Investigation into the Cementitious Properties of a Mixture of Rice Husks Ash with Building Lime

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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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Date...............................

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APPROVAL

This thesis has been submitted for examination with my approval as University Supervisor.

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ABSTRACT

The aim of this study was to investigate the cementitious properties of the product resulting from a mixture of rice husk ash (RHA) and building lime.

Chemical analyses were done using Gravimetric and Atomic Absorption Spectroscopy, while particle size distribution of RHA carried out using hydrometer analysis. Concrete mixes containing different proportions of lime:RHA binder were cast. The binder was made by replacing lime with RHA at intervals of 20% and reducing the interval to 10% closer to the optimum. The same binder: sand: ballast mix proportions of 1:2:4 respectively at a constant 0.5 w/c ratio was used in all concrete mixes and subjected to air and water curing at room temperature. Workability tests were performed on all the concrete mixes. Standard consistency, initial and final setting times, and mortar compressive strength of the optimal blend were established. Characteristic compressive and tensile strength of optimal lime:RHA concrete were determined and the results compared with those of Portland Pozzolana Cement (PPC) concrete and cost analysis carried out.

Results show that RHA has high silica content (more than 70%). Workability was found to reduce with increase in RHA content in the mix as indicated by reduction in slump values from 10mm to 2mm and reduction in compaction factor values from 0.78 to 0.69. For concrete samples cured in air the optimal blend was at 50% lime with 50% RHA while for water cured samples was at 30% Lime and 70%RHA. Initial and final setting time of the optimal lime:RHA binder was found to be 285 and 1485 minutes respectively, its 28 day mortar compressive strength was 7.07 N/mm^2. Mean compressive and tensile strengths of optimal lime:RHA concrete were found to be 10.83N/mm^2 and 1.49 N/mm^2 respectively while that of PPC concrete was 20.08 N/mm^2. The overall cost of the lime:RHA binder and hence the concrete was found to be less than half compared with an equivalent concrete grade made of PPC.

DEDICATION

This thesis study is dedicated to my parents Mr. and Mrs. Ahenda Okoya for their love and care and for according me the opportunity to go to school.

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NOMENCLATURE

Ca…………..calcium

CaO…………lime (calcium oxide)

CaO $(OH)_2$…hydrated lime (calcium hydroxide)

ΔHr…………change in heat heat of hydration

D…………...diameter of particle in cm

D_C ………….density of the specimen, in kilograms per cubic meter

fc……………compressive strength of concrete (N/mm^2)

f_{ct}………….. tensile splitting strength of concrete (N/mm^2)

f_{cu}…………...characteristic compressive strength of concrete (N/mm^2)

f_{tu}……………characteristic tensile strength of concrete (N/mm^2)

f_m ……….. target mean strength

f_{min} ………...characteristic strength

g…………….gravitational acceleration in cm/sec^2

γ_w …………..density of water in gm/ml

Gs…………..specific gravity

H……………hydrogen

H_2O…………water

K...................statistical factor

kN…………..kilonewton

M ....margin (difference between the target mean and characteristic strength of concrete

MAS………. maximum aggregate size

MPa ………..megapascal

m…………... mass of the specimen in water-saturated condition, in kilograms

m1…………..mass of partially compacted concrete

m2…………..mass of fully compacted concrete

η …………….viscosity of water at T^0 in g.sec/cm^2

O…………….oxygen

Pa …………..pascal

S....................standard deviation

SiO_2 …………silica (silicon dioxide)

V_h …………...velocity of a spherical particle sinking in a fluid

V……………....velocity

v ……………..volume of specimen

ABBREVIATIONS

RHA…………..Rice Husk Ash

AASHTO……. American Association of State Highway and Transportation Officials

ACI …………...America Concrete Institute

ASTM ………..American Society for Testing and Materials

BS EN ……….British Standard European Norm

BSI……………. British Standard Institution

EAS ………….East African Standard

IS……………..Indian Standard

KS…………....Kenya Standard

NYSDT……….New York State Department of Transport

OPC…………Ordinary Portland Cement

PPC…………Portland Pozzolana Cement

LCD…………Liquid Crystal Display

SF……..……Silica Fume

1 INTRODUCTION

1.1 Background

Concrete is the most commonly used material in the construction industry. Concrete is made by mixing binder (cement) and various aggregates (sand and ballast) with water and allowing the mixture to harden by hydration.

The strength of concrete is commonly considered its most valuable property. This property of concrete is so important such that it requires the production of concrete to be monitored carefully starting from supply and storage of material, batching, mixing, transportation, placing, compacting, through to curing. However, in many practical cases, other characteristics, such as permeability and durability, may in fact be more important. Improved workability of concrete, lower heat of hydration, lower thermal shrinkage; increased water tightness, improved sulphate resistance, improved seawater resistance, and reduced alkali-aggregate reaction are some of the factors which positively influences durability of concrete.

Cement is an essential ingredient in concrete production because it acts as the vital binding agent. Cement used in construction is characterized as **hydraulic** or **non-hydraulic**. Hydraulic cements (*e.g.,* Portland cement) harden because of hydration, chemical reactions that occur independently of the mixture's water content; they can harden even underwater or when constantly exposed to wet weather. The chemical reaction that results when the anhydrous cement powder is mixed with water produces hydrates that are not water-soluble. Non-hydraulic cements (*e.g.,* lime and gypsum plaster) must be kept dry in order to retain their strength.

Early types of cement included lime, gypsum, lime plus pozzolana, and lime plus clay. Historically concrete made from mixtures of lime plus pozzolana was first used by the Ancient Macedonians and three centuries later on a large scale by Roman engineers. They used both natural pozzolans (trass or pumice) and artificial pozzolans (ground brick or pottery) in these concretes. Many excellent examples of structures made from these concretes are still standing, notably the huge monolithic dome of the Pantheon in Rome and the massive Baths of Caracalla. The technical knowledge of making hydraulic cement was later formalized by French and British engineers in the 18th century [11].

Modern hydraulic cements began to be developed from the start of the Industrial Revolution (around 1800), driven by three main needs: finishing of brick buildings in wet climates, mortars for masonry construction of harbor works, etc., in contact with sea water and the development of strong concretes.

Modern hydraulic cements can broadly be categorized as either pozzolanic or non-pozzolanic.

Non-pozzolanic cement e.g. Portland cement is produced by grinding clinker with a small amount of gypsum into a powder to make 'Ordinary Portland Cement' often referred to as OPC [11].

Pozzolanic cements on the other hand are those obtained by either inter-grinding and or blending part of portland clinker with pozzolanic materials such as fly ash. These are referred to as Portland cement blends. Or by direct mixing of pozzolanic material with an alkaline substance most economically using lime and does not involve the use of Portland clinker. These are known as Non-Portland hydraulic cements. An example of Non-Portland hydraulic cements is a mixture of fly ash with lime and are the cements used by the Romans, and can be found in Roman structures still standing e.g. the Pantheon in Rome. They develop strength slowly, but their ultimate strength can be very high. The hydration products that produce strength are essentially the same as those produced by Portland cement [26].

A pozzolanic material is that which contain active silica (SiO_2) and is not cementitious in itself, but will, in a finely divided form combine chemically with lime in the presence of water at ordinary temperatures to form a strong cementing material [11]. They include: fly ash, volcanic ash, burnt shale, ash from some burnt plant materials (such as rice husk ash) and siliceous earths.

Pozzolanic reaction is a simple acid-base reaction between calcium hydroxide ($Ca(OH)_2$), and silica. Simply, this reaction can be schematically represented as follows: [11]

$$3Ca(OH)_2 + 2SiO_2 \rightarrow 3CaO.2SiO_2.3H_2O \quad (1.1)$$

Or summarized in abbreviated notation of cement chemists as

$$3CH + 2S \rightarrow C_3S_2H_3 \quad (1.2)$$

Pozzolanic cement which is the focus of this study is known to have a number of advantages over OPC when used in concrete production and include the following:

- The pozzolanic reaction continues for many years with the effect that compressive strength as well as the flexural strength of concrete will continue to increase for a long time. This unique characteristic is one of the main reasons many great ancient structures have lasted for over two thousand years.
- They improve closer packing of concrete particles in the fresh state leading to overall reduced porosity of the hardened cement paste which will in turn minimize ingress of harmful chemicals such as chloride ions. This results in increased resistance to chloride ion attack and also protects steel reinforcement from corrosion hence producing a more durable concrete.
- Since pozzolanic reaction in concrete proceeds for a long time, it has the effect of removing calcium hydroxide from concrete and by so doing, it preempt the reaction of the calcium hydroxide with acids

which forms salts that can be leached out by soft water leaving cavities in concrete which has detrimental effects.

- Most of the pozzolanic materials mentioned above are either naturally occurring with little alternative use, or are industrial wastes. Thus their use in cement production lowers production costs and also reduces environmental pollution by reducing the amount of gasses generated during the production of clinker hence resulting in a green cement.
- Improved Durability**:** The benefits and characteristics of Natural Pozzolanas mentioned above clearly explain why the ancient structures built by the Romans have survived over 2000 years of weathering [11].

Rice husk (RH) is a major agriculture byproduct obtained from the food crop of paddy (Plate 1.1). For every four tons of rice one ton of rice husk is produced. The husk is disposed of either by dumping it in an open heap near the mill site or on the roadside to be burnt. Burning rice husk (RH) generates about 15-20% of its weight as ash. The ash being very light is easily carried by wind and water in its dry state. It is difficult to coagulate and thus contributes to air and water pollution. Cumulative generation of ash requires a large space for disposal [7].

Recycling of waste materials is needed to establish a clean and healthy environment. Utilization of rice husk ash (RHA) by exploiting its inherent pozzolanic properties is an effective way to solve the environmental and disposal problem of the ash. A number of researchers [10] have studied the physical and chemical properties of rice husk ash and established that even though RHA alone lacks cementitious properties, the high percentage of siliceous material in rice husk ash indicates that it has potential pozzolanic properties [10].

It is hoped that this research will help in some way to improve knowledge by bringing out the results of an experimental program carried out to evaluate the effectiveness of using a mixture of RHA with lime as alternative cement for production of low cost concrete. As a basis for in-depth understanding of the performance of this cement in concrete, this research was geared towards checking its basic mechanical and chemical properties and also investigating its effect on the critical properties of concrete covering workability, density, and strength characteristics.

Utilization of RHA by exploiting its pozzolanic properties in making concrete coupled with the numerous advantages of lime- pozzolana cements in concrete formed the basis of this research.

The study draws its motivation from the readily and abundantly available rice husks, in rice growing regions of Kenya, more specifically the Mwea irrigation scheme in Central, Ahero irrigatition scheme in Nyanza and Bunyala irrigation scheme in Western provinces. Annual rice production is estimated at about 52,000MT from approximately 12,000 hectares of irrigated rice in Kenya [12].

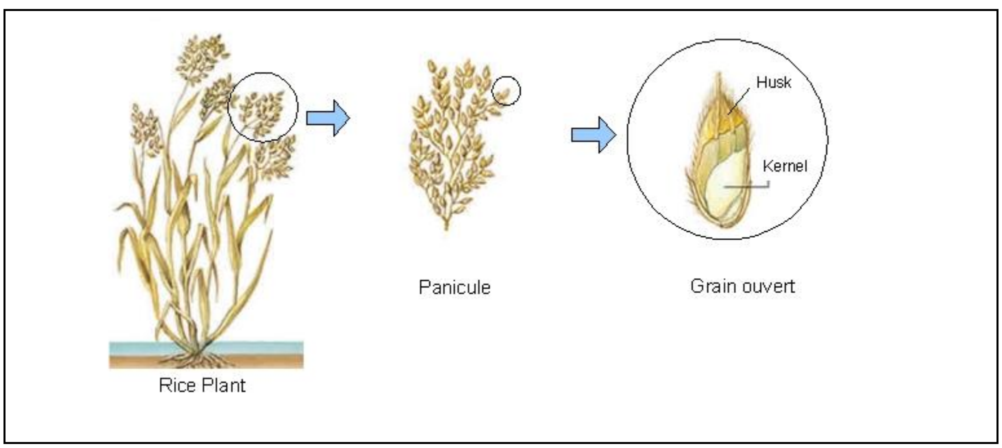

Plate1.1-Rice Husk [26]

1.2 Problem statement

Research on the physical and chemical properties of rice husk ash has established that RHA is a highly reactive pozzolanic material which is suitable for use in the production of lime-pozzolana cement. The non-crystalline silica and high specific area of RHA are known to be responsible for its high pozzolanic reactivity. Chemically, RHA is mainly composed of amorphous silica>70% which reacts with calcium hydroxide at ordinary temperature to form cementitious compound according to the following chemical equation:

$2SiO_2 + 3Ca(OH)_2 = 3CaO.2SiO_2.3H_2O$ [11] (1.3)

Such pozzolanic reaction leads to improvement of many of concrete properties, such as microstructure, resistance to alkali silica reaction, reduction in the risk of corrosion of reinforcement and reduction in drying shrinkage [2].

Several research studies on the cementitious properties of lime:RHA mixes have been carried out both locally and internationally.

Cook & Suwanvitaya; [23] used a controlled burn RHA to make lime:RHA mortars with cement: sand ratio of 1:3 and tested according to ASTM C109. The highest strengths of 8.5 N/mm^2 at 28 days were obtained with the 40:60 lime:RHA mix [1].

Wachira; [24] examined the pozzolanic activity of RHA with commercially hydrated lime (CHL), and noted that a 67:33 blend of lime:RHA gave the best results of 13.0 N/mm^2. On the other hand Waswa-Sabuni B.et al; [10] examined the pozzolanic activity of RHA made from rice husks from Mwea rice mills (Kenya) and established that of all the lime:RHA ratios used, the highest of 50:50 lime:RHA mix gave the best results with a 28 days mortar compressive strength of 2.8 N/mm^2 and concrete cube strength of 12.7 N/mm^2. Workability and setting times were found to decrease with increased amounts of RHA. The study however failed to establish the optimum lime:RHA mix proportion since lime:RHA blends beyond the 50:50 were not investigated.

The above mentioned research studies on the cementitious properties of lime:RHA mixes show that there exists contradiction regarding the magnitude of compressive strength achieved with a given blend of lime:RHA mortar mixes and as regards the optimum lime:RHA mix ratio for maximum strength gain.

The information gap addressed in this respect was to determine the optimum Lime:RHA blend that would be utilized in lime:RHA concrete for maximum strength gain and to establish the engineering properties of the resulting binder together with those of the concrete resulting made from the optimal cement.

1.3 Objectives

In an effort to gain improved understanding of the above-mentioned phenomena, this study was undertaken with the broad objective of investigating the cementitious properties of a mixture of rice husks ash with building lime in concrete production.

The specific objectives outlining the research were;

1. To investigate the physical and chemical characteristics of RHA in order to determine the potential for use as pozzolana.

2. To determine the optimum mix ratio of lime:RHA binder for maximum strength gain in lime:RHA concrete mixes cured both in water and air at room temperature.

3. To observe changes in properties of lime:RHA concrete mixes such as density and workability with increasing RHA content.

4. To establish the engineering properties of the resulting binder at optimal RHA content such as standard consistency, initial setting time, final setting time, and mortar compressive strength. And also the engineering properties of the lime:RHA concrete at optimal RHA content such as density, tensile and compressive strengths.
5. To compare the strength of Portland Pozzolana cement concrete with those of the lime:RHA concrete at optimal RHA content.
6. To compare the trends in strength developments for lime:RHA concrete at optimal RHA content with those of PPC concrete.
7. To carry out a comparative cost analysis between lime:RHA concrete at optimal at optimal RHA content with an equivalent grade of PPC concrete.

2 LITERATURE REVIEW

2.1 Cement:

In general terms, cement is a binder, a substance with adhesive and cohesive properties which sets and hardens independently and binds other materials together into a compact whole [11]. The most commonly used cements are hydraulic cements, meaning they set when mixed with water.

2.2 Lime

There are two forms of lime: quicklime and hydrated lime. Quicklime is produced by heating rock or stone containing calcium carbonate (limestone, marble, chalk, shells, etc.) to a temperature of around 1000°C for several hours in a process known as ’calcining’. Chemically, lime is calcium oxide (CaO) and is made by roasting calcite ($CaCO_3$) to drive off carbon dioxide (CO_2). It is an unstable and slightly hazardous product and therefore is normally ’hydrated’ or ’slaked’, by adding water, becoming not only more stable but also easier and safer to handle.

Quicklime produces heat energy by the formation of the hydrate, calcium hydroxide, by the following equation:

$$CaO\ (s) + H_2O\ (l) \rightleftharpoons Ca\ (OH)_2\ (aq)\ (\Delta Hr) = -63.7\ \text{kJ/mol of CaO} \qquad (2.1)$$

In the construction industry, lime, in its hydrated form is mixed with fine aggregate and water to produce mortar. Plain lime-sand mortars are quite weak; any early adhesive strength results from drying out, and longer term hardening occurs through carbonation absorbing carbon dioxide primarily from the air and converting itself to calcium carbonate.

$$CO_2\ (g) + Ca\ (OH)_2\ (aq) \Rightarrow CaCO_3 + H_2O\ (l) \qquad (2.2)$$

In the past lime renders and plasters were often mixed with animal hair to improve cohesion. Today, addition of gypsum or Portland cement and/or pozzolanas to increase durability and give faster setting times is usual [11].

Annual worldwide production of quicklime is around 283 million metric tons. China is by far the world's largest producer, with a total of around 170 million metric tons per year. The United States is the next largest with around 20 million metric tons per year [11].

Lime works extremely well in dry conditions but it has two drawbacks:

- Lime cement takes a long time to cure.
- Lime cement does not harden in water but stays soft, i.e., it is not hydraulic cement. Therefore, there are situations where it cannot be used [11].

2.3 Properties of RHA

Rice husks are a waste product of rice milling and are available in large quantities in many parts of the world. When burnt, it produces a large quantity of ash - about one tone for every five tons of husks. The ash typically contains approximately 80 per cent silica and is therefore an excellent pozzolana.

The disadvantage of rice husks is that for its ash to be highly pozzolanic, it has to be burnt under controlled conditions at temperatures below 700°C; otherwise the silica becomes crystalline and loses a degree of reactivity. [11].

Studies by Chandrasekar et al. [8] have shown that the physical and chemical properties of ash are dependent on the soil chemistry, paddy variety, and climatic conditions. Other studies made by Maeda et al [9] also show that differences may also be due to fertilizers applied during rice cultivation. The chemical compositions of RHA from various locations are presented in Table 2.1.

Table 2.1: Comparison of chemical properties of RHA from various locations in % by weight [7, 10]

Constituents	Malaysia	Brazil	Netherlands	Kenya
Silica (SiO_2)	93.1	92.9	86.9	75.8
Alumina (Al_2O_3)	0.21	0.18	0.84	1.15
Iron Oxide (Fe_2O_3)	0.21	0.43	0.73	0.86
Calcium Oxide (CaO)	0.41	1.03	1.4	3.25
Potassium Oxide (K_2O)	2.31	0.72	2.46	1.5
magnesium Oxide (MgO)	1.59	0.35	0.57	0.23
Sodium Oxide (Na_2O)	-	0.02	0.11	0.35
Sulfur Oxide (SO_3)	-	0.1	-	-
Loss of Ignition (LOI)	2.36	-	5.14	10.2
TotalSiO_2+Fe_2O_3+Al_2O_3	93.52	93.51	88.47	77.81

The average particle size of rice-husk ash ranges from 5 to 10μm. Physical properties values as reported by some authors are given in Table 2.2.

Table 2.2: Physical properties of RHA [7]

Property	Value			
	Mehta et al	Zhang et al	Feng et al.	Bui et al.
Specific gravity	2.06	2.06	2.10	2.10
Mean particle size (μm)	-	-	7.4	5.0
Fineness: Passing 45 μm	99	99	-	-

For RHA to be used as pozzolana in cement and concrete, it should satisfy requirements for chemical composition of pozzolans; the combined proportion of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) in the ash should not be less than 70% as per ASTM C618 [20] and 50% as per the requirement by the Kenya Bureau of Standard, KS -02-1263 [29] and loss of ignition (LOI) should not exceed 12% as stipulated in ASTM C618 [20] requirement. The local RHA meets all these requirements.

2.4 Previous studies on Lime:RHA cements

Studies on the cementitious properties of lime:RHA mixes show that there exists contradiction regarding the magnitude of compressive strength achieved with a given blend of lime:RHA mortar mixes and as regards the optimum lime:RHA mix ratio for maximum strength gain. Mehta & Pitt; [7] examined the compressive strength properties of rice husks ash: lime cements using an 20:80 lime: ash blend and found out that at 3 days, a mortar strength greater than 10 N/mm^2 was achieved and at 28 days strength greater than 35 N/mm^2 was achieved. [7]

In Australia, Cook &Suwanvitaya; [23] used a controlled burn RHA (600°C) to make lime:RHA mortars with cement: sand ratio of 1:3 and tested according to ASTM C109 [30]. The cement proportions were 1:4; 1:1.5; 1:0.67 and 1:0.25 limes: RHA. Mortars were fog-room cured for 1 or 2 days and then cured in limewater at 200°C until test. Cube strength and shrinkage were determined in accordance with ASTM C157 [31]. The best strengths of 8.5 N/mm^2 at 28 days were obtained with the 40:60 Lime:RHA mix; this mix also showed the lowest shrinkage. However, all mortars were over 4 N/mm^2 strength level; a carbon content of up to 20% by mass in the ash did not significantly influence the strength development.

In Kenya, Wachira et al; [24] while examining the pozzolanic activity of RHA with commercially hydrated lime (CHL) noted that a 2:1 ratio of lime:RHA gave the best results.

Waswa-Sabuni B. et al; [10] examined the pozzolanic activity of RHA made from rice husks from Mwea rice mills (Kenya) using a controlled burn RHA (500-700°C) to make lime:RHA mortar and concrete cubes. The cement proportions were 100:0, 80:20, 70:30, 60:40 and 50:50 lime:RHA. Chemical analysis of the ash showed high silica content (greater than 70%) indicating high pozzolanic property (Table 2.1).They established that RHA improved the compressive strength of lime greatly with the strength increasing with increased amount of RHA. Of all the lime:RHA ratios used, the 50:50 lime:RHA mix gave the best results with a mortar strength of 2.8 N/mm^2 and concrete cube strength of 12.7 N/mm^2, workability and setting times were found to decrease with increased amounts of RHA.

2.5 Previous studies on Replacement of OPC with Rice husk ash in concrete

Zhang and Malhotra [3] investigated the influence of 10% RHA inclusion as partial replacement of cement on the compressive strength of concrete and compared it with the compressive strength of concrete containing 10% silica fume (SF). Water-to- binder ratio was maintained at 0.40. At 28 days, the RHA concrete had a compressive strength of 38.6 N/mm^2 compared with 36.4 N/mm^2 for the control concrete (100% OPC) and 44.4 N/mm^2 for SF concrete. At 180 days, RHA concrete exhibited compressive strength of 48.3 N/mm^2 compared with 44.2 N/mm^2 for the control concrete and 50.2 N/mm^2 for SF concrete.

Saraswathy and Song [25] investigated the effect of partial replacement of cement with rice husks ash (RHA) on the porosity and water absorption of concrete. Cement was replaced with 0, 5, 10, 15, 20, 25, and 30% RHA. Proportion of control (without RHA) mix was 1:1.5:3 with w/c ratio of 0.53. Porosity and water absorption test was carried out as per ASTM C642 [32]. They concluded that: (i) porosity values decreased with the increase in RHA content because small RHA particles improved the particle packing density of the blended cement, leading to a reduced volume of larger pores; and (ii) coefficient of water absorption for rice husk ash replaced concrete at all replacement levels was found to be less when compared to control concrete.

In Egypt, Ramy ZAHRAN.et al [2] studied the effects of using rice husk ash (RHA), as a cement replacement material, on the workability, rate of workability loss and compressive strength of cementitious materials in a controlled experimental program. The possibility of using RHA for producing high strength concrete was also investigated. Various OPC mortar mixes at 0.5 w/c ratio and containing different contents of RHA were prepared and subjected to the mortar flow test at different elapsed periods from mixing. Cubical specimens were taken from these mixes, cured with different curing regimes (air, moist and sealed) and finally tested for compressive strength at age of 56 days. Concrete specimens made with different RHA contents and water cement ratios (0.4, 0.3 and 0.25) were also prepared and tested for compressive strength. It was found that the incorporation of RHA in OPC mixes led to a notable reduction in the initial flowability, rate of flowability loss, and an increase in the compressive strength.

Here in Kenya, Waswa-Sabuni B. et al; [10] examined the engineering properties of binder resulting from a mixture of OPC with RHA made from rice husks from Mwea rice mills (Kenya) and established that the compressive strength of OPC/RHA concrete cubes increases with increased amount of RHA but the compressive strength of OPC/RHA mortar cubes decreases with increased amount of RHA. Workability and setting times were found to decrease with increased amounts of RHA.

In conclusion, the improvement in the compressive strength of cementitious material that is produced as a result of incorporating RHA in OPC is due to the pozzolanic reaction occurring between RHA and free lime in hydrating cement. The presence of free Ca^{2+} and OH^- ions, in hydrating cement is limited and is attributed to the hydration reaction of calcium silicates. For example tricalcium silicates hydrate in water as follows:

$$2(3CaO.SiO_2) + 6\ H_2O = 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \qquad (2.3)$$

These studies show that due to the high specific surface of RHA, the incorporation of RHA in OPC concrete leads to loss of workability, indicating why most of published studies have used fairly higher water: cement ratios in order to achieve a workable concrete mix.

3 MATERIALS AND METHODOLOGY

3.1 Materials and Sources

The raw materials used in this research included rice husks, lime, river sand, coarse aggregates, Portland pozzolana cement, and tap water. .

3.1.1 Rice Husk Ash

Rice husk ash used in this study was produced by burning of rice husks from Mwea Irrigation scheme in a burnt brick kiln at a controlled temperature of between 500 to 700 degrees centigrade. The kiln measured about 1.5 x 1.5 meters in plan and about 2 meters high. The walls are made of ordinary burnt bricks and a metal sheet with chimney for the roof (Plates 3.1 and 3.2). A small fire was lit at the bottom of the kiln using pieces of timber. The firing continued until the husks also caught fire and continued burning without further fuelling for two days.

The control was achieved by opening or closing the holes on the kiln wall and observing the temperature using a thermocouple. Research has shown that reactive ash is obtained by maintaining the temperature between 500 to 700 degrees centigrade. If burning temperature raises to above 750°C, a crystalline and less reactive ash develops [7].

The burnt ash was heaped and left to cool for 24 hours, which is sufficient to turn most of the burnt ash into white ash (amorphous material). The white ash was then ground for 30 minutes to achieve the minimum surface area of pozzolanic materials specified by ASTM C618 [20],using a laboratory ball mill.

Samples of the ground ash were then taken for chemical and physical test at The Ministry of Roads Material Testing and Research Department laboratory in industrial area Nairobi.

Table 4.1 shows chemical properties of the RHA while Table 4.2 and Figure 4.1 show physical properties of the RHA.

Plate 3.1: Ordinary burnt brick kiln

Plate 3.2: Rice Husks burning in the kiln

3.1.2 Aggregate

3.1.2.1 Coarse Aggregates

The coarse aggregates were Natural graded crushed stone obtained from National Concrete Company in Nairobi and was used in all the concrete mixes prepared.

The results of chemical properties from a geochemical analysis undertaken on aggregate samples are presented in Table 4.3.

These properties show very little presence of Chloride (Cl-) which is associated with corrosion of steel imbedded in concrete. Also, the properties show minimal presence of Sulphates (SO_3) which causes formation of secondary ettringite (calcium sulfoaluminate) in concrete leading to its expansion and rupture; thus the coarse aggregates are deemed to be innocuous and are suitable for production of concrete.

The physical properties of the coarse aggregates are presented in Table 4.4.

3.1.2.2 Fine Aggregates (River Sand)

The river sand was obtained from deposits within Machakos County. Most of the sand derived from river bed deposits has originated from the weathering and erosion of rock encountered within the higher reaches of the surrounding areas and has subsequently been transported into the river beds through the natural drainage channels and water courses during periods of heavy rains.

Table 4.5 shows the chemical properties from a geochemical analysis undertaken on the river sand sample. These properties show no presence of any form of chloride.

The physical properties of the river sand are presented in Table 4.6.

3.1.3 Lime

Lime used was building lime manufactured by Coast Calcium Limited and obtained from the open market .The chemical properties of the building lime should comply with the values in Table 2 of KS 1780-1 [27] when tested in accordance with KS 1780-2 [33]. The results of the chemical tests performed on sample of the lime are presented in Table 4.7.

3.1.4 Cement

The cement used in this study was obtained from the open market, manufactured to Standard Specification KS EAS 18-1 [28] and is classified as CEM IV/B-P 32.5N Portland Pozzolana Cement. This cement, produced by Bamburi Cement Limited has a wide range of applications from domestic building construction to large civil engineering projects.

The physical and chemical properties of the cement used are shown in Tables 4.8 and 4.9 respectively.

3.1.5 Water

Potable tap water was used to prepare all the test samples. The source of water for production of concrete, and curing of the concrete test specimens was from the Nairobi Water and Sewerage Company Limited's pipelines, drawn from taps at university of Nairobi department of civil engineering laboratory.

The quality of water in a concrete mix is important because impurities in it may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface, and may also lead to corrosion of reinforcement. Generally, the quality of the water to be used in production of concrete should be portable. Table 4.10 shows these properties.

3.2 Methodology

3.2.1 General

Analyses of the concrete raw materials, actual laboratory tests on fresh and hardened concrete were all undertaken at different laboratories.

Testing of the chemical properties of coarse and fine aggregates, lime and RHA were undertaken at the Ministry of Roads Material Testing and Research Department (chemistry) Laboratory in industrial area Nairobi; physical tests of coarse and fine aggregates, tests on fresh concrete, tests of density, compressive strength and tensile strength of concrete were undertaken at the University of Nairobi Department of Civil and Construction Engineering Laboratory; while tests on the properties of the resulting optimal blend of lime and RHA was performed at the Kenya Bureau of Standards (KEBS) Laboratory. The key test equipment and apparatus that were used in this research included:

a) Scoops
b) Sampling trays
c) Test sieves, fitting pan and lid
d) Washing equipment
e) Weighing scales
f) Trays and brushes
g) Electric pan mixer
h) Vibrating Table
i) Slump test apparatus
j) 150mm cube moulds
k) 150mm diameter by 300mm high moulds
l) Compressive testing machine

3.2.2 Test Regime

The proposed sequence for analysis entailed tests on RHA and lime followed by tests on the aggregates of concrete, then tests on fresh concrete and lastly tests on hardened concrete. Tests on RHA involved chemical tests to establish the elemental oxide contents in ash and physical tests covering geometrical properties of the ground ash. Tests on aggregates covered the geometrical properties, mechanical and physical properties, and chemical properties to guidelines given in BS EN 12620 [34]. Tests on fresh concrete included slump and compaction factor tests to guidelines given in BS EN 12350-1 [14], while tests on hardened concrete included specimen dimensions, density, tensile and compressive strength to guidelines given in BS EN 12390-1 [15].

Tests on raw materials can broadly be grouped into two; namely chemical tests and physical tests.

3.2.3 Chemical Characterization Tests

These were carried out at the Chemistry laboratory of the Ministry of Roads Material Testing and Research Department laboratory in industrial area Nairobi on samples of coarse aggregates(ballast), fine aggregates(sand), building lime and ground ash in order to confirm the elemental oxide contents in the ash, especially the silica which is a criterion for good pozzolana. Representative sample sizes were digested using combination of mineral acids and then filtered. The filtrates then set aside for the determination of various elements. The following methods were employed:

3.2.3.1 Gravimetric Method

This was used to determine SiO_2 content. The residue from the filter paper was heated at about 900^oC, cooled and weighed. A drop of sulphuric acid added followed by treatment with hydrofluoric acid in order to expel SiO_2 present. The residue was then fumed, dried, cooled and then weighed. The difference between the weight of the residue and the weight of the ash represent the weight of SiO_2 which was then expressed as a percentage of original samples.

3.2.3.2 Atomic absorption Spectroscopy Method

This was used to determine Al_2O_3, CaO, Fe_2O_3, MgO, MnO_2 and CuO contents in the samples.

3.2.3.3 Flame Photometry Method

This was used to determine Na+ and K+ content in the samples.

3.2.3.4 Loss of Ignition (LOI)

This was used to determine the organic content in the samples. A representative known weight of the sample was ignited in a muffle furnace and heated gradually to 900^0c. The heating was maintained at this temperature for 30 minutes.

The crucible is cooled and weighed. The LOI expressed as a percentage of original sample weight represents the organic content.

% Loss on ignition=Loss in wt. x 100 (3.1)

The results of the chemical tests on various samples are given in the Table 3.2.

3.2.4 Physical Characterization Tests

These were undertaken at the University of Nairobi department of civil engineering and at the Kenya Bureau of Standards (KEBS) laboratories and entailed the following.

3.2.4.1 Particle Size Distribution

Particle size distribution of RHA and building lime was determined by hydrometer analysis test performed at the University of Nairobi Department

Civil and Construction Engineering Soils Laboratory. The method is based on Stokes equation governing the rate of sedimentation of a free falling spherical particle suspended in water and is generally adopted for determining the particle size distribution for fractions that are finer than No.200 sieve size (0.075mm). The lower limit of particle size determined by this procedure is 0.001mm. By use of Stokes equation (3.2) for velocity of free falling spheres, the equivalent particle size and corresponding percent of sample in suspension are computed. [19]

It is assumed the particles are all spheres and the velocity as given by Stokes's law is:

$$V_h = \frac{g(Gs-\gamma^{W})D^2}{18\eta} \quad \text{(Cm/sec)} \tag{3.2}$$

Where V_h = velocity of a spherical particle sinking in a fluid

g = gravitational acceleration in cm/sec^2

G_s = specific gravity

γ_w = density of water in gm/ml

D = diameter of particle in cm

η = viscosity of water at T^0 in g.sec/cm^2

If it takes t seconds for a particle of diameter D to fall through a distance H_R cm then

$$V = \frac{H_R}{t} \quad \text{(Cm/sec)} \tag{3.3}$$

$$D = \sqrt{\frac{18\eta\, H_R}{gt(Gs-\gamma^{W})}} \quad \text{(cm)} \tag{3.4}$$

In this method, 50g sample of RHA and lime were weighed out and dried in oven at 110^{0}C for 24 hours. These samples were then mixed with 100ml of water and a dispersing agent, sodium haxametaphosphate added to prevent coagulation. The mix was then put in a 1000ml measuring cylinder and topped up with water to 1000ml. hydrometer readings were then taken against time. These were used to calculate the particle sizes in samples using equation 3.4. The particle size distributions of the RHA as well as that of the lime samples were then determined and plotted [19].

Particle size distributions of sand and ballast were determined by Sieve analysis to establish in accordance to BS EN 12620 [34].

A sample of air-dried aggregate was graded by shaking a nest of stacked sieves, with the largest sieve size at the top so that the material retained on each sieve represents the fraction coarser than the sieve in question but finer than the sieve above.

The results of the sieve analysis were then reported in tabular form, the mass retained on each sieve was expressed as a percentage of the total mass of sample. Working from the finest size upwards, the cumulative percentage passing each sieve was calculated and used for plotting of the grading curves. The grading curves are plotted on the grading chart where the ordinates represent the cumulative percentage passing and the abscissa are the sieve apertures plotted on a logarithmic scale, which gives a constant spacing for the standard series of sieves [13].

From the results of the sieve analysis, **fineness modulus** was computed for the fine aggregates by dividing the sum of the cumulative percentage retained on the standard series divided by 100. The fineness modulus is useful in detecting slight variations in aggregates from same source which could affect workability of the fresh concrete [11].

3.2.4.2 Specific Gravity and Water Absorption

Specific gravity, water absorption test were performed on samples of the RHA, Lime, sand and ballast to BS EN 1097 [35].

3.2.4.3 Standard Consistency

This was done using a Vicat Apparatus in order to establish the quantity of water required for lime:RHA binder to form a cement paste of standard consistency. This quantity of water gives the water content of the paste required for the determination of both initial and final setting times of the binder.

A sample mix of about 500g made from Lime and RHA at optimum ratio were weighed. A known quantity of water was added to the sample and mixed thoroughly for about 5 minutes on a non-porous surface by means two trowels avoiding loss of water or cement. The paste was transferred immediately to the mould of the Vicat Apparatus, which had previously been placed on a lightly greased plane glass base-plate, and filled to excess without compacting or vibrating. The excess material was removed by a gentle sawing motion with a straight edge.

The Vicat apparatus was calibrated with the plunger by lowering the plunger to rest on the base plate to be used and adjusting the pointer to read zero on the scale. The plunger was raised to the stand-by position. Immediately after leveling the paste, the mould and the base-plate was transferred to the Vital Apparatus and positioned centrally under the plunger. The plunger was lowered gently until it was in contact with the paste. The plunger was allowed to pause in this position for two seconds in order to avoid initial velocity. The moving parts were then quickly released and the plunger allowed penetrating vertically into the center of the paste. The scale was read when penetration ceased.

The recorded scale reading indicates the distance between the bottom face of the plunger and the base-plate. The water content of the paste was determined which is expressed as a percentage by mass of the lime:RHA cement.

The plunger was cleaned and the process repeated with pastes containing different water contents until one was found to produce a distance between plunger and base-plate of 6mm. The water content for this paste was calculated as a percentage of the mass of the dry lime:RHA cement and recorded as water required for standard consistence.

3.2.4.4 Setting Time Tests

The setting time tests were performed at Kenya Bureau of Standards (KEBS) laboratories on the optimal Lime:RHA blend and were carried out in accordance with Kenyan Standard KS EAS148-3 [36]. Both the final and initial setting times were established.

For the determination of the initial set, the Vicat apparatus was again used, this time with 1 mm (0.04 in.) diameter needle, acting under a prescribed weight on the paste of standard consistency. When the needle penetrates to a point of 5 mm (0.2 in.) from the bottom of a special mould, the initial set is said to occur, the time being measured from adding the mixing water to the cement. Kenyan Standard KS EAS 18 [28] prescribes a minimum initial setting time of 75 minutes for Portland Pozzolanic cements.

Final set was determined using a needle with a metal attachment hollowed out so as to leave a circular cutting 5 mm in diameter and set 0.5 mm behind the tip of the needle. Final set occurs when the needle makes an impression on the surface of paste but the cutting edge fails to do so. Kenyan Standard KS EAS 18 [28] prescribes a maximum final setting time of 600 minutes for Portland Pozzolanic cements.

3.2.4.5 Strength of Lime:RHA Binder

Mortar compressive strength test was conducted on the optimal mix of Lime:RHA in order to give an indication of strength of the resulting binder. This was performed in accordance to BS EN 196-1 [37], using standard mortar prism test. The prismatic test specimens were 40 mm x 40 mm x 160 mm in size and were cast from a batch of plastic mortar containing one part by mass of cement and three parts by mass of standard sand with a water-cement ratio of 0.8.

The standard water-cement ratio for mortar compressive test is usually 0.5, however a higher water-cement ratio of 0.8 established from the standard consistency was used for the optimal mix of Lime:RHA binder due to it high water demand.

3.2.5 Concrete Tests

On completion of the initial mix proportion calculations, a control concrete mix incorporating 100% lime was formulated and run. Thereafter a total of 8 other mixes were conducted with a constant 20% increment replacement of lime with RHA. The incremental replacement was reduced to 10% at after 50% total replacement. On each of these batches, slump and compaction factor tests were performed on the fresh concrete while cubes were made for compressive strength and density testing at 3,7 and 28 days.

Once the optimal blend of lime and RHA was established, setting time and mortar compressive strength tests was performed on the optimal blend. A further 27 number concrete cubes and 27 concrete cylinders were cast from the optimal binder for determination of the characteristic compressive and tensile strength respectively.

The laboratory tests batching procedure that was adopted had a defined sequence as discussed in the following sections:

3.2.5.1 Preparation of Aggregates

All the aggregates were sampled from stock piles from which the preliminary analysis was undertaken. The aggregates were saturated and allowed to attain surface dry conditions before being sealed in plastic bags to prevent loss of moisture prior to use.

3.2.5.2 Batching

Batching was done by weight. The batching procedure entailed, first, weighing of all the individual material fractions which included coarse aggregates, fine aggregates, lime, RHA, and water.

The mixing equipment that was used in the production of the laboratory mixes comprised a 0.03 m^3 capacity electric pan mixer, and is shown in Plate 3.3.

Plate 3.3: Laboratory pan mixer

Secondly, the pan mixer was slightly lubricated with a very weak mixture of binder grout of minimal quantity so as not to affect the performance of the actual mixes. The weighed coarse aggregates were then discharged into the pan mixer, followed by the fine aggregates then RHA and lime in that order. The dry fractions were pre-mixed for a period of two minutes prior to addition of the designed quantity of mixing water. After addition of the water, the mixing was extended for a further period of two minutes.

Tests on fresh concrete were then undertaken.

3.2.5.3 Slump Test

The concrete slump test is an empirical test that measures the workability of fresh concrete. Workability is the ability of a fresh, plastic concrete mix to properly fill a mould with the desired vibration, and without reducing the concrete's quality. More specifically, it measures the consistency of the concrete in a specific batch, and is also used to determine consistency between individual batches.

The test procedure entailed, first, ensuring that the mould and base plate were dampened and placed on a level ground. With the mould being held firmly on to the base plate, the mould was filled up in three layers, each being compacted with 25 strokes of the steel tamping rod of 16mm diameter and 110cm length, the tamping being evenly distributed After the top layer had been compacted, the surface of the concrete was struck off by a sawing and rolling motion of the tamping rod.

The spilled concrete was then removed from the base plate and the mould was raised by a steady uplift. The difference between the height of the mould and that of the highest point of the slumped test specimen was measured using a straight edge and recorded as the slump value.

The slump test was undertaken to procedures outlined in BS EN 12350-2 [36]. Plate 3.4 shows part of the slump test apparatus.

Plate 3.4: Slump Test Apparatus

All tests performed had forms of slump that can be described as “true slump”, meaning that the concrete simply subsided, keeping more or less to shape. A true slump is an indication that the concrete is not too wet or of very high workability, and that it has a suitable amount of fines.

3.2.5.4 Compaction Factor Test

The fresh concrete was placed in the upper hopper of the compaction factor test apparatus (Plate 3.5) and then allowed to drop into the lower hopper to bring it to a standard state before dropping it further into the cylinder. The concrete in the cylinder was then streamed and the mass of concrete in the cylinder was measured, (m_1). The concrete in the cylinder was then compacted and more added to fill the cylinder with compacted concrete whose mass is also measured, (m_2). Compaction factor is calculated as the ratio of the two masses.

$$\text{Compaction Factor} = \frac{Mass\ of\ Partially\ Compacted\ Concrete\,(m1)}{Mass\ of\ Fully\ Compacted\ Concrete\,(m2)} \qquad (3.5)$$

Plate 3.5: compaction factor test apparatus

3.2.5.5 Concrete cubes and cylinders

After tests on the fresh concrete were done, specimens for strength tests were made. This involved remixing of the fresh concrete and filling 150mm steel cube moulds and 150mm diameter by 300mm high concrete cylinder moulds in layers and vibrating using a vibrating table. The excess concrete above the upper edge of the mould was removed using steel trowels and the surface was carefully leveled.

The test specimens were clearly marked and left to cure in air for at least 16 hours. Care was taken to avoid any forms of vibration and dehydration.

Making and curing specimens for strength tests was undertaken to procedures outlined in BS EN 12390-2 [16].

Part of the preparation exercise for these specimens is shown in Plate 3.6.

Plate 3.6: Preparation of Concrete Specimens for Strength Tests

After at least 16 hours of air curing, the specimens were de-moulded and moved to the curing tanks. Plate 3.7 shows some of the specimens being cured.

Plate 3.7: Curing of Concrete Test Specimens

3.2.5.6 Density of Hardened Concrete Test

Density determinations were done on cube and cylinder samples for all mixes, after the various curing periods, and prior to testing for strength.

After removing specimens from the curing water tank, they were dried with absorbent tissue paper and then weighed using an AVERY balance to +/- 1 gram accuracy and cube dimension taken by a meter rule to +/- 1mm accuracy. The volume of each specimen was calculated from the measured dimensions.

The density was then determined using equation 3.6:

$$D_C = \frac{m}{V} \qquad (3.6)$$

Where D_C = density related to the condition of the specimen, in kilograms per cubic metre.

m = mass of the specimen in water-saturated condition, in kilograms

v = volume determined by calculation

The density of hardened concrete test was undertaken to procedures outlined in BS EN 12390-7 [18].

3.2.5.7 Compressive Strength of Concrete

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. The compression testing machine that was used for this exercise had a capacity of 2000kN, manufactured by Controls®.

Part of the test machine is shown in Plate 3.8.

The testing procedure which was adopted involved, first wiping the excess moisture from the surface of the specimen. Similarly, all the testing machine bearing surfaces were wiped clean, removing any loose grit.

The test specimen was then placed centrally on the lower platen of the testing machine. The glass shutter between the specimen and the operator was then shut and the load applied to the specimen without shock. This load was applied at a constant rate of 0.5MPa/s until no greater load was sustained. The maximum load at failure and corresponding compressive strength of the specimen was read from the compressive machine's LCD and the type of failure assessed.

The compressive strength of concrete test was undertaken to procedures outlined in BS EN 12390-3 [17].

Plate 3.8: Compressive Strength Testing Machine

The maximum load of failure and corresponding compressive strength was read off the machine's Liquid Crystal Display (LCD) screen.

On assessment of type of failure, all the test specimens showed that the test had proceeded satisfactorily as shown in Plate 3.9.

Plate 3.9: Concrete Cube Specimen Mode of Failure

3.2.5.8 Tensile strength of concrete (Cylinder splitting)

The principle of the tensile splitting test is such that the cylindrical specimen is subjected to a compressive force applied to a narrow region along its length. The resulting orthogonal tensile force causes the specimen to fail in tension [21].

The test was carried out in accordance to BS EN 12390-6 [21]. The 28 day old concrete cylinder was removed from the curing bath and placed on its side in a compression testing machine and loaded across its vertical diameter. Plywood strips were inserted at the interfaces of cylinder and steel loading platens to ensure an even loading over the length of the cylinder. Loading was applied gradually such that the time from the start of the loading to sample failure was about 30 seconds to achieve an average loading rate of about 0.05 N/mm^2 /sec based on the expected tensile splitting strength of 1.5 N/mm^2. This was done to achieve the loading rate specified in the code [21] of between 0.04 N/mm^2 and 0.06 N/mm^2

Failure occurs by a split or crack along the vertical plane, the specimen falling into two neat halves (Plate 3.10).

Plate 3.10: Concrete Cylinder Specimen Mode of Failure

The tensile stress is calculated using equation 3.7:

$$f_{ct} = \frac{2P}{3.142LD} \qquad (3.7)$$

Where: P = Failure load,

L = Length of cylinder

D = Diameter of cylinder.

Figure 3.1 show the cylinder splitting test arrangement

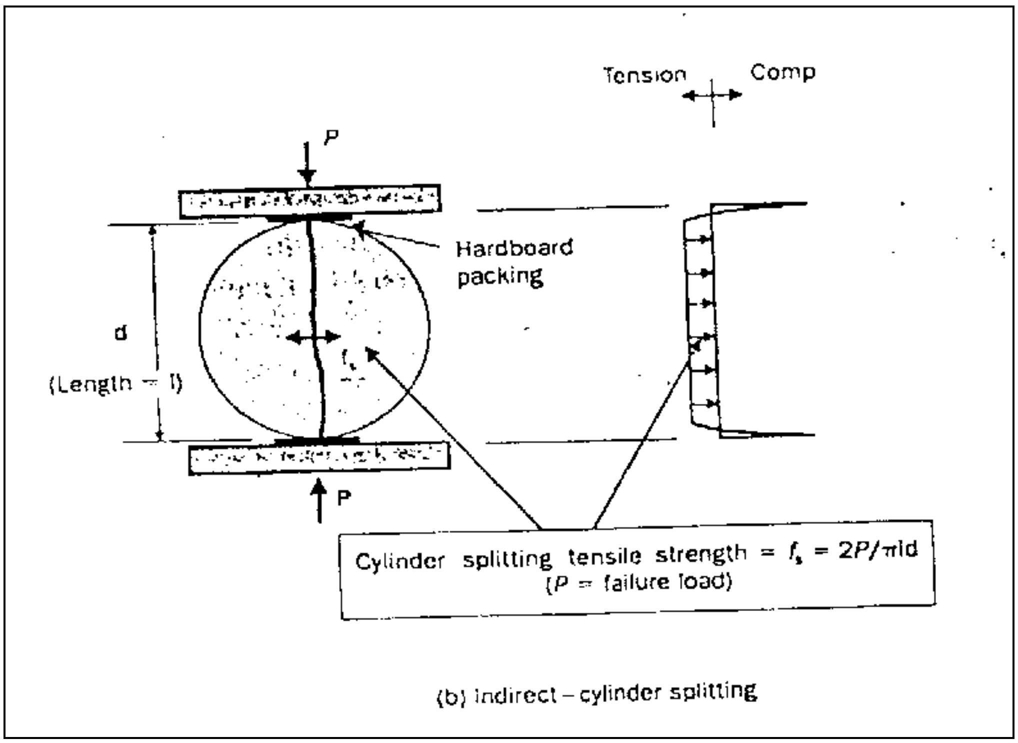

Figure 3.1: Cylinder Splitting Test Arrangement

3.2.5.9 Characteristic and Mean Strengths of Concrete

The design of concrete structures is based on the assumption of certain minimum or maximum properties of concrete, such as strength. However the actual strength of concrete obtained during a job, whether on site or in the laboratory is subject to variability resulting from variation in the quality of the materials used, variation in the mix proportions due to the batching process, changes in concrete making and placing, and also, with respect to test results, the variation due to sampling and the very testing. Variation in material quality can be in the form of variations in cement characteristics, grading of aggregates, level of silt and dust content of the aggregates, and in whether or not admixtures are present. Variations in the batching process are due to variations in the weights of the components, mixing, transporting, delivery time, temperature, workability, and air content, while variations due to sampling and testing are due to sampling, specimen preparation, initial and final curing of specimens, transporting, test procedures and equipment.

Owing to these variations, when designing a concrete mix the practice is to aim at a mean strength higher than the minimum required from the structural point of view so that every part of the structure can be expected to be made of concrete of adequate strength. This mean strength aimed at is known as the **target mean strength**. The minimum required strength is termed the **characteristic strength** and the difference between the target mean strength and the specified characteristic strength is known as the **margin**.

The relationship between the above parameters is expressed as follows:

$$f_m = f_{\min} + ks \quad (3.8)$$

Where:

f_m = Target mean strength;

f_{min} = characteristic strength; and

ks = M = margin, which is the product of:

S = standard deviation; and

k = statistical factor.

The statistical factor *k* depends on the permissible proportion of defectives. The lower the permissible proportion of defectives is, the higher the value of the statistical factor. Accordingly,

For 5% defectives specified in BS EN 206-1, k = 1.64

Thus:

$$f_m = f_{\min} + 1.64s \tag{3.9}$$

In this case, the characteristic strength is that strength below which only 5% of results may be expected to fall.

In this study, in order to establish characteristic strength, mean strength and the margin of strength of the lime:RHA concrete, 27 cubes and 27 cylinders were cast using the optimal lime:RHA (30%:70%) as the binder for 28 day compressive and tensile strengths respectively. The binder: sand: ballast ratio used was 1:2:4 respectively by weight (Table 3.1) and the cubes and cylinders were cast using the procedure outlined in clause 3.3.5.5 and cured in water until testing at the 28th day.

Table 3.1: Mix Proportions in 1 m^3 of Concrete

Binder (kg)	Sand (kg)	Ballast (kg)	Water (kg)
342.86	685.71	1371.43	171.43

Testing for density, compressive strength and tensile strengths were carried out using the procedures outlined in clauses 3.3.5.6, 3.3.5.7 and 3.3.5.8 respectively. Results were tabulated and used to calculate characteristic strength, mean strength, the margin of strength and to prepare frequency distribution curves

Standard deviation was calculated using the following formula:

$$S = \sqrt[2]{\frac{\sum_1^n (f_i - f_m)^2}{n-1}} \qquad (3.10)$$

or

$$S = \sqrt[2]{\frac{n\sum_1^n f_i{}^2 - (\sum_1^n f_i)^2}{n(n-1)}} \qquad (3.11)$$

and

Characteristic strength $f_{min} = f_m - 1.64s$ (3.12)

In order to classify the data into a frequency distribution curve, Rice and Turgis's rules were used to establish number of class intervals and range.

Number of class intervals

- $Rice\ Rule = 2 * \sqrt[3]{n}$ (3.13)
- $Sturgi's's\ Rule = 1 + 3.3log_{10}n$ (3.14)

4 RESULTS AND DISCUSSIONS

4.1 Properties of RHA

4.1.1 Chemical Properties of RHA

Table 4.1: Chemical Properties of the RHA used, %

Property	Results Obtained	ASTM C 618 [20] Requirements
Loss of Ignition (L.O.I), % m/m	15.99	Maximum =12
Silica as SiO_2 , % m/m	70.55	Combined Minimum = 70
Aluminum as Al_2O_3 , % m/m	4.76	
Iron as Fe_2O_3, % m/m	0.96	
Insoluble Residue (I.R), % m/m	2.02	–
Calcium as CaO, % m/m	1.26	–
Magnesium as MgO, % m/m	0.75	–
Sulphates as SO_3, % m/m	0.30	Maximum = 5
Sodium as Na, % m/m	0.0146	Maximum = 1.5
Potassium K, % m/m	0.0054	–

Table 4.1 shows the results of the chemical analysis performed on the RHA. The combined percentage of Silica (SiO_2), Iron Oxide (Fe_2O_3,) and Alumina (Al_2O_3) is 76.27%. This is more than 50% which is the minimum requirement by the Kenya Bureau of Standard for a good pozzolana and is also more than 70% which is the minimum requirement by ASTM C 618 [20]. The presence of Silica (SiO_2), Iron Oxide (Fe_2O_3,) and Alumina (Al_2O_3) in the RHA are responsible for the formation of cementitious compounds when they react with lime.

The chemical properties of the RHA show only minimal presence of Sulphates (SO_3) content of 0.3% which is also within the maximum content of 5% as per ASTM C 618-93 [20]. Sulphates (SO_3) causes formation of secondary ettringite (calcium sulfoaluminate) in concrete leading to its expansion and rupture, thus its low presence makes the RHA good for concrete production.

The loss of ignition (LOI) of 15.99% was however relatively high compared to the requirement of other pozzolanas used as cement replacement materials. This could be attributed to some small quantities of un-burnt material in the ash. Although the ash was burnt at about 700^0c, it is possible that some pockets of material came out either un-burnt or partially burnt. Fly ash used in concrete is typically required to have a LOI less than 7% as per BS EN 450 [39], though ASTM C 618-93 [20] allows up to 12% subject to availability of performance records or laboratory test results.

The CaO content of 1.26% is relatively low and hence the RHA can be classified as having “low CaO” content [22]. The use of low CaO fly ash has been found to be effective in reducing pore solution alkalinity [22]. The RHA used, being of low CaO content, is therefore expected to show similar results and is expected to be more effective in controlling expansion due to alkali silica reaction.

From the above results and discussions, it can therefore be concluded that the rice husk ash used is a good pozzolanic material for use in concrete production.

4.1.2 Physical Properties of RHA

Specific gravity of the RHA was measured (for the purpose of performing hydrometer analysis) to be 1.96. Table 4.2 shows the results of the hydrometer analysis performed on the RHA.

Table 4.2: Particle Size Distribution of RHA- Hydrometer analysis

DATE/ TIME.	ELAPSED TIME IN MIN.	TEMP. IN °C	Rh_1	Rh	HR	D. mm.	k %
9.45am	0.5	20	23.0	23.5	10.9	0.0632	92
	1		21.0	21.5	11.7	0.0463	84
	2		18.5	18.5	12.7	0.0341	74
	4		15.0	15.5	14.1	0.0254	59
	8		12.0	12.5	15.3	0.0187	47
	15		10.0	10.5	16.1	0.0140	39
	30		7.5	8.0	17.1	0.0102	29
	60		5.5	6.0	17.9	0.0074	20
	120		4.5	5.0	18.2	0.0053	16
	240		4.5	5.0	18.2	0.0037	16
	300		4.5	5.0	18.2	0.0033	16
9.45am	1440		4.5	5.0	18.2	0.0015	16

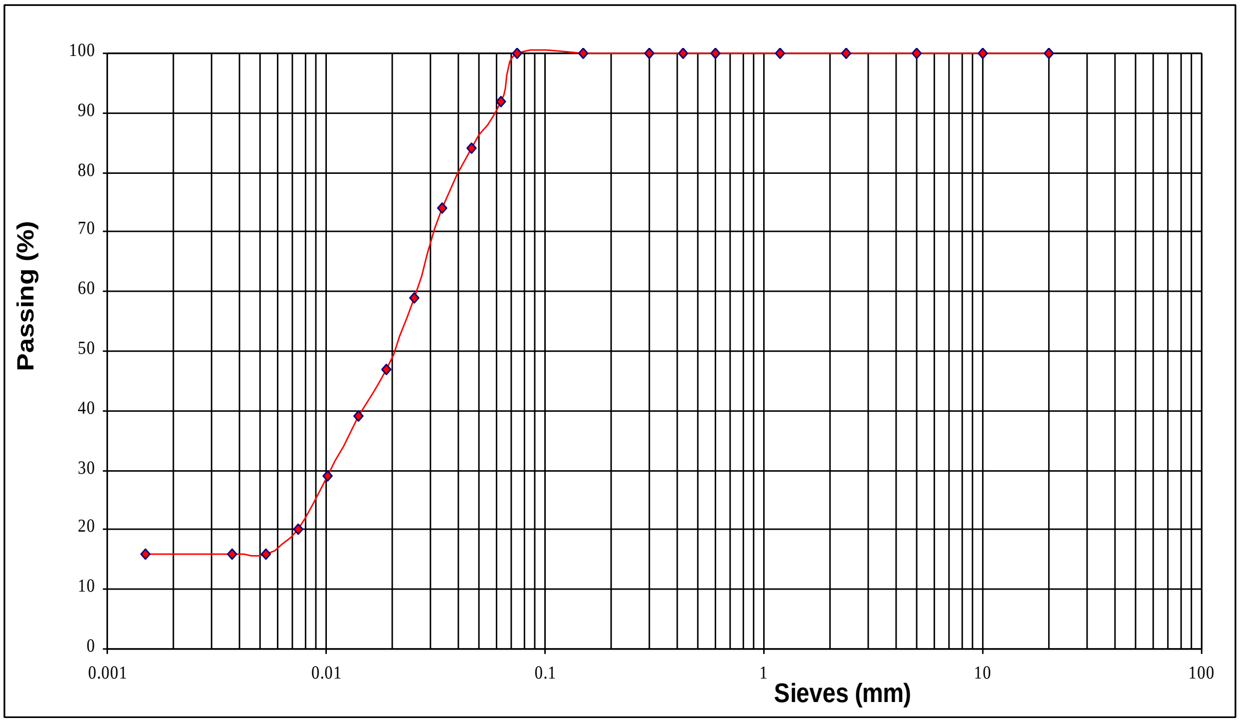

Figure 4.1: Particle size distribution of RHA

Figure 4.1 shows the plot of particle size distribution (hydrometer analysis) of RHA used in this study. It was found that the particle size ranges from 1.0 µm to around 65 µm.

4.2 Properties of Aggregates

4.2.1 Chemical Properties of Aggregates

This basically gives the type and quantity of minerals present in the aggregates. Chemical examination of aggregates is useful in assessing its quality, detecting adverse properties such as presence of chlorides and sulphates and in comparing aggregates from different sources with one which service records are available.

Tables 4.3 and 4.4 show the chemical properties of the coarse and fine aggregates used in this study. These properties very little presence of Chloride (Cl-) which is associated with corrosion of steel imbedded in concrete. Also, the properties show minimal presence of Sulphates (SO_3) which causes formation of secondary ettringite (calcium sulfoaluminate) in concrete leading to its expansion and rupture; thus the aggregates are deemed to be innocuous and are suitable for production of concrete.

Table 4.3: Chemical Properties of the Coarse Aggregates, %

Property	Results Obtained	EN12620 [34] Requirements
Loss of Ignition (L.O.I), % m/m	3.84	4
Silica as SiO_2 , % m/m	76.35	–
Insoluble Residue (I.R), % m/m	4.72	–
Aluminum as Al_2O_3 , % m/m	7.52	–
Iron as Fe_2O_3, % m/m	2.80	–
Calcium as CaO, % m/m	0.98	–
Magnesium as MgO, % m/m	0.47	–
Sulphates as SO_3, % m/m	0.94	≤ 1
Sodium as Na, ppm	190	–
Potassium K, ppm	54	–

Table 4.4: Chemical Properties of River Sand, %

Property	Results Obtained	EN12620 [34] Requirements
Loss of Ignition (L.O.I), % m/m	0.84	4
Silica as SiO_2 , % m/m	84.78	_
Insoluble Residue (I.R), % m/m	2.12	_
Aluminum as Al_2O_3 , % m/m	0.49	_
Iron as Fe_2O_3, % m/m	0.84	_
Calcium as CaO, % m/m	1.12	_
Magnesium as MgO, % m/m	0.46	-
Sulphates as SO_3, % m/m	0.49	≤ 1
Sodium as Na, ppm	3.0	_
Potassium K, ppm	3.6	_

4.2.2 Physical Properties of Aggregates

The physical properties of aggregates referred to in this research include water absorption, specific gravity and particle size distribution (grading).

Specific gravity, though not a direct measure of the quality of aggregates influences the overall density of the resulting concrete. Apparent specific gravity of a majority of naturally occurring aggregates for use in the production of normal weight concrete should range between 2.6 and 2.7 [11]. Results of specific gravity of both coarse and fine aggregates used in this study are given in Tables 4.5 and 4.6 respectively, and are within the acceptable range of aggregates for normal weight concrete.

Water absorption of the aggregates for concrete is important as it influences the bond between it and the cement paste, the resistance of concrete to freezing and thawing, as well as chemical stability, resistance to abrasion and specific gravity. The actual water absorption of aggregate has to be deducted from the total water requirement of the mix to obtain the effective water/cement ratio, which controls both the workability and strength of concrete

Grading of aggregates is known to influence to a great extent the workability of concrete and hence strength. This is because high strength requires a maximum compaction with reasonable amount of work, which can only be achieved with a sufficiently workable mix. In the manufacture of good quality concrete, it is common to obtain aggregates in at least two separate lots, with the main division being at size of 5 mm (3/16 in.) or No. 4 ASTM sieve. This divides fine aggregate (sand) from coarse aggregates (ballast)

For this study, the concrete was made with aggregates covering a range of sizes up to a maximum size of 20mm (3/4 in.). One coarse aggregate and one fine aggregate fraction were tested.

An analysis was carried out by means of a series of sieves having conveniently related size of openings as described in BS EN 12620 [34]. Because aggregates are usually composed of a continuous series of sizes, the sieve analysis was reported in terms of the amount passing each of the sieves in the series.

Table 4.5: Physical Properties of Coarse Aggregates

Property	Results Obtained	EN12620 [34] Requirements
Bulk Specific Gravity (on saturated and surface dry state)	2.62	2.6 - 2.7
Apparent specific gravity	2.74	To be declared
Water Absorption	2.9%	To be declared

Table 4.6: Physical Properties of River Sand

Property	Results Obtained	EN12620 [34]Requirements
Specific Gravity	2.64	Range from 2.6-2.7
Water Absorption	1.05%	To be declared
Fineness Modulus	2.395	Range from 2.4-4.0 for coarse graded fine aggregates

Note: The code [34] requires that the values for specific gravity and water absorption of samples from a specific source should be declared once tested.

4.2.2.1 Coarse Aggregates

For the coarse aggregates used in this study, the particles range was between 6mm and 20mm as shown in Figure 4.2.

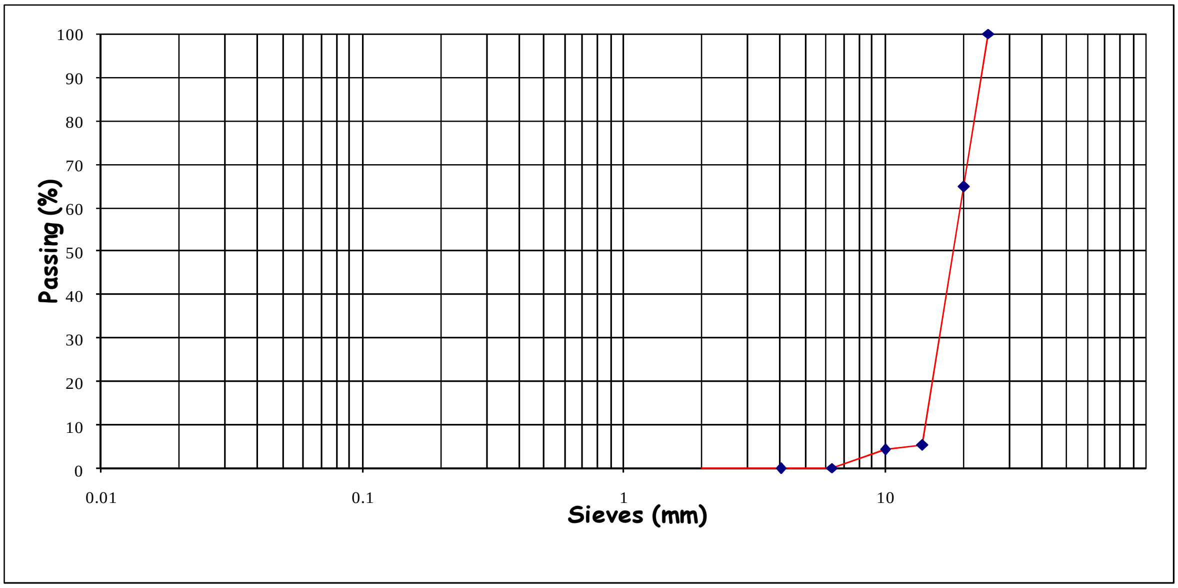

Figure 4.2: Particle Size Analysis of Coarse Aggregates

Results of the coarse aggregate fractions analyzed shows compliance with specified practical grading limits for coarse aggregates according to BS EN 12620 [34]. These results show that the geometrical properties of the coarse aggregates used in this study were satisfactory for the production of normal concrete mixes.

4.2.2.2 Fine Aggregates

The fine aggregate fraction that was used for this study, the particle was between 0.08mm and 5mm as shown in Figure 4.3.

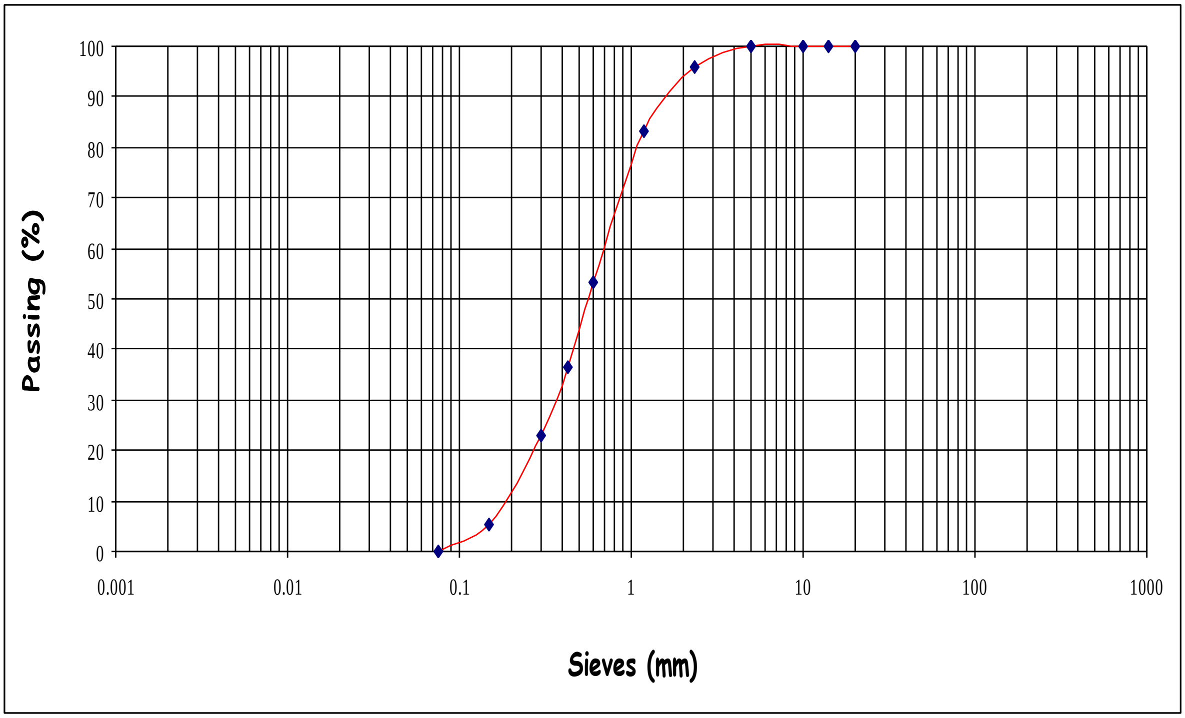

Figure 4.3: Particle Size Analysis of River Sand

Results of the fine aggregate fractions analyzed showed compliance with specified practical grading limits for coarse aggregates according to BS EN 12620 [34].

The fineness modulus of the fine aggregates as shown in Table 4.6 is 2.395. This show compliance with CP-coarse graded.

These results show that the geometrical properties of the fine aggregates used in this study were satisfactory for the production of normal concrete mixes.

4.3 Properties of Lime

The chemical properties of the building lime used comply with the values in Table 2 of KS 1780-1[27] when tested in accordance with KS 1780-2 [33]. Table 4.7 shows these properties.

Table 4.7: Chemical Properties of Lime

Property	Results Obtained	KS 1780-1 [27] Requirements CL60
Loss of Ignition (L.O.I), % m/m	25.24	–
Silica as SiO_2 , % m/m	2.07	–
Insoluble Residue (I.R), % m/m	0.33	–
Aluminum as Al_2O_3 , % m/m	0.43	–
Iron as Fe_2O_3, % m/m	1.6	–
Calcium as CaO, % m/m	64.26	≥ 60
Magnesium as MgO, % m/m	0.51	≤ 5
Sulphates as SO_3, % m/m	1.48	≤ 2
Sodium as Na, ppm	16.0	–
Potassium K, ppm	16	–

4.4 Properties of Cement

The physical and chemical properties of the cement used are shown in Tables 4.8 and 4.9 respectively.

Table 4.8: Physical Properties of Cement

Property	Results Obtained	KS EAS 18-1 [28] Requirements
Specific Gravity	2.96	2.9-3.15
Initial Setting Time (min)	190	Minimum = 75
Final Setting Time (min)	310	Maximum = 600
28-day Compressive Strength (MPa)	39	Minimum = 32.5

Table 4.9: Chemical Properties of Cement, %

Property	Results Obtained	KS EAS 18-1 [28] Requirements
Loss of Ignition (L.O.I), % m/m	2.96	≤ 5.0
Silica as SiO_2 , % m/m	34.73	-
Insoluble Residue (I.R), % m/m	34.18	≤ 5.0
Aluminum as Al_2O_3 , % m/m	8.49	-
Iron as Fe_2O_3, % m/m	4.80	-
Calcium as CaO, % m/m	35.56	-
Magnesium as MgO, % m/m	1.62	2.7
Sulphates as SO_3, % m/m	1.87	≤ 3.5
Sodium as Na_2O	1.25	-
Potassium K_2O	2.06	-
C_3A	7.49	-
Chloride Cl^-	0	≤ 0.1

4.5 Properties of Water

Table 4.10: Properties of Water

Property	Unit	Results Obtained	KS 05-459:1 [40] Requirements (max.)
pH	pH Scale	8.14	6.5-8.5
Colour	mgPt/l	<5	15
Turbidity	N.T.U	5	5
Conductivity (25ºC)	μS/cm	1310	-
Iron	mg/l	0.01	0.3
Manganese	mg/l	0.01	0.1
Calcium	mg/l	0.8	250
Magnesium	mg/l	4.37	100
Sodium	mg/l	190	200
Potassium	mg/l	12	-
Total Hardness	Mg/$CaCO_3$/l	20	500
Chloride	mg/l	121	250
Fluoride	mg/l	6.84	1.5
Nitrate	mgN/l	3.9	10
Nitrite	mgN/l	0.01	-
Sulphate	mg/l	50.9	400
Free Carbon Dioxide	mg/l	Nil	-
Total Dissolved Solids	mg/l	812.2	1500

4.6 Workability of Concrete

The workability of concrete depends on a number of interacting factors: as mentioned in section 4.2, the grading (particle size distribution) and shape of the constituent aggregates, aggregate/cement ratio, water/binder ratio as well as the consistencies and fineness of the binder constituents. The design approach undertaken in this study entailed leaving all the other workability influencing factors constant while only varying the proportions of binder constituents. It involved varying the RHA content by a 20% increment whilst reducing the lime content, and formulating the mixes accordingly. Both the slump test and compaction factor tests were carried out.

Results of these tests are presented in Table 4.11 and Figures 4.4 and 4.5.

Table 4.11: Slump and compaction factor test results

Mix Ratio Lime:RHA	Slump (mm)	Compaction Factor
100:0	10	0.78
80:20	7.5	0.77
60:40	5	0.76
50:50	4	0.75
40:60	3	0.74
30:70	2.5	0.72
20:80	2	0.7
0:100	2	0.69

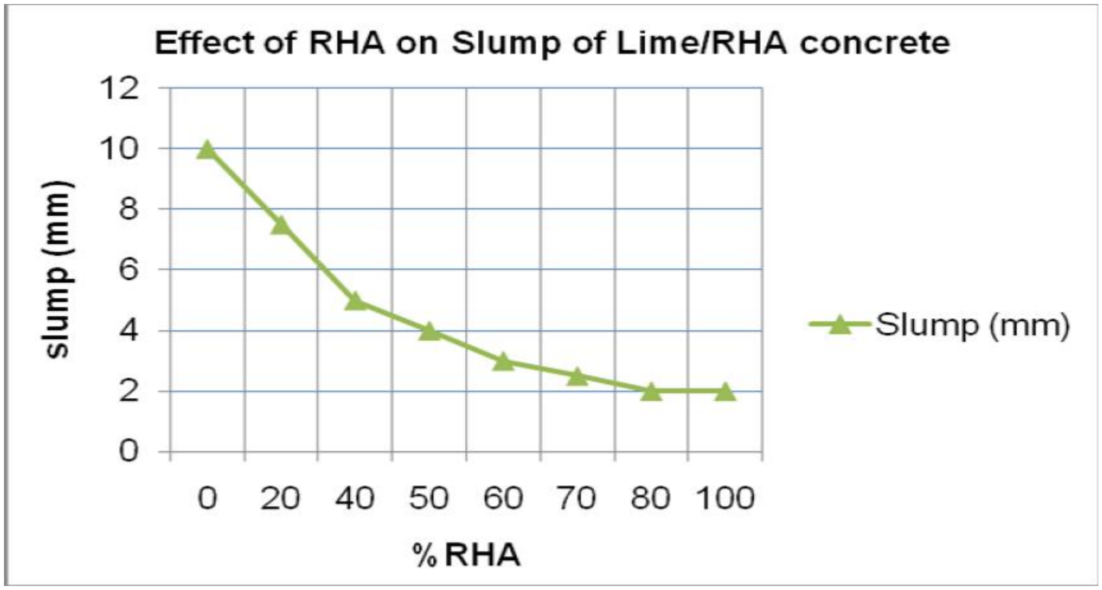

Figure 4.4: Effect of RHA on Workability of Lime:RHA Concrete- Slump Test Results

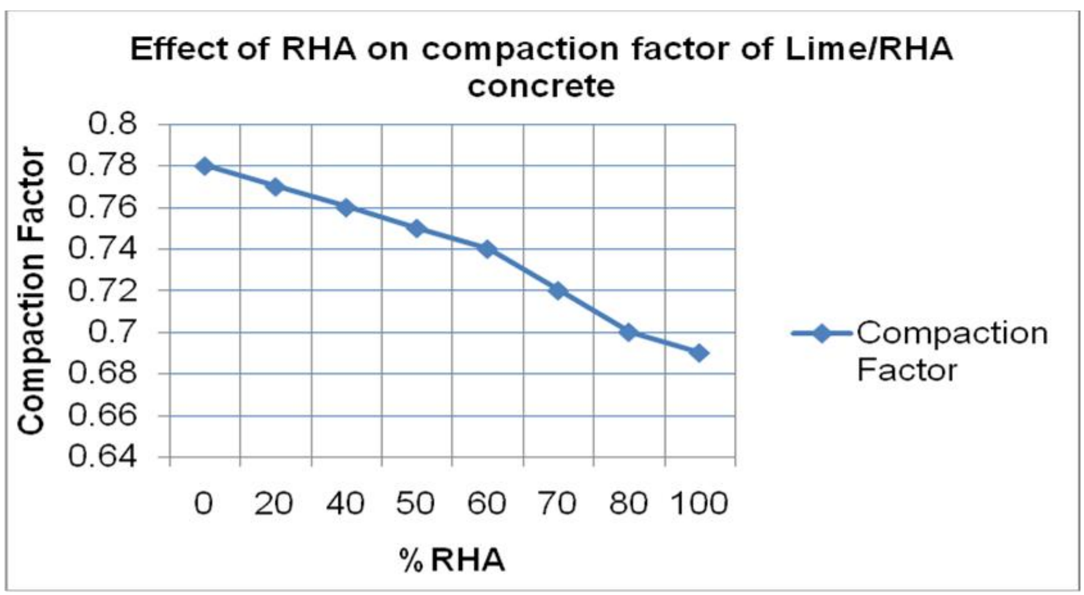

Figure 4.5: Effect of RHA on Workability of Lime:RHA Concrete- Compaction Factor Test Results

Considering a fixed water/cement ratio, it is shown that as the RHA content was increased in the concrete mix, there was a reduction in workability levels as reported by reduction in slump values from 10mm to 2mm and reduction in compaction factor values from 0.78 to 0.69. This means that a lesser workable (stiff) mix is obtained when RHA is used as lime replacement.

It should also be noted that the values of slump and compaction factor are relatively low indicating that water demand of lime:RHA binder is very high. More water is therefore required to make a workable mix.

The presence of RHA results in increased amount of fines in the concrete mix and hence the increased water demand. I.e. the high specific surface of RHA results in high water demand. Also the lime pozzolana reactions require more water.

Similar results of slump were reported by B. Waswa-Sabuni et al [10] when they tested both concrete made with OPC/RHA and that made with Lime:RHA cement at constant water/cement ratio. They replaced OPC with RHA and Lime with RHA at 20% intervals upto a maximum of 50% replacement. For the concrete made with OPC/RHA cement, slump reduced from 42.5mm at 0% replacement to 15.4mm at 50% replacement. For the concrete made with Lime:RHA cement, slump reduced from 10mm at 0% replacement to 2.5mm at 50% replacement

4.7 Density of Hardened Concrete

4.7.1 Air cured concrete samples

The results of density tests for samples cured in air at room temperature and perfomed to BS EN 12390-7 [18] are presented in Table 4.12 and Figure 4.6.

Table 4.12: Density of Lime:RHA concrete cubes cured in air

Mix Ratio	Density (Kg/m³) at different curing periods		
Lime:RHA	3days	7 days	28 days
100:0	2254	2193	2144
80:20	2237	2178	2156
60:40	2195	2168	2148
50:50	2178	2136	2093
40:60	2160	2133	2074
30:70	2136	2093	2045
20:80	2133	2074	2033
0:100	2133	2045	1925

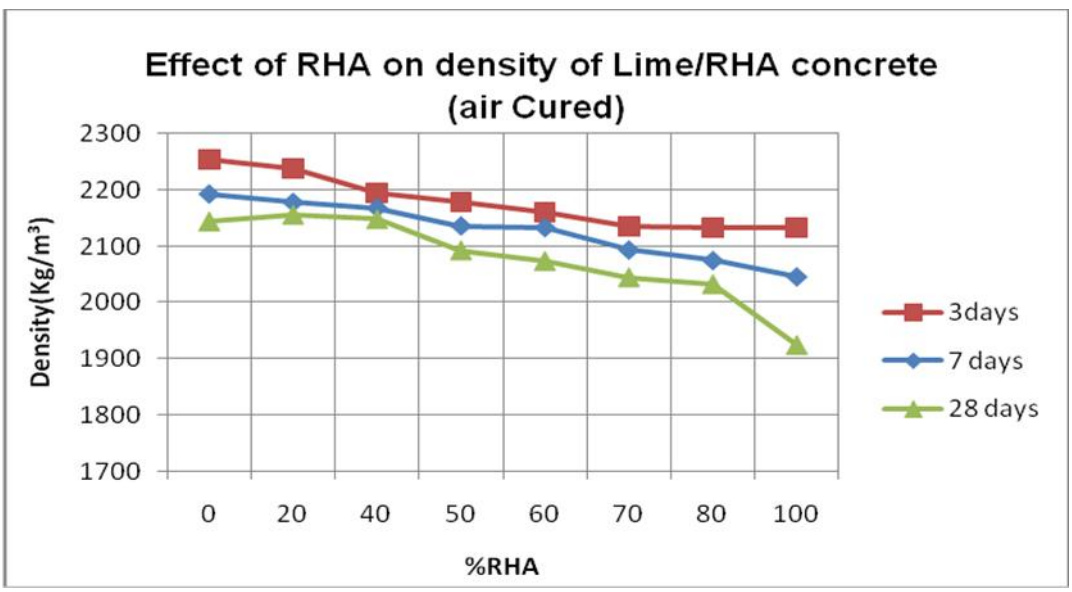

Figure 4.6: Density of Lime:RHA concrete cubes cured in air

4.7.2 Water cured concrete samples

The results of density tests for samples cured in water at room temperature and perfomed to BS EN 12390-7 [18] are presented in Table 4.13 and Figure 4.7.

Table 4.13: Density of Lime:RHA concrete cubes cured in water

Mix Ratio	Density (Kg/m³) at different curing periods		
Lime:RHA	3days	7 days	28 days
80:20	2237	2251	2258
60:40	2195	2223	2237
50:50	2178	2193	2225
40:60	2160	2178	2217
30:70	2136	2148	2215
20:80	2133	2136	2208

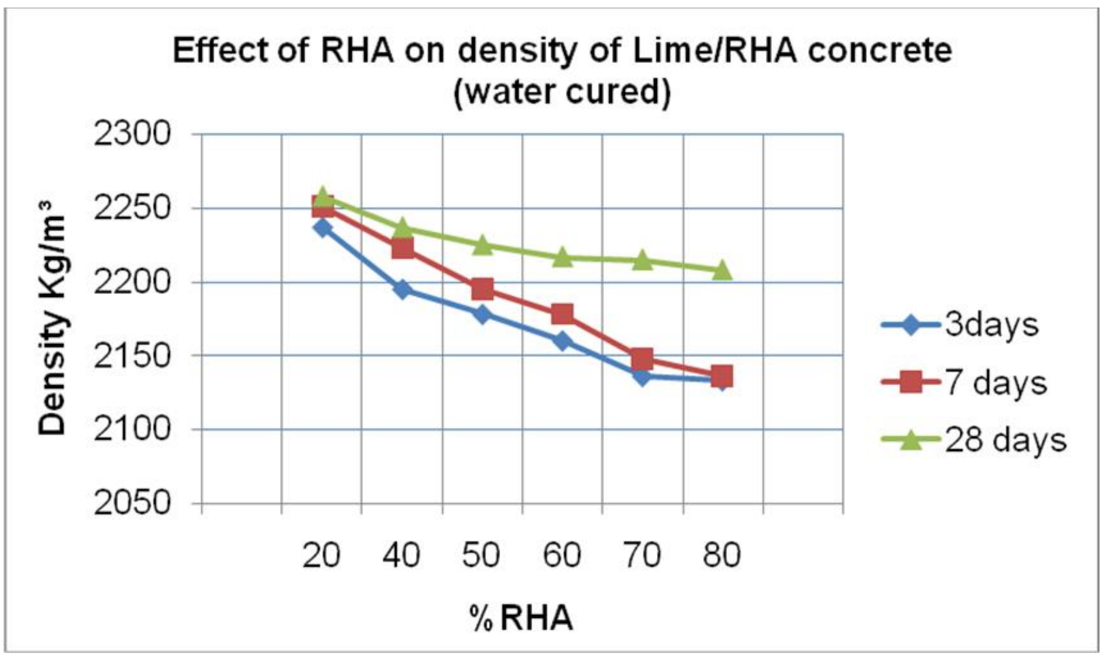

Figure 4.7: Density of Lime:RHA Concrete cubes cured in water

From all the two curing conditions analysed, it is shown that as the amount of RHA was increased in the concrete mixes, there was a slight decrease in density. This can be attributed to the fact that the RHA used had a slightly lower specific gravity value than the lime. Specific gravity of RHA used was 1.96 and that of the hydrated lime used was 2.24.

Considering samples cured in air at room temperature, the density of concrete reduced with the age of concrete. This can be attributed to loss of moisture to the air with time. On the other hand, for samples cured in water at room temperature, the density of concrete increased with the age of concrete. This can be attributed to absorption of curing water into the pores of concreter with time.

Air curing at room temperature also gave the lowest density values compared to water curing regime and this can also be attributed to to loss of moisture to the air with time.

The avarage 28 day density of concrete made from optimal Lime:RHA (30:70) and cured in water at room temperature was about 2313 Kg/m^3. This is within the acceptable range of normal weight concrete.

Similar results were reported by B. Waswa-Sabuni et al [10] when they tested both concrete made with OPC/RHA and that made with Lime:RHA cement at constant water/cement ratio.

4.8 Compressive strength

Results of cube compressive strength of various concrete mixes made with a binder: sand: ballast ratio of 1:2:4 respectively at constant water cement ratio of 0.5 are given in Tables 4.14 -4.19 and Figures 4.9-4.17.

4.8.1 Compressive Strength of Air cured concrete samples

Results of the compressive strength of concrete cubes made with different Lime:RHA mixes cured in air at room temperature and performed to BS EN 12390-3 [17] are presented in Table 4.14 and Figure 4.8.

Table 4.14: Compressive Strength for Lime:RHA concrete cubes cured in air

Mix Ratio	Compressive strength (N/mm²)		
%RHA	3days	7 days	28 days
0	0.15	0.33	0.34
20	1.29	2.16	4.01
40	1.73	4.56	6.95
50	2.78	5.95	8.33
60	1.88	5.67	7.53
70	1.67	4.64	6.87
80	1.18	3.64	5.64
100	0.25	0.67	0.45

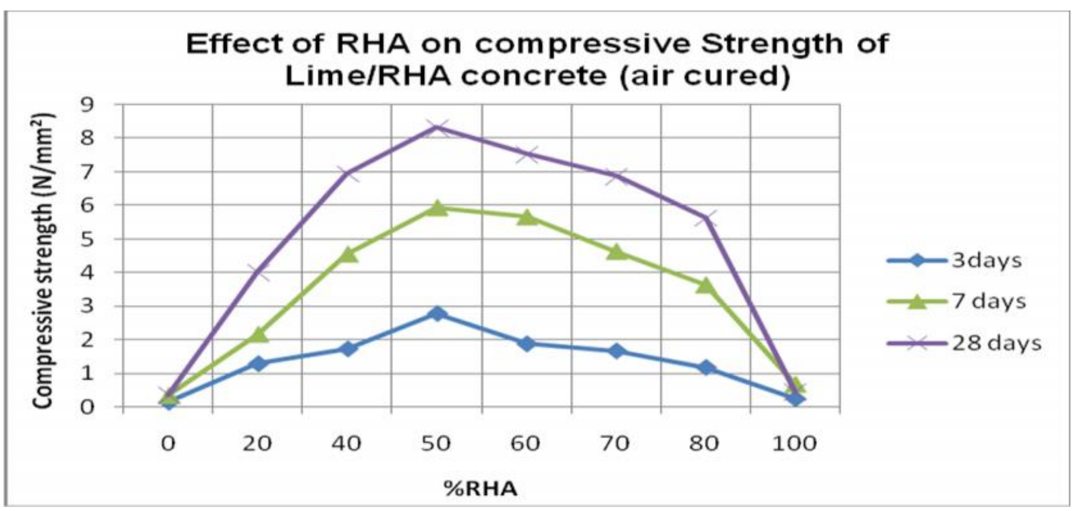

Figure 4.8: Compressive Strength of Lime:RHA (Air Cured) concrete cubes

4.8.2 Compressive Strength of Water cured concrete samples

Results of the compressive strength of concrete cubes made with different Lime:RHA mixes cured in water at room temperature and performed to BS EN 12390-3 [17] are presented in Table 4.15 and Figure 4.9.

Table 4.15: Compressive Strength for Lime:RHA concrete cubes cure in water

Mix Ratio	Compressive strength (N/mm²)		
Lime:RHA	3days	7 days	28 days
100:0	0.15	0.33	0.34
80:20	1.29	2.16	3.67
60:40	1.73	4.07	6.23
50:50	2.78	4.95	7.89
40:60	1.88	5.12	8.56
30:70	1.67	3.73	8.72
20:80	1.18	3.63	7.39
0:100	0.25	0.67	0.45

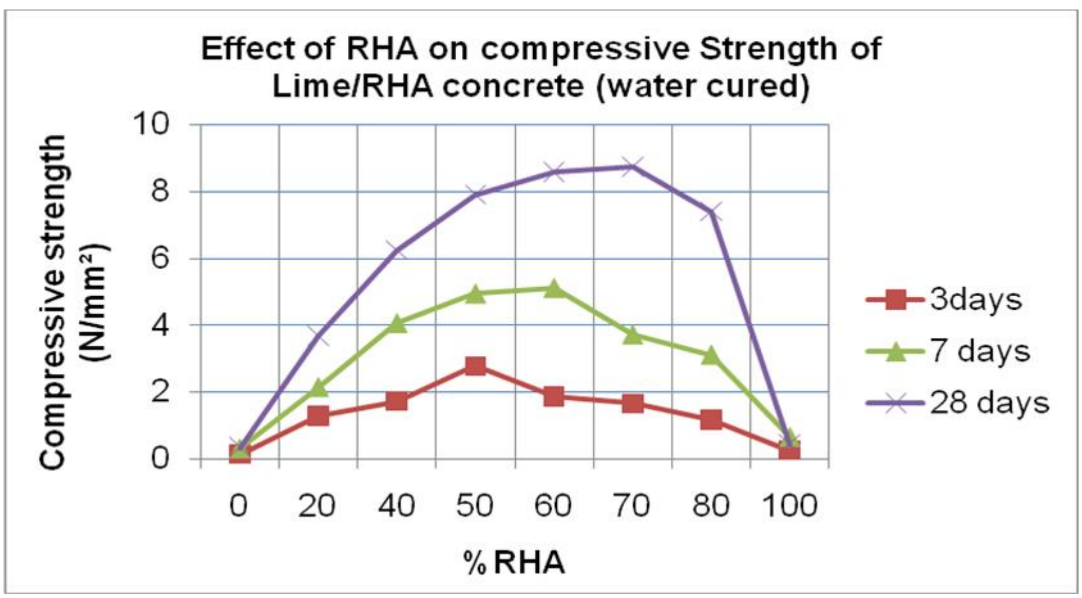

Figure 4.9: Compressive Strength of Lime:RHA (Water cured) concrete cubes

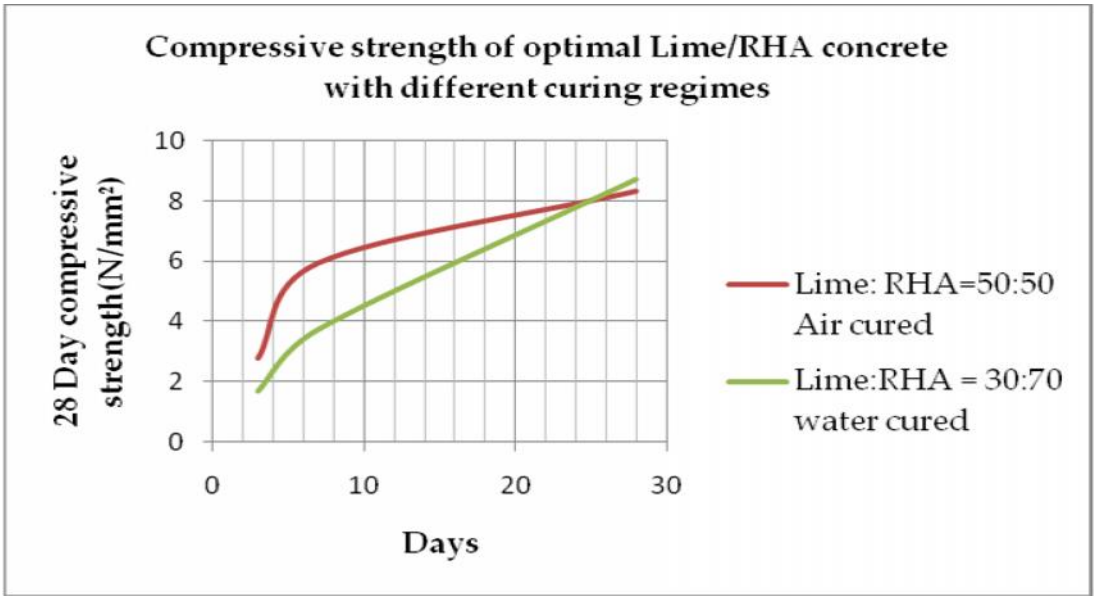

Figure 4.10: Compressive Strength of Optimal Lime:RHA concrete cubes with age.

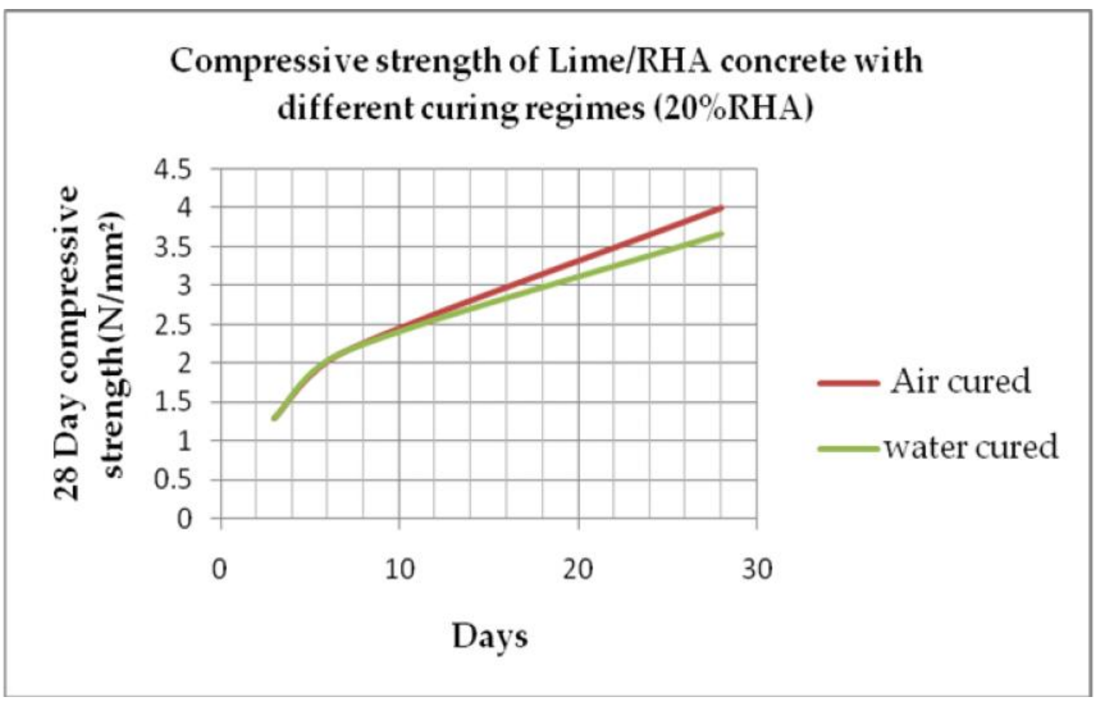

Figure 4.11: Compressive Strength of 20%RHA concrete cubes with age.

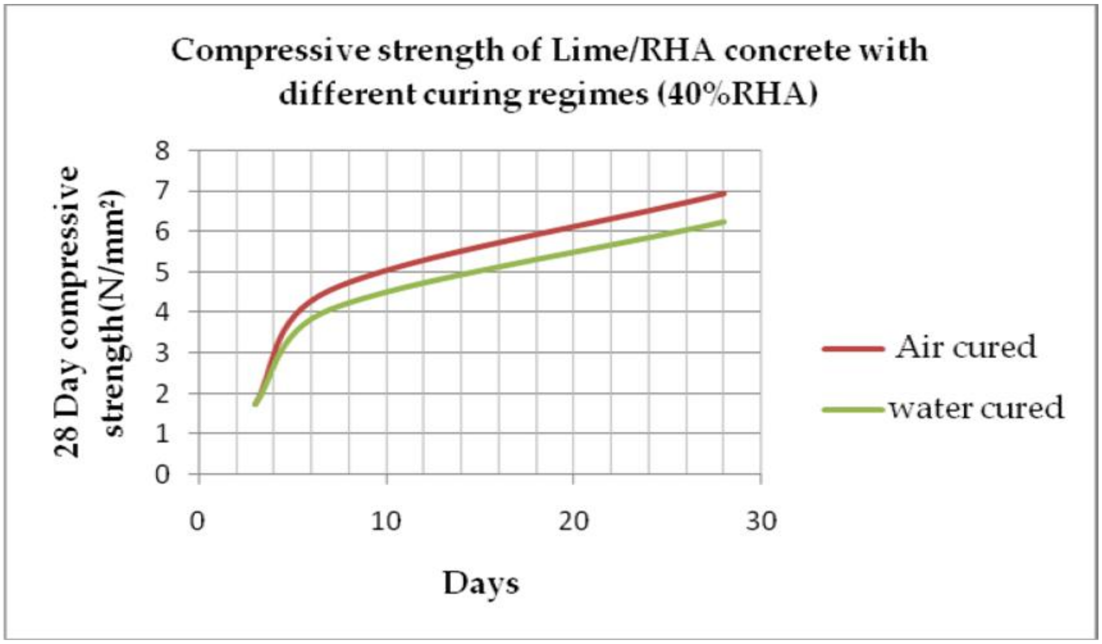

Figure 4.12: Compressive Strength of 40%RHA concrete cubes with age.

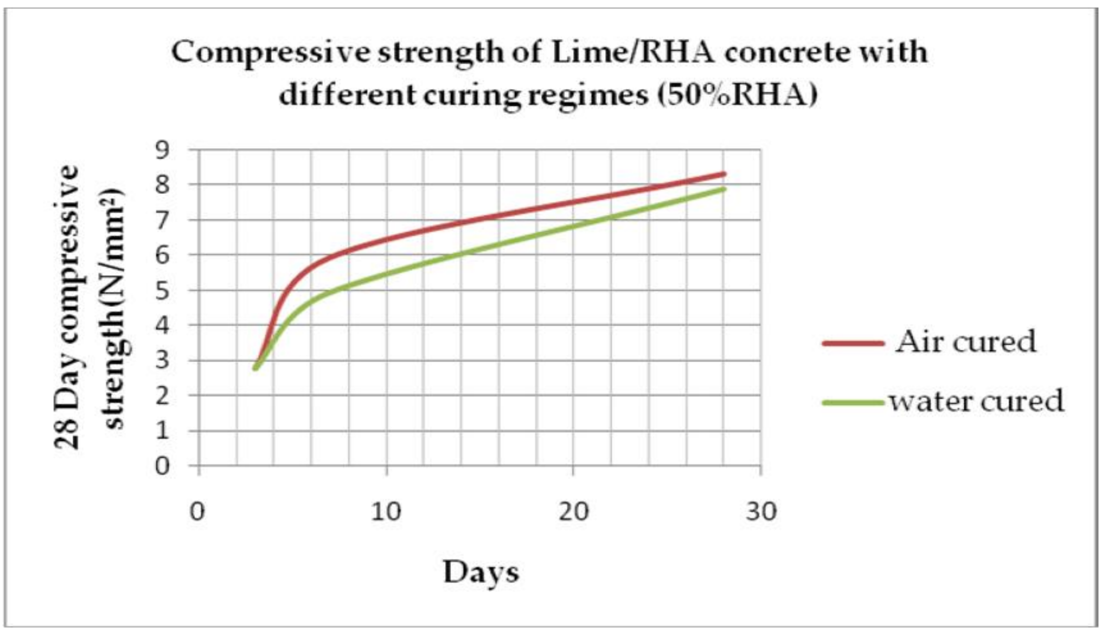

Figure 4.13: Compressive Strength of 50%RHA concrete cubes with age.

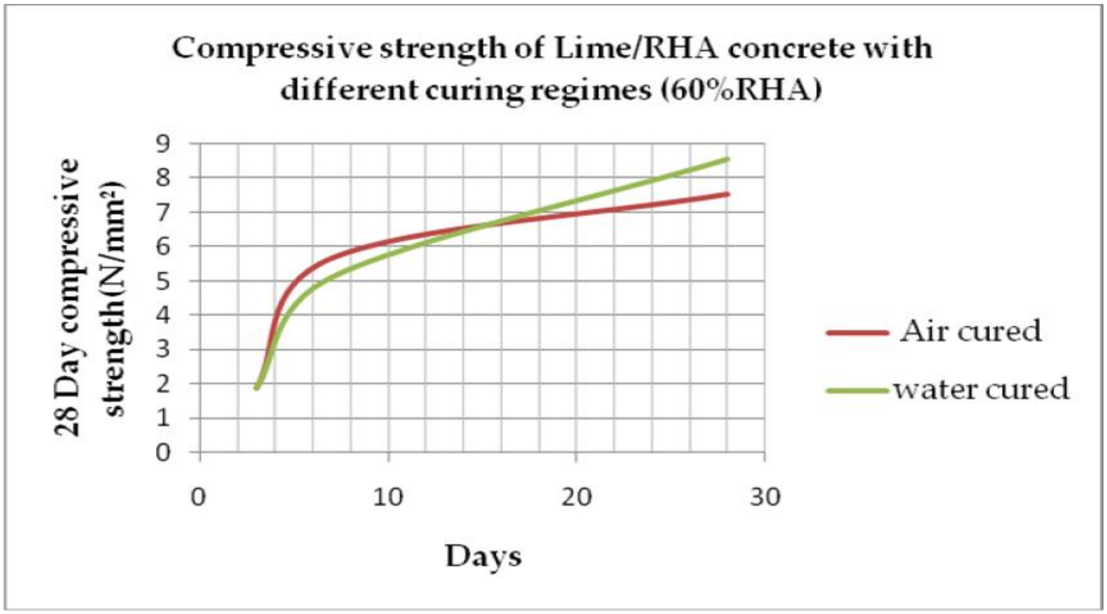

Figure 4.14: Compressive Strength of 60%RHA concrete cubes with age.

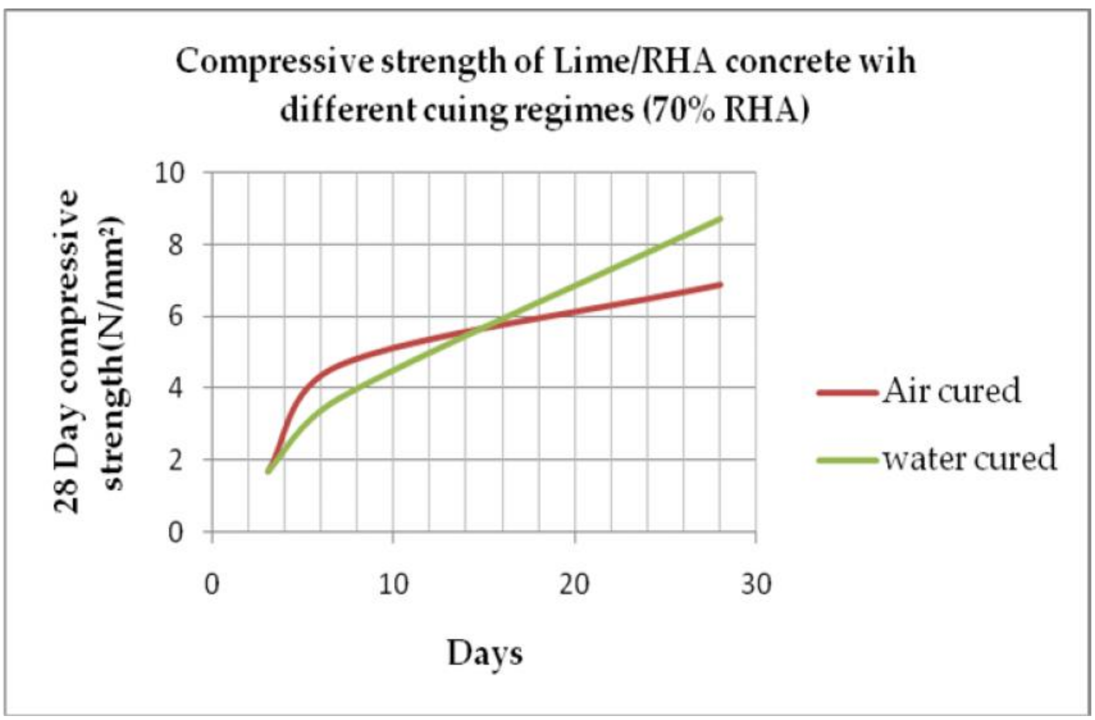

Figure 4.15: Compressive Strength of 70%RHA concrete cubes with age.

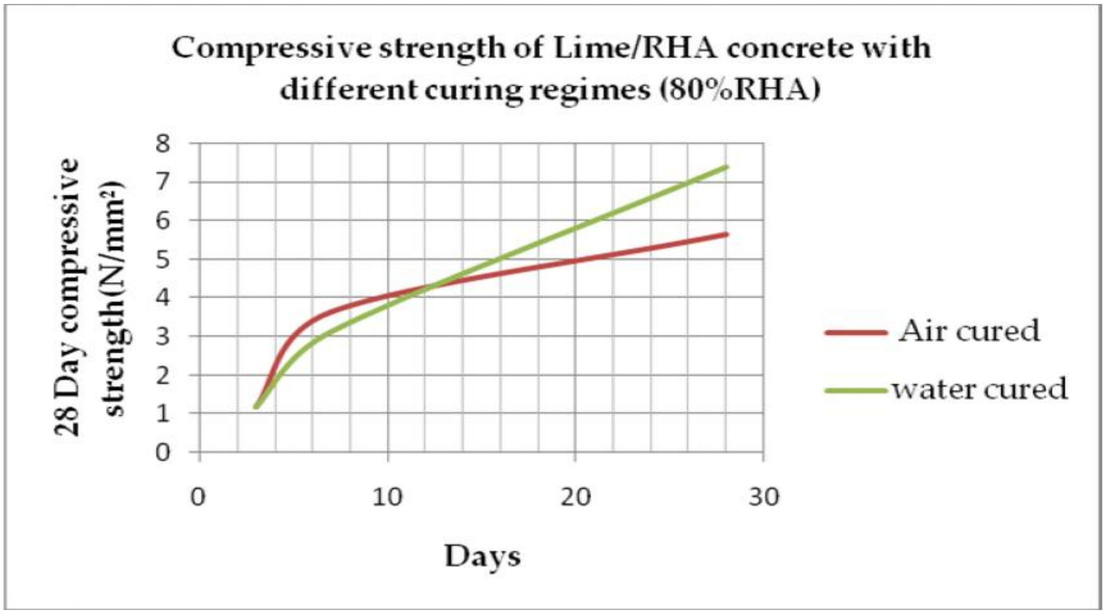

Figure 4.16: Compressive Strength of 80%RHA concrete cubes with age.

In general, for the two curing regimes (air and water) considered, it can be seen RHA greatly improves the compressive strength of lime. Compressive strength of lime:RHA concrete mixes was found to generally increase with increased amount of RHA until the optimum blend of Lime:RHA is reached then it starts to reduce. Below the optimum blend, there is adequate calcium hydroxide $Ca(OH)_2$ available to react with the Silica, Alumina and Iron Oxide in the RHA. Therefore as the RHA content increases, more cementitious products such as calcium silicates and calcium aluminates are formed thus increasing the compressive strength of the concrete. At the optimum blend, it is thought that the amount of Silica, Alumina and Iron Oxide in the RHA is just enough to react with all the available calcium hydroxide $Ca(OH)_2$. Beyond the optimum mix, the reduction of lime in the mix resulted in the reduction of available CaO which in turn reduced the amount of $Ca(OH)_2$ available for reaction with Silica, Alumina and Iron Oxide in the RHA. This led to reduced amount of C-S-H compound within the mix and is thought to have caused the reducing strength beyond the optimal blend.

The optimum Lime:RHA blend in terms of compressive strength was found to vary with curing condition. For concrete samples cured in air the optimal blend was at 50% lime with 50% RHA while for water cured samples was at 30% Lime and 70%RHA.

For concrete samples continuously cured in air, the loss of moisture resulted in reduction in the amount of H_2O with time which reacts with CaO to form $Ca(OH)_2$ in the mix, and since the water/cement ratio used was fixed for all the mixes , the amount of H_2O available is only so much and once it is exhausted no further $Ca(OH)_2$ could be formed hence limiting the amount of available $Ca(OH)_2$ for the hydration reaction. Limited amount of $Ca(OH)_2$ requires also limited amount Silica in the mix hence the 50% optimum RHA found for air cured sample compared to 70% for water cured sample. For concrete samples continuously cured in water, there is no loss of moisture hence the amount of available $Ca(OH)_2$ for the hydration reaction is relatively high requiring a relatively higher amount of Silica in the mix hence the 70% optimum RHA found. There is need to carry out a study using varying water/cement ratio in order to establish optimum water content.

The need for air curing arose from the fact that lime hardens when exposed to the air by absorbing carbon dioxide from the air to form calcium carbonate hence its strength. Thus in the case of air curing, it is expected that both hardening and hydration reaction contribute to the compressive strength of the mix. The hydration reaction between $Ca(OH)_2$ and SiO_2 from RHA is controlled by equation 4.1.

$$3Ca(OH)_2 + 2SiO_2 \rightarrow 3CaO.2SiO_2.3H_2O \qquad (4.1)$$

From molecular mass theory calculations based on equation 4.1, and reducing for the percentages of CaO in the lime and SiO_2 in the RHA, it was found that the optimum mix, based purely upon the hydration equation, should be 52% Lime with 48% RHA. The results of air cured concrete samples are approximately confirmed using this calculation. This is however dependent on the available H_2O which reacts with CaO to form $Ca(OH)_2$.

Concrete cured in air however registered relatively higher compressive strengths at early ages and at RHA% below 50% compared with water cured concrete samples (Figures 4.10 to 4.16). The reaction between lime and silica from RHA shown in equation 4.1 is exothermic. The resulting heat of hydration further elevates the temperature of the mix hence increasing the rate of chemical reaction of hydration and of gain of strength in case of air curing at early ages. For water cured samples, the wet curing environment plays an important role of lowering the concrete temperature raised by the heat of hydration and hence a slower rate of chemical reaction of hydration and of gain of strength at early ages. At RHA percentages below 50%, the quantity of lime in the mix is higher than that of RHA and hence contributing to additional concrete strength through the process known as lime hardening.

On the other hand, samples cured in water registered significantly higher 28 day compressive strength than those cured in air. This is due to the fact that for water cured samples, the wet curing environment plays an important role of lowering the concrete temperature raised by the heat of hydration of the binder, thereby preventing the formation of shrinkage cracks which could result in reduced strength. The wet environment also ensures the hydration takes place gradually, thereby producing concrete of high-long term strength. Again Hydration reaction only takes place in water-filled capillaries and since loss of water by evaporation from is not prevented in the case of air curing hence resulting in reduced strength.

Because samples cured in water registered significantly higher strength than those cured in air and also since cost of RHA is lower than lime, the optimal blend of the lime:RHA binder in terms of concrete compressive strength and cost can be said to be 30% Lime with 70%RHA and with moist curing.

4.8.3 Compressive Strength of lime:RHA concrete at optimal mix

The relationship between characteristic strength, mean strength and standard deviation as discussed in chapter three and is given by equation (3.8). Assuming there is a probability that only 1 in 20 of the strength values will fall below the minimum strength, the probability factor becomes 1.64 and the relationship between characteristic strength, mean strength and standard deviation is given by equation (3.9).

Table 4.16 shows results of density and 28 day compressive strength of 27 concrete cubes samples made with the identified optimal blend of Lime:RHA and cured in water at room temperature. The binder: sand: ballast was 1:2:4

Table 4.16: 28 Day Compressive Strength and Density of the optimal Lime:RHA Concrete

Cube	Density	compressive	Cube	Density	Compressive
1	2218	12.3	15	2218	11.5
2	2357	13.0	16	2380	9.6
3	2356	12.3	17	2333	10.3
4	2333	12.3	18	2287	9.7
5	2356	11.1	19	2284	9.8
6	2284	12.1	20	2307	11.1
7	2333	11.3	21	2286	11.5
8	2353	8.9	22	2331	10.3
9	2262	10.5	23	2309	10.7
10	2262	9.7	24	2379	10.2
11	2309	8.8	25	2330	11.4
12	2343	10.7	26	2307	10.9
13	2309	10.7	27	2327	11.3
14	2309	10.9			

Standard deviation was calculated using the following formula:

Characteristic strength $f_{min} = f_m - 1.64s = 8.83\ N/mm^2$

The results are summarized in Table 4.17.

Table 4.17: Summary of 28 day compressive strength and density of optimal Lime:RHA concrete

Average density	2313 Kg/ m^3
Mean compressive strength	10.83 N/mm^2
Standard deviation	1.05 N/mm^2
Characteristic compressive strength	9.11 N/mm^2

The average density of the optimal Lime:RHA concrete can be said to be within the range for normal weight concrete. It can therefore be concluded that even though the workability of the concrete was very low, the final degree of compaction was not affected by the stiffening caused by addition of RHA as indicated by the density results.

The 28 day compressive strength obtained with a binder (optimal): sand: ballast mix proportion of 1:2:4 respectively is approximately 10N/mm^2.

The low value of standard deviation can be attributed to laboratory control condition as opposed to site condition where the level of quality control may not be that high.

In order to classify the above data into a frequency distribution curve, Rice and Turgis's rules were used to establish number of class intervals and range.

Number of class intervals for 27 samples:

- $Rice\ Rule = 2 * \sqrt[3]{n} =$ 6
- $Sturgis's\ Rule = 1 + 3.3log_{10}n =$ 5.72

Using 6 number class intervals, frequency distribution table and curve were developed. Table 4.18 and Figure 4.17

Table 4.18: Frequency distribution table of 28 day compressive strength of optimal Lime:RHA concrete

intervals	Mid	Frequency	%
8.8-9.5	9.15	2	7.4
9.5-10.2	9.85	5	18.5
10.2-10.9	10.55	8	29.6
10.9-11.6	11.25	7	25.9
11.6-12.3	11.95	4	14.8
12.3-13	12.65	1	3.7

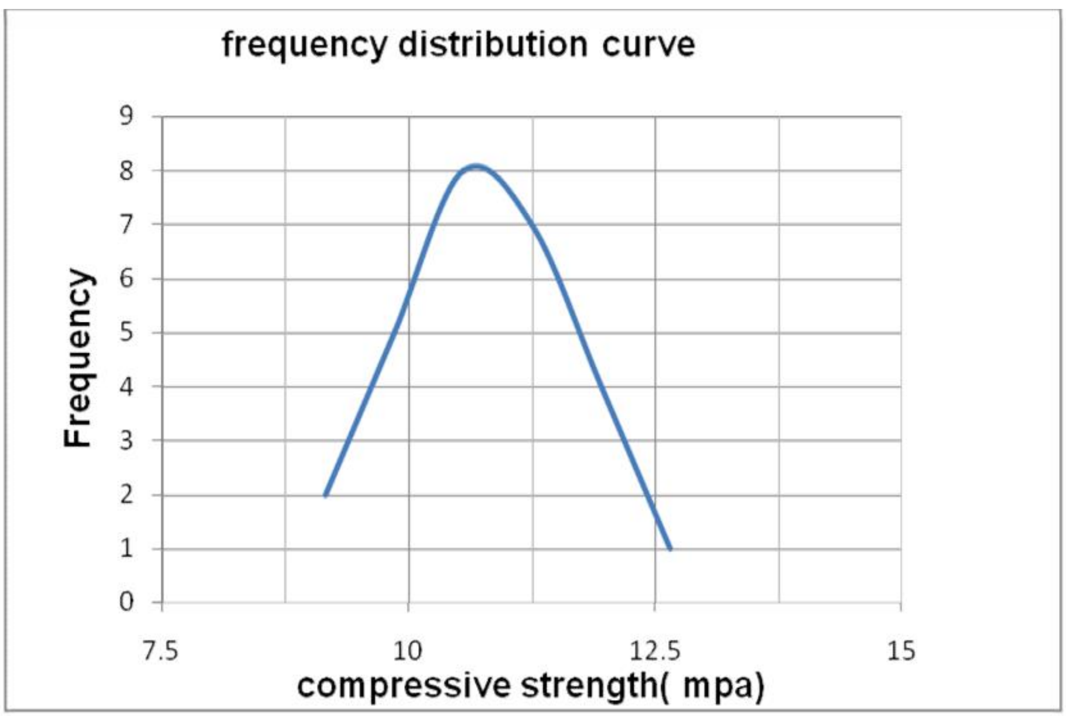

Figure 4.17: Frequency distribution curve of 28 day compressive strength of optimal Lime:RHA concrete

The resulting frequency distribution curve for compressive strength is nearly symmetrical about the mean strength and extending to plus and minus infinity and it can be said to be near normal or Gaussian distribution.

It has been found that the optimal Lime and RHA mix of 30% and 70% respectively, when used as binder for concrete production with a binder: sand: ballast mix proportion of 1:2:4 respectively produces concrete with a mean compressive strength of 10.83 N/mm² and a characteristic compressive strength of 9.11 N/mm².

4.8.4 Compressive Strength of PPC Concrete

Table 4.19 shows a summary of results of density and 28 day compressive strength of 27 concrete cubes samples made with the Portland Pozzolanic Cement and cured in water at room temperature. The binder: sand: ballast was 1:2:4 at a constant water/cement ratio of 0.5

Table 4.19: Summary of 28 day compressive strength and density of PPC concrete

Average density	2428 Kg/ m^3
Mean compressive strength	20.08 N/mm²
Standard deviation	1.85 N/mm²
Characteristic compressive strength	18.24 N/mm²

Portland Pozzolana cement, when used as binder for concrete production with cement: sand: ballast mix proportion of 1:2:4 respectively produce concrete with a mean compressive strength of 20.08 N/mm² and a characteristic compressive strength of 18.24 N/mm². These strengths are approximately twice those of Lime:RHA concrete at optimal blend.

4.9 Tensile Strength

Results of tensile strength tests of various concrete mixes made with a binder: sand: ballast ratio of 1:2:4 respectively at constant water cement ratio of 0.5 are given in Tables 4.20 - 4.22.

4.9.1 Tensile Strength of lime:RHA concrete at optimal mix

Table 4.20 shows results of density and 28 day tensile strength of 27 concrete cylinder samples made with the 30%:70% Lime:RHA optimal blend and cured in water at room temperature. The binder: sand: ballast was 1:2:4

Table 4.20: 28 day tensile strength and density of the optimal Lime:RHA concrete

Cylinder No.	Density (Kg/ m^3)	Tensile strength(N/mm²)	Cylinder No.	Density (Kg/	Compressive strength(N/mm²)
1	2386	1.63	15	2443	1.6
2	2367	1.30	16	2457	1.2
3	2348	1.60	17	2227	1.6
4	2198	1.60	18	2179	1.3
5	2443	1.60	19	2348	1.6
6	2179	1.60	20	2169	1.5
7	2386	1.50	21	2336	1.3
8	2424	1.30	22	2386	1.6
9	2198	1.60	23	2317	1.5
10	2179	1.30	24	2235	1.5
11	2348	1.40	25	2254	1.4
12	2198	1.60	26	2311	1.6
13	2198	1.40	27	2367	1.3
14	2424	1.60			

Standard deviation and characteristic strengths were calculated as in section 4.5.3 and the results are summarized in Table 4.21.

Table 4.21: Summary of 28 day Tensile strength and density of optimal Lime:RHA concrete

Average density	2308 Kg/ m^3
Mean Tensile strength	1.49 N/mm^2
Standard deviation	0.133 N/mm^2
Characteristic tensile strength	1.27 N/mm^2

The cylinder strength was found to obey the universal rule of thumb

$$tensile\ strength, f_t \quad = \quad a(f_c)^b$$

Where fc = compressive strength

a = 0.3

b = 0.67

For fc = 10.83 N/mm^2

$$tensile\ strength, f_t \quad = \quad 0.3(10.83)^{0.67} \ = 1.48\ \mathrm{N/mm^2}$$

4.9.2 Tensile Strength of PPC concrete

Table 4.22 shows results of density and 28 day tensile strength of 27 concrete cylinder samples made with Portland Pozzolanic Cement and cured in water at room temperature. The binder: sand: ballast was 1:2:4 at a constant water/cement ratio of 0.5.

Table 4.22: Summary of 28 day Tensile strength and density of PPC concrete

Average density	2410 Kg/ m^3
Mean Tensile strength	2.18 N/mm^2
Standard deviation	0.194 N/mm^2
Characteristic tensile strength	1.95 N/mm^2

4.10 Setting Times and Mortar Compressive Strength of Optimal Lime:RHA mix

Table 4.23, Table 4.24 and Figure 4.18 show the results of setting times and mortar compressive strength of the optimal lime:RHA blend respectively.

Table 4.23: Setting Times of optimal Lime:RHA binder (30%Lime + 70%RHA)

Mix Ratio	Setting Time (Min)	
Lime:RHA	Initial	Final
30:70	285	1485

Table 4.24: Mortar compressive strength of optimal Lime:RHA binder (30%Lime + 70%RHA)

Lime:RHA Mix Ratio	Age (Days)	Mortar Compressive Strength (N/mm^2)
30:70	2	3.03
	3	3.21
	7	5.46
	14	7.00
	28	7.07

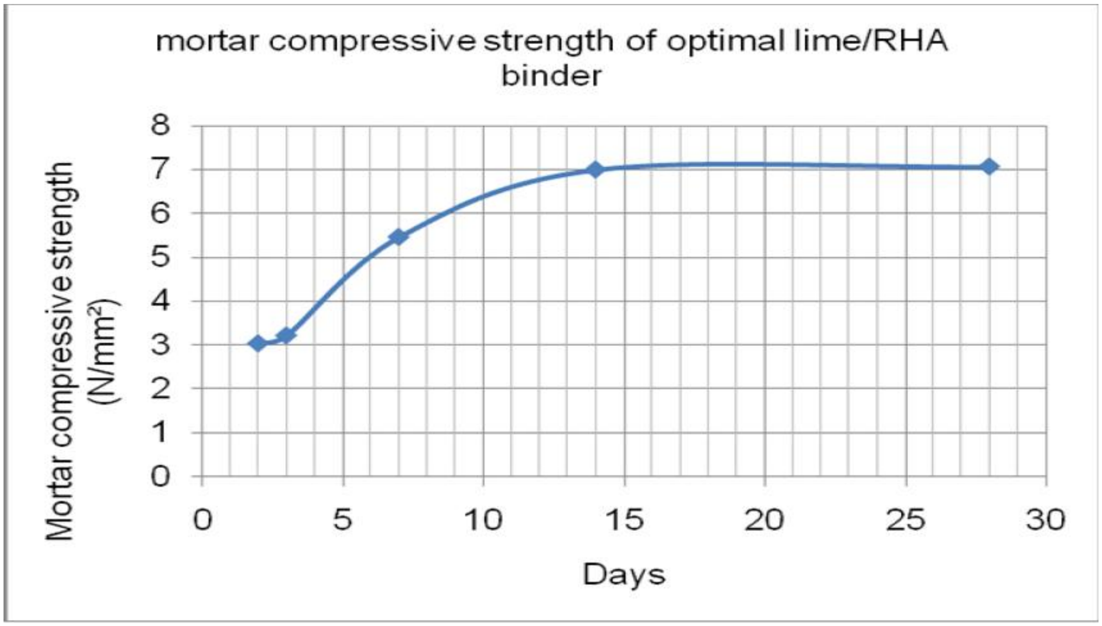

Figure 4.18: Mortar compressive strength of optimal Lime:RHA Binder with age

In accordance to KS EAS 18-1 2001: *composition specification and corformity criteria of common cements*,PPC is required to conform to the following: minimum initial setting time of 75 minutes,maximum final setting time of 600 minutes,a 2 day minimum mortar compressive strength of 7mpa, and 28 day minimum mortar compressive strength of 32.5mpa.

Setting is the term used to describe the stiffening of the cement paste and generally refers to change from a fluid to a rigid state caused by a selective hydration of tricalcium silicate (C_3S) and tricalcium aluminate (C_3A). Initial set corresponds to a rapid rise in temperature while final set corresponds to the peak temperature. The results of the setting times in Table 4.15 indicate that the optimal Lime:RHA binder meets the minimum requirement of initial setting time but does not conform to the maximum requirement for final setting time of portland pozzolanic cement in accordance to KS EAS 18-1 [28]. The results show that the binder takes a longer time to reach the peak hydration temperature; the final setting time is approximately 25 hours as compared to the required maximum of 10 hours. This means that the hydration of the binder is very slow compared to that of PPC cements. Since setting of cement paste is controlled by reactionof C_3A with water, the high setting times found could also be due to the low quantity of alumina in the RHA. Table 4.1 shows that the amount of alumina in the RHA is only 4.76% which means that in the optimal binder the total amount of alumina is approximately 3.33% whereus in the production of portland cements, alumina constitutes approximately 7% of the raw material. Thus there is need to introduce an accelerating admixure to to increase rate of hydration and lower the setting time of the binder to the required range and to also achieve high early strengths.

The mortar compressive strength of optimal Lime:RHA binder was determined at various ages of 2 days, 3 days, 7 days, 14 days and at 28 days. KS EAS 18-1 [28] specifies only a 2 day minimum mortar compressive strength of 7mpa, and 28 day minimum mortar compressive strength of 32.5mpa. The 3 days, 7 days and 14 days strengths were only done in order to observe the trends in strength development of the binder (Figure 4.18). It can be concluded that though the optimal binder does not meet the required mortar compressive strengths for pozzolanic cements, the strengths achieved are quite significant for certain structural applications. The 28 day mortar compressive of 7.07 N/mm^2 is good enough for structural applications such as in the production of masonry mortar, floor screed, plaster, mass concrete and even concrete masonry blocks.

Figure 4.12 shows the variation of the mortar compressive strength with age. The rate of strength development is rapid between the 3^{rd} day and the 7^{th} day of curing as can be seen by the increase in gradient of the curve, then the rate reduces until approximately the 15^{th} day when it achieves approximately 99% of the 28 day strength. At the 7^{th} day approximately 77% of the 28^{th} day strength has been achieved, this is more than the two third limit specified by the standards. It can therefore be concluded that though there was delayed setting as shown by the results of the setting time test, the actual strength was achieved within reasonable period of time.

4.11 Cost Analysis

After confirming the engineering properties of the optimal lime:RHA binder, an attempt was made to give comparative cost implications of the product. The cost of producing the RHA was worked out at about Kshs. 255.00 for 25kg or Kshs. 7400.00 per ton.

In terms of volume:

1 m^3 of RHA cost 425x255/25 = Kshs. 4335.00

1 m^3 of PPC cost 1442x800/25 = Kshs. 23072.00

1 m^3 of lime cost 515x500/25 = Kshs. 10300.00

By blending lime with RHA at 30%: 70% respectively, 1 m^3 of the resulting binder will cost: (10300x30/100)+ (4335x70/100) = Kshs. 6124.5

We have also seen in chapter 4 that when the optimal lime:RHA (30:70) binder is used for concrete production using a 1:2:4 binder: sand: ballast mix proportion respectively, we end up with grade 10 concrete.

From the results of concrete cubes made with PPC, in order to produce grade 10 concrete using Portland pozzzolanic cements (PPC), the nominal binder: sand: ballast mix proportion should be approximately1:4:8 respectively.

Therefore;

The amount of PPC required to produce 1.0 m^3 of class 10 concrete (1:4:8) = 1x1/13 = 0.077m^3

This will cost = 0.077x23072 = Kshs. 1776.54

And,

The amount of optimal lime:RHA binder required to produce class 10 concrete (1:2:4)

= 1x1/7 = 0.143m^3

This will cost = 0.143x6124.5 = Kshs. 875.8

From the above calculations, it can be concluded that concrete produced using lime:RHA binder mixed in the ratio of 30%lime plus 70% RHA can be used to produce a less expensive concrete compared to an equivalent grade of concrete made with Portland Pozzolana cement. The cost of Lime:RHA concrete was found to be less than half the cost of an equivalent grade of concrete made using PPC cement.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions were made during this study;

1. From the results of chemical composition tests it can be concluded that the RHA studied is a good pozzolanic material for use in concrete production, with a combined percentage of Silica (SiO_2), Iron Oxide (Fe_2O_3,) and Alumina (Al_2O_3) of more than 70%.
2. That consistency or workability of lime:RHA concrete reduces with increase in the quantity of RHA in the mix. The slump of the optimal lime:RHA concrete was found to decrease by about 75%.
3. That the hardened state density of lime:RHA concrete reduces slightly with increase in the quantity of RHA in the mix.
4. The optimal lime:RHA cement can be used to produce normal weight concrete with a wet average density of 2313Kg/m^3.
5. RHA greatly improves the compressive strength of lime irrespective of the curing regimes adopted. Compressive strength of lime:RHA concrete generally increase with increased amount of RHA until the optimum is reached then it starts to reduce.
6. The optimum Lime:RHA blend in terms of concrete compressive strength varies depending on the curing condition. For concrete samples cured in air the optimal blend was found to be 50% lime with 50% RHA while for water cured concrete samples the optimal blend was found to be 30% Lime and 70%RHA.
7. Water curing of lime:RHA concrete gives rise to concrete of higher compressive strength than air curing. Because of this an optimal blend of the lime:RHA binder of 30% Lime with 70%RHA and with moist curing is recommended.

8. The optimal Lime and RHA mix of 30% and 70% respectively, when used as binder for concrete production with a binder: sand: ballast mix proportion of 1:2:4 respectively and cured in water produces concrete with a mean compressive strength of 10.83 N/mm², a standard deviation of 1.05 N/mm², and a characteristic compressive strength of 9.11 N/mm². The compressive strength of optimal lime:RHA concrete is about half that of PPC concrete.
9. The tensile strength of the optimal lime:RHA concrete cured in water was found to be 1.49 N/mm² which is within acceptable percentage of the compressive strength and is about two thirds of that of PPC concrete.
10. The optimal Lime:RHA binder has an initial setting time of 285 minutes with a final setting time of1485 minutes indicating that the binder takes a longer time to reach the peak hydration temperature as compared to PPC cement. This means that the hydration of the binder is very low compared to that of PPC cements.
11. Even though the optimal binder does not meet the required mortar compressive strengths for pozzolanic cements [28], the strengths achieved are quite significant for certain structural applications. The 28 day mortar compressive of 7.07 N/mm^2 is good enough for structural applications such as masonry mortar, floor screed, plaster, mass concrete, stabilized soil blocks and concrete masonry blocks for use in low cost housing.
12. Lime:RHA binder can be used to produce a less expensive concrete compared to PPC cement. The cost of optimal lime:RHA binder is approximately one quarter of that of PPC cement. The cost of optimal Lime:RHA concrete was found to be less than half the cost of an equivalent grade of concrete made using PPC cement.

5.2 Recommendations

5.2.1 Recommendations

The following recommendations are made from this work:

1. RHA is a suitable material for use as a pozzolana and can be used to replace lime with the optimum content being 70% when cured under water. In this regard, moist curing is recommended for all lime:RHA concrete.
2. RHA improves greatly the strength of lime; the compressive of concrete made from the resulting optimal blend is good enough for structural applications such as in the production of masonry mortar, floor screed, plaster, mass concrete, compressed soil blocks and even concrete masonry blocks.
3. It is recommended that a Kenyan Standard for RHA blending with lime be developed. The standard should give guidelines on requirements on chemical composition, grinding, optimal blend, particle size distribution, packaging and storage of RHA.
4. Use of RHA is highly recommended as this will reduce environmental pollution and encourage further production of rice within and outside the rice growing regions of the country and hence boost food security.

5.2.2 Further Studies

The following further studies are proposed from this work:

1. To investigate the effect of incorporating an accelerating admixure to the lime:RHA binder to increase rate of hydration and lower the setting time of the binder to the required range and to also achieve high early strengths.
2. To investigate the long term performance of the Lime:RHA binder. Durability and permeability tests should be perfomed.

3. To investigate the appllication of the Lime:RHA binder in soil blocks production and soil stabilization in road construction.
4. It will also be of interest to investigate the behaviour of the Lime:RHA concrete on structural members and additional strength properties such as bond,shear , and cracking behaviours.

6 REFERENCES

1. ROBERT L. DAY. ***Pozzolanas for use in low-cost housing***. International Development Research Centre, Ottawa Canada. September, 1990.

2. RAMY ZAHRAN, ASSEM ABDELALIM, GAMAL ELSAYED ABDELAZIZ. ***Fresh and mechanical properties of the cementitious materials containing rice husk ash***. Zagazig University, Egypt. 2003.

3. ZHANG M. H. and MALHOTRA V.M. ***High-performance concrete incorporating rice husk ask as a supplementary cementing material.*** ACI Material Journal, Vol. 93, No. 6, pp. 629-636. November-December 1996.

4. NASR E.A., SHAKERF. A. and ELKARMOUTI H.Z. ***Strength and durability aspects of high performance concrete incorporating rice husk ash***. Faculty of Engineering, Cairo, Egypt, Ain Shams University. 10-12 April 2001.

5. ABDELMONEM A. ***The use of rice husk ash as a partial replacement material for cement in concrete mixes***. Ph. D. Thesis, Civil Engineering Department, Faculty of Engineering in Shoubra, Zagazig University. 2000.

6. JOSE JAMES and M.SUBBA RAO. ***Reaction product of lime and silica from rice husk ash***. Indian Institute of Science, Bangalore - 560 012 India.1985.

7. ABU BAKAR, RAMADHANSYAH P. and HAMIDI A. ***Malaysian rice husk ash – Improving the durability and corrosion resistance of concrete***. Concrete Research Letters, Vol. 1. 2010.

8. CHANDRASEKAR S., SATYANARAYANA K.G. and RAGHAVAN P.N. ***Processing, properties and applications of reactive silica from rice husk***. Journal of Materials Science. 2003.

9. MAEDA N. ***Development of a new furnace for the production of rice husk ash***. ACI International Conference on Fly ash, Silica Fume, Slag and Natural Pozzolans in Concrete. Vol. 2 Chennai, India. 2001.

10. WASWA-SABUNI B., SYAGGA P.M, DULO S.O and KAMAU G.N. ***Rice husk ash cement- an alternative pozzolana cement for Kenyan building Industry***. Journal of Civil Engineering, JKUAT, Vol.8. March 2002.

11. NEVILLE A. M and BROOKS J. J. ***Concrete Technology***, Dorling Kindersley Limited, India. 2006

12. MINISTRY OF AGRICULTURE, LIVESTOCK and FISHERIES DEVELOPMENT, 2004. ***Strategy for Revitalization of Agriculture (SRA)***.2004.

13. BS EN 933.***Tests for Geometrical Properties of Aggregates - Part 1: Determination of Particle Size Distribution – Sieving Method.*** BSI, London, United Kingdom. 1997

14. BS EN 12350.***Testing Fresh Concrete - Part 1: Sampling***. BSI London, United Kingdom. 2000.

15. BS EN 12390. ***Testing Hardened Concrete - Part 1: Shape, Dimensions and Other Requirements for Specimens and Moulds***. BSI, London, United Kingdom. 2001

16. BS EN 12390.***Testing Hardened Concrete - Part 2: Making and Curing Specimens for Strength Tests***. BSI, London, United Kingdom. 2001.

17. BS EN 12390.***Testing Hardened Concrete - Part 3: Compressive Strength of Test Specimen***. BSI, London, United Kingdom. 2001.

18. BS EN 12390.***Testing Hardened Concrete - Part 7: Density of Hardened Concrete***. BSI, London, United Kingdom. 2001.
19. NYSDT, ***Geotechnical Test Method GTM-13: Test Method and Discussion for Particle Size Analysis by Hydrometer Method***. Geotechnical Engineering Bureau. 2007.
20. ASTM C618.***Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.*** American Society for Testing Material.1993
21. BS EN 12390. ***Testing Hardened Concrete - Part 6: Flexural Strength of Test Specimens.*** BSI, London, United Kingdom. 2006
22. SHEHATA M.H., THOMAS M.D.A. and BLESZYNSKI R.F. ***The Effects of Fly Ash Composition on the Chemistry of Pore Solution in Hydrated Cement Pastes***. Cement and Concrete Research volume 29.1999.
23. COOK D.J and SUWANVITAYA P. ***Properties and behavior of lime-rice husk ash cements.*** University of NSW, Civil Engineering, 1982.
24. WACHIRA, MUTHENGIA JACKSON; ***Pozzolanic Activity of RHA with Commercially Hydrated Lime (CHL).*** 2003 Msc. Kenyatta University. researchkenya.or.ke
25. SARASWATHY V., SONG HA-WON. ***Corrosion Performance of Rice Husk Ash Blended Concrete***. Construction and Building Materials, Volume 21 (8). 2007.
26. Http://cementjack1_blcgspot.com/2011/03/non portland hydraulic cement-html. and https://www.google.co.ke/search?q=rice+husk+pictures
27. KS 1780. ***Building Lime - Part 1: Definitions, Specifications and Conformity Criteria***. KEBS, Kenya. 2010.
28. KS EAS 18. ***Cement Standard - Part 1: Composition, Specifications and Conformity Criteria***. KEBS, Kenya. 2001.

29. KS 02-1263. ***Kenyan standard for manufacture of Portland Pozzolana Cement***. KEBS, Kenya. 1994.
30. ASTM C109. ***Standard Test Method for Compressive Strength of Hydraulic Cement Mortars.*** American Society for Testing Material. 1993.
31. ASTM C157. ***Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.*** American Society for Testing Material.1994
32. ASTM C642. ***Standard Test Method for Density, Absorption, and Voids in Hardened Concrete.*** American Society for Testing Material.1 997.
33. KS 1780. ***Building Lime - Part 2: Test Methods***. KEBS, Kenya. 2010.
34. BS EN 12620. ***Aggregates for Concrete.*** BSI, London, United Kingdom. 2002
35. BS EN 1097. ***Tests for Mechanical and Physical Properties of Aggregates. Determination of Particle Density and Water Absorption.*** BSI, London, United Kingdom.1998.
36. KS EAS 148. ***Cements Test methods - Part 3: Determination of Setting Time and Soundness.*** KEBS, Kenya. *2000.*
37. BS EN 196. ***Methods of Testing Cement- Part 1: Determination of Strength.*** BSI, London, United Kingdom. 2005
38. BS EN 12350. ***Testing Fresh Concrete- Part 2: Slump Test.*** BSI, London, United Kingdom. 2000
39. BS EN 450. ***Fly ash for concrete -Part 1: Definition, specifications and conformity criteria.*** BSI, London, United Kingdom. 2012.
40. KS 05-459. ***Standard Specification for Drinking Water and Containerized Drinking Water***. KEBS, Kenya. *1996.*

7 APPENDICES

7.1 Setting Time and Mortar Compressive Strength Tests Results

Kenya Bureau of Standards

Fax: +254 (0) 20 604031/609660
E-Mail:info@kebs.org
Website: www.kebs.org

Laboratory Test Report

KEBS Centre, Popo Road
P.O. Box 54974, 00200 Nairobi
Tel.: (+254 020) 605490, 605550

Page 1 of 1

Report Ref: KEBS/TES/B/2140/12

PRIVATE SAMPLE

Date: 14 November 2012

1. Description of Sample: Cement Binder
2. Sample Submitted by: M.S.C STUDENT, UNIVERSITY OF NAIROBI
3. Customer Contact: Barrack Omondi Okoya
4. Customer's Ref. No:
5. Customer's Address: P. O. BOX 12012-00100, NAIROBI KENYA
6. KEBS Sample Ref.No: BS/23347/12
7. Date of Receipt: 08 October 2012
8. Date Analysis Started: 09 October 2012
9. Sample Submission Form No: 76125
10. Additional information provided by the customer:
11. Acceptance criteria-title and number of specification against which it is tested:
    As per Customer's Specifications
12. Parameters tested and Method(s) of test: as listed in the report below

LABORATORY TEST REPORT

No.	Parameters		Results	Requirements	Test Method No
1.	Compressive Strength				
I	14 Days	N/mm²	7.00	-	TES/MEC/TM/09*
II	2 Days	N/mm²	3.03	-	TES/MEC/TM/09*
III	28 Days	N/mm²	7.07	-	TES/MEC/TM/09*
IV	3 Days	N/mm²	3.21	-	TES/MEC/TM/09*
V	7 Days	N/mm²	5.46	-	TES/MEC/TM/09*
2.	Setting time				
I	Final setting time	Minutes	1485	-	KS EAS 148-1
II	Initial setting time	Minutes	285	-	KS EAS 148-1

Please note that tests marked with an * are covered by our current UKAS accreditation scope.

COMMENTS/REMARKS:
The sample performed as shown

Alvince Korero - Officer - Civil Engineering
FOR: MANAGING DIRECTOR

14 November 2012
Date of Issue

7.2 Chemical Analysis Test Results

MINISTRY OF ROADS

Telegraphic Address: "MINWORKS", Nairobi
Telephone: Nairobi 554950/3/4 Fax: 554877
E-mail: chief.engineer@materials.go.ke
If calling or telephoning ask for
When replying please quote

MATERIALS TESTING AND RESEARCH DEPARTMENT
MACHAKOS ROAD
INDUSTRIAL AREA
P. O. Box 11873
NAIROBI

Ref. No. M. 866/35/F/82/556

And date

30 August, 2012

Barrack Omondi Okoya
MSc Student Nairobi University
P.O. Box 12012 00100
NAIROBI

Dear Sir,

RE: CHEMICAL ANALYSIS OF AGGREGATES, RICE HUSKS ASH AND LIME
JOB CARD NO.00393/CH/12

The samples you submitted on 17/08/2012 gave the results shown below:-

Our Ref Your Ref	482/Ch/12 Sand	483/Ch/12 Ballast	484/Ch/12 Rice Husks Ash	485/Ch/12 Lime
Silica as SiO_2, % m/m	64.78	76.35	70.55	2.07
Insoluble Residue, % m/m	2.12	4.72	2.02	0.33
Loss on Ignition, % m/m	0.87	3.84	15.99	25.24
Iron as Fe_2O_3, % m/m	0.84	2.80	0.96	1.60
Aluminum as Al_20_3, % m/m	0.49	7.52	4.76	0.43
Calcium as CaO, % m/m	1.12	0.98	1.26	64.26
Magnesium as MgO, % m/m	0.46	0.47	0.75	0.51
Manganese as MnO, % m/m	0.20	0.04	-	-
Titanium as TiO, % m/m	0.65	0.23	-	-
Sulphates as SO_3, % m/m	0.44	0.94	0.30	1.48
Sodium as Na, ppm	3.0	190.0	146.0	16.0
Potassium as K, ppm	3.6	54.0	50.0	16.0

Your account of Kshs.4, 000/= has been settled vide receipt No. MR. 0284507 dated 17/08/2012.

Yours faithfully,

CHIEF ENGINEER MATERIALS
MINISTRY OF ROADS
P.O. Box 11873

Eng. S.K. Kogi
CHIEF ENGINEER (MATERIALS)

MINISTRY OF ROADS Enhancing Connectivity

7.3 Compressive Strength Tests Results

MINISTRY OF ROADS
CERTIFICATE OF TEST ON CONCRETE
(According to KS 02-594: 1986)

Telegraphic Address: "MINWORKS", Nairobi
Telephone: Nairobi 554950/3/4 Fax: 554877
E-mail: chief.engineer@materials.go.ke
If calling or telephoning ask for
When replying please quote
Ref. No. **M.077/35/J/1**

MATERIALS TESTING & RESEARCH DEPARTMENT
MACHAKOS ROAD
INDUSTRIAL AREA
P. O. Box 11873
NAIROBI

RECEIPT NO:**8840872**

8-Mar-12

PART A: CLIENTS INFORMATION
Project: **MSC Thesis project**
Sample Description/Structure:**B1a & B1b**
Job Card No:001472/**B/12**
Client's Name:**Barrack Omondi**
PART B:SAMPLE DESCRIPTION

Concrete Cube Marking:						
Design Concrete Class *	C20	C20				
Date Casted	3/3/2012					
Material Source:						
•Cement	Homalime					
•Sand	Machakos					
•Aggregates	National Concrete					
Cement Type (Strength)						
Mixing Ratio by Volume/Weight						
PART C: TEST REQUISITION/RESULTS						
Sample No.	96	97				
Date Tested	6/3/2012	6/3/2012				
Slump(mm)						
Age at Crushing Test (Days)	3	3				
Sample Dimensions:						
•Nominal (mm)	150	150				
•Measured (mm)						
Density as Received (Kg/m^3)						
Saturated Density(Kg/m^3)	2210	2130				
Loaded Area (mm^2)	22500	22500				
Maximum Load (KN)	3.1	1.4				
Compressive Strength(N/mm^2)	0.1	0.06				

* See Specifications Overleaf

CHIEF ENGINEER MATERIALS
MINISTRY OF ROADS
P. O. Box 11873,
NAIROBI.

Eng. S. K. Kogi,
CHIEF ENGINEER (MATERIALS)

MINISTRY OF ROADS
CERTIFICATE OF TEST ON CONCRETE
(According to KS 02-594: 1986)

Telegraphic Address: "MINWORKS", Nairobi
Telephone: Nairobi 554950/3/4 Fax: 554877
E-mail: chief.engineer@materials.go.ke
If calling or telephoning ask for
When replying please quote
Ref. No. **M.91/35/J/1**

MATERIALS TESTING & RESEARCH DEPARTMENT
MACHAKOS ROAD
INDUSTRIAL AREA
P. O. Box 11873
NAIROBI

RECEIPT NO:**9574506** **19-Mar-12**

PART A: CLIENTS INFORMATION

Project:**Thesis Project for Mr Barrack Omondi Okoya**
Sample Description/Structure:**1 & 2**
Job Card No.**001519/B/12**
Client's Name:**Barrack Omondi Okoya**

PART B:SAMPLE DESCRIPTION

Concrete Cube Marking:	B2a	B2b				
Design Concrete Class *						
Date Casted	7/3/2012					
Material Source:						
•Lime	Homa lime					
•Sand	Machakos					
•Aggregates	National concrete					
Cement Type (Strength)						
Mixing Ratio by Volume/Weight	1:2:4					
PART C: TEST REQUISITION/RESULTS						
Sample No.	371	372				
Date Tested	15/3/2012	15/3/2012				
Slump(mm)						
Age at Crushing Test (Days)	8	8				
Sample Dimensions:						
•Nominal (mm)	150	150				
•Measured (mm)						
Density as Received (Kg/m^3)						
Saturated Density(Kg/m^3)	2110	2130				
Loaded Area (mm^2)	22500	22500				
Maximum Load (KN)	74.2	62.8				
Compressive Strength(N/mm^2)	3.3	2.8				

*** See Specifications Overleaf**

CHIEF ENGINEER MATERIALS
MINISTRY OF ROADS
P.O. Box 11873,
NAIROBI

Eng. S. K. Kogi,
CHIEF ENGINEER (MATERIALS)

7.4 Laboratory Results of Fineness Modulus Tests on Fine Aggregates

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(Soil Mechanics Laboratory)

Sieve sizes	Cumulative mass	Cumulative % mass
2.36mm	19.6	3.9
1.18mm	65.3	13.1
600µm	148.6	29.7
300µm	68.6	13.7
150µm	88.6	17.7

FINNESS MODULUS

DATE: 22/9/2012 DESCRIPTION: SAND

Dry weight of Original Sample = 500.3g

Fineness Modulus = (3.9 + 13.1 + 29.7 + 13.7 + 17.7)/100 = 0.781

Fineness Modulus = 0.78

7.5 Laboratory Results of Specific Gravity and Water Absorption Tests on Coarse Aggregates

TEST No		1	2	AVERAGE
A	Mass of Saturated surface dry in Air (g)	725.5	829.6	
B	The mass of Pycnometer containing sample and filled with water (g)	2000.5	2056.6	
C	The mass of Pycnometer filled with water only (g)	1548.0	1549.1	
D	The mass of oven dried sample in Air (g)	704.1	807.8	
	Relative density on an Oven dried basis = D/A-(B-C)	2.66	2.57	2.62
	Relative density on a saturated and surface dried basis = A/A – (B-C)	2.66	2.58	2.62
	Apparent Relative Density = D/D-(B-C)	2.79	2.69	2.74
	Water Absorption (% of dry mass) = 100(A-D)/D	3.0	2.7	2.9%

7.6 Laboratory Results of Water AbsorptionTests on Fine Aggregates

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(Soil Mechanics Laboratory)

WATER ABSORPTION OF SAND

S/No	Determination No	I	II	III
1	Weight of saturated surface dried sample in g (A)	185.7	186.2	183.4
2	Weight of Oven dried sample in g (B)	183.7	184.0	181.5
3	Water Absorption $= \frac{A - B}{B} \times 100\%$	1.09	1.01	1.05
	Average Value = 1.05%			

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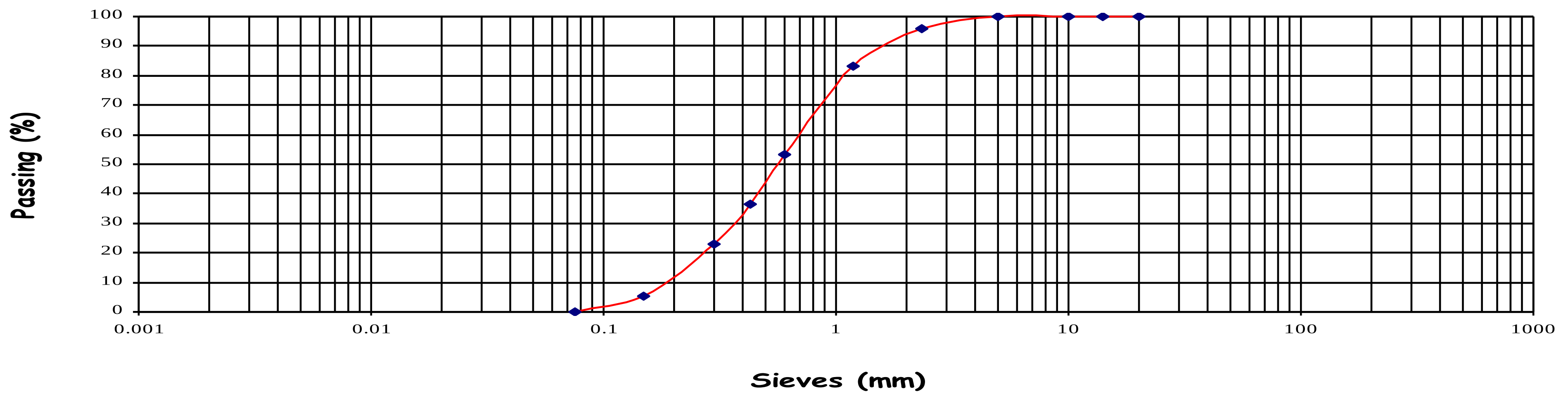
Sieve Analysis

CLIENT			
Sample source			
Depth (m)	SAMPLE No.		Sr. No.
Test date:	22-Sep-12	Location:	
Specification	According to BS 1377:1990.	Sample Description:	SAND



CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	COBBLES	BLD
	SILT			SAND			GRAVEL				

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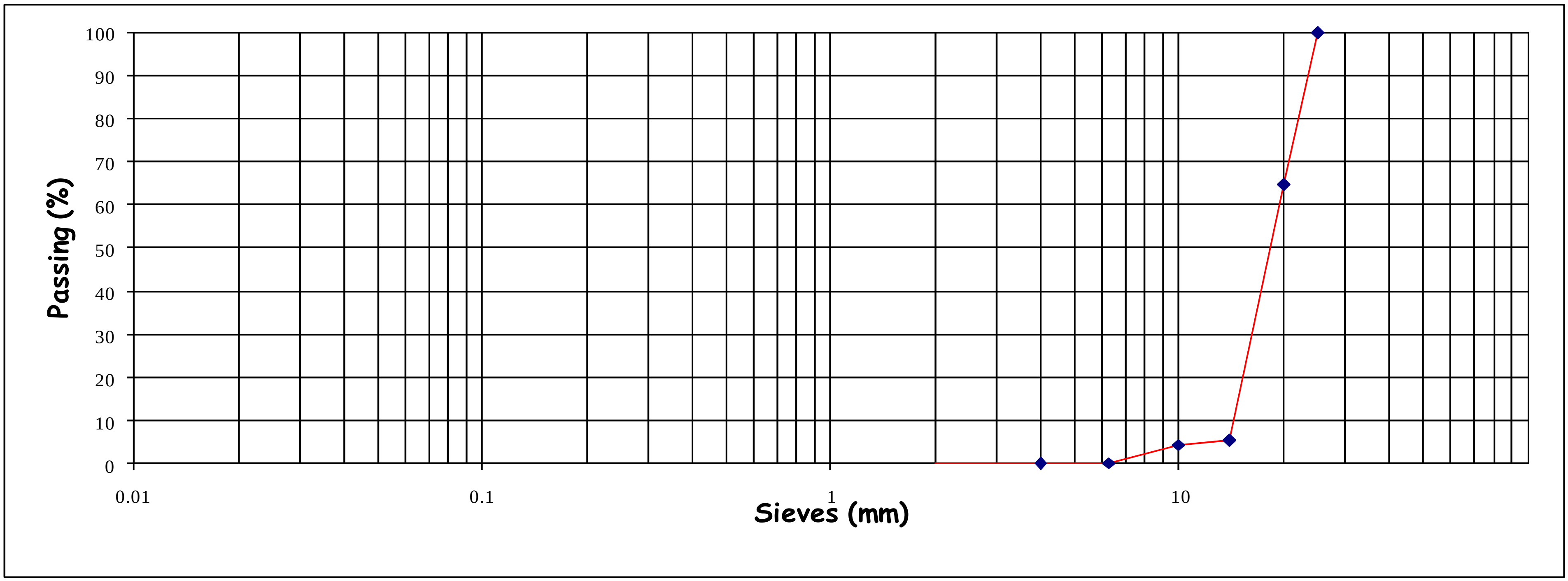
(Soil Mechanics Laboratory)

Sieve Analysis

Sample Type	AGGREGATES		
Sample source			
Sample Date		Sample N° :	
Test date:	24-Sep-12	Sample time	
Specification			



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SPECIFIC GRAVITY OF SAND

CLIENT					
Sample	SAND				
Depth (m)		**Test pit ID:**		**Sample. No.**	
Test date:	22-Sep-12	**Sample Description:**			
Specification	According to BS 1377:1990 Part			**Location:**	

Sample Number	**1**	**2**
Bottle Number	C	E
Mass of empty bottle (W_1)	74	59.9
Mass of bottle + Soil (W_2)	89.1	74.9
Mass of bottle + Soil+ Water (W_3)	195.4	175.5
Mass of bottle full of Water (W_4)	186	166.2
Mass of Water used ($W_3 - W_2$)	106.3	100.6
Mass of soil used ($W_2 - W_1$)	15.1	15
Volume of Soil ($W_4 - W_1$)- ($W_3 - W_2$)	5.7	5.7
Specific Gravity of Soil	**2.649**	**2.632**

$$GS = \frac{(W2 - W1)}{(W4 - W1) - (W3 - W2)}$$

Average Gs = 2.6405