PRELIMINARY INVESTIGATION ON PRODUCTION OF CEMENT FROM RICE HUSKS, SEASHELLS AND KAOLIN

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ABSTRACT

This paper presents one of the methods which could be used for production of cementitious material from rice husk ash. The rice husk ash (RHA) used had a specific gravity of 1.54 and its chemical constituents met the BS 3892 and ASTM C-618 requirements for pozzolanas. On the basis of the chemical composition of the raw materials, the required percentage composition of these materials in the mixture were: rice husk (47% w/w), sea shells (46% w/w), and clay (7% w/w). the amount of dry cow dung added as binder and combustion enhancer was 6% w/w) of the total mixture. The RHA cement produced by burning this mixture and ground to a fine powder (40 μm -sieve size) when mixed in the ratio of 1:3 with sand according to BS 12; the average compressive strengths of the blocks moulded were 2.2 and 23.9 N/mm^2) after 3 and 7 days of curing in water respectively. The strength acquired by the RHA Cement blocks, i.e, 23.9 N/mm^2, after 7 days of curing was 75% of the strength acquired by cement blocks prepared by using Industrial Portland Cement from Wazo Hill Factory (Twiga Cement), i.e., 32 N/mm^2.

INTRODUCTION

The shortage of good quality housing is indeed one of the most pressing problems facing developing countries like Tanzania. One alternative to reduce this problem is to develop appropriate and affordable technologies that utilise local skills and local materials that are in abundance. Therefore, there is a need for governments to consider possible avenues of research on indigenous construction techniques and on building materials for construction housing. Most developing countries have abundant natural resources, ranging from clays soils, timber and grasses, agricultural wastes, mineral deposits etc., from which building materials can be developed.

Portland cement is produced by burning a mixture of calcium carbonate (chalk, marble, limestone) and silica (clay at a clinkering temperature (>1400oC) and then the grinding the of resulting clinker (Lea, 1988, Bye, 1983). However, in the production of Portland cement the clinkering process is an energy intensive step and it has been estimated that 120 kWh are needed to produce a tonne of cement (Bye, 1983). This energy is usually derived from coal or oil. Majority of the people have resorted in using affordable and easily available building materials such as grass, mud bricks, animal dung, ghrass and trees. The high and continuously increasing demand of building materials in the developing countries and the need to exploit natural resources have necessitated the search for alternatives.

Considerable efforts are therefore being made to find cement substitutes, the so called supplementary cementing materials to replace part of the cement in concrete. The less energy intensive technologies can utilise raw materials, such as agricultural residues and industrial wastes and by-products that are easily available; and require little or no pyro-processing and have inherent cementitious properties. One good example is Rice Husk Ash (RHA) that is obtained by burning rice husk, which has been found to contain a high percentage of silica (93%), a basic chemical compounds of cement (Smith, 1984). Rice husk contains active silica which, when heated in the furnace with clay soils and sea shells in certain proportion, provides cementitious material. The husk is not suitable as animal feed because of its harshness and abrasive character, almost negligible digestible protein and high silica content. Also Mehata (1979) reported that high ash and lignin contents (20-30% lignin) make the husk unsuitable as a raw material for making paper Therefore, whenever it is produced in large quantity, the husk cause disposal problems because of its low bulk density and slow rate of bio-degradation.

The production of rice in Tanzania is shown in Table 1. The Table shows the annual production of paddy produced inTanzania by only four National farms. The husk content of rice has been estimated to be about 20% (Nnanna, 1988). Hence it is expected that about 8000 tonnes of husk are produced annually in these farms. On the average each tonne of rice husks on combustion produces 200 kg of ash.

There are a number of developed technologies based on rice husk ash which has a potential for exploitation on commercial basis. Good quality cement can be made by simply blending active silica and alumina with lime. The natural or artificial materials which contain silica and alumina are called pozzolanas. These can replace 14% to 40% of Portland cement without significantly reducing the long term strength of the concrete (Smith, 1984).

Table 1. Annual production of paddy in NAFCO farms

Farm		Annual production (tons)
1.	Kapunga rice farm	15000
2.	Mbarali rice farm	15000
3.	Ruvu rice farm	5100
4.	Dakawa rice farm	5200

Therefore the objective of this investigation was to develop appropriate technology for production of cementitious material using renewable resources from agricultural residues like rice husks, rice straw, bagasse, coffee husk, and sea shells without utilising any additional fuel.

BASIC CHEMISTRY OF PORTLAND CEMENT

Portland cement is made by burning a mixture of calcium carbonate (chalk, marble, limestone) and silica (clay). Initially the calcium carbonate decomposes to calcium oxide, CaO and carbon dioxide. The CaO then reacts at a high temperature with silica to form calcium silicates, most calcium silicates made in this way are reactive to water (i.e., unstable) to form relatively stable but undefined calcium silicates hydrates. That is relatively stable because a slow reaction with CO_2 from the atmosphere takes place. The formation of complexes takes place as follows (Lea, 1988):

$$CaCO_3 \xrightarrow{900^o C} CaO + CO_2$$

$$MgCO_3 \xrightarrow{750^o C} MgO + CO_2$$

$$CaO + Al_2O_3 \xrightarrow{1375^o C} C_3A(3CaO.Al_2O_3)$$

$$CaO + SiO_2 \xrightarrow{1375^o C} C_2A(2CaO.SiO_2)$$

$$2CaO.SiO_2 + CaO \xrightarrow{1400^o C} C_3A(3CaO.SiO_2)$$

The hydration process and hydrolysis of silicates and aluminates cause setting in cement and strength of hardened cement is due to Si-0-Si-0 bond. The common ingredients of cement are approximately given in Table 2 (Lea, 1988):

Table 2 Common ingredients of Portland Cement

compounds	range (percentage)
calcium oxide	60 - 67
silica	17 - 25
alumina	3 - 8
ferric oxide	0.5 - 6
magnesium oxide	0.1 - 5.5
sulphur trioxide	1 - 3
alkalis (K_20 and Na_20)	0.5 - 1.3
others $C0_2$ and H_20	1 - 2

MATERIALS AND EXPERIMENTAL PROCEDURES

Raw Materials and Their Properties

Rice husk was obtained locally from a local milling machine in Dar es Salaam. The husk was used as obtained without further modification except for grinding it in a ball mill for some of the experiments. Sea shells, another raw material which was used, were obtained from Indian Ocean Coastal belt, Kigamboni area in Dar es Salaam. There is no data available on the annual production of this material. However this product is mainly used locally for small scale for production of lime.

Clay soil (Kaolin), a source of alumina, was obtained from Pugu Kaolin Works in Pwani Region. Clay can also be obtained from other Regions in the country, like Kilimanjaro, Arusha, Morogoro, Ruvuma, Mbeya, Iringa and Dodoma etc., where it is mainly being used for production of mud bricks, burnt bricks, tiles and pottery.

The desired chemical properties of the rice husk are the ash and silicon dioxide contents, while that of the sea shells is the CaO content. For clay the contents of SiO_2 Al_2O_3 and Fe_2O_3 are important. These properties were determined according to standard procedures summarised by Lema (1995).

Preparation of RHA Cement

The process developed by Morgeyera (1985) for production of RHAcement was adapted for this study. The reasons for selecting this method are: (a) makes use of locally available raw materials, (b) high cost of Portland cement, (c) process is labour intensive, and (d) process is energy efficient.

In his process (Morgeyera, 1985), rice husk, sea shells and clay were pulverised to fine powder then are mixed in the proportion of rice husk (52% w/w), sea shells (38% w/w) and clay (10% w/w). The block diagram of the process, showing the main steps of the process is shown in Figure 1. Since the composition of rice husks, clay and sea shells varied from one place to another the percentage composition of the raw materials in the mixture will vary accordingly (seeTable 3). Finally about 6% w/w of cow dung added to the mixture.

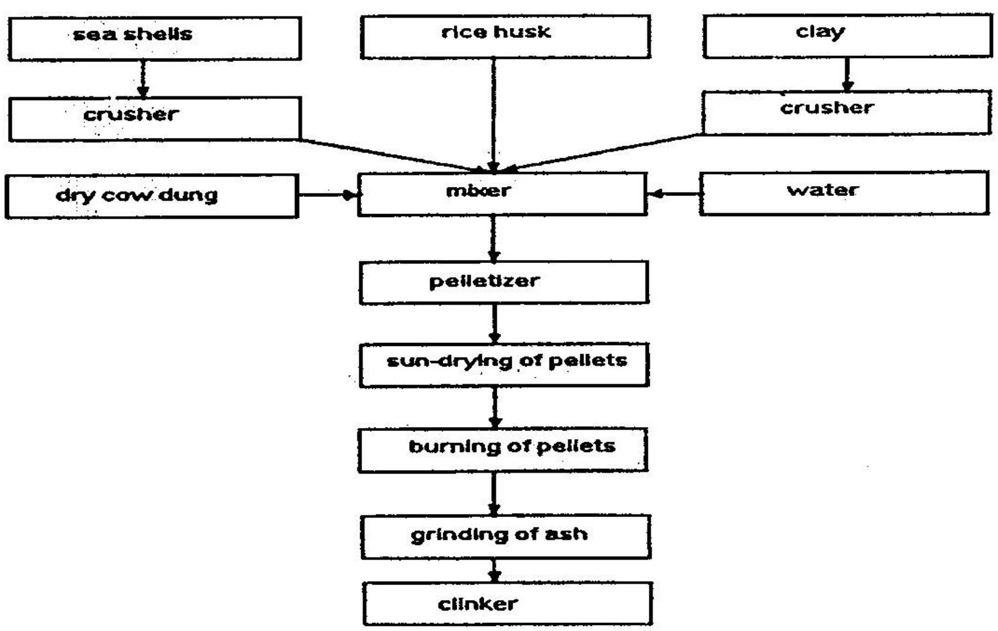

Fig. 1: Block diagram for production of RHA-Cement

Calculation of the mix ratio for raw materials

The calculation of the mix ratio was done on the basis of raw material (1 kg of seashells) and percentage composition of the constituents. It has been found that 52% of CaO which is equal to 520 gms of CaO (Table 3) is available in 1 kg of sea shells and this should form 63% of cement. Therefore weight of cement will be:

$$\frac{520}{0.63} = 825\ grams$$

Also about 25% SiO_2 (silica) available in the rice husk is reactive one. In Table 1 rice husk ash gives 22% ash which contain about 93% of SiO_2 (Table 2). Therefore 1kg of rice husk contains SiO_2 equal to:

$$1000x\frac{92.9}{100}x\frac{22}{100} = 204.38\ grams$$

For 825 grams of cement, amount of rice husk required is:

$$825x\frac{25}{100}x\frac{1000}{204.38} = 1009.14\ grams \approx 1.01\ kg$$

For production of Portland cement about 6% of Al_2O_3 is required. However, in clay only 32.34% of Al_2O_3 is available (Mogeraya, 1985) Therefore clay required is:

$$825x\frac{6}{100}x\frac{100}{32.34} = 153.06\ grams \approx 0.153\ kg$$

Also about 6% w/w of a moderately thick cow dung is to be added. And 6% w/w of 2.163 = 0.129 kg. Cow dung is added mainly for two reason: (a) it is used as a binding material in the mixture so that the pellets can be moulded in a desired shape without affecting the desired properties of the product (b) also cow dung enhance combustion process due to its methane content.

According to chemical analysis of materials, to produce a certain quantity of cement, the following percentage of raw materials should be available in the mixture (Table 3).

Table 3. Feed composition of raw material

Raw material	weight (gram)	percentage (%)
Rice husks	1010	44.05
Sea shells	1000	43.65
Clay	153	6.67
Cow dung	129	5.63
Total	**2293**	**100.00**

Then water was added to the raw materials to form a thick paste which was moulded into cylindrical pellets. The pellets were moulded using a pelletizer which was made out of perspex glass (lema, 1995). The pellets were made cylindrical in order to facilitate complete combustion of the pellets since combustion travels radially (Mogeraya, 1985). Incomplete combustion of the pellets would produce carbon particles in the ash is undesirable for cement quality. Mogeraya (1985) found that the optimum dimensions of the cylindrical pellets for efficient and effective combustion should be: height 5cm, and inner diameter 2.5cm. However, for this study the dimensions which were found to be suitable and easy for fabrication were: height 5cm, outside diameter 8cm and inner diameter 4cm (Lema, 1995).

The pellets were sun dried for 3 days. The pellets were burnt in an open brick furnace. The refractory bricks were arranged as a furnace with a wire mesh in between for staking the pellets. One side of the furnace, below the wire mesh, was left open to allow flow of air into the furnace, by free convection, in order to sustain the combustion process to completion. Fuel was required only for the initiation of firing and combustion was self sustained. Combustion of the pellets, which was attained at a temperature of 800oC, measured by a thermocouple. After complete combustion the ash was collected below the mesh and was left to cool to a room temperature. The ash was then ground to a fine size in a ball mill for 2 hours. The resulting powder was sieved in a 40 μm -sieve size to get a cement clinker

Cement Compressive Strength Test

The compressive strength test of the rice husk cement was done as recommended in BS 12. First cement blocks for the test samples were fabricated from sand. The ratio of cement of sand used was 1:3 and that of water to cement ratio was 0:4. Three cement blocks, each having a standard dimension of 70.7 x 70.7 x 70.7 mm^3, were moulded for each test. Al the test were conducted in Materials Testing Laboratory of the Department of Civil Engineering, University of Dar es Salaam.

RESULTS AND DISCUSSION

Chemical Properties of Raw Materials

The ash content of some agricultural waste are shown in theTable 4 below. It was observed that rice husk contain the highest ash content (22.2%) compared to the rest of the material that were analysed in this investigation. Literature information (Smith 1984, Mogeraya, 1985) reveals that the chemistry of rice husk ash cement involves the chemical reaction of the amorphous silica in the ash with lime to form calcium silicate hydrates which is the compounds in cement primarily responsible for strength. Smith (1984) established that the silica in the ash undergoes structural transformation under varied temperature range of 550-700°C and is generally found to produce amorphous silica in the ash which is highly pozzolanic while temperature in excess of 900°C produce unwanted crystalline forms of low pozzolanic (Smith, 1984).The type of ash suitable for the pozzolanic activity is amorphous rather than crystalline ash.

Table 4. The content by weight of common agricultural wastes

Plant	Part of plant	Ash %
Wheat	leaf sheath	10.48%
Wheat husk	husk	20.90%
Sugar cane	bagasse	14.71%
Rice (paddy)	husk	22.15%
Oil palms	nut shell	9.80%
Rice straw	straw	24.65%

The specific gravity of the rice husk ash used was found to be 1.54. With a carbon content of 8.20% as determined by loss on ignition, the carbon content is below the maximum value of 12% recommended inASTM C-618 (Lema, 1995) for pozzolanas, but is higher than the maximum loss on ignition recommended by BS 3892 (Lema, 1995). Also Smith (1984) observed that ash with carbon content up to 20% when mixed with lime produced mortar of acceptable strength. The variation in the carbon content could mainly be attributed to the level of completion of combustion process to produce the ash.

From the chemical analysis Table 5, the sum of Si02, A1203 and Fe20c was found to be 93.61%. This satisfies the minimum percentage requirement for pozzolana when these constituents are added together which is 70% for ASTMC 618. A maximum Mg0 of 4% and 5% were recommended by BS 3892 and ASTM C 618 while the rice husk ash has got Mg0 value of 0.4%, the moisture content obtained was 1.18% while it is required not to exceed or to be greater than 1.5%. Therefore, on the basis of BS 3892 and ASTMC 618 standards, the requirement for pozzolanas, the rice husk used can be considered to be good pozzolana.

Table 5. Physical properties and chemical composition of the rice husk ash

Properties	value
Rice husk	
Specific gravity	1.54
Moisture content	1.18%
Loss on ignition	8.20%
Chemical composition	
S_i0_2	92.90%
$A1_20_3$	0.47%
Fe_20_3	0.24%
Ca0	0.46%
Mg0	0.40%
Na_20	2.26%
P_20_5	0.20%
K_20	3.01%

The second raw material (sea shells) properties are summarised inTable 6 below. The total $CaCo_3$ in the sea shells used is about 96.5%. Lea (1988) reported that sea shells contain about 95% $CaCo_3$. This implies that our sea shells are suitable as raw material for production of cement.

The chemical composition of clay soil is shown in Table 7 below. The kaolin contains high percentage of silica and alumina. It is also suitable as a raw material for cement production.

Table 6. Chemical composition of the sea shells

Properties	value
Sea shells	
$Si0_2$	0.35%
$A1_20_3$	0.90%
Fe_20_3	0.42%
Ca0	52.01%
Ng0	0.28%
Loss on ignition	44.50%

Table 7. Some physical properties and chemical composition of clay soil

Properties	value
Clay soil	
$Si0_2$	52.33%
$A1_20_3$	32.34%
Fe_20_3	0.95%
Ca0	0.02%
Na_20	0.10%
K_20	0.15%
Others	14.11%
Loss on ignition	12.20%

Physical Properties of Raw Materials

It was observed that when the raw materials (rice husk, sea shells and kaolin) were ground to find powder before mixed, the pellets made from the fine powder did not combust easily. This difficulty in combustion could be attributed to lack of pores within the dried pellets to sustain combustion. Generally fine particles produce pellets which are less porous compared to coarse particles. Therefore all the rice husk was used as obtained from a milling machine while sea shells were crushed to particles having sizes in the range of 2-5 mm. Since combustion of the pellets have a greater influence on quality of the cement, the optimum size of sea shells particles that would produce pellets with high porosity and facilitate complete combustion should be determined.

Quality of the RHA-Cement

The fineness of product taken is 40 μm-sieve size which mixed in a ratio of 1:3 cement sand gives a compressive strength after 3 days of curing of 2.12 N/mm^2 and after 7 days curing of 13.8 N/mm^2.

The compressive strength test results for the rice HuskAsh (RHA) Cement and Portland Cement from Wazo Hill Factory (Twiga Cement) are shown in Table 8. It was observed that curing of the cement blocks in water for 7 days increases the strength of RHA-Cement by at least 10 times as compared to 1.5 times for Wazo Hill Portland Cement.

Table 8. Compressive strength of the RHA cement and Portland cement

Type of Cement	batch number	strength after 3 days of curing (Nmm^{-2})	strength after 7 days of curing (Nmm^{-2})
RHA-Cement	1	1.95	13.8
RHA-Cement	2	2.23	23.9
Portland Cement	3	22.8	32.0

There was also a big difference in compressive strength of the RHA-Cement after 7 days of curing. For the first batch, the compressive strength after 7 days of curing was 13.8 N/mm^2 while the strength for the second batch was 24.0 N/mm^2. This difference could partly be attributed to preparation of raw materials i.e., the size of the raw material particles in the mixture. For the first batch the raw materials were ground in a ball mill to produce fine powder prior to mixing and making pellets. Therefore pellets with relatively low porosity were produced compared with the pellets of the second batch. Since in the preparation of the second batch the raw materials, rice husk, sea shell and clay sieved to get particles in the range of 600 μm -sieve size before mixing according to ratios. Generally low porosity in pellets will result in incomplete combustion of the pellets and therefore quality cement will be affected.

For ordinary Portland cement to comply with BS 12 the minimum strength achieved in the concrete cube test must be 13 and 29 N/mm² at 3 and 28 days respectively. The 28 days strength is regarded as an important indication of concrete quality for structural engineering purposes (Bye, 1983). Although the compressive strength tests after 28 days of curing was not conducted, the strength achieved after 7 days of curing (24 N/mm2) is a good indication that it is possible to produce RHA cement with a high strength.

CONCLUSION

The objective of this investigation i.e. production of cementitious material from rice husk using a low energy process and affordable technology has been achieved. The chemical analysis of raw materials shows that all the necessary composition from rice husks, sea shells and clay that is SiO_2, CaO and Al_2O_3 are present in excess of the amounts required. For every batch of product the composition of raw material required are: Rice husk (47% w/w), sea shell (46% w/w), sea shell (46% w/w) and clay (7% w/w). The particle size of the materials (rice husk and seashells have greater influence on the product properties as they determine the extent of combustion and the strength of the cement.

RHA-Cement showed a compressive strength of about 24 N/mm² which is 75% of the strength of Portland cement from Wazo Hill Factory. The RHA-Cement can not be used for making concrete until more improvement on the strength has been done. However, it can be used for other purposes like decoration.

The benefits to be achieved are enormous, and these include utilisation of agricultural waste (rice husk) and development of appropriate and affordable technology for production of low cost cement.

RECOMMENDATIONS

It is possible to produce RHA-Cement with relatively high compressive strength. It requires additional control of quality for individual ingredients, rational mixture proportioning procedures, and performance oriented specifications. To improve the quality of the RHA-Cement, the following should be studied:

(1) Particle size of seashells and rice husk that will produce pellets that could make the combustion process more effective and efficient should be determine.

(2) The optimum size of pellets to be put in the furnace for firing so that combustion will take place uniformly to avoid incomplete combustion (production of carbon) should be determined.

(3) After combustion of the pellets at the desired temperature 800°C, it is required to use shortest time to cool the ashes to room temperature in order to have high quality cement. In this study rapid cooling of the ashes was not done. Therefore, ways of achieving fast cooling of the ashes should studied.

(4) The furnace must be designed in such a way to allow the pellets to burn uniformly to avoid unburned carbon to remain in the final product.

(5) Other sources of raw materials source, $CaCO_3$, silica and alumina, should be studied. These should include the testing of bagasse from sugar industry as it is a big pollutant.

(6) Other cement quality tests, like setting time, consistency and compressive strength after 28 days of curing, should be performed.

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