 6.6 and 9.3% respectively above the control. The concrete mix with 10% partial cement replacement was found to have split tensile strength of 2.45, 3.40, 3.75, 3.8 and 3.85 N/mm^2 representing an increase of 23.5, 9.3, 8.8, 8.6 and 11.3% strength increase above the control for concrete ages of 7, 14, 28, 56 and 90 days, respectively. However, for mixes with partial cement replacements of 15, 20, 25 and 30%, the results showed a progressive decline in tensile strength below the control for all ages. These findings are similar to those of Muhammad *et al.*, (2013) and Khusbu and Sharma (2014) that tensile strength increases marginally for partial cement replacement of up to a limit and then any further replacement of cement results in a decline in strength. The decrease in strength with increase in cement replacement can be attributed to the reduction in CaO required to form cementitious materials as illustrated in Equations (2.1) and (2.2). This is occasioned by differences in CaO content as illustrated by the chemical oxide analysis in Appendix 6. Cement was found to have 72.4% CaO by weight with rice straw ash which from Appendix 3 was found to have only 5.0% CaO by weight.

The split tensile strength was found to vary with percentage partial replacement of cement with rice straw ash. The concrete with 5 and 10% replacement of cement with rice straw ash recorded higher strength than the concrete with zero replacement of cement with rice straw ash at all ages. The ratio of 90 days compressive to 90 days splitting tensile strength for concrete having cement replaced with 10% RSA was found to be 11.08 for concrete with 10% partial replacement of cement and 10.92.While the ratio for 90 days compressive strength to 90 days splitting tensile strength the control concrete having 0% partial cement replacement with RSA was found to be 10.92. These ratios are within the range of 8 – 15% of the compressive strength as reported by Nihal *et al.*, (2006). It was observed that rice straw ash affected splitting tensile strength the same way it affected compressive strength. The splitting tensile strength generally increased with curing age. This can be attributed to the filler effect of pozzolans at early ages of curing and pozzolanic reactions between silica from the pozzolan and $Ca(OH)_2$ from cement hydration that formed additional cementitious materials during latter days of curing.

From the foregoing results, it can be observed that the strength of mixes was found to increase with partial replacement of cement with rice straw ash up to 10% partial replacement. After which a decline in strength is observed. It can, therefore, be concluded that for this mix, the optimum percentage partial cement replacement of cement with rice straw ash is 10%. Therefore, it can be said that beyond 10% partial replacement of cement with rice straw ash leads to excess silica which has no matching $Ca(OH)_2$ produced by the hydration of cement to react with and form additional cementitious materials. This is what led to decrease in compressive strength since the unreacted silica only acts as a filler material in the cement matrix with no cementitious properties.

4.3 Mechanical properties and durability of concrete having cement partially replaced with rice straw and egg shell ash

To address the deficit in CaO in the concrete, egg shell ash was added to the cement-rice straw ash blended concretes so as to consume the silica brought about by the rice straw by combining with CaO from egg shell ash in presence of water to form additional calcium silicate hydrates and enhance the concrete strength.

4.3.1 Compressive strength for concrete having cement replaced with 15%RSA and various percentages of egg shell ash

Egg shell ash was added in increments of 2.5, 5, 10, 15 and 20% by weight of concrete to the concrete with 15% partial replacement of cement with rice straw ash and the strength determined for various ages of curing. The results of the compressive strength tests are illustrated by Figure 4.13 and presented in Appendix XI.

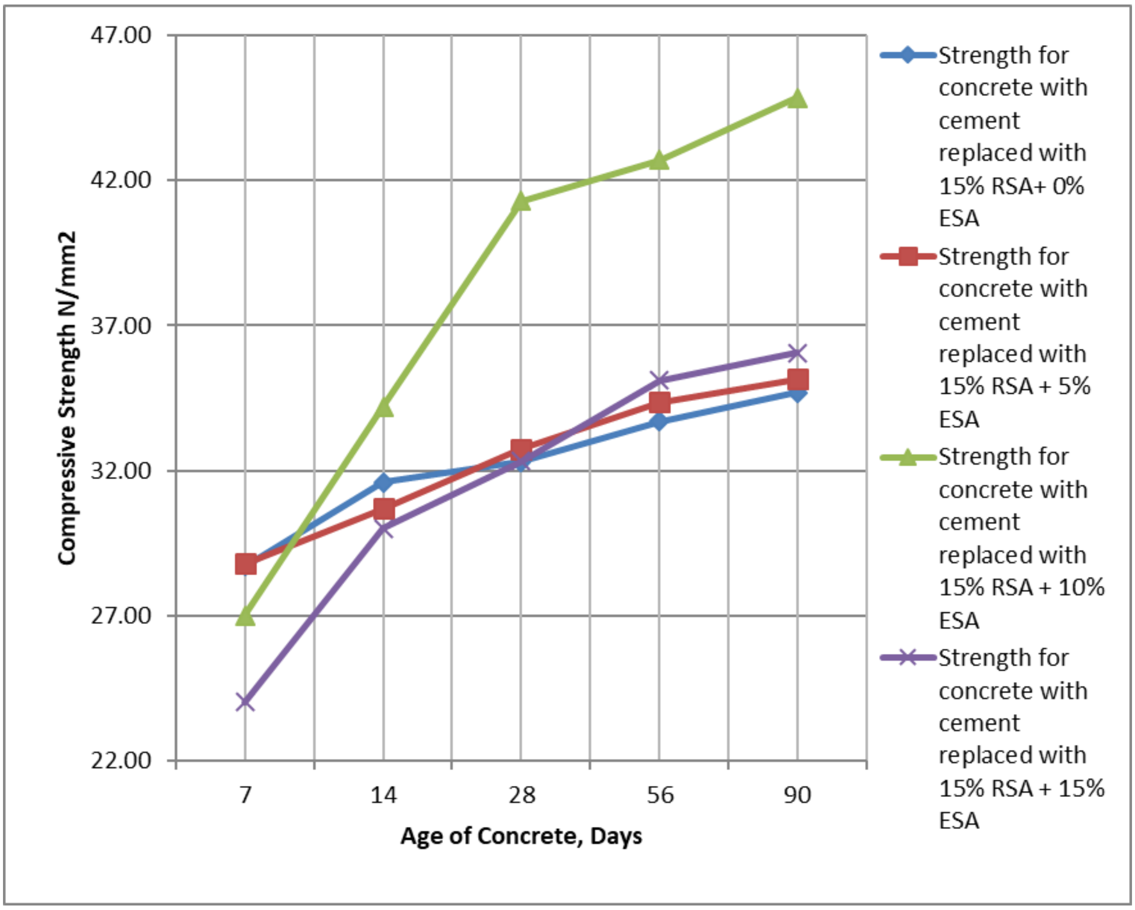

Figure 4.13: Compressive strength versus age of concrete having cement replaced with 15% RSA and various percentages of ESA

From Figure 4.13, it can be observed that there was an increase in compressive strength with continued increase in the percentage of egg shell ash. The addition of 2.5% egg shell recording the lowest percentage increment of 0.35% at 7days age. Addition of 10% egg shell ash to concrete mix with 15% partial cement replacement recorded the highest strength increment of 17.9% at 56 days age compared to the concrete with OPC+15% RSA at the same age of testing. For 2.5, 5 and 10% egg shell ash that was added to the concrete with OPC+15%RSA and a water/cement ratio of 0.5 used in this study, it can be concluded that 10% addition of egg shell ash was the optimum.

Afolayan (2017) also reported an optimum partial replacement of cement with egg shell powder to be 5%. This result is lower than the 10% obtained in this research. The researcher substituted cement with egg shell ash alone in concrete. Therefore low replacement level could have been caused by both chemical similarity between cement and egg shell ash and lack of a pozzolan to provide silica to react with CaO from egg shell ash to form additional cementitious materials. Higher additions of egg shell ash beyond the 10% were not possible for the water/cement ratio of 0.5 owing to the fineness, porosity and hygroscopic nature of RSA particles and ESA particles that reduced water meant for workability (Bali & Singh, 2019).

The 28 day compressive strength for OPC+15%RSA and OPC+15%RSA+10% ESA is illustrated in Figure 4.14 and presented in Appendix 12.

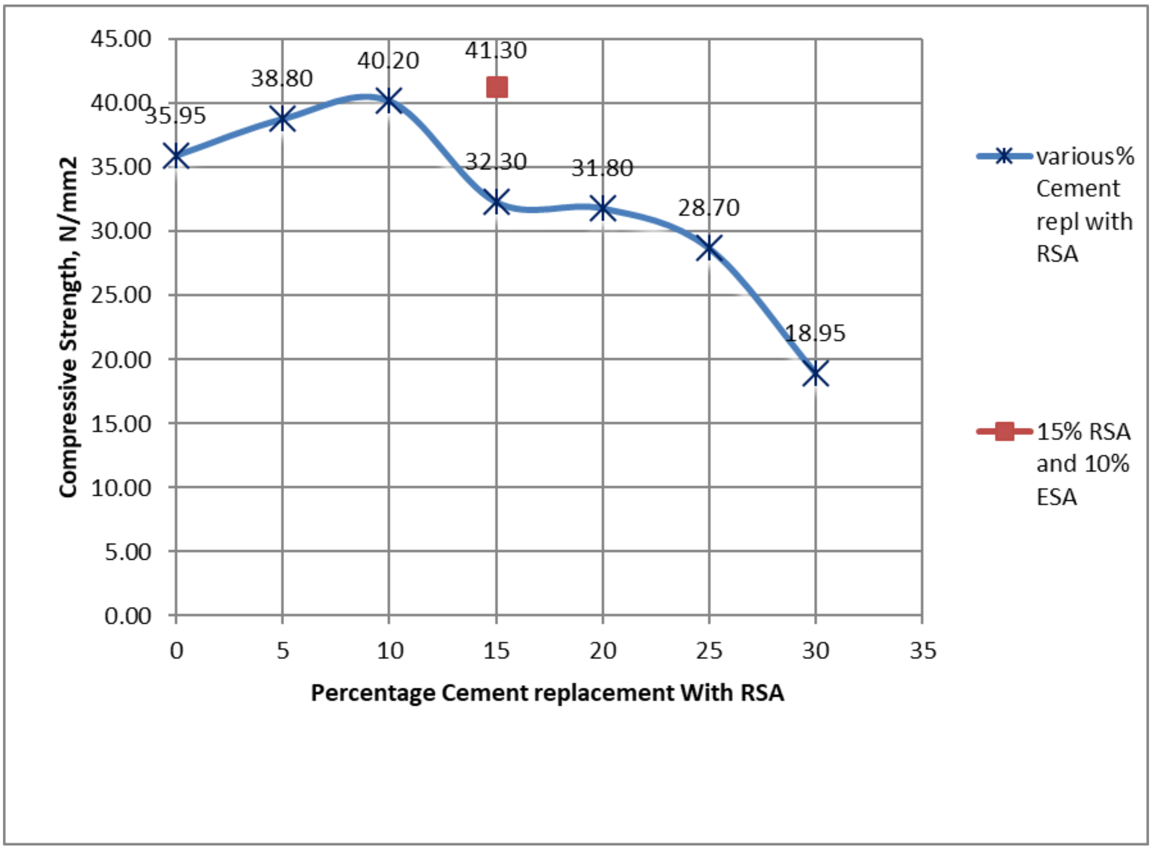

Figure 4.14: 28 days compressive strength for concrete having cement replaced with various % of RSA and concrete having cement replaced with 15% RSA and 10% ESA

From Figure 4.13, it can be observed that the concretes with OPC+15% RSA and above exhibited a decrease in compressive strength. When 10% ESA was added to the OPC+15% RSA concrete, the OPC+15% RSA+10%ESA blended concrete recorded a higher compressive strength than concrete with OPC+15%RSA alone for the same age of testing. The 28, 56 and 90 day compressive strength for OPC+15%RSA concrete was found to be 32.3, 33.7 and 34.7 N/mm^2 while the compressive strength for OPC+15% RSA+10 % ESA concrete was found to be 41.3, 42.7 and 44.85 N/mm^2 representing a strength increase of 25.3, 26.7 and 29.2% increase respectively. The increases in strength can be attributed to the chemical composition of egg shell ash. Egg shell ash is rich in CaO (with 97.04% CaO by weight). Therefore its addition restored the CaO deficit created by partial replacement of cement (found to comprise of 72.04% CaO, and 14.18% Silica by weight respectively) with rice straw ash (found to be composed of 72.37% silica and 5.087% CaO). CaO is one of the most important ingredients in cement and is responsible for formation of compounds that are responsible for development of strength in cement during hydration and therefore should be available in prescribed optimum quantity in order for a concrete mix to develop the required strength (Abdullah *et al*., 2012, Afolayan, 2017, Quariconi *et al*., 2015). This is what formed the basis of adding egg shell ash which from chemical analysis was found to be composed of 96.76% CaO by weight.

4.3.2 Compaction Factor for concrete having cement partially replaced with rice straw and egg shell ash

Table 4.3 presents the results of compaction factor for cement-rice straw ash blended concretes with various percentages of egg shell ash.

Table 4.3: Compaction factor for concrete with 15% partial replacement of cement with RSA and various percentages of egg shell ash

Mix No.	Blended Concrete Mix Description	Compacting factor
1	OPC + 15% Rice Straw Ash +10% ESA	0.6617
2	OPC + 15% Rice straw ash +15% ESA	0.6347

The compaction factor for concrete with 15% RSA alone was 0.6685 as presented in Table 4.2, whereas that of concrete with 15% RSA and 10% ESA was found to be

0.6617 in Table 4.3. The compaction factor for concrete with 15% RSA and 15% ESA was found to be 0.6347. It can be observed that the compaction factor decreased with increase in the amount of egg shell ash. A decrease in compaction factor shows a decrease in workability. This can be attributed to the water demand exerted by the CaO in the egg shell ash as it reacts to form $Ca(OH)_2$ in the concrete mix that consumed part of the water meant for workability hence making the concrete mix less workable.

4.3.3 Accelerated Durability Test

Table 4.4 presents the results of reduction in compressive strength of various concrete mixes immersed in dilute sulphuric acid solution.

Table 4.4: Compressive strength for concrete having cement replaced with RSA before and after immersion in 0.5% sulphuric acid

Sample No.	Concrete Mix ID	Compressive strength before immersion in dilute sulphuric acid, MPa	Compressive strength after immersion in dilute sulphuric acid, MPa	Percentage change in strength
1	0% Partial replacement of cement(control)	38.7	36.47	-5.77
2	10% Partial replacement of cement with rice straw ash	42.65	41.1	-3.56
3	15% Partial replacement of cement with rice straw ash and 10% egg shell ash	44.85	42.57	-5.09

The mix without partial replacement of cement with rice straw ash had the highest reduction in compressive strength at 5.77% while the concrete with 10% partial replacement of cement with rice straw ash recorded the lowest compressive strength reduction of 3.56% Since the rice straw particles were found to be smaller in particle size than those of cement from Appendix 5, the concretes with partial replacement of cement with rice straw ash achieved denser packing of particles and therefore were less porous to penetration of acid solution. Further, the density of rice straw ash was found to be lower than that of cement. Consequently, for the same mass of partial replacement of cement with rice straw ash there was a greater volume of rice straw ash. The smaller sizes of rice straw ash particles had an impregnating filling the voids in the cement matrix. Further the silica in rice straw ash reacted with $Ca(OH)_2$ from cement hydration to form calcium silicate hydrates gel that further sealed the voids in cement matrix. This filling of voids enhanced the chemical resistance and capillary penetration of acid solution in the concrete matrix resulting in slowed corrosion effect and leading to reduced mass loss. These findings are consistent with those of (Salim & Davin, 2017).

Loser and Leemann (2015), in their study on accelerated sulphate resistance testing protocols concluded that eight weeks (56 days) is the best balance between sulphate ingress, expansion and test duration. The results of the tests on concrete cubes cured for 56 days in water and immersed in bath containing 0.5% dilute sulphuric acid for 30 days are presented in Table 4.4. It shows variation of mass for concrete cubes after subjecting them to sulphuric acid for 30 days. It was observed that the control recorded the highest mass loss of 1.01%, while the cubes with 10% partial cement replacement with rice straw ash recorded the least of loss in mass at 0.29%. The mass loss in concrete cube specimens can be attributed to formation of gypsum, part of which dissolved in the solution and part of which appeared as a precipitate in the acid solution bath. Equation 4.1 represents the sulphuric attack on concrete to form gypsum.

$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4.2H_2O(Gypsum) \quad (4.1)$$

(Reddy, Rao, George, 2012)

For the specimen with no partial replacement of cement the above reaction takes place and consumes the $Ca(OH)_2$ that was formed by hydration reaction. These specimens did not have a pozzolan in their mixes to consume the $Ca(OH)_2$ formed by hydration hence there was greater opportunity for the Equation 4.1 above to occur. They also lacked the packing effect of pozzolan particles in their concrete matrix to prevent percolation of acid solution into the concrete cube matrix. These factors could explain why they recorded the highest mass loss through formation of gypsum.

On the other hand, the specimens with 10% partial replacement of cement with rice straw ash, the $Ca(OH)_2$ formed during hydration (Equation 2.5 and 2.6) was consumed by the pozzolanic reactions presented by equation 2.9, with silica in rice straw ash to form additional cementitious materials hence reducing opportunity for reaction that lead to formation of gypsum to take place hence reducing mass loss.

Finally for the specimen with 15% partial cement replacement with rice straw ash and 10% egg shell ash, there was a slight increase in mass loss compared to the concrete with 10% partial replacement of cement with rice straw ash alone owing to the availability of $Ca(OH)_2$ that was not consumed by hydration reactions occasioned by the addition of egg shell ash. This $Ca(OH)_2$ provided opportunity for the reaction that leads to formation of gypsum to take place hence leading to a slight increase in mass loss compared to the specimen with 10% partial replacement of cement with rice straw ash.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study evaluated the properties of concrete with cement partially replaced with rice straw ash and egg shell ash. The main findings of the study are listed below:

Objective No.1

1. Cement used in this research met the requirements of Kenyan standards for cement. Rice straw ash used in this study obtained from Bunyala irrigation scheme in Busia County, Kenya was found to contain 72.38 % silica, 1.09 % alumina which when combined gives 74.34 %. This meets the requirements of ASTM C 618 that the combined percentage of silica (SiO_2), alumina (Al_2O_3) and ferric oxide (Fe_2O_3) should be 70 % minimum. Therefore the rice straw ash is suitable for use as a pozzolan.
2. Egg shells used in this study were found to contain 96.8 % CaO, 2.5 % K_2O and 0.61 % SrO. The CaO is the ingredient present in raw materials used in the manufacture of cement and therefore were suitable for enhancing CaO content in Portland cement.
3. The grading of the coarse and fine aggregate used in this study was found to fall within the grading envelopes specified

Objective No.2

4. The optimum percentage partial replacement of Portland cement with rice straw ash in concrete was found to be 10 % by weight of cement. The control concrete recorded a 7, 14, 28, 56 and 90 days compressive strength of 27.9, 33.0, 35.9, 36.6 and 38.7 N/mm^2 while the concrete with cement partially replaced with 10 % rice straw ash recorded a 7, 14, 28, 56 and 90 day compressive strength of 33.7, 37.1, 40.2, 41.1 and 42.65 N/mm^2

5. The concrete with cement partially replaced with rice straw ash at 10% was found to have higher residual compressive strength when subjected to acid attack than the control concrete.

Objective No. 3

6. The optimum amount of egg shell ash that can be added to a concrete with 15% replacement of cement with rice straw ash for the range of percentages that could form a concrete paste with a fixed water/cement ratio of 0.5, that is 2.5%, 5% and 10% was found to be 10% by weight of cement. The 7, 14, 28, 56 and 90 days compressive strength for concrete with 15% RSA and 10% ESA were found to be 27.0, 34.2, 41.3, 42.7, and 44.9 N/mm^2 ,respectively, compared to the control which recorded 27.9, 33.0, 35.9, 36.6 and 38.7 N/mm^2 for the 7, 14, 28 56 and 90 days, respectively. The strengths for the OPC-RHA-ESA blended concrete were higher than for OPC concrete for all of testing ages except 7 days.
7. Addition of egg shell ash to rice straw ash-cement blended concrete resulted in achieving strength higher by between 3.26 and 29.2% for the various ages of curing at a higher percentage partial replacement of cement with RSA (15%) compared to that obtained at the 10% optimum cement replacement with rice straw ash. This allowed recovery of strength lost by partial substitution of cement with rice straw ash in concrete at percentage replacements beyond the optimum.

5.2 Recommendations

The following are the recommendations from this research:

5.2.1 Recommendation from the study

1. Rice straw ash may be used to partially replace cement in concrete up to 10% by weight of concrete resulting not only in cost savings but also in environmental sustainability by consuming agro based wastes that currently pose a disposal problem.

2. Egg shell ash and rice straw ash may be used in combination at 10% and 15% partial replacement of cement in concrete reducing the cement content required in concrete and hence cost of concrete and still achieve the design strength.
3. Incorporating rice straw and egg shell ash in concrete may be used as an avenue to reduce cement demand and production by the construction industry and consequently reduce the damage to the environment through reduced extraction of raw materials, reduce green house gases emissions and energy demand by cement industries.
4. The rice straw ash-cement blended concrete can be used for construction in environments that are susceptible to acid attack or with acidic soils since they have demonstrated better resistance to acid attack that the unblended concretes. The areas with acid soils in Kenya constitute 13% of Kenyan land area and are located in the highlands East of Rift Valley and Western regions (Kisinyo, 2011).

5.2.2 Recommendation for further research

1. Using the concrete mix in this research but varying the water/cement ratio above 0.5 or below 0.5 with addition of super plasticizers and evaluate the performance of resultant concretes.
2. Conduct microstructure and morphology investigations on the mineral assemblage for the OPC-Rice straw ash, and OPC-Rice straw ash- egg shell ash blended concrete by use of scanning electron or x-ray microscopy.
3. Incinerating the straw at different temperatures and different durations from those used in this study and evaluate the effect of partial substitution of cement with the rice straw ash on concrete properties.
4. Use egg shell ash with pozzolans of mineral origin (non – agricultural) to partially replace cement in concrete and study the effects on the properties of concrete.

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APPENDICES

Appendix I: Concrete mix proportions for making one cubic metre of concrete

Mix code	Water/cement ratio	Cement (Kg),	Water (Kg),	Fine Aggregate(Kg)	Coarse aggregate (Kg),	% cement replacement	RSA (Kg),	No. of Specimens
1	0.5	476	238.4	700	1010	0	0	15 Cubes, 15 cylinders
2	0.5	452.2	238.4	700	1010	5	23.8	15 Cubes, 15 cylinders
3	0.5	428.4	238.4	700	1010	10	47.6	15 Cubes, 15 Cylinders
4	0.5	404.6	238.4	700	1010	15	71.4	15 Cubes, 15 cylinders
5	0.5	380.8	238.4	700	1010	20	95.2	15 Cubes,15 cylinders
6	0.5	357	238.4	700	1010	25	119	15 Cubes, 15 cylinders
7	0.5	333.2	238.4	700	1010	30	142.8	15 Cubes, 15 cylinders
							Total specimens	30x7= 210

The water/cement ratios used was 0.5 for all the mixes.

Concrete mix design using Building Research Establishment (BRE) method.

Mix design calculation sheet for 35N/mm^2 concrete mix (28 Day strength)

Job title: Thesis Proposal: Use of Rice straw & Egg shell ash as partial replacements of cement in concrete

Reference: EN352/0769/2013

Stage Item or calculation Values

1.1 Characteristic strength Specified ⌠ 30 N/mm^2 at 28 days

Proportion defective**10**%

1.2 **Standard deviation** selected from Fig 3____N/mm^2 or where there is no data **4** N/mm^2 (for over 20 results, page 8)

1.3 **Margin** C1 = k x standard deviation, (k = **1.28 for 10% defectives**) thus C1 = **1.28**×**4**= **5.12** N/mm^2

Or Specified ____N/mm^2

1.4 Target mean strength, C2 =30+5.12=35.12N/mm^2

1.5 **Cement strength** class Specified: 42.5/~~52.5~~ MPa (Cement strength is 42.5 MPa)

1.6 **Aggregate type**: coarse Crushed/~~uncrushed,~~ (crushed coarse aggregate will be used)

Aggregate type: fine ~~Crushed~~/uncrushed, (uncrushed fine aggregate will be used)

1.7 **Free-water/cement** ratio (Selected from Table 2, Fig 4) …**0.4**

……………………………………… Use the lower value

1.8 **Maximum free-water/cement ratio** Specified N/A (not specified)

2.1 Slump or Vebe time Specified Slump**60-180** mm or Vebe time_____ s

2.2 Maximum aggregate size specified **20**mm

2.3 Free-water content selected from Table 3, **205** kg/m^3

3.1 **Cement content C3** = 205÷ **0.43** = 476kg/m^3

3.2 **Maximum cement content** Specified _________kg/m^3 (not specified)

3.3 **Minimum cement content** Specified __________ kg/m^3 (not specified)

use 3.1 if < 3.2

use 3.3 if > 3.1 kg/m^3

3.4 Modified free-water/cement ratio **0.43** (Selected from Table 2, Fig 4)

4.1 **Relative density** of aggregate (SSD) **2.65** known/assumed (assumed value of 2.65)

4.2 **Concrete density** selected from Fig 5 **2360** kg/m^3

4.3 **Total aggregate content** C4 is given by **2360– 205–476=1679**kg/m^3

5.1 **Grading of fine aggregate** Percentage passing 600 μm sieve (to be determined), **54%**

5.2 Proportion of fine aggregate selected from Fig 6, 41%

5.3 Fine aggregate content ⎫ ⎧**1679** ×**41%** = **688.4**kg/m^3

C5

5.4 Coarse aggregate content⎭ ⎩**1679–688.4** = **990.6**kg/m^3

Summary of Quantities for 1m^3 Trial Mix (SSD)

	Cement	Water	Fine aggregate	Coarse aggregate
Quantities	Kg	Kg or litres	Kg	Kg(~~10mm~~/20mm/~~40mm~~)
Per m^3 to the nearest 5kg	475	205*	690	990
Per trial mix of __m^3 to the nearest 5kg				

*Water content increased to 0.5 was used to take care of pozzolanic reactions. This Water /cement ratio of 0.5 was as determined during trial mixes.

Items in italics are optional limiting values that may be specified (see Section 7).

Concrete strength is expressed in the units N/mm2. 1 N/mm^2 = 1 MN/ m2 = 1 MPa. (N = newton; Pa = pascal.)

The internationally known term ‘relative density’ used here is synonymous with ‘specific gravity’ and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.

SSD = based on the saturated surface-dry condition.

The quantities for the trial mix were used to prepare a mix, test whether or not the aggregate and cement selected for use will behave as anticipated. Adjustments were made according to how much the results differ from design values line with section.

Appendix II: Sieve analysis of coarse aggregates

Nominal Size, mm.	% Passing BS Sieve Size	Specification Limit For Single Size Aggregates (20mm)
2.5	1	0 – 20 %
5.0	20.0	10 – 40 %
10.0	30.0	25 – 55 %
14.0	48.0	35 – 70 %
20.0	96.0	90 – 100 %
37.5	100.0	100 – 100 %
Flakiness index %	27	
Aggregate crushing value %	19	

Appendix III: Sieve analysis of fine aggregates

BS sieve size, mm	Cumulative % passing (by weight)	Specification limits for fine aggregates (overall limits)
Dry sieving		
37.5	100	100 - 100
20	100	90 - 100
14	48	35 - 70
10	29	25 - 55
5	13	10-40
2.5	1	5-10

Appendix IV: Particle size distribution of rice straw ash

Sieve size ,mm	% passing
0.01	17
0.013	21
0.018	22
0.026	28
0.038	30
0.052	54
0.075	60
0.1	62

Appendix V: Particle Size distribution of egg shell ash by hydrometer analysis

Sieve size	% Passing
0.0152	3.85
0.037	3.87
0.053	3.87
0.074	3.87
0.01	6.62
0.014	9.39
0.02	14.9
0.03	20.4
0.04	25.9
0.05	31.47
0.07	36.53
0.15	59.60
0.21	65.25
0.30	73.33
0.43	85.05
0.6	94.74
1.18	99.19
2.0	99.19

Appendix VI: Particle size distribution of Portland cement

Sieve size ,mm	% passing
0.019	4
0.026	9
0.038	17
0.05	36
0.071	44
0.1	49

Appendix VII: Chemical analysis of rice straw ash

Element name	Result (%)
Al_2O_3	1.094
SiO_2	72.379
P_20_5	1.513
S	0.919
Cl	1.450
K_2O	16.174
CaO	5.067
Ti	0.1
V	0.006
Cr	0.006
Mn	0.256
Fe	0.836
Ni	0.002
Cu	0.013
Zn	0.080
Rb	0.070
Sr	0.021
Zr	0.007
Nb	0.003
Total	99.996

Appendix VIII: Chemical properties of Portland cement

Element name	Percentage composition	Tolerance (KS EAS 18-1:2001 STANDARD)
Al_2O_3	4.076	3 – 8%
SiO_2	14.18	17 – 25%
P_20_5	0.857	
S	4.303	
Cl	0.138	0 - 5%
K_2O	0.746	
CaO	72.041	60 – 67%
Ti	0.222	
V	0.003	
Mn	0.057	
Fe	3.087	
Cu	0.004	
Zn	0.005	
Rb	0.004	
Sr	0.204	
Y	0.003	
Total	99.973	

Appendix IX: Compressive strength for concrete having cement partially replaced with rice straw ash

Grade of concrete	Mix Code	Percentage Partial Cement Replacement with rice straw ash	Compressive Strength, MPa				
			7 Days	14 Days	28 Days	56 Days	90 Days
M-35	1 (Control)	0%	27.90	33.00	35.95	36.55	38.70
	2	5%	32.70	36.70	38.80	40.25	41.30
	3	10%	33.65	37.10	40.20	41.80	42.65
	4	15%	28.70	31.60	32.30	33.70	34.70
	5	20%	28.40	29.55	31.80	32.60	33.45
	6	25%	24.00	26.20	28.70	31.85	32.80
	7	30%	10.85	15.25	18.9	20.05	23.1

Appendix X: Splitting tensile strength concrete having cement partially replaced with rice straw ash

Grade of concrete	Mix Code	Percentage Partial Cement Replacement with rice straw ash	Splitting Tensile Strength, MPa				
			7 Days	14 Days	28 Days	56 Days	90 Days
M-35	1 (Control)	0%	2.0	3.15	3.45	3.5	3.55
	2	5%	2.35	3.20	3.65	3.70	3.80
	3	10%	2.45	3.40	3.75	3.80	3.85
	4	15%	2.4	2.75	3.05	3.25	3.30
	5	20%	2.2	2.5	2.65	2.7	2.75
	6	25%	1.85	2.20	2.40	2.45	2.60
	7	30%	1.20	1.50	1.65	1.80	1.95

Appendix XI: Compressive strength of concrete having cement partially replaced with rice straw ash and egg shell ash

Grade of concrete	Mix Code	Percentage Partial Cement Replacement with rice straw ash	Egg shell ash added as a Percentage Cement	Compressive Strength, MPa				
				7 Days	14 Days	28 Days	56 Days	90 Days
M-35	4	15%	0	28.70	31.6	32.30	33.70	34.70
	4	15%	2.5%	28.80	30.70	32.75	34.35	35.15
	4	15%	5%	27.65	32.40	33.25	36.20	38.70
	4	15%	10%	27.05	34.20	41.35	42.70	44.85

Appendix XII: Compressive strength results for concrete having cement replaced with -rice straw ash and egg shell ash

Age of testing (Days)	% Partial replacement of cement in concrete			
	15% RSA + 2.5% ESA	15% RSA+5% ESA	15% RSA+10% ESA	20% RSA+10% ESA
7	28.8	27.6	27.0	25.7
14	30.7	32.4	34.2	28.6
28	32.75	33.3	41.3	33.5
56	34.35	36.2	42.7	34.7
90	35.15	38.7	44.85	34.9

Appendix XIII: Particle size distributions of cement and rice straw ash