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USE OF RICE HUSK ASH BLENDED CEMENT TO MANUFACTURE CELLULAR MASONRY BLOCKS

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Abstract: This paper summarises the research work on determining suitability of rice husk ash (RHA) to partially replace cement in manufacturing cellular masonry blocks. The particle size distribution and chemical composition of RHA were measured for samples taken at different temperatures. In this research, mixtures have been prepared in combinations of four binder-sand ratios namely 1:3, 1:4, 1:5 and 1:6, three water-binder ratios namely 0.4, 0.5 and 0.6 and five levels of cement replacement with RHA namely percentages of 0, 5, 10, 15 and 20 by weight. One hundred and twenty cubes were cast (4x3x5x2=120) and tested for compressive strength at 7 and 28 days. Based on the compressive strength values, 1:5 binder-sand ratio was chosen as the appropriate mix proportion to cast cellular masonry blocks for different water-binder ratios namely 0.5 and 0.6 as per SLS 855Part 1:1989.

RHA was blended with cement in percentages of 0, 5, 10, 15 and 20 by weight in producing cellular masonry blocks of size 390 x 190 x 200 mm. These were tested for water absorption in addition to compressive strength. The compressive strengths of cellular masonry blocks at 7, 14 and 28 days for 1:5 binder-sand ratio, water-binder ratio 0.5 and 5 per cent cement replaced with RHA were 2.05 N/mm^2, 2.24 N/mm^2 and 3.37 N/mm^2 respectively. Likewise the values for 1:6 binder-sand ratio for water-binder ratio 0.5 and 5 per cent cement replaced with RHA were 1.6 N/mm^2, 2.18 N/mm^2 and 3.24 N/mm^2 respectively. The minimum compressive strength as per SLS 855 Part I: 1989 is 1.2 N/mm^2. The water absorption rates for water-binder ratios 0.5 and 0.6 are 9.8 and 10.5 respectively, which are within limits; the allowable limit is 10-15% as per BS EN 1996-1-1. The study concludes that 15 per cent cement replacement level is permissible.

Key words: Rice husk ash, Cellular masonry blocks, Blended Cement

1. Introduction

Rice husk is the outer covering of rice grain, generated during the rice milling process. This is an agricultural by-product used mostly as a fuel in brick kilns to generate heat. Still a large amount of rice husk is burnt in heaps in open ground as a measure of disposal. The disposal of rice husk ash (RHA) so generated is still a problem. On the other hand, the cost of producing cellular masonry blocks is increasing due to the escalating prices of cement. This has influenced researchers to investigate the use of waste materials as a supplementary cementitious material, and RHA is thought to be a potential candidate in this cause. Research studies to explore various aspects of using RHA, produced by controlled burning of the rice husk, as a substitute for cement have been in existence for quite some time.

The research reported here is on RHA, with respect to chemical and physical properties at varying temperature, level of replacement of cement and water absorption of RHA blended cement. The main objectives of this study are as follows;

- To explore the chemical and physical properties of RHA in relation to burning temperature.
- To determine the optimum level of replacement of cement with RHA in the manufacture of cellular masonry blocks.

2. Literature Review

2.1 Focus of past studies

Rice is Sri Lanka's staple food, therefore paddy is produced in large scale. Mude *et al.* (2013) have revealed that 22 per cent of the weight of paddy comes as rice husk and 25 per cent of the weight of husk is converted to RHA during the firing process. An important determinant of quality of RHA when considered as an alternative for cement is the extent of silica content. Al-Khalaf and Yousiff (1984) report that when husk is converted to ash by uncontrolled burning below 500^0C, the ignition does not become complete and considerable amount of unburnt carbon is still found in the ash. A study by Boating and Skeete (1990) reveals that the ash produced by controlled burning of the rice husk between 550^0C and 700^0C, and one hour of incineration transforms the formation of silica into amorphous form. The increasing cost of cement has motivated researchers to identify suitable alternative material for block making. Hence an objective of the study is to examine cementitious properties of RHA.

In a pioneering study by Bandara (1994), it is concluded that firing temperature and isothermal firing time for attaining high amount of amorphous silica in fired ash depends on the variety of rice husk ash. The study also reveals that, as an approximation, a firing temperature of 700°C seems to be the optimum for the four Sri Lankan varieties of rice husk examined in that study; an isothermal firing time of 30 to 60 minutes is to be adopted based on the knowledge of the variety of rice husk.

A number of authors namely, De Silva and Uduweriya (2011) and Ganesan *et al.* (2008) have investigated the replacement levels of cement for concrete containing RHA. Dolage *et al.* (2011) investigated the replacement levels of cement to produce cement sand blocks. A study extending the scope of the former by mixing lime with RHA was conducted by Pushpakumara and Subashi (2012). Subsequently, Baskaran *et al.* (2012) have studied the possibility of using RHA in stabilized soil blocks. Most of these studies, in addition, have investigated the particle size distribution of RHA. Since evidently, only a few studies have explored the effect of temperature on the chemical composition and thereby the strength, this study expects to shed some light on this.

2.2 Chemical Reaction of RHA with Cement and Water

The duration of incineration and temperature at which it is incinerated are important parameters influencing the reactivity of RHA. Silica in RHA initially exits in the amorphous form, but may become crystalline when RHA is continued to be burnt at higher temperature. The chemistry of the pozzalonic action of RHA includes the reaction of the amorphous silica in ash with water to form calcium silicate hydrates.

Reactions that take place in the preparation of RHA cellular masonry block are given below. Silicon burnt in the presence of oxygen gives silica.

$$Si + O_2 \rightarrow SiO_2$$
$$C_3S\ (Cement) + H_2O \rightarrow CSH + Ca(OH)_2$$

The highly reactive silica reacts with calcium hydroxide released during the hydration of cement, resulting in the formation of Calcium Silicate Hydrate, which is responsible for the strength.

$$SiO_2 + Ca\ (OH)_2 \rightarrow CSH + SiO_2$$

2.3 Availability of Rice Husk

Paddy and rice husk production in Ampara district for the year 2014/15 is shown below in Table 1. This indicates if RHA is suitable as an alternative for partial replacement of cement, availability of rice husk would not be a problem in Ampara district.

Table 1: Paddy and rice husk production in Ampara district

Paddy (MT)			Rice husk (MT)
Maha	*Yala*	Total	Rice husk (MT)
307,661	199,265	506,926	101,386

Source: Department of Census and Statistics, 2014

A total of 87 rice mills are located in Ampara district and their milling capacities are shown in Table 2.

Table 2: Milling capacity of rice mills in Ampara district

Milling capacity (kg/day) Capacity = C	Number of mills
<1000	9
1000<C<2500	4
2500<C<5000	8
5000<C<8000	11
C>8000	55

2.4 Cellular Masonry Blocks

Cellular blocks are masonry units that contain one or more formed voids that do not fully penetrate the block. The use of cellular masonry blocks can have significant advantages over solid blocks in situations where weight is a prime consideration. The reduced unit weight results in easy handling, reduced floor/ foundation loading, economic and efficient productivity. There are two block types available in cellular format: dense aggregate cellular block (typical material density range is 1800-2100 kg/m^3) and light weight aggregate blocks (typical material density range is 850-1500 kg/m^3). Cellular masonry blocks are available in various types namely standard common, close textured/paint grade common, standard, facing and architectural masonry facing blocks. The compressive strength of the cellular masonry block ranges from 1.2 N/mm^2 to 10.0 N/mm^2. The standard specification deals with requirements for compliance and specifies materials, sizes and dimensional tolerances and minimum performance levels for cement blocks for construction work. It covers solid, hollow and cellular masonry blocks not exceeding 650 mm in any work size dimension (SLS 855 Part 1: 1989).

3.0 Methodology

3.1 Materials used

OPC conforming to Sri Lankan standard SLS 107: Part 1: 2008 was utilised in preparing the binder. Graded river sand passing through 2.36 mm sieve with fineness modulus of 2.83 (between sieve sizes of 5 mm and 160 micro meters) and having specific gravity of 1.6 was used as fine aggregate, as per Sri Lanka Standard 855:1989. While the RHA sample burnt at approximately 700°C was collected from a thermal power plant, the samples burnt at 650°C and 750°C were obtained from a brick kiln. The RHA samples were sieved through BS standard sieve size 63 micrometer and its colour was grey.

3.2 Casting of solid and cellular masonry blocks

Samples were prepared with four binder-sand ratios, namely 1:3, 1:4, 1:5 and 1:6 for three water-binder ratios, namely 0.4, 0.5 and 0.6. A mixture of cement and RHA was used as the binder; five mixtures of binder were prepared by varying the RHA percentages, namely 0, 5, 10, 15 and 20 by weight. Compressive strength test was carried out on cubes of size 100 x 100 x 100 mm casted using these 120 combinations (4 X 3 X 5 X 2 = 120).

By using the cube strength values the optimum binder sand mix proportion, 1:5 was chosen to prepare cellular masonry blocks. By varying the water-binder ratios 0.5 and 0.6, RHA was blended with cement in percentages of 0, 5, 10, 15 and 20 by weight in producing cellular masonry blocks of size 390 x 190 x 200 mm. Altogether 50 samples of cellular masonry blocks were prepared for both compressive strength and water absorption tests. Out of these, 40 samples were used for testing of compressive strength and the remaining 10 for testing of water absorption. From each mix proportion, five cellular masonry blocks were cast for testing. The details of material usage to cast different masonry block samples is presented in Table 3.

Water was mixed with the dry binder sand mixture until the required workability was obtained. The mixture was then placed in the standard mould fitted to the cellular masonry block manufacturing machine belonging to one of the largest cellular masonry block manufacturers in Sri Lanka. The cellular masonry block was compacted with the use of the vibratory mechanism attached to the machine.

Table 3: Materials usage to cast cellular blocks

Water / Binder	Sample Name	Cement (%)	RHA (%)	Quantities (kg)			
				Sand	Cement	RHA	Water
0.5	X1	100	00	90	18	00	9.0
	X2	95	05	80	15.2	0.8	8.0
	X3	90	10	80	14.4	1.6	8.0
	X4	85	15	80	13.6	2.4	8.0
	X5	80	20	80	12.8	3.2	8.0
0.6	Y1	100	00	90	18	00	10.8
	Y2	95	05	80	15.2	0.8	9.6
	Y3	90	10	80	14.4	1.6	9.6
	Y4	85	15	80	13.6	2.4	9.6
	Y5	80	20	80	12.8	3.2	9.6

3.3 Testing Procedure

Two samples of RHA burnt at 650°C and 750°C were collected from a brick kiln and the third sample of RHA burnt at 700°C from the thermal power plant. The temperature measurement was conducted using an improvised thermo couple connected to a multimeter.

The RHA samples were sieved through BS standard sieve size 63 micrometer. The test for chemical composition was conducted at the research laboratory of the Holcim Pvt. Ltd. After 24 hours, cellular masonry blocks were demoulded and cured for 7 days (10 blocks), 14 days (10 blocks) and 28 days (20 blocks). At the end of these periods cellular masonry blocks were tested for crushing strength.

Figure 1: Cellular block manufacturing machine

The water absorption test was conducted on the cellular masonry blocks. The 10 cellular masonry blocks that had been cured for 28 days were weighed and oven dried for 24 hours at a temperature between 100°C to 115°C. Then the blocks were weighed (dry mass) and immersed completely in water at the room temperature for 24 hours. Thereafter the wet blocks were taken out of the water bath, wiped off with a damp cloth and weighed immediately (wet mass).

4. Results and Discussion

Temperature impact on Chemical composition

The test to determine chemical composition of RHA was carried out at the Holcim Research Laboratory in Puttalam. This was done on a sample of 100 g using the apparatus of X-ray fluorescence (XRF). The results are shown in Table 4.

Table 4: Composition of RHA at different temperatures

Compound	Percentage		
	650°C	700°C	750°C
SiO_2	88.61	89.22	91.11
Al_2O_3	0.94	1.40	1.23
Fe_2O_3	0.22	0.21	0.27
CaO	2.73	2.56	2.43
MgO	0.42	0.41	0.44
SO_3	0.15	0.09	0.11
K_2O	2.17	2.36	2.47

According to the test results, when the temperature increases, percentage of silica content has also increased. All the three samples were examined through a microscope to notice the presence SiO_2 and unburnt carbon. It was observed that the content of crystallised SiO_2 is greater in the sample burnt at 750°C and the presence of unburnt carbon was higher in the sample burnt at 650°C. Since the higher amorphous SiO_2 and lower the unburnt carbon are desirable properties, the sample incinerated at 700°C was selected to cast solid and cellular masonry blocks in this research.

Particle Size Distribution of RHA

The particle size distribution (PSD) curves of OPC and RHA are shown in Figure 1. The particles of RHA are nearly four times coarser than those of OPC and are better well graded in their distribution. The resulting lower surface area of RHA negates the requirement of coating expected of the cementitious material.

Table 5: Summary of Compressive strength of cubes

Sample Set	Water/Binder Ratios	Mix Proportion		28 Days Compressive Strength (N/mm^2)			
				Binder-Sand ratio			
		RHA (%)	OPC (%)	1:3	1:4	1:5	1:6
1	0.4	00	100	12.75	13	11.5	5.5
2		05	95	13.25	14	12.5	5.2
3		10	90	5.25	12	9	3.2
4		15	85	4.50	4.5	4.5	1.5
5		20	80	2.50	3.5	3	-
6	0.5	00	100	13.50	18	16.5	5.2
7		05	95	14.50	18.5	17.5	5.45
8		10	90	11.70	17	13.5	4
9		15	85	5.50	7	7	2.65
10		20	80	4.25	5.5	5	-
11	0.6	00	100	13.00	15.5	13.5	5.15
12		05	95	13.25	16	14.5	5.25
13		10	90	7.00	14	12	3.75
14		15	85	5.25	5.5	6	1.75
15		20	80	4.25	4	4	-

Table 6: Summary of compressive strength of cellular masonry blocks

Binder: Sand Ratio	Water: Binder Ratio	Sample Name	Cement (%)	RHA (%)	Compressive Strength (N/mm^2)		
					7 Days	14 Days	28 Days
1:5	0.5	X1	100	00	1.67	2.18	3.21
		X2	95	05	2.05	2.24	3.37
		X3	90	10	1.22	1.79	2.69
		X4	85	15	1.15	1.54	2.34
		X5	80	20	0.77	1.28	2.12
	0.6	Y1	100	00	1.54	2.12	3.11
		Y2	95	05	1.6	2.18	3.24
		Y3	90	10	1.47	1.73	2.47
		Y4	85	15	1.35	1.67	2.28
		Y5	80	20	1.03	1.47	1.92

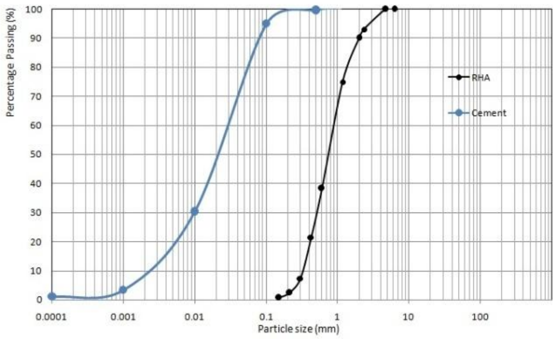

Figure 2: PSD curves for RHA and OPC

Compressive Strength of solid blocks

Table 5 summarises 28 day compressive strength results for binder-sand ratios namely 1:3, 1:4, 1:5 and 1:6, and for the three water- binder ratios namely 0.4, 0.5 and 0.6. According to SLS 855: Part 1:1989, the minimum compressive strength for cement sand blocks is 1.2 N/mm^2. As can be expected, higher the binder-sand ratio, the larger is the compressive strength. Although, binder-sand ratio 1:6 is the most economical, at replacement levels 15 and 20 per cents, it shows compressive strength values lower than 1.2 N/mm^2. According to the above cube testing results, for the binder-sand ratio 1:5 and water-binder ratios 0.4, 0.5 and 0.6, for 7 days and 28 days, compressive strength values satisfy the required compressive strength of cement sand cellular masonry blocks. The prize observation in this study is that when 5 per cent cement is replaced with RHA the compressive strength is increased by 6 per cent.

Compressive Strength of cellular masonry blocks

The compressive strength results of the cellular masonry blocks casted for different mix proportions are computed and presented in Table 6. It is observed that the compressive strength values do not decrease noticeably when water binder ratio is increased from 0.5 to 0.6; decrease only by 3 per cent. Further the results confirm that when 5 per cent cement is replaced with RHA the compressive strength is increased by 6 per cent. Nevertheless, with further increases in cement replacement levels, the strength gradually and noticeably decreases. However, even at the cement replacement level of 15 per cent, the compressive strength (2.34 and 2.28 N/mm^2) is greater than the minimum specified in the SLS 855: Part 1:1989, which is 1.2 N/mm^2.

Water absorption

The water absorption was computed as per SLS 855: Part 2:1989 and a summary of results is presented in Table 7. The water absorption of the cellular masonry blocks with no RHA was 8.3 per cent. However, as per results, when the cement replacement level is increased the water absorption too is proportionately increasing. Water absorption is not a physical requirement as specified in the SLS 855: Part 1. However, it is a useful index to determine whether wetting of block is necessary before the laying of blocks.

Table 7: Summary of water absorption rates

Binder-Sand Ratio	Composition of Binder		Water Absorption (%)	
	RHA (%)	OPC (%)	W/B=0.5	W/B=0.6
1:5	00	100	8.3	9.2
	05	95	9.8	10.5
	10	90	11.4	12.9
	15	85	13.6	14.1
	20	80	14.3	14.6

5. Conclusions

The following conclusions can be made:

1. The chemical composition of RHA and OPC are the same, having the following compounds namely SiO_2, Al_2O_3, Fe_2O_3, CaO, K_2O, MgO, SO_3 and Na_2O. The particle sizes of RHA are coarser than OPC.

2. The rice husk incinerated at temperature 700°C produces the most preferable chemical composition. It contains a high content of amorphous SiO_2 and a low content of unburnt carbon.

3. The compressive strength increase until the cement replacement level of 5 per cent. Thereafter gradually compressive strength

decreases with the increase of cement replacement level. The higher value for the compressive strength can be attributed to the greater compactive effort rendered by the block manufacturing machine.

4. A cement replacement level of 15 per cent can be recommended with respect to producing cellular masonry blocks in keeping with the requirements stipulated in the SLS 855: Part 1.

5. As the cement replacement level is increased the water absorption of cellular masonry blocks too proportionately increases.

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