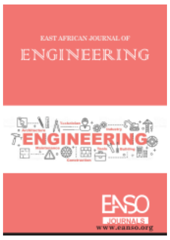

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Original Article

Investigation into the Effect of Rice Husk Ash in Partial Replacement of Cement in Concrete

John Alex Muthuri Njagi[1*], *Eng. Barrack Omondi Okoya*[1] *& Muthomi Munyua*[1]

[1] University of Nairobi P. O. Box 30197, GPO, Nairobi, Kenya.
* Author for Correspondence ORCID: https://orcid.org/0000-0003-1133-6610; Email: alexmuthuri1@gmail.com

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Rice Husk Ash, Burning, Pozzolana, Ordinary Portland Cement, Concrete.

ABSTRACT

The purpose of this study was to investigate the properties of Rice Husk Ash (RHA) as a partial cement replacement material in concrete production based on analysis of its contribution to strength in comparison with Ordinary Portland Cement (OPC). The analysis was focused on: the chemical properties of RHA, workability, density, compressive strength, and tensile strength of concrete. The RHA was obtained from Mwea, Kirinyaga County, Kenya and burned in a kiln to produce white ash which was tested. Chemical analysis to determine the pozzolanic properties of RHA was done using the Gravimetric method, Flame Photometry and Atomic Absorption Spectroscopy while particle size distribution of RHA was carried out using sieve analysis and hydrometer analysis. Concrete mixes with different ratios of OPC to RHA binder were cast into cuboid and cylindrical samples. The binder was made by replacing OPC with RHA at intervals of 10% by mass to a maximum of 50% replacement. A binder, sand, and ballast ratio of 1:1.5:3 were maintained with a constant water-cement ratio of 0.6. The cast samples were subjected to water curing on the third day at room temperature. Workability tests were performed on fresh concrete while compressive strength tests and tensile strength tests were performed on hardened concrete in all the mixes. The results were compared with OPC concrete. Results indicated that Kenyan RHA has high silica, alumina, and iron oxide content of about 92%. The workability slightly improves with 10% partial replacement of OPC with RHA but decreases with further addition of RHA. It was also deduced that the optimal binder mix was 10% partial replacement of OPC with RHA however the compressive strength was lower than the OPC concrete by 2.3%. The tensile strength of concrete increased with the addition of RHA up to an optimum of 10%.

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INTRODUCTION

According to Business wire (2021), the construction industry accounts for about 5.6% of Kenya’s GDP. Concrete is considered the backbone of the construction industry as it is one of the most common and widely used materials within the industry. Its versatility makes it suitable for construction as it is strong, durable, low maintenance and fire resistant. Cement is a key component in the production of concrete and its main raw material is limestone. As reported by the Business Daily (2021), the local demand and consumption of cement have risen gradually over the years to 6.5 million tonnes annually in 2020. Cements constitutes of about 75% limestone. Other ingredients include chalk or marl combined with shale, clay, slate, blast furnace slag, silica sand, and iron ore. These materials are incinerated in a clinker and then ground and mixed with a small amount of gypsum to produce cement. With limestone being a non-renewable natural resource and the demand for cement increasing, there is a necessity for alternative sustainable solutions for cement production that will have fewer adverse environmental effects compared to mining.

In Kenya, rice is the third most important cereal crop after maize and wheat (Romano M. Kiome (PhD), 2019). Milling of white rice during production results in about 28% of rice husk produced as a by-product. According to the local farmers and millers, the main varieties grown are Aromatic Rice, popularly known as Pishori and non-Aromatic Rice locally known as Sindano. The total annual world production of milled rice currently stands at 400 million metric tonnes with Kenya accounting for an estimated 0.04% of the global rice production at 160,000 metric tonnes (Romano M. Kiome (PhD), 2019; Knoema, 2020b). This results in annual rice husk waste of 44.8 metric tons meaning it is abundantly available and the bulk of it ends up being dumped in rivers or burnt in the open air. Rice husk contains about 40% carbon. Burning of rice husks in uncontrolled conditions results in this carbon being released into the atmosphere. The manufacture of cement on the other hand produces about 0.9 kilograms of CO2 for every kilogram of cement. Incorporating the use of rice husk ash in concrete production will thus help reduce the carbon emissions.

Rice Husk Ash (RHA) is considered a pozzolan due to its high abundance of silica, whose content is approximately 80-85% depending upon the temperature of incineration. The pozzolanic properties make rice husk ash a suitable material for mixing with cement to develop a stronger, durable cement. Studies have shown that the properties of RHA vary significantly with locality and the manufacturing process of the ash. The controlled temperature and environment of burning yield better quality rice husk ash as its particle size and surface area are dependent on the burning condition (Siddique & Khan, 2011).

The overall objective of this research was to investigate the properties of RHA as partial cement replacement material in concrete production based on analysis of its contribution to the strength and its comparison with Ordinary Portland Cement. The specific objectives of this research were:

- To ascertain the pozzolanic qualities of RHA.

- To observe the workability trend on fresh concrete with increase in RHA.
- To observe the density trend on fresh concrete with increase in RHA.
- To determine the optimum RHA to OPC ratio.
- To find out the maximum compressive strength of the optimum RHA to OPC mix ratio.
- To find out the maximum tensile strength of the optimum RHA to OPC mix ratio.
- To observe the compressive and tensile strength trend on hardened concrete with increase in RHA.

In the transformation of rice husk to ash, the combustion process eliminates the organic matter leaving a silica ash residue. The pozzolanic reaction will take place when reactive silica, which is denoted as SiO_2, is in an amorphous state. Reactions that take place in the preparation of Rice Husk Ash concrete are;

$$Si + O_2 \rightarrow SiO_2$$

Equation 1

$$C_3S \text{ (Cement)} + H_2O \rightarrow CSH + Ca(OH)_2$$

Equation 2

At temperatures of around 40°C and in the presence of water, the amorphous silica contained in rice husk ash (RHA) can react with $Ca(OH)_2$ to form one kind of C-S-H gel ($Ca_{1.5}SiO_{3.5} \cdot x\ H_2O$) (Yu et al., 1999). The highly reactive silica reacts with the unwanted calcium hydroxide released during the hydration of ordinary Portland cement, resulting in the formation of Calcium Silicate which is responsible for strength.

RHA in the past has been discovered to be a suitable raw material for making hydraulic cement (Mehta, 1977), a good corrective admixture for reducing expansion due to alkali - silicate reaction (Mehta & Polivka, 1976) and also to reduce the temperature in high-strength mass concrete (Mehta & Pirtz, 1978). The controlled temperature and environment of burning yield better quality of rice-husk ash as its particle size and specific surface area are dependent on the burning condition.

In 1984, it was discovered that the most convenient and economical burning conditions required to convert rice husks into homogenous and well-burnt ash, taking into consideration the quality of the produced ash and the energy used in its preparation, are 500 °C for 2 hours. The RHA produced can be classified as an artificial pozzolana of siliceous material, the material conforming to the chemical and physical requirements of class N pozzolan (ASTM C618) (Al-Khalaf & Yousif, 1984). The burning of RHA at different temperatures in the air always leads to the formation of silica ash, varying in colour. At 600°C the silica ash will form a white-grey colour, at 800°C a white colour and at 1000°C a white-pink colour (Mohd Amin et al., 2013). RHA is composed mostly of silica (87-97%) in the form of non-crystalline or amorphous silica with small amounts of inorganic salts. The type of ash varies considerably according to the burning technique. At 550–800 °C, amorphous ash is formed and at higher temperatures, crystallization will occur. The ash produced by controlled burning of the rice husk, i.e., between 550 and 700 °C of incinerating temperature for 1 hour, transforms the silica content of the ash into an amorphous phase (James & Rao, 1986). The burning temperature should be less than 900 °C to avoid the formation of α-cristobalite (a crystalline polymorph of quartz) (Hamad & Khattab, 1981). This is because the most important property of RHA that determines pozzolanic activity is the amorphous phase content. Hwang & Wu (1989), observed that at 400°C, polysaccharides begin to depolymerize. Above 400°C, dehydration of sugar units occurs. At 700°C, the sugar units decompose. At temperatures above 700°C, unsaturated products react together and form a highly reactive carbonic residue. The X-ray data and chemical analyses of RHA produced under different burning conditions given from their experiments showed that the higher the burning temperature, the greater the percentage of silica in the ash. According to

ASTM C618-19 (2019), if the sum of Silicon Oxide, Iron Oxide and Aluminium Oxide is more than 70% in a material, then the material would be declared as a pozzolanic material. As per the Kenya Bureau Standards, the sum should be 50%.(KS 02-1262, 1993)

C. L. Hwang & Chandra (1996), concluded that the high surface area in RHA is due to the micro-porous structure of individual particles therefore the RHA particles need not be very fine. RHA particles, in the range of 10-75 µm, exhibit satisfactory pozzolanic behaviour. Also, the impurities normally present in rice husk ash do not cause any adverse effect on the properties of Portland cement concrete.

Zhang & Malhotra (1996), investigated the influence of 10% RHA inclusion as a partial replacement of cement on the compressive strength of concrete. 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).

In Kenya, Kamau et al. (1993), investigated the properties of Kenyan RHA as a cement replacement and observed that the Silica content of Kenyan RHA ranges from 85% ± 1.47% (Mwea) to 89.44% ± 0.52% (Ahero). In addition, the Kenyan RHA met the ASTM C-618 standards for pozzolanic materials. They concluded that the amount of carbon in RHA can be controlled during rice husk pyro processing.

Amorphous silica in RHA was found to be transformed into crystalline states by heating to high temperatures around 1000 °C. Waswa-Sabuni et al. (2002), 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 an increased amount of RHA but the compressive strength of OPC/RHA mortar cubes decreases with an increased amount of RHA. Workability and setting times were found to decrease with increased amounts of RHA. Okoya (2013), found that the Kenyan RHA met the ASTM C-618 standard for a good pozzolana material with the combined percentage of Silica (SiO2), Iron Oxide (Fe_2O_3,) and Alumina (Al_2O_3) being 76.27%. However, the Silica content obtained after burning was significantly below the range provided by Kamau et al. in 1993.

MATERIALS AND METHODS

Source of Materials

Rice Husk Ash

The rice husk was obtained from Mwea Irrigation Scheme, Kirinyaga County, Kenya. The husks were first burnt under uncontrolled conditions in the open air for 24 hours. The open-air burnt rice husks were incinerated in a kiln at a controlled temperature of between 500°C and 700 °C. The kiln dimension is 46 cm by 56 cm by 50 cm. It is double insulated with thermal insulating diatomite bricks. The rice husks were placed in a cone-like sagger made of clay to protect the heating elements of the kiln. To observe the temperature, a thermocouple was inserted into the kiln and connected to a pyrometer from which the temperature reading was obtained. The kiln took 1 hour to fire between 500-750°C and 1 hour to cool the RHA back to 500°C from 750°C. Therefore, the temperature was maintained at between 500°C and 700°C for 2 hours with a 20-minute soaking time. If burning temperatures rises above 750°C, crystalline and less reactive ash develop (Bakar et al., 2010). The RHA obtained was white in colour. However, due to uneven heat distribution in the kiln, there were traces of black (unburnt) ash. To eliminate this, the ash was sieved and the residue which contained the large particles of unburnt ash was re-incinerated. The sieve used was a 250°m sieve as this would eliminate the unburnt ash.

Plate 1: Rice obtained after burning and sieving

The cement used was Bamburi Powerplus Ordinary Portland Cement (OPC). The cement was manufactured to standard specification KS EAS 18-1: 2001 and European Norm Standard EN 197 Part 1. It is classified as CEM I 42.5N Portland cement.

Water

The source of water for the production of concrete, and curing of the concrete test specimens were from the Nairobi Water and Sewerage Company Limited's pipelines, drawn from taps at the University of Nairobi department of Civil Engineering Laboratory.

Coarse Aggregates

The coarse aggregates were provided by the University of Nairobi. They were natural graded crushed stones (Basalt). Sieve analysis was carried out on the coarse aggregates. The aggregates ranged between 1 inch and ¼ inches.

Fine Aggregates

The fine aggregates were provided by the University of Nairobi as well. The river sand was obtained from river bed deposits originating from weathered and eroded rock.

Research Methodology

Chemical Characterization Tests

The chemical composition of the RHA samples was determined using Energy Dispersive X-ray Spectroscopy (EDXS), Atomic Absorption Spectroscopy (AAS), Gravimetric Method, Flame Photometry method and Loss on Ignition (LOI) at the State Department of Infrastructure, Materials Testing and Research Division Laboratories in Nairobi. Moisture content was determined at the University of Nairobi laboratory.

Physical Characterization Tests

The physical composition of the RHA samples was determined using the Specific gravity test, Sieve analysis and Hydrometer analysis at the University of Nairobi labs.

Batching, Mixing, Casting and Curing

Concrete of characteristic strength of 25 mPa was prepared using a standard mix proportion ratio of 1:1.5:3 with a water/cement ratio of 0.6. A control mix of 100% OPC was prepared and thereafter, 5 other mixes in which OPC was replaced with RHA by weight at a constant 10% incremental replacement up to 50% cement replacement with RHA.

The cement, RHA and aggregates were first dry-mixed in the mixer. The water was added gradually as the concrete is mixed. The mixer had a capacity of 0.065 m^3 therefore a mixing time of 2 min was adopted.

The concrete was placed in 150 mm cubes and 150 by 300 mm long cylinders. For each sample, 8 cubes and 2 cylinders were cast to give a total of 48 cubes and 12 cylinders. Casting was done as per BS- 1881-3:1970 specifications. De-moulding was done on the third day after casting and curing began immediately.

Workability Tests

This was determined by conducting a slump test and compaction factor test on each concrete mix.

Tests On Hardened Concrete

The mass of each sample was taken before the sample was subjected to a compressive and tensile strength test.

The compression testing machine that was used for this exercise was manufactured by ELE International. The machine meets the requirements of BS EN 12390-3, -4, -5, 12504-1, 1354, 1521, 3161, 1338, 772-6, 13286-41. The sample was placed centrally on the plate and the door closed. The load was applied at a constant loading rate of 6.8 kN/s until no greater load was sustained. The maximum load at failure and corresponding compressive strength of the specimen were read from the compressive machine's LCD screen.

Plate 2: Compressive Test and Tensile Test Machine

The tensile test machine used had a capacity of 2000 kN and was manufactured by Denison & Son Ltd. The test was carried out in accordance with BS EN 12390-6. The dried samples were placed horizontally on the testing machine with the sides in contact with the platen faces of the machine and a load was gradually applied to the cast sample till failure. The failure mode and failure load were noted.

RESULTS AND DISCUSSION

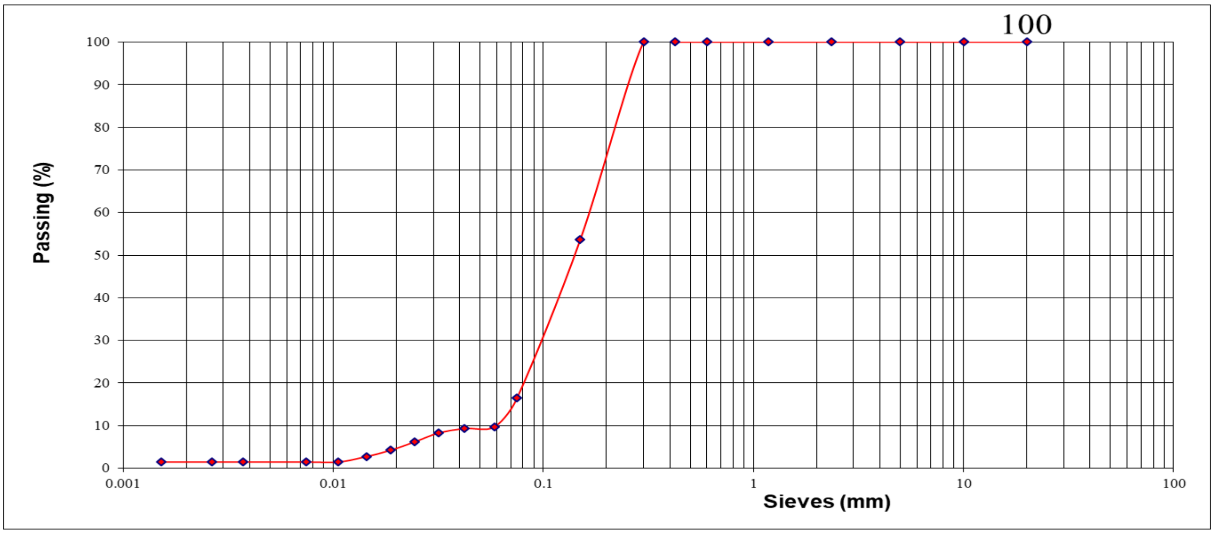
Physical Properties of RHA

Specific Gravity

The specific gravity of the RHA was found to be 2.11; significantly less than that of cement and is therefore within the recommended range and can be used to partially replace cement. The specific gravity of pozzolan is only slightly less than cement. It ranges from 2.1 to 3.0. A greater value affects the workability and strength of the concrete. Lower specific gravity is an indicator of a lower density; this means the partial replacement of cement substantially lowers the overall bulk density of concrete.

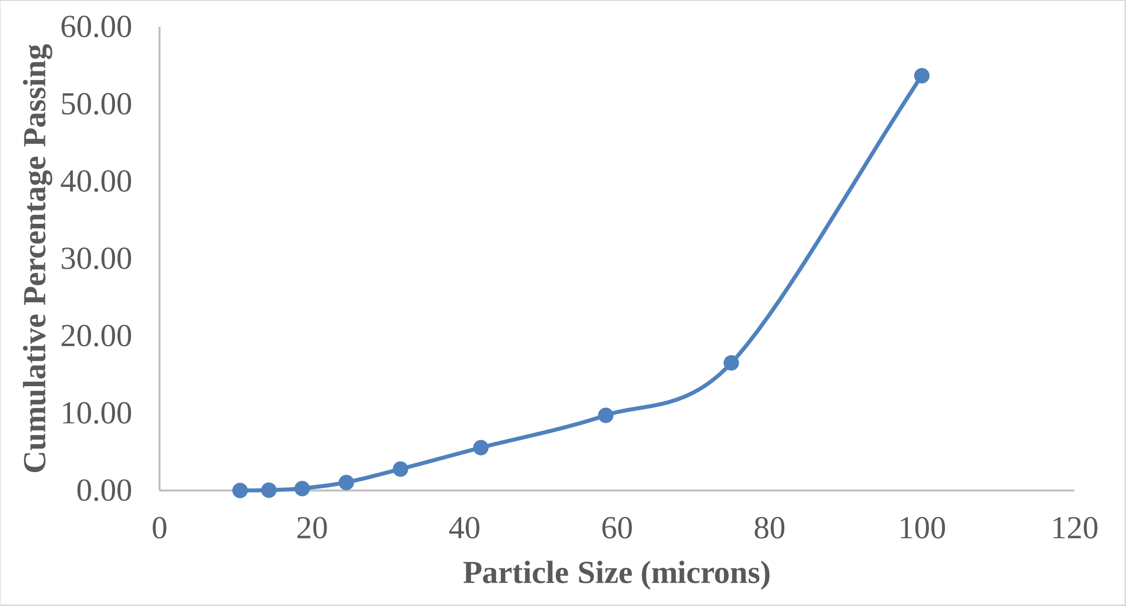
Particle Size Distribution

Figure 1: Particle Size Distribution of Hydrometer Analysis



From the shape of the gradation curve, a steep rise in the sieve size indicates a poorly graded sample. A poorly-graded sample has either an excess or a deficiency of a certain particle size. In the curve, particle sizes between 0.06 mm to 0.3 mm are excessively present (more than 90%). The particle sizes range from 10µm to around 59µm.

Figure 2: Cumulative Particle Size Distribution of RHA



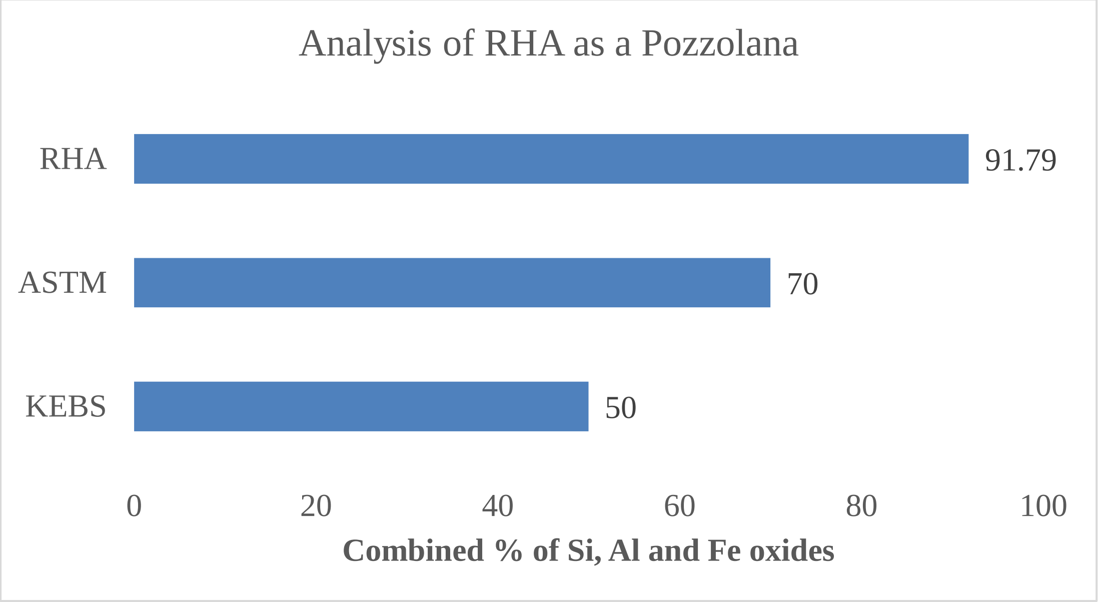
From the graph, it is observed that 53.7% of the particles in the sample has a size greater than 100 microns while the smallest particle size is 10.56 microns.

Chemical Properties of RHA

Table 1: Chemical Properties of the RHA

Property	Results Obtained	ASTM C 618 Requirements	Local Standards KS-02-1263
Loss of Ignition (L.O.I), % m/m	4.65	Maximum = 6	Maximum = 7
Silica as SiO_2, % m/m	91.79	Combined minimum = 70	Combined minimum = 50
Aluminium as Al_2O_3, % m/m	0		
Iron as Fe_2O_3, % m/m	0.217		
Calcium as CaO, % m/m	0.67	-	-
Magnesium as MgO, % m/m	7.33	-	-
Sulphates as SO_3, % m/m	0.069	Maximum = 5	Maximum = 3
Sodium as Na, % m/m	0.057	Maximum = 1.5	
Potassium K, % m/m	0.652	-	
Moisture Content	0.93	Maximum = 3	

Figure 3: Comparison of Chemical Properties of RHA with different standards



The chemical analysis of RHA indicates a combined percentage of 92.007% of Silica (SiO_2), Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3). 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 for Class F pozzolana. These three elemental oxides are the key potential indicators of a pozzolana. They react independently with CaO in the presence of water to form cementitious compounds such as calcium silicates, calcium aluminate and tetra calcium alumino-ferrite respectively. The silica imparts strength to the cement, the iron oxide is responsible for the hardness and strength of cement and the alumina imparts quick setting properties to the cement

$CaO + SiO_2 \rightarrow CaSiO_3$ (calcium silicate) Equation 3

$CaO + Al_2O_3 \rightarrow CaAl_2O_4$ (calcium aluminate) Equation 4

$CaO + Al_2O_3 + Fe_2O_3 \rightarrow (CaO)4 \cdot Al_2O_3Fe_2O_3$ (tetracalcium alumino-ferrite)

Equation 5

The analysis shows a Sulphur trioxide (SO_3) presence of 0.069% which is below the maximum amount of 5% and 3% as per the American and Local standards respectively. A high percentage of SO_3 causes the formation of secondary ettringite (calcium sufflaminate) in the concrete leading to its expansion and rupture, thus its low presence makes the RHA good for concrete production. sulphate ion reacts with $Ca(OH)_2$ to form gypsum which inhibits the flash setting of concrete by changing the course of hydration of calcium aluminate to form calcium aluminate hydrate which keeps cement in a plastic state at an early age of hydration. (Okoya et al., 2021).

$SO_4^{2-} + Ca(OH)_2 \rightarrow CaSO_4 \cdot 2H_2O$ (gypsum)

Equation 6

The CaO content of 0.67% is relatively low. The use of low CaO fly ash has been found to be effective in reducing pore solution alkalinity. The RHA used, being of low CaO content, is therefore expected to be more effective in controlling expansion due to the alkali-silica reaction.

The RHA has a sodium (Na) and potassium (K) content of 0.057% and 0.652% respectively. The oxides of the two elements are known as alkalis. They react with aggregates that have silica constituents and the product of the alkali-aggregate reaction causes the disintegration of the concrete. They also affect the rate of gain of strength of the concrete. Therefore, a low amount of the two elements makes the RHA good for concrete production.

The RHA has a moisture content of 0.93% which is below the maximum set limit of 3% for a class F pozzolana as per ASTM C 618.

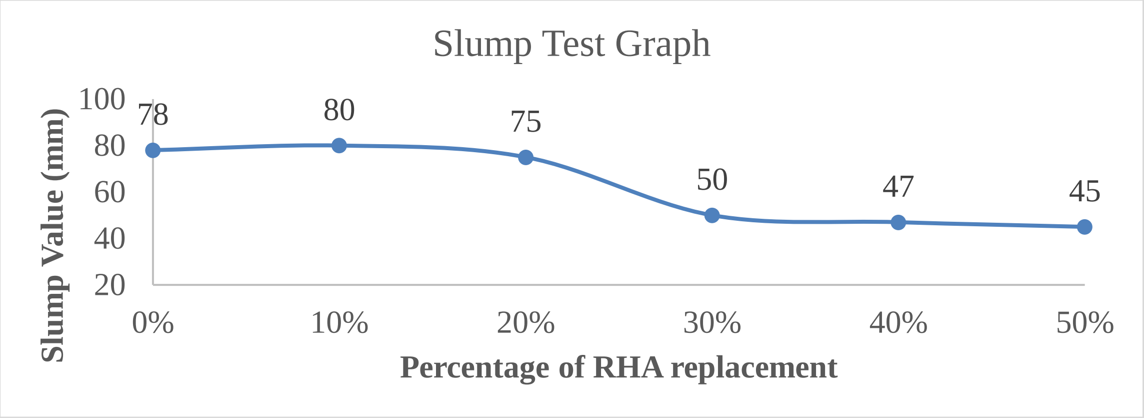
The loss of ignition (LOI) of 4.65% was within the limit of 6% for ASTM C 618 and 7% for Kenyan Standards which is the requirement of other pozzolanas used as cement replacement materials. The LOI is an indicator of inorganic matter in the RHA samples. It indicates to what extent the pyro-processing was incomplete. The LOI determines the water content and/or carbonation in the binder as these reduce the quality.

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.

Workability

Slump Test

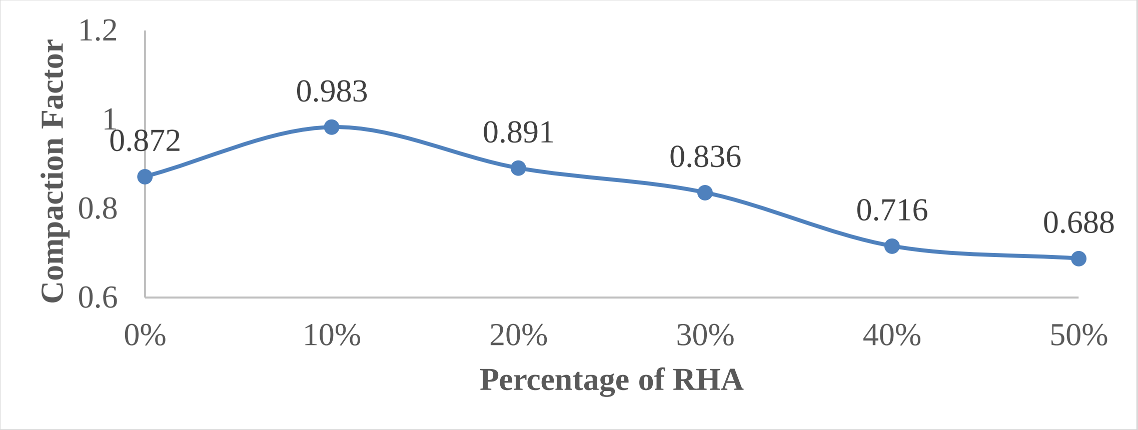
Figure 4: A Graph of Slump against RHA replacement in cement



From the graphical analysis presented above, we can observe that the slump slightly increases by 2.6% with the addition of RHA up to 10% partial replacement. Afterwards, an increase in RHA results in a corresponding gradual decrease in the slump values. 0%, 10% and 20% of RHA in the binder mix can be considered to have medium workability while the 30%, 40% and 50% mixes are considered to have low workability.

Compaction Factor Test

Figure 5: Compaction Factor Graph



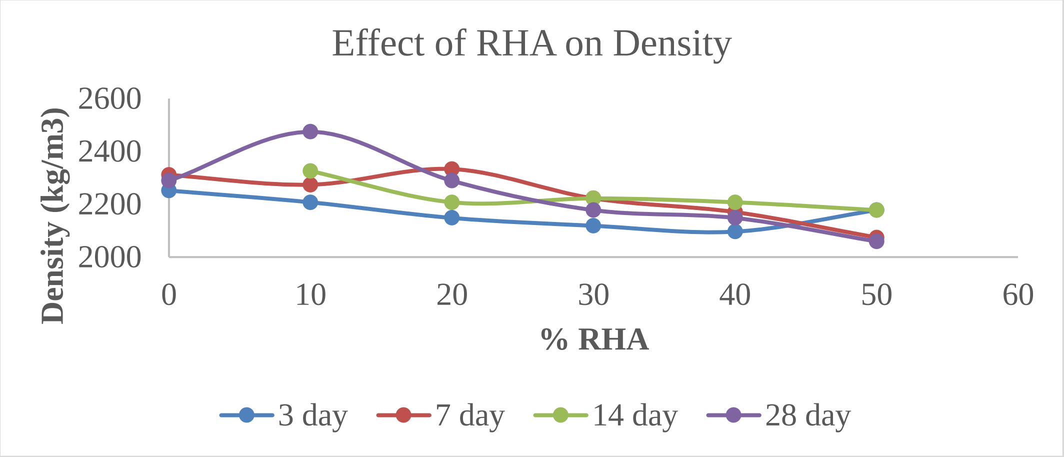
From the graph above, it is observed that there is an initial increase in workability with partial replacement of cement with RHA up to 10%. Thereafter, there is a gradual decrease in workability. 0% and 20% mixes of RHA in the binder can be considered to have low workability, the 20% mix can be considered to have high workability while the 30%, 40% and 50% mixes are considered to have low workability.

The slump and compaction factor test results show a similar trend in terms of the workability of the mixes with the 10% mix being the optimum. This can be attributed to the RHA being of coarser particles than the cement particles hence the slight increase in workability as less water is required to wet the specific surface of the binder. However, as the RHA content increases, the water demand increases due to the larger surface area of the RHA and thus the workability reduces. This can be compromised by the incorporation of Super-plasticizers or any adequate admixtures.

Hardened Concrete Test Results

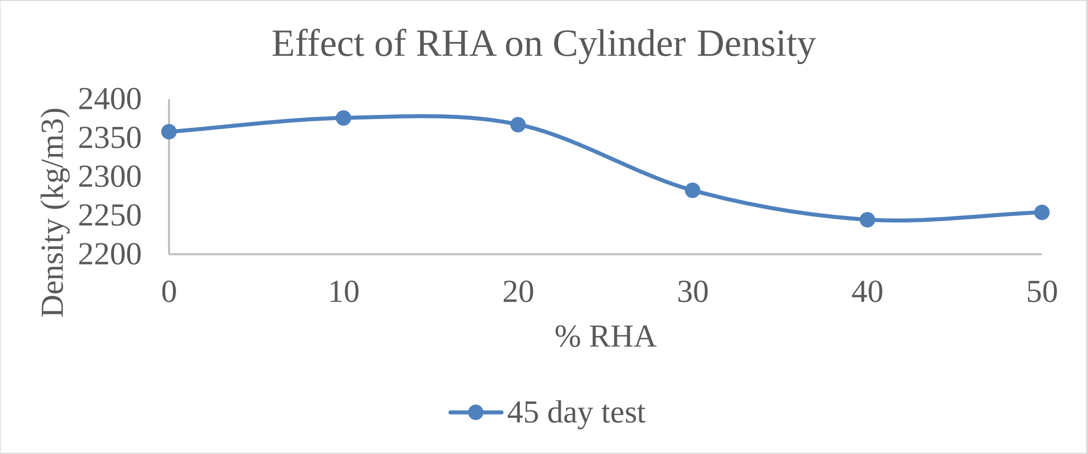
Density

Figure 6: Comparison of Cube Density



Good quality concrete has a density of 2400 kg/m3. From the graph above, only the 10% RHA mix can be considered to have good quality concrete after 28 days of curing. The density of the 10% RHA mix is steadily increasing as the curing days progress while for the other mixes, the optimum density occurs before the 28th day. It can also be noted that for all the mixes apart from the 50% mix, the 7-day density is higher than the 3-day densities. This can be attributed to the fact that water curing began after 3 days hence the immediate increase in density once water curing begins. For the 50% mix, the maximum density is achieved on the 3rd day when the sample has only been air cured. The 28-day density is highest in only the 10% mix, while in the 20%, 30% and 40% mixes, the 7-day test is the highest. There is also a general decrease in densities as the percentage of RHA in the binder mix increases.

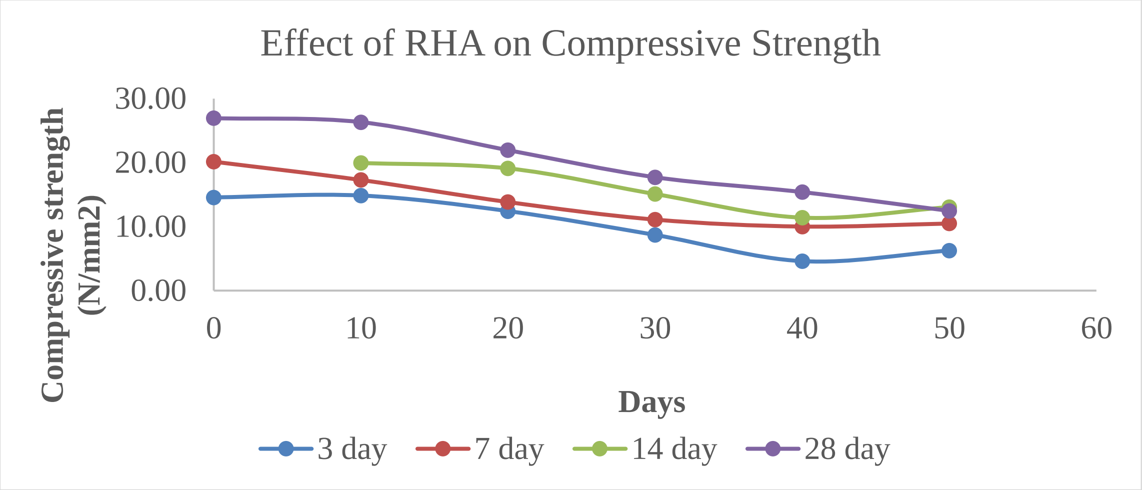
Figure 7: Comparison of Cylinder Density



It can be observed that the density of the cylinder increases for the 10% and 20% mix compared to the control mix. However, despite the increase in density, the value is below 2400 kg/m^3, which is the density of good quality concrete. The 30%, 40% and 50% mixes were below the control strength.

Compressive Strength

Figure 8: Comparison of Compressive Strength



From the above graphical analysis, there is a steady increase in compressive strength in all the mixes as the 28th day approaches apart from the 50% mix which peaked at 14 days. The 10% mix attained the highest compressive strength of 26.33 N/mm^2. This was however below the compressive strength attained by the control experiment.

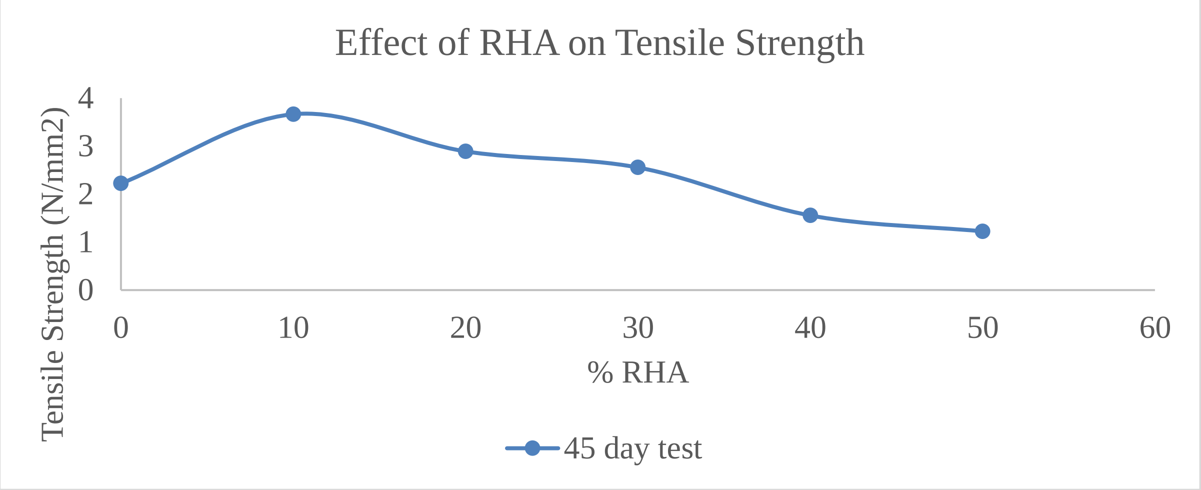
The variations in strength between the control and 10% are observed to be diminishing as the days progress with the 10% mix showing a steeper strength trend line than the control. The RHA mixes are indicating signs of late strength gain apart from the 50% mix.

The gradual increase in strength can be attributed to the formation of Calcium Silicate Hydrate (CSH) as the silica in RHA reacts with the Calcium Hydroxide (CH) produced when the cement reacts with water. The CSH is responsible for the strength gain in cement while the CH is the weak link in cement in that the amount of CH is not a desirable product in the concrete mass as it is soluble in water and may get leached out making the concrete porous, weak, and not durable. CH also reacts with sulphates present in water to form calcium sulphates which further react with C3A and causes deterioration of concrete. For the CSH to be produced, the cement must first react with water to produce the CH and only afterwards will the RHA react with CH. This explains why the RHA mix gains strength with time hence the steep upward curve.

The 50% has a 14-day peak which can be an indicator of the endpoint of the reaction between the RHA and the CH. The cement in the mix reacted with water and CH was produced, however, the silica required to react with the CH was in abundance and hence more RHA was present than required. The loss of strength may also be attributed to the crystallization of unreacted RHA that leads to the formation of voids hence loss of strength. The 20%, 30% and 40% mix show an increase in deviation from the control as the days progress. They are yet to reach an optimum value within the 28 days meaning that the endpoint of the reaction has not been reached.

Split Tensile Strength

Figure 9: Comparison of Tensile Strength



The tensile strength of concrete increases with an increase in RHA up to an optimum of 10% replacement and beyond that the strength decreases as shown in the graph. The increase in the tensile strength of 10% and 20% replacement is probably due to the formation of CSH gel and less voids due denser configuration of the concrete. The decrease in strength may be attributed to the crystallization of excess RHA that did not react leading to the formation of more voids, the presence of residual silica that may lead to leaching and the lack of further formation of CSH gel that is responsible for strength gain in concrete.

CONCLUSION AND RECOMMENDATIONS

Conclusions

The following conclusions were made during this study;

- The RHA studied is a good pozzolanic material for use in concrete production, with a combined percentage of Silica (SiO_2), Iron Oxide (Fe_2O3) and Alumina (Al_2O_3) of about 92%.

- The workability of fresh concrete slightly improves with 10% partial replacement of cement with RHA. Further increase in the amount of RHA in the binder decreases the workability of fresh concrete.

- The density of hardened concrete increases with 10% partial replacement of cement with RHA. Further addition in the amount of RHA in the mix reduces the density of the concrete to below the control density.

- The optimum mix ratio of OPC to RHA binder is 10% RHA to 90% OPC.

- Maximum compressive strength of 26.33 N/mm^2 was achieved at 10% partial replacement of OPC with RHA.

- The maximum tensile strength obtained was 3.67 MPa, achieved at 10% partial replacement of cement with RHA.

- The tensile strength just like the compressive strength increases with an increase in the RHA partially replaced up to an optimum value then the strength gradually decreases beyond the optimum.

Recommendation

Based on the findings, the following recommendations were made:

- RHA is a suitable material for use as pozzolana and can be used to replace OPC with the optimum content being 10%.

- The optimal OPC to RHA mix (10%) could be used to make class 25 concrete. The compressive strength of concrete made from the resulting optimal blend is good enough for structural applications that require class 25 concrete.

- The use of RHA as a partial replacement for cement is sustainable therefore it is recommended to reduce environmental degradation such as the utilization of rice husk waste hence reduction in landfill and reduction in emission of greenhouse gases as a result of reduced cement manufacture. It will also encourage further production of rice within and outside the rice-growing regions of the country and hence boost food security.

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