Rice Husk Ash and its Application as a Cement Replacement Material in Kenya

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AAS and XRD analysis of rice husk ash (RHA) from Mwea and Ahero regions in Kenya, and physical tests of the strength of cementitious materials obtained when the ash is used to replace ordinary portland cement (OPC) are reported. The major constituent of the RHA was silica (82.3-89.9%) which was mainly amorphous. Both regions had minor variations in the amount of Si, K, Fe, Al, Mn, Mg, and Ca, but significant differences in the levels of Na and P were found. Heating RHA to 1000°C was found to induce crystallinity in the silica. An indirect method of determining the amount of silica in RHA by use of the loss on ignition (L.O.I.) is suggested. Results show that a stronger cementitious material is obtained by replacing upto 23.4% OPC with RHA.

INTRODUCTION

During recent years, the rice husk ash (RHA) has gained much attention from the construction industry as a useful and increasingly Important raw material [1]. There has been a particular interest to researchers aimed at use of RHA as a cement replacement material [2]. Once considered an unmanageable environmental burden, rice husks (RH) are now a promising solution to the ever rising cost of ordinary portland cement (OPC) [3].

The process of recycling RH for use as a cement replacement involves burning it to obtain the ash. When burned, rice husks yield 20-25% of their own weight as a silica rich ash with pozzolanic properties [4]. Pozzolanas are materials which combine with lime at ordinary temperatures to form stable components with cementing properties [5].

Useful qualities of RHA relate to its chemical composition. This may, however, vary widely, depending on the source of RH and pyroprocessing conditions. Oxides of Al, Mn, Fe, Ca, K, Mg, Na, and P occur in variable proportions in RHA in addition to silica. Carbon, sulphates and traces of other elemental oxide have also been reported in RHA [6].

The annual production of rice in Kenya was about 41 000 tonnes in 1989. By 1993, production is projected to be 69 000 tonnes, while long term expansion programmes aim at producing 135 000 tonnes of rice per year [2,7]. Processing of rice yields 20-25% husks relative to the weight of paddy [8,9].

Based on the above data on rice production and composition, the available RHA in Kenya was 1640 tonnes in 1989. This is projected to increase to 2790 tonnes by 1993 and further to 5414 tonnes when the planned long-term expansion programmes are implemented. RHA is thus an enormous resource whose potential in Kenya has been neglected.

Our aim was, therefore, to study in detail the physical and chemical characteristics of this abundantly available agro-waste material, and to examine its possible utilisation in Kenya.

In the present work, physical and chemical characteristics of Kenyan RHA were investigated. Comparisons were made between the composition of RHA from Mwea and Ahero, which are the two major rice growing areas in Kenya, and the influence of RH combustion conditions on the composition of RHA investigated. X-ray diffraction studies of RHA, and strength development tests for different RHA cement mortar formulations were also done.

EXPERIMENTAL

Chemicals

Chemicals used (analar) included sulphuric acid, nitric acid, and perchloric acid (all from Rie de Haen), hydroflouric acid (Hopkins and William), sodium carbonate (BDH), and sodium di-hydrogen phosphate (Baker Analyser).

Instrumentation

A Varian Techtron A.A.6. atomic absorption spectrophotometer (A.A.S.) was used for the analysis of Na, K, Mn, Ca, Mg, Al, Fe, and Si. A Bausch and Lomb Spectronic 20 Colorimeter was used for the determination of P. X-ray diffraction studies were done using a Phillip X-ray diffractometer with a PW 1710 diffractometer control, PW 1050/81 goniometer, Zephyr ZEM 2500°C power generator and a PM 8203A on-line recorder.

Sampling

RH from Ahero was collected from various heaps at the Municipal Council of Kisumu (MCK) dumping ground near Kisumu Technical Institute. RH from Mwea was obtained from a proccessed heap inside Mwea Rice Millers (MRM) factory. Samples were then packed in nylon gunny bags and transported to the laboratory. Field burned RHA samples from Ahero were collected from several heaps at the MCK dumping ground.

At Mwea, RHA sampling was done from different heaps within about 5km radius of the MRM factory. Only the inner whitish-grey layer was collected, the upper layer with charred husks being avoided.

Cement was from Bamburi Portland Cement factory (specification - Kenya Bureau of Standards KS-02:1976) [10] Sand was the commercially available quality from Thwake river in Machakos District.

Procedures

a) Burning the Husks: Two brick- work incinerators were constructed at our laboratory ground at HRDU. The bigger kiln had a cross-sectional area of approximately 1.5 m^2 and was 3.32 m tall including the chimney. Each side had four air inlet holes, each 8cm by 8cm. Total capacity for this kiln was 1.5 m^2. Its design was a modified version of the kiln designed by the

Pakistan Council for Scientific and Industrial Research [11]. The smaller kiln had a cross-sectional area of 0.75m² and was similar in design to the large kiln. It was 1 metre high and had a capacity of 0.7m³. The air inlet holes on each side had a cross-sectional area of 25cm².

12 kg of RH were fed into the large kiln and a fire started from the bottom. The ash formed was allowed to cool then pulverised for six hours. 4kg of RH was used for the smaller kiln and the fire started from the top. At first all the air inlets were kept open. Subsequent burning was done with 4, 8 and 12 holes closed. Another 4kg batch was burned in the open. The ball milling was done using a commercially fabricated steel rolling ball mill. The ash was then sampled for analysis.

b) Chemical analysis. All the samples were analysed in triplicate. For Na, K, Ca, Mg, Al, Fe, Mg and Mn, 0.50g of sample were digested with 9mls of a mixture of nitric, sulphuric and perchloric acids (3:1:1 vol/vol). The solution was then filtered on ashless filter paper, residue ignited, and treated with HF to expel silica [12]. The digests were topped to the 100cm³ mark and analysed using AAS. P was determined as the phosphovanadomolybdate complex using the acid digested solution [13].

For the determination of Si by AAS, 0.25g of RHA was fused with 4.0g of sodium carbonate and 3.0g of borax, dissolved in 50% HCl, then topped to 250 cm³ [14].

Loss on ignition (LOI) was determined by igniting 0.5000g of RHA at 1000°C for 20 minutes. The loss in weight was reported as LOI [15].

Finely powdered RHA was mounted on a glass slide and an X-ray diffractogram obtained. The X-ray tube was operated at 30mA, 30kV and a scan speed of 2° per minute was used [16].

c) Casting mortar cubes: Casting was according to British Standards Institution BS-12:1971 [18]. Sand:cement:water ratio was 7.5:2.5:1. For experimental cube, pulverised RHA was used to replace 15, 20, 25, and 30% OPC. 185g of the "RHA cement" thus obtained was mixed thoroughly with 555g of dried and sieved sand. 74cm³ of water were added and the uniform mix compacted into a 70.7mm x 70.7mm x 70.7mm casting mould. The cubes formed were left for 24 hours on the bench then cured in water.

Compressibility tests were done at 3, 7, 28 and 60 days using a Denison compression testing machine model TIB Control cubes were similarly cast using OPC with no RHA replacement. For each RHA cement blend, three cubes were crushed per test and the average strength reported.

RESULTS AND DISCUSSION

Analysis of 10 Mwea and 6 Ahero RHA samples showed that silica is the major component (Table 1). In addition, oxides of Fe, Mn, K, Ca, Na, Al, Mg and P are also present. The L.O.I. in RHA can be attributed to carbon and carbonaceous matter. These results compare to those reported previously [19-21]. The percent total weight of the above constituent is less than 100%. Oxide of B, Zn, Ti, Sr and Cu have been reported in RHA and may account for the lower total percentage observed [5].

The American Society for Testing of Materials (ASTM) [22] has defined pozzolana on the basis of chemical composition. The amount of $SiO_2 + Fe_2O_3 + Al_2O_3$ should be at least 70.0% for good binding properties. For Mwea and Ahero samples, the average total amount of these three components was 85.5% and 90.3% respectively. Thus these results suggest that on the basis of chemical composition, the ash from Kenyan rice husks (RH) is suitable pozzolanic material. Since currently RH in Kenya is an environmental burden with no major economic use, the utilisation of RHA as a cement replacement material is attractive.

Table 1. Composition of RHA from Mwea and Ahero

CONSTITUENT	MWEA (n = 10)		AHERO (n = 6)	
SiO_2	85.00	±1.47	89.44	±0.52
Fe_2O_3	0.23	±0.06	0.41	±0.02
Mn_2O	0.12	±0.01	0.14	±0.01
MgO	0.43	±0.12	0.42	±0.31
Ca	0.67	±0.30	0.58	±0.05
Na_2	0.07	±0.02	0.47	±0.08
AO_3	0.32	±0.08	0.46	±0.11
K_2O	1.24	±0.29	1.35	±0.08
P_2O_5	0.71	±0.42	1.55	±0.25
Loss on ignition	6.93	±1.33	3.66	±0.06
Total %	95.72	±1.25	98.48	±0.41

n = no of samples analysed in triplicate

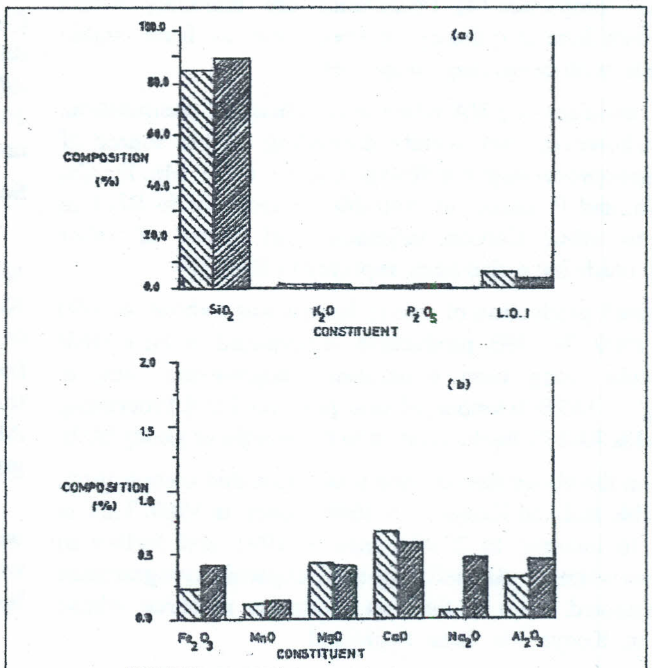
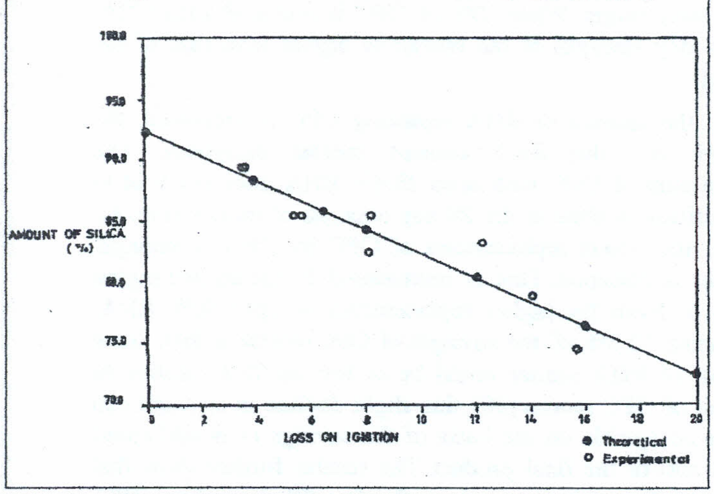


Fig.1 COMPARISON OF SOME (a) MAJOR (b) MINOR CONSTITUENTS OF RHA

For both areas, the oxides of K and P are in considerably higher proportion than the oxides of other elements (fig. 1). Since these two elements are essential plant nutrients, it is expected that they occur in higher quantities than other elements due to preferential uptake by the plant.

Mn_2O_3 and MgO occur in comparable proportion in RHA from both areas. The amount of CaO was however about 16%

Fig.2 VARIATION OF THE AMOUNT OF SILICA WITH LOSS ON IGNITION



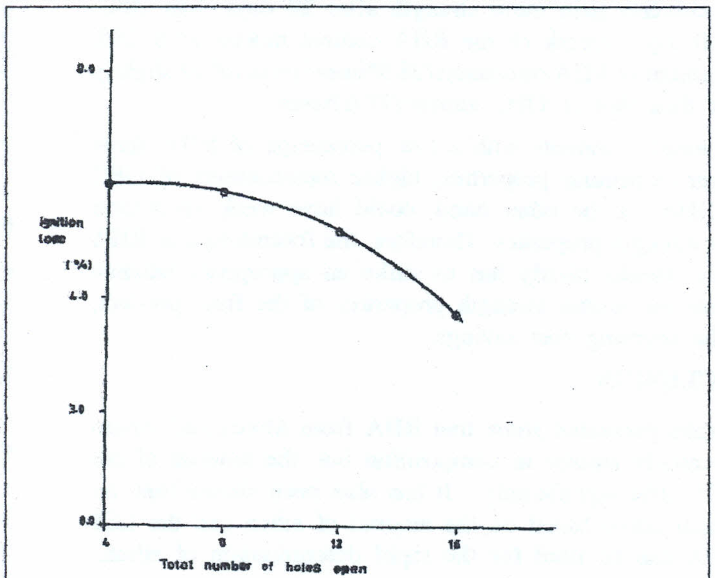


Fig. 3 EFFECT OF AERATION ON IGNITION LOSS

higher for Mwea samples while the amount of Al_2O_3 and Fe_2O_3 were lower (30% and 44% respectively) compared to Ahero samples. Since the uptake of minerals by plants is closely related to soil conditions, the above differences could be due to variations in the composition of soil in the two areas

The analysis of silica using AAS is tedious and expensive because platinum crucibles are required for fusion. Furthermore, incomplete fusion can give inaccurate result. However, since silica is the major reactive component in RHA, it is important that prior to blending with cement, the silica content of RHA be known.

In this work, a rapid indirect method of determining the amount of silica in RHA was utilised. A study of the relationship between the SiO_2 content of RHA obtained from AAS analysis and the LOI showed that a linear correlation existed (Fig. 2). Regression analysis of the data gave the equation:

$$Y = 92.4 - 1.0X \qquad (1)$$

where Y and X are the amount of silica and the LOI respectively. Based on the above equation, the amount of silica can be calculated if LOI is known. It represents total amount of carbon, organic carbon and other volatiles [23]. A high percentage of carbon is undesirable in RHA cement. Apart from a possible contribution to the lowering of the strength of RHA cement mortar, the darker product obtained from RHA with a high percentage of carbon might not be readily acceptable to the consumer [24,25]. Rice husk pyroprocessing parameters like combustion rate, aeration and temperature can affect the amount of carbon in RHA. The variation of LOI with aeration was therefore investigated.

Airflow was controlled by closing a number of holes in the mini-kiln during the burning of RH. As the airflow increased, the LOI decreased (Fig. 3). However, for RH burned in the open, LOI was higher than when burning was done with the kiln fully ventilated.

When rice husks are burned under controlled conditions as in the kiln, an increase in the supply of oxygen leads to near complete oxidation of carbon and carbonaceous matter hence a decrease in the LOI. When burning is done in the open however, the rate of combustion is probably rapid, which may leave a high amount of unburned carbon. These results therefore have practical implications. The amount of carbon in RHA can be controlled by regulating air flow during RH pyroprocessing. Since LOI strongly correlates to the amount of silica, then, the overall quality of RHA cement can be controlled during the burning of RH.

Although a high percentage of silica in RHA is desirable for good binding properties of RHA cement, its amorphous nature is also significant. Crystalline silica has low reactivity and is not suitable for RHA cement [26]. It has been shown that when RH is burned at temperatures exceeding 600°C,

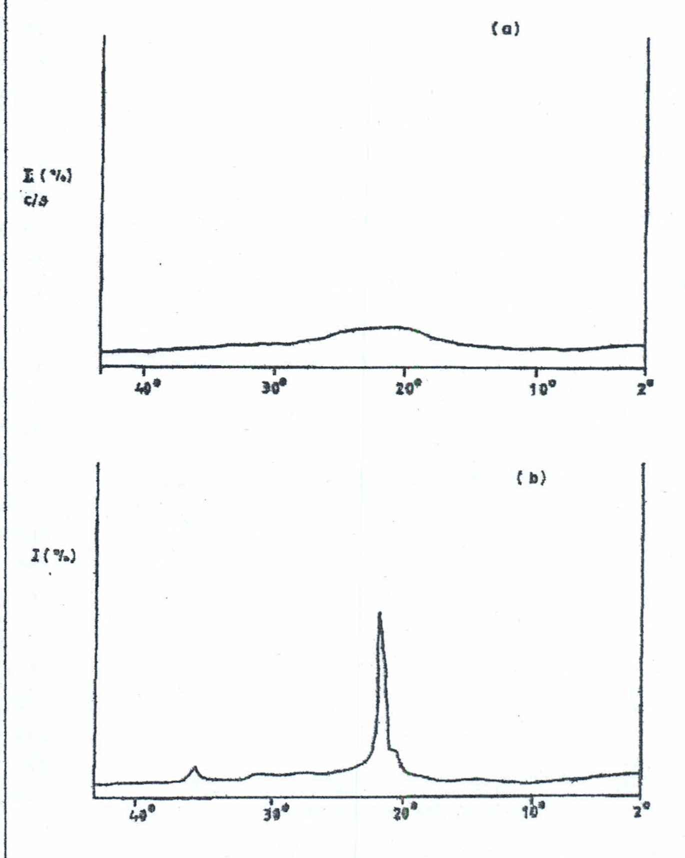


Fig.4. X-ray diffractograms for (a) Field burned RHA (b) RHA ignited at 1000° C for 20 minutes

crystalline silica is formed [27-29].

X-ray diffractometry indicated no major characteristic peaks in the diffractograms (Fig. 4a). This suggests that the samples were largely composed of amorphous silica because when one of the samples was ignited at 1000°C, the XRD pattern showed major peaks (Fig. 4b).

The occurrence of these peaks is as a result of high temperatures inducing polymorphic phase transitions, changing amorphous form of silica to crystalline form. Therefore, conditions of uncontrolled burning are likely to achieve high temperatures which can potentially yield undesired crystalline silica.

During the combustion of RH in small heaps such as the ones sampled, the heat is rapidly dissipated hence the silica formed is in the amorphous state. These results suggest that the RHA obtained from small scale burning of RH in the field could be suitable for use in RHA cement.

The variation of mortar strength with increasing percentage of RHA in cement was investigated (fig. 5). Results show that, the strength of RHA cement mortar does not vary significantly from that of OPC mortar during periods less than 1 week. This is possibly because the lime/silica reaction responsible for cementing properties is not well developed at these early stages. When 15% of OPC is replaced with RHA, the 28 day strength of the mortar is higher than that of the control.

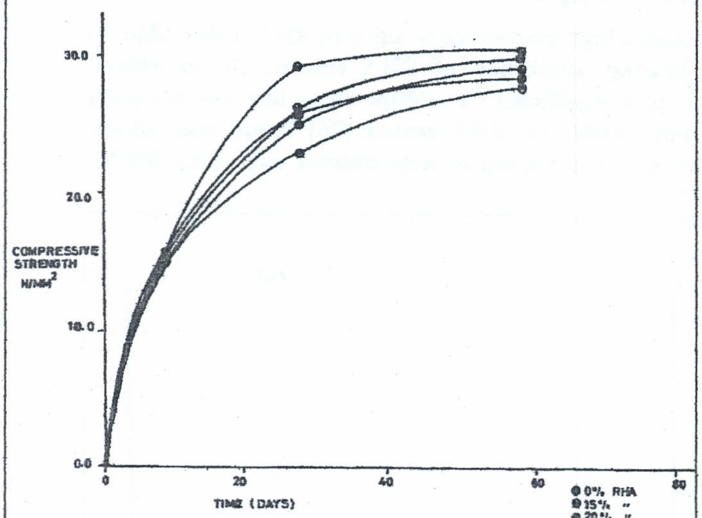


Fig.5 COMPRESSIVE STRENGTHS OF RHA CEMENT MORTAR

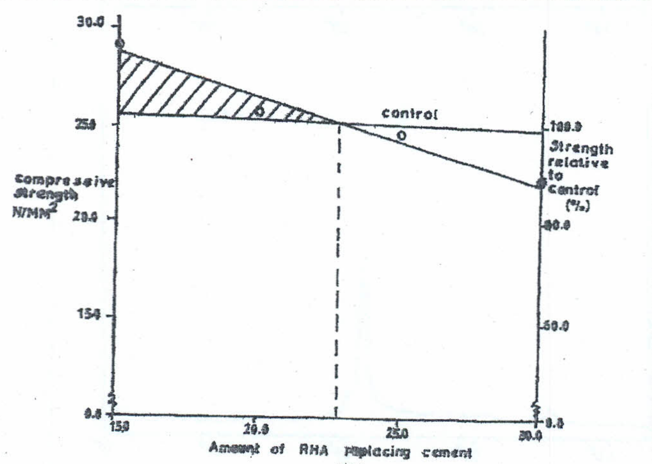


Fig 6 Variation of 28 day mortar strength with increasing amount of RHA in cement

As the amount of RHA replacing OPC is increased, the strength of the RHA cement mortar decreases. The replacement of OPC with upto 23.4% RHA does not lead to a significant decline in the 28 day strength of mortar (Fig. 6). Infact for lower replacements of OPC by RHA, a stronger product is obtained. This is represented by the shaded region in Fig. 6. Even for higher replacements of upto 30% RHA, only about 12.8% of the strength of OPC mortar is lost. Since the cost of RHA mortar could be as low as 75% relative to the cost of OPC mortar [30], this slight decline in strength can still be acceptable on the basis of the savings it would entail on the cost of the final product. The results further show that RHA cements gain more strength after 28 days than OPC. The 60 day strength of the RHA cement mortar with 25% replacement of RHA on cement (28.9Nmm^{-2}) was infact slightly higher than that of OPC mortar (27.6 Nmm^{-2}).

Although cements with a low percentage of RHA show stronger cementing properties, higher replacements of OPC with RHA on the other hand, could have weak short-term mortar strength properties. Therefore, the formulation of RHA cement blends clearly has to strike an appropriate balance between the mortar strength properties of the final product, and the accruing cost savings.

CONCLUSION

Results presented show that RHA from Mwea and Ahero is essentially similar in composition but the amount of Na and P differ significantly. It has also been shown that, an empirical curve based on the amount of silica and the LOI in RHA can be used for the rapid determination of silica.

The amount of carbon in RHA can be controlled during RH pyroprocessing. Amorphous silica in RHA was found to be transformed to crystalline states by heating to high temperatures around 1000°C. This further emphasizes the need for controlled pyroprocessing of RH. Field burned RHA was found to be amorphous hence it could possibly be suitable for RHA cement.

On the basis of 28 day strength of RHA cement mortar, formulations with upto 23.4% RHA and 76.6% OPC can be used without losing the mortar strength properties of OPC. Higher percentages of upto 30% RHA can still be used with a minimal loss of long term mortar strength.

Since Kenyan RHA is clearly a suitable pozzolanic material, field trials should be done in order to understand the behaviour of RHA cement products under varying environmental conditions and in large scale applications.

There is also a need to further evaluate the characteristics of RHA from the Tana delta region in order to be wholly conclusive on the characteristics of RHA from all the major rice growing areas in Kenya. The need to analyse soils from all the rice growing areas and relate them to RHA compositionis also very important.

Further research should also be done with respect to marketing and production strategies for RHA cement in Kenya. Some of the production parameters which require further investigation include pyroprocessing temperature, ball milling time, water requirements of RHA cements and methods of blending RHA cement formulations. All the above parameters should be studied in relation to strength of RHA cement mortar.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the University of Nairobi and the GTZ for funding this research. We are also grateful to the Department of Mines and Geology, Ministry of Environment and Natural Resources for granting us the use of their laboratory facilities and the International Atomic Energy Agency (IAEA) and theNational Council for Science and Technology(NCST) for equipment support at CNST.