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Characteristics of Kenyan Rice Husk Ash Produced Under Controlled Burning

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Abstract*: Rice husk is an agriculture by-product obtained from theprocessing of food crop of paddy, with no major alternative use. Research publications have concluded that rice husk ash possesses pozzolanic properties and that these properties vary very much with locality and depend on the manufacturing process including the burning and grinding process. Use of pozzolanic alternative or cement replacement materials is expected to reduce construction costs as well as reduced carbon emissions resulting from cement manufacturing process. In addition pozzolanas increases compressive and flexural strengths, reduces permeability and boosts resistance to chemical attack in concrete. The scope of the research in this paper covered an experimental analysis of the physical and chemical properties of the rice husk ash produced from a controlled burning of rice husk sourced from Mwea Irrigation Scheme, Kenya. Prior to the experimental analysis, controlled burning of the rice husks was conducted at a temperature range of 300 - 500˚C; 500 - 700˚C and 700-900 ˚C each with a 3-hour soaking time. The resulting ash samples were then characterized using energy dispersive x-ray spectroscopy, atomic absorption spectroscopy, loss of ignition, color, specific gravity, particle size distribution and fineness. The results show that, the rice husk ash had distinct color variation at each burning temperature. The amount of silica present in the rice husk ash varied with the burning temperature, approximately in the range of 80% to 89% taking more than 50% of the total elemental composition. Rice husk ash indicated higher, loss of ignition when produced at lower temperatures. It was established that amorphous rice husk ash in a controlled burning could be produced at temperature range of 500-700^{0}C.

Keywords: Controlled burning, amorphous ash, Rice Husk Ash, Burning temperature and time.

I. INTRODUCTION

Concrete is one of the most widely used materials in the construction industry in Kenya. Concrete is produced by mixing cement, coarse aggregates (ballast), and fine aggregates (sand) with water. The mixture is allowed to harden by hydration. Cement, which is the basic binding agent of all the concrete constituents, is becoming increasingly expensive, and in addition, the manufacturing process results in increased carbon emissions. Cement manufacturing is a highly energy intensive process and produces emissions such as dust, noise, CO_2, NO_2, SO_2. The need for a sustainable construction has led to the exploitation of agricultural wastes such as Rice Husk Ash(RHA), Sugarcane Bagasse Ash(SCBA), Palm Oil Fuel Ash (POFA) to be used as partial replacement of the high energy intensive Portland cement to produce durable concrete. Among the plant wastes, RHA is the most reactive pozzolan since it contains the highest proportion of silica. The rice plant ingests orthosilicic acid from the ground water which is polymerized to form amorphous silica in the ash, Kamiya et al., (2000).

According to Mehta and Malhotra (1996), pozzolans are defined as siliceous or siliceous and aluminous material which in themselves possess little or no cementing property but will react with calcium hydroxide($Ca(OH)_2$ in a finely divided form in the presence of water at ordinary temperature to form compounds possessing cementing properties. This reaction forms compounds with cementing properties according to the following chemical equation:

$2SiO_{2(S)}+3Ca(OH)_{2(aq)} =3CaO.2SiO_2.3H_2O_{(s)}$ …….Equation 1

The RHA can be used as a pozzolanic material since it has a highly microporous structure and contains an amorphous silica which is responsible for the pozzolanic reaction in mixtures containing Portland cement. Abdul Kadir (2006), B Waswa Sabuni et al., (2002), did a chemical analysis of the RHA which showed the presence of minor elements in RHA with silica taking up more than 50% of the elemental oxide composition meeting the requirement of a good pozzolanic material. Sugita (1994), James and Rao (1986), showed that the amorphous silica in RHA and $Ca(OH)_2$ in hydrating cement can react to form calcium silicate hydrate gel (C-S-H) which is responsible for hardening of the concrete mortar. Andrea B et al., (2019) studied the structure of the RHA and found that it has three layers (outer, inner and interfacial) with honeycombed and interstitial pores. These pores are responsible for the high chemical reactivity and large surface area.

Factors determining the applicability of RHA as a pozzolanic material are; its availability and accessibility of reactive silica sites which is crucial for the development of durable concrete. However, production of such reactive pozzolanic material is dependent on burning. On average Rice Husks (RH) forms 20% of the total paddy and can generates 25% of ash upon burning according to R Siddique, (2008). Annual consumption of rice in Kenya is

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estimated at 3,000,000 metric tons according to the National Cereals and Produce Board, (2013) hence availing 600,000 metric tons of RH annually with little or no alternative use.

Burning condition (controlled or uncontrolled) is the major determinant of the burning temperature and time to produce RHA with maximum reactivity. Combustion destroys the inorganic matter (cellulose and lignin matrix) in the rice husks (RH) leaving a porous silica skeleton ash with a high surface area capable of a pozzolanic reaction. Combustion affects the surface area, reactive sites of the RHA, therefore temperature, time and burning environment must be properly selected to produce a predominantly amorphous ash.

Previous research has utilized RHA derived from uncontrolled burning in their investigation. This burning condition presented a high carbon content ash, dominant crystalline ash which compromised the reactivity of the ash and longer burning duration. Smith and Kanyamwanja (1986) observed that at 800ºC with along exposure time of 12 hours resulted in small proportion of crystalline silica. Chandrasekhar et al (2003), observed that in uncontrolled burning, RHA produced at a temperature below 400^0C contained unburnt cellulose material under short burning time nevertheless has a maximum reactivity with 6 – 12 hours and 500^0C with 8-12hours.

Controlled burning condition for example in a programmable electric kiln produces satisfactory ash: a white highly reactive pozzolan with amorphous silica, small carbon content and high specific surface area is produced and the burning time is also shorter. Khassaf et al., (2014), observed that in a controlled burning process the combustion temperature should be about 550˚C and at duration of about 2hours to produce optimum amorphous ash. Madandoust et al., (2011), produced ash by controlled burning of the RH between incinerating temperature of 550^0C-700^0C for 1hour. Khalaf and Yusuf, (1984), produced a highly reactivity ash when RH is burnt at 500^0C for 2 hours.

Toledo and Morcaes, (2009), in their study of the application of ultrafine RHA as a pozzolan described an amorphous RHA as a white highly reactive ash with low Loss of Ignition (LOI) and high specific surface area. Jaya et al, (2013) did a study on silica phases of grey, white and white pink ash. Results from XRD analysis show that the amorphous ash phase was exhibited in the grey and white ash, while crystalline phase was in the white pink ash.

Therefore, to produce silica in amorphous form or become crystalline, two factors are important: incineration temperature and time, Della et al (2002). RHA presents silica in distinct phases that is; amorphous – quartz – crystobalite - tridymite which is a gradual transition from one phase to the other as the burning time and temperature increases. Gonzalves and Bergmann (2007) showed that the properties of the RHA depend on the ecological circumstances of its origin (soil chemistry, fertilizer applied, type of rice) as well as the burning process.

This study is aimed at analyzing the chemical and physical properties of the RHA in Kenya; a case study on Mwea RHA produced under controlled burning with burning temperature as the only variable.

II. METHODOLOGY

A. Sampling

One gunny bag (approximately 90kg) of RH was collected from Taji rice millers of Mwea, Kirinyaga County in Kenya.The RH sampled was free from impurities such as soil blocks, grains which would otherwise accelerate crystallization process.

B. Rice Husk Incinerator

Thermal treatment of the specimen was carried out in a laboratory programmable furnace (Nabertherm, model N300). The electrical connection was 3-phase with a maximum heating temperature of 1300^0C. The chamber kiln was being heated from five sides and a special arrangement of the heating elements ensured optimal temperature uniformity. Heating elements on support tubes ensured free heat radiation. The programmable furnace was self-aerating with semi-automatic air inlet flaps for optimum ventilation of the kiln.

C. Burning the Rice Husks

The specimen was subjected to a controlled isothermal burning. RHA samples were prepared by burning 90grams of rice husks placed in a ceramic tray inside the programmable furnace at different burning temperature of 300-500-700-900˚C each with a 3-hour soaking time. Complete combustion was ensured by; burning just enough rice husks, working with a shallow crucible so that the rice husks are always below the air inlet flaps and allowing the RHA samples to slowly cool inside the furnace. Testing regimes incorporated were; controlled isothermal burning, temperature variation, constant burning duration of 3 hour and slow cooling of the RHA.

Plate 1: Programmable Furnace (Nabertherm, model N300)

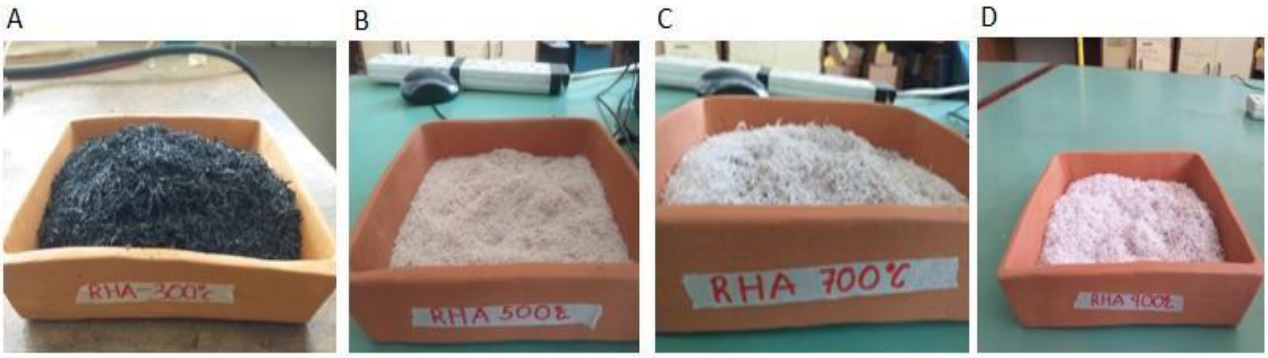

Plate 2: Rice Husk Ash Produced at Different Burning Temperature:
(A - Black**, **B - White Grey**, **C White** and **D - White Pink)

RHA samples produced were stored in airtight zip bags to prevent any kind of chemical reaction of the ash samples with the atmospheric air. The bags had unique designations to avoid any confusion.

D. Testing of Chemical composition of the Rice Husks Ash

Chemical composition of the RHA samples was determined using Energy Dispersive X-ray Spectroscopy (EDXS) and Atomic Absorption Spectroscopy (AAS) at the State Department of Infrastructure, Materials Testing and Research Division Laboratories in Nairobi

III. RESULTS AND DISCUSSION

A. Physical properties of RHA

1) Color

The rice husks burnt at different temperatures gave distinct colours (Plate 2), i.e. at 300^0 C (black), 500^{0}C (white grey), 700^0 (white), 900^{0}C (white pink). Rice husks contain carbon which is eliminated upon burning. The amount of carbon being eliminated is dependent on the firing temperature. At lower temperatures of 300^{0}C, the ashes were observed to be black, and then turned into white grey, white and pink white at higher burning temperature. The difference in colour transition is due to the removal of unburnt carbon content in the rice husks ash. As the temperature increases, residual carbon content decreases. At these temperature ranges, there is a complete reaction of sequence from amorphous silica to crystalline silica; crystobalite and quartz. To eliminate significant amount of unburnt carbon from the ashes, burning should be done to higher temperature of at least 500^{0}C with significant amount of burning time. Colour is an indicator of the amount of carbon content present in the ash.

2) Odour

The obtained RHA were odourless.

3) Appearance

The ashes obtained from the different temperature ranges were all solid and irregularly shaped. There was a disparity in their texture. At a temperature of 3000C, the ashes were rough in texture. As the temperature increased from 5000C to 9000C, the ashes were fine powder. This is because the elevated ash temperature resulted into a more complete burning of the rice husks greatly reducing its size and particle distribution.

4) Particle size distribution

The average diameter of RHA was about 60.54 um with a specific gravity of 2.05.

B. Chemical Characterization of RHA

The results of the chemical analysis are shown in Table 1. From the results, silica is the dominating elemental oxide taking more than 80% of the composition. Silica content generally increased with increase in burning temperature. The abundance and consistency were because, silica content

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in the RHA is dependent on ecological circumstances and type of rice grown.

The combined percentage proportion of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) in the RHA is of major interest in this chemical analysis. 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, tetracalcium alumino-ferrite and calcium aluminate respectively. These hydration products aid in initial setting of the concrete where Calcium Silicate Hydrate, (C-S-H) gel forms a coating on cement grain retarding hydration at the initial setting phase. At the final setting stage, these hydration products hinder movement of cement grains such that the paste becomes rigid.

This chemical reaction of the elements is a long-term process if moisture is available and release of lime is continued as well as enhancing continual strength development in concrete. The American Society for Testing and Materials (ASTM C618) standards on pozzolana and fly ash suggests that materials with a mean amount of (SiO_2 + Fe_2O_3 + Al_2O_3) exceeding 70% in composition could be suitable for use as a pozzolana. Comparatively,

Kenya Bureau of Standards (KEBS) KS -02-1263 suggests a minimum of 50% for the mean amount of (SiO_2 + Fe_2O_3 + Al_2O_3) in the RHA. The values reported in Table 1 and analyzed in Figure 2 shows that all the samples meet this criterion for ASTM C618 and KEBS (KS -02-1263) standards for chemical composition of the pozzolana.

Table 1: Chemical properties of the RHA in Percentage (%) by Weight

Property	RHA 300^{0}C	RHA 500^{0}C	RHA 700^{0}C	RHA 900^{0}C	ASTM C618 Standards	Local standards KS -02-1263
Loss of Ignition (L.O.I)	55.8	6.12	2.78	1.3	Maximum=12%	Maximum=7%
Silica as SiO_2	82.06	80.50	83.28	89.33	Combined > or =70%	Combined > or =50%
Aluminium (Al_2O_3)	0.087	0.020	0.013	0.011		
Iron oxide (Fe_2O_3)	0.70	0.79	0.49	0.70		
Calcium oxide (CaO)	1.63	1.38	1.28	1.25	_	
Manganese oxide (MnO)	0.72	0.62	0.63	0.66	_	
Potassium oxide(K_2O)	14.71	16.53	14.00	7.90	_	
Phosphorous Oxide(P_2O_5)	2.03	2.82	2.07	1.53		
Sulphate (SO_3)	0.18	0.16	0.19	0.14	Maximum=5	Maximum = 3
Sodium (Na)	0.045	0.029	0.045	0.049	Maximum=1.5	
Potassium as K,	0.138	0.073	0.188	0.1702	_	
Zinc oxide as ZnO,	0.016	0.02	0.01	0.016	_	

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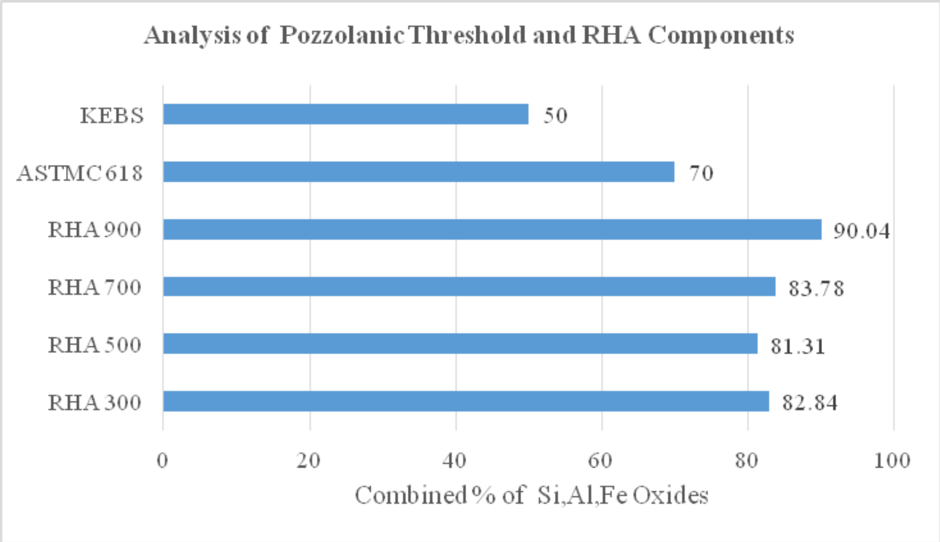

Fig. 1: Chemical Properties of RHA with Different Temperatures

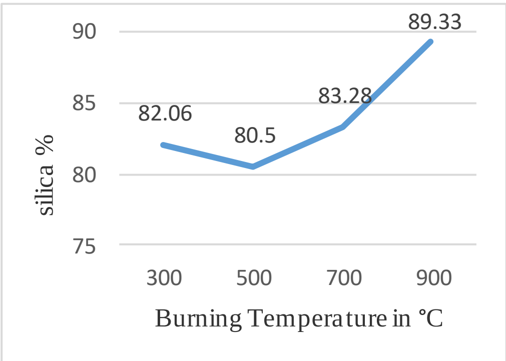

Fig. 2: Variation of Silica Content in the RHA with Burning Temperature

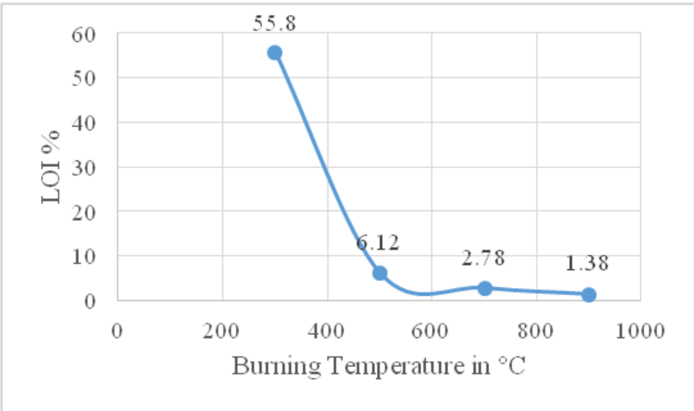

Fig. 3: Variation of Loss of Ignition with Burning Temperature

The loss of ignition (LOI) is an indicator of inorganic matter in the RHA samples. It indicates to what extent the pyro-processing was incomplete. The results indicate that thermal treatment is directly proportional to the LOI. Burning at 300^0C had the highest LOI of 51.49% with 900^0C having the least (LOI) of 0.80%. ASTM C618 sets a maximum LOI value of 12% and KS -02-1263 sets a limit of 7%. All other burning temperatures attained this criterion except for 300^0C with a LOI value of 55.8% which could be attributed to incomplete combustion. Therefore, RHA with acceptable LOI values can safely be produced under high burning temperature of 500^0C and above with sufficient burning time. Under low temperatures (<300^0C), the production of RHA does not meet the quality standards especially on carbon emitted to the environment. High LOI values influence the strength properties of concrete mortar by inhibiting setting of concrete.

RHA used has exhibited very small amounts of sulphate contents with a range of 0.14% -0.19% which is below the max requirement of 5% by ASTM C618 and 3% by KS -02-1263. Sulphate has a dual role in concrete depending on its concentration in the concrete mix. Sulphate is beneficial when used in small quantity up to about 3% as stipulated by Specification on Portland Pozzolana cement IS 1489:1991. In a threshold limit sulphate ion react with $Ca(OH)_2$ to form gypsum which inhibits flash setting of concrete by changing the course of hydration of calcium aluminate to form calcium aluminate hydrate which keeps cement in plastic state at early age of hydration. Ettringite formed within limits at initial stages of hydration, the expansion results to internal compaction matrix by filling the porosity of the matrix resulting into densification and strength in the concrete. Excessive amounts of sulphate derived from concrete constituents can cause expansion in the concrete. Sulphate reacts with products of cement hydration phases causing Internal Sulphate Attack (ISA).

Minor elemental oxides such as Mn, P, Zn, K were present in the RHA samples. These minor elements are introduced into the soil through fertilizer application. The amounts of these minor oxides were generally low. However, the oxide of potassium occurred in considerably higher proportions. It was found to be in a range of 7.9% - 16.53%. Potassium is an essential nutrient in plant growth. It Keeps plants from wilting and helps in proper stomata opening. For continuous increase in yield, soil should always be replenished with K^+ ions nutrients. Availability of rice husks will promote its application as a pozzolanic material. Continued growth and harvest of rice could lead to deficiency of these nutrients from the soil hence constant replenish should be encouraged.

In conversion of the RH to RHA the combustion process removes the organic matter and leaves a silica residue ash. However, such thermal treatment of the silica in the ash results in structural transformation of the ash from amorphous to crystalline. This transition is a gradual process influenced by burning time and temperature. As observed, the RHA produced gave distinct colors, an indication of a complete reaction from amorphous to crystobalite and tridymite (crystalline phases.) Many researchers have suggested that RHA produced under low temperature of 700^0C and below with a burning time ranging between 1-3 hours is mainly amorphous, which has been associated with white color. From this study the ashes produced between 500^0C -700^0C were observed to be white brown and purely white respectively. From previous findings, it can be concluded that the ashes from these temperatures were amorphous.

From literature above, exposing rice husks to temperatures of 800^0C and above with considerable amount of burning time (past 30mins), crystobalite and tridymite are crystallized at these temperatures. At a temperature of 900^0C, the ash observed was pinkish white in color. It could have attained its crystalline phase at this temperature. These physical distinct differences give a clear indication in differences of their structural form. This suspicion in structural form difference can be verified by XRD which gives the crystalline phases and SEM which outlines the surface morphology of the ash.

IV. CONCLUSION

The results of the study on RHA has established it as an efficient pozzolanic material and meets the set standards by the ASTMC 618 and KEBS which are applicable in Kenya when burned at temperatures above 500^0C.

The chemical composition of the RHA is significantly dependent on combustion conditions such as burning time and temperature. To keep the silica ash in an amorphous phase burning should be under low temperature. Based on the colour changes, it can be concluded that amorphous ash was produced at a temperature below 700^0C and above it was crystalline ash therefore, an optimum temperature range of $(500\text{-}700)^0$C produce a highly amorphous ash.

Silica is the major reactive component in the RHA which makes it suitable for use as a pozzolanic material. It is important that the amount of the silica in the RHA needs to be known prior to incorporating RHA in a cement mix or as ingredient in the manufacture of the cement.

V. RECOMMENDATION

There is need for chemically analyze the surface morphology and the amorphous phase of RHA.

There is need for continuous investigation on the properties of RHA blended cement when used at the manufacture should be established and a comparison done. Further research should be done on the RHA produced from other rice growing regions in Kenya. In order to have a whole conclusive characteristic of the Kenyan RHA, a better starting point towards consumer acceptability of the economic viability of the RHA is of essence.

There is need to study the soils from rice growing region to relate it to the composition of the ash. This could help in improving the chemical composition of ash and discover other potential rice growing areas.

REFERENCES

[1] Andrea Baraitam et al., (2019); Synthesis of rice as cash through various methods and determination of the highest silicon content for subsequent applications.
[2] ASTM C618-19; Standard Specifications for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM International, West Conshohocken, PA. (2019)
[3] Chandrasekhar, S.A.T.H.Y., Satyanarayana, K.G., Pramada, P.N., Raghavan, P. and Gupta, T.N., 2003. Review processing, properties and applications of reactive silica from rice husk—an overview. *Journal of materials science*, *38*(15), pp.3159-3168.
[4] Composites and Lightweight Concrete, 6(4), pp.241-248.Al-Khalaf, M.N. and Yousif, H.A., 1984. Use of rice husk ash in concrete. International Journal of Cement
[5] Della, V.P., Kühn, I. and Hotza, D., 2002. Rice husk ash as an alternate source for active silica production. *Materials Letters*, *57*(4), pp.818-82.
[6] GC Cordeiro, RD Toledo Filno, EMR Fairbairn. Use of ultrafine rice husk ash with highcarbon content as pozzolan in high performance concrete…Materials and Structures,
[7] 2009- Springer.
[8] Gonzalves MRF, Bergmann CP. (2007); Therman insulators made with rice husk ashes; production correlation between properties and microstructure contr. Build. Mater.: 2007;21(12): 2059-2065
[9] James, J. and Rao, M.S., 1986. Silica from rice husk through thermal decomposition. *Thermochimica acta*, *97*, pp.329-336.
[10] K. Kamiya, A. Oka, H. Nasu, T. Hashimoto, Comparative study of structure of silica gels from different sources, Journal of Sol-Gel Science and Technology 19 (2000) 495-499.
[11] Kenya National Bureau of Statistics (2016). '*Production of rice in major Irrigation Schemes in Kenya'*
[12] Khassaf, S.I., Jasim, A.T. and Mahdi, F.K., 2014. Investigation on the properties of concrete containing rice husk ash to reduction the seepage in canals. *International Journal of Scientific Technology Research*, *3*, pp.348-354.
[13] KS 02-1262-1993. Specification Requirements for the Composition, Manufacture, Strength, Physical and Chemical Properties of Portland-Pozzolana Cement
[14] Madandoust, R., Ranjbar, M.M., Moghadam, H.A. and Mousavi, S.Y., 2011. Mechanical properties and durability assessment of rice husk ash concrete. *Biosyst*
[15] Ministry of Agriculture (2018). National Rice Development Strategy (2008 – 2018), Kenya.
[16] Neville A.M, (2005); Properties of Concrete. 4th Edition, Pearson Education.
[17] R- Siddique – Waste materials and by-products in concrete, 2008 – Springer.
[18] RP Jaya, MAAM Nor, ZAAhmad. Properties of mortar containing rice husk ash at different temperature and exposed to aggressive environment… Advanced Materials…,
[19] 2013- Trans Tech Publ.
[20] Smith, R.G. and Kamwanja, G.A., 1986, October. The use of rice husk for making a cementitious material. In *Proc. Joint Symposium on the Use of Vegetable Plants and their Fibers as Building Material, Baghdad*.
[21] V.M. Malhotra, P.K. Mehta, Pozzolanic and cementitious Materials, Gordon & Breach Publishers, Amsterdam, 1996.
[22] 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.