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Reactive pozzolanas from rice husk ash: An alternative to cement for rural housing

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Abstract

This paper discusses the properties of rice husk ash samples produced from different types of field ovens to compare the performance of the ovens and to identify the most feasible method to produce a reactive pozzolana as an alternative to cement for building applications requiring lower strengths. Different types of ashes are produced and long-term strength of rice husk ash pozzolanas with lime or cement is investigated to suggest a sustainable affordable option in rural building applications, especially for rural housing in Kerala, a southern state of India.

Keywords: Long term strength; RHA pozzolanas; Mortar; Alternative cement; Field incinerator

1. Introduction

Conventional building materials are beyond the reach of a majority of the world population due to their poor affordability [18]. Besides the escalation in the cost of building materials, rising environmental concerns due to the extensive exploitation of natural resources connected with general construction and other housing development activities urge the search for alternative technological options. This paper attempts to identify a sustainable affordable alternative to replace cement for the primary building applications in rural areas. Ashes produced from three different types of field ovens are analyzed for their reactivity and pozzolanic properties to identify the most feasible method to produce a reactive pozzolana as an alternative to cement for construction applications like masonry and plastering. However, the economical aspects for the bulk production of rice husk ash could not be considered. Along with bulk production, utilisation of the fuel value of rice husk can further improve the affordability of RHA pozzolana [6,13]. It has been suggested as the next phase of this research.

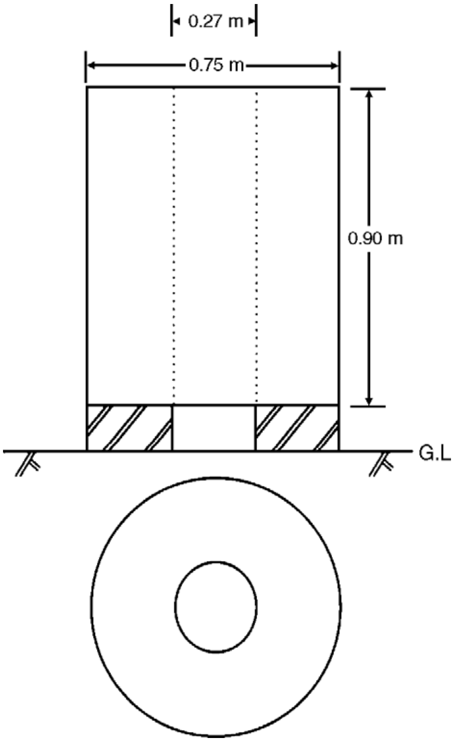

Fig. 1. Plan and section of annular enclosure for burning rice husk ash.

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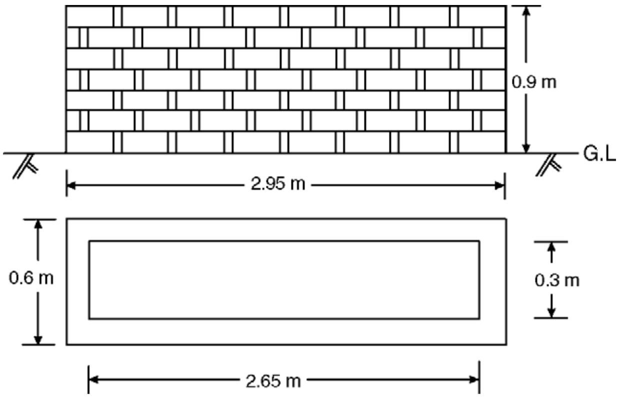

Fig. 2. Plan and front elevation of the enclosure made of brick for burning rice husk ash.

The use of RHA in concrete was patented in the year 1924 [1]. Up to 1972, all the researches were concentrated to utilise ash derived from uncontrolled combustion. Mehta published several papers dealing with rice husk ash utilisation during this period. He established that burning rice husk under controlled temperature–time conditions produces ash containing silica in amorphous form [2]. Chopra, Ahluwalia and Laxmi have reported that for an incinerator temperature up to 700 °C the silica was in amorphous form and silica crystals grew with time of incineration [3]. The combustion environment also affects specific surface area, so that time, temperature and environment also must be considered in the pyroprocessing of rice husks to produce ash of maximum reactivity [4,17]. James and Rao indicated that isothermal heating at a minimum of 675 K (402 °C) is required for complete destruction of organic matter from rice husk and to liberate silica. On combustion, the cellulose–lignin matrix burns away, leaving a porous silica skeleton, this on grinding will give very fine particles having large surface area. Parameters influencing the surface area of ash samples are temperature, duration of combustion and the treatment of rice husk before burning. The decrease in surface area can be attributed to crystalline growth and pore opening [5].

M.R.Yogananda and K.S.Jagadish from Indian Institute of Science (IISC), Bangalore [6,13] did several studies on the pozzolanic properties of rice husk ashes produced by different field incinerators. They had arrived at the following conclusions.

- Pre-grinding of RHA before intergrinding with lime is essential to achieve higher strength mortars.
- The long-term strength of RHA pozzolanas produced from field arrangements in certain cases showed a decrease in strength after 28 days.

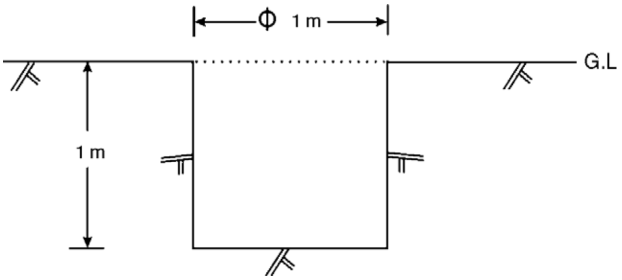

Fig. 3. Arrangement for pit burning.

Table 1
Properties of different RHA samples

Samples	Colour	LOI %	SiO_2 Total %	Percentage of soluble silica in ash %	Percentage of soluble silica in total SiO_2 %	Variation in electrical conductivity (pozzolonicity) (mS/cm)
RHA-A	Light grey	10.8	81.95	67.7	82.6	2.6
RHA-B	Light grey	12.1	85	61.8	72.7	2.55
RHA-C	Grey	15.3	82	27	32.9	2.05
RHA-D	Dull white	0.84	88.5	61.1	69	3.9
RHA-E	Black	20.5	76.7	35.9	46.8	1

The decrease in strength of RHA pozzolanas was a great concern for the popularity of RHA in building applications. This research was an attempt to verify this fact. The ash samples produced from different types of field ovens in this research are from the same type of incinerators as that of IISC [6]. This paper presents a discussion on the comparison of RHA samples from different field ovens and recommends a feasible method to produce rice husk ash pozzolana in uncontrolled conditions in rural environments.

2. Experimental

Rice husk ash samples are produced from three different types of field ovens. These are subjected to various tests to analyse the amorphous silica content, loss of ignition and particle size distribution. The long-term strength of the lime/cement pozzolana mortar produced from these samples are compared with that of a reference sample produced at optimised conditions in the lab and also with the pozzolana mortar of waste ash from parboiling operation of paddy.[1]

2.1. Types of field ovens

2.1.1. Annular oven

An annular enclosure (Fig. 1) of a height of 0.9 m consisting of two co-axial hollow cylinders (open at the top) are made with weld meshes. The inner cylinder has a diameter of 0.27 m and an outer cylinder with a diameter of 0.75 m. The base and exterior of this arrangement is protected with an extra layer of chicken mesh to prevent the escape of ash samples. Rice husk is filled in the annular portion between the two cylinders. This arrangement can be kept elevated from the ground using bricks so as to apply heat from the bottom. Temperature is measured at different parts of the sample using a temperature probe. Maximum temperature was found varying

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[1] Parboiling is a hydrothermal treatment of paddy to separate rice grain.

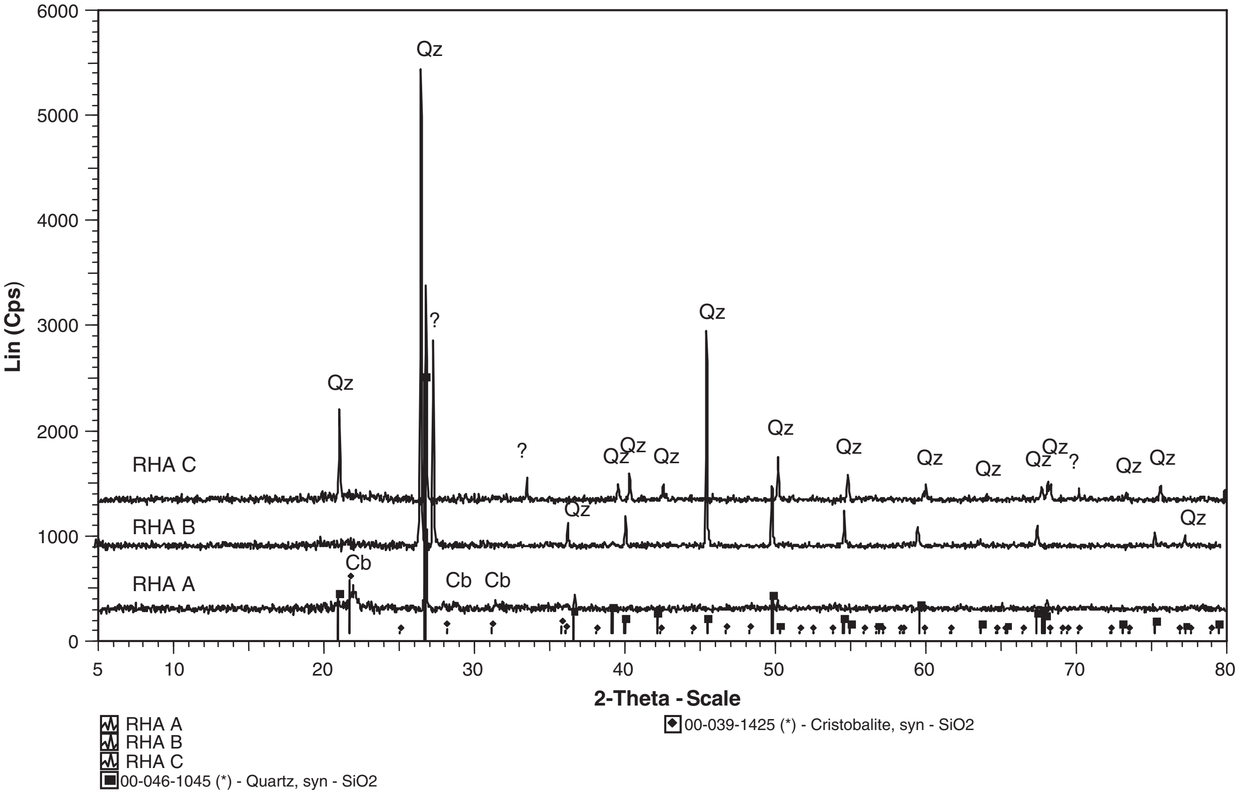

Fig. 4. XRD of RHA A, RHA B and RHA C (Field samples).

from 500 to 600 °C. It took almost 9 h for complete burning. RHA samples were collected (RHA A) after cooling of the entire ash.

2.1.2. Brick oven

A rectangular enclosure (2.95 × 0.6 × 0.9 m) as shown in the picture (Fig. 2) is built with bricks having a number of small

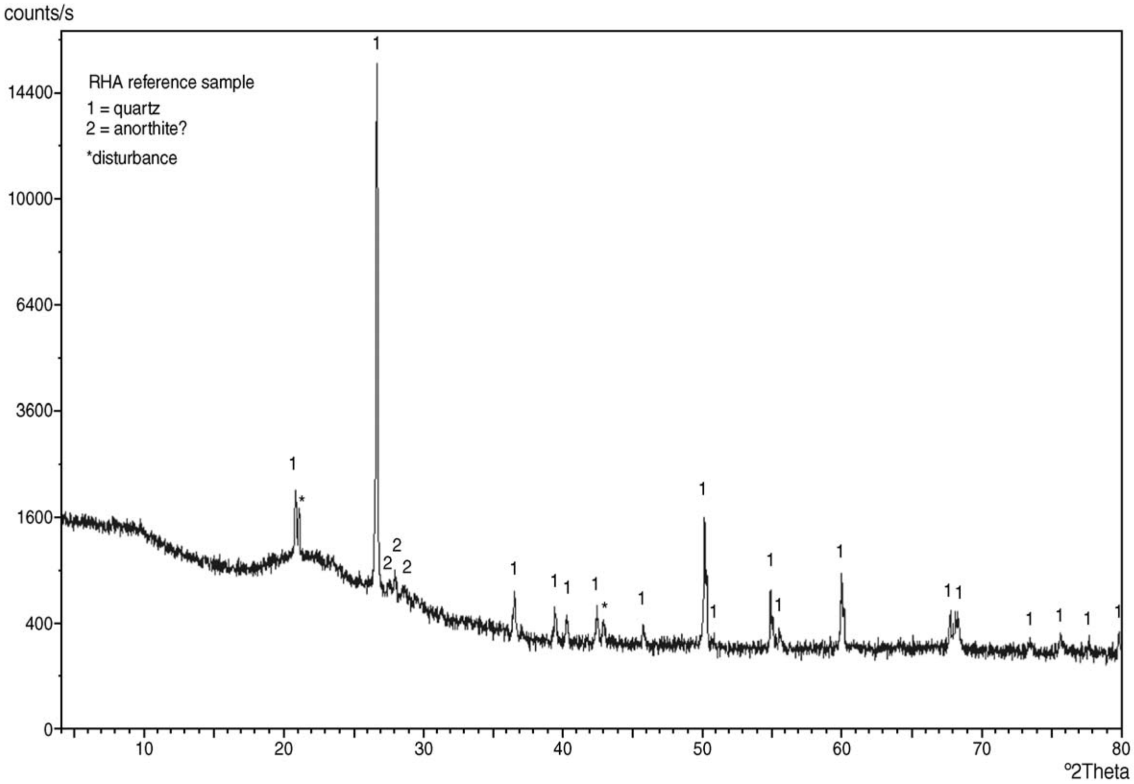

Fig. 5. XRD of RHA D (Reference Sample).

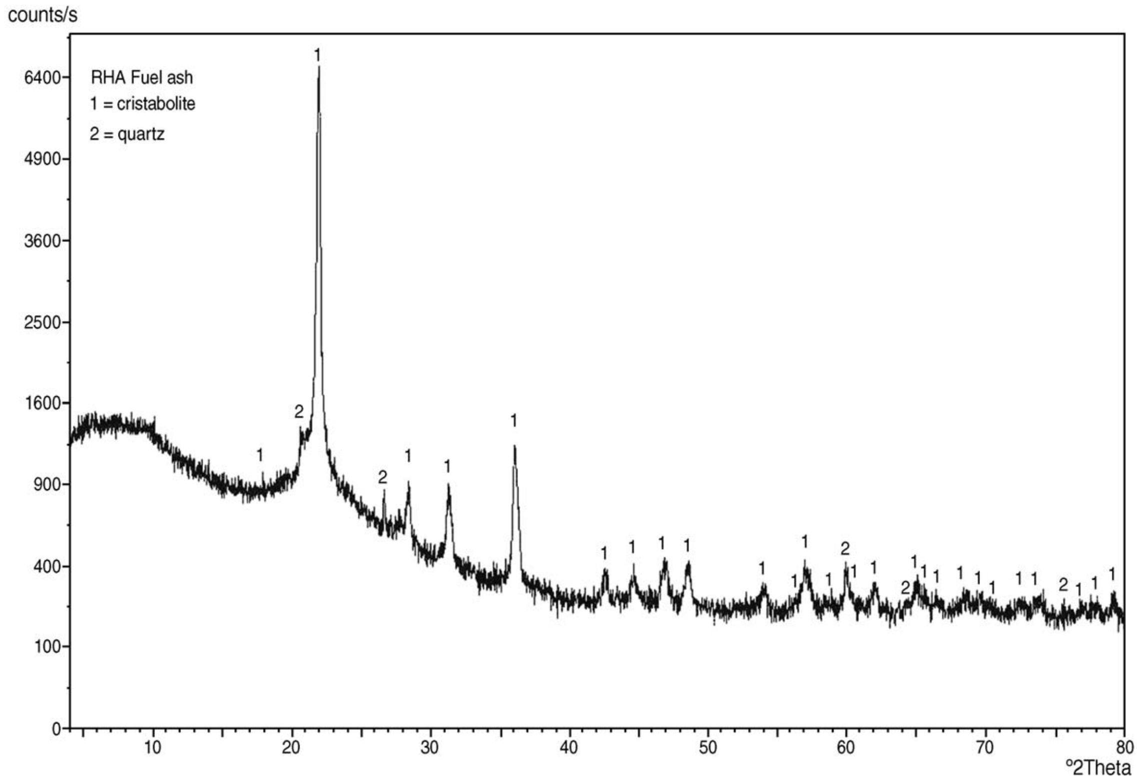

Fig. 6. XRD of RHA E.

openings (5 cm wide) in the body of the enclosure to allow smooth flow of air. It is filled with rice husk and burning of sample is started from the top, slowly progressing towards the bottom. The burning process was slow compared to the annular enclosure and it took almost three days for complete burning. Temperature was measured at different points of the samples to see the variation and here also the maximum temperature was found varying from 500 to 600 °C as in the annular enclosure. The ash samples collected from this oven is denoted as RHA B.

2.1.3. Pit burning

A pit of a diameter and depth of 1 m is dug in the ground (Fig. 3) and filled with rice husk. The burning of rice husk was allowed to take place from the top surface in the same manner as in the rectangular enclosure. Burning proceeded from the top surface slowly downwards. It took almost one week for the complete burning and simultaneous cooling of the sample. Ash samples were tested at different points using a temperature probe to check the maximum temperature and it was found to vary from 500 to 600 °C as in the above two cases. The ash samples collected from this burning arrangement is denoted as RHA C.

In all the three cases mentioned above RHA samples were collected after one week from the date of burning to keep consistency.

2.1.4. Laboratory oven

RHA D is the reference sample made at controlled conditions in the lab using a muffle furnace with continued supply of air. Ash samples of 500 g were used for each burning operation. After keeping the rice husk in a porcelain container, the oven was switched on and an initial duration of 2 h was given to reach the desired temperature of 500 °C. The oven was then maintained at this temperature for 12 h. After 12 h of heating, the oven was switched off (maintaining the air supply) and kept closed for another 24 h and samples were collected (after complete cooling).

2.1.5. RHA E

This is the waste ash collected from a rice factory where rice husk was using as the fuel for the parboiling operation for paddy.

The ash samples collected from different sources (A to E) were subjected to grinding in a ball mill for 60 min and the powder thus obtained was used for further tests. As these ashes are supposed to be produced in the rural environments for practical applications, no limits of fineness were prescribed for final samples and instead the duration of grinding was maintained constant for all the samples for keeping the uniformity in procedure.

Table 2
Particle size distribution of different RHA samples

RHA samples	D10 μm	D50 μm	D90 μm
RHA.A	7.3	40.9	152
RHA.B	9.1	47.3	171
RHA.C	7.1	44.5	320
RHA.D	3.7	18.9	60.7

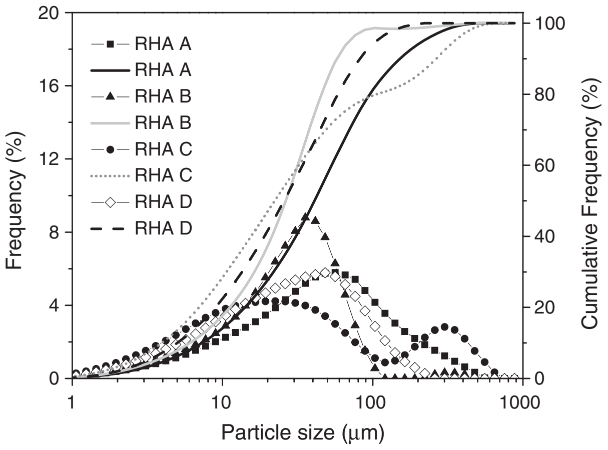

Fig. 7. Particle size distribution of different RHA smaples.

2.2. Chemical analysis

ASTM C 311-71 standards [7] were used for the determination of loss of ignition (LOI) and silica.

2.2.1. Loss on ignition and total silica

Pre weighed RHA sample is kept in an oven (800 °C) and weighed again. The difference in weights is the weight of carbon that released as CO_2. The same sample (carbon removed) is taken and boiled in nitric acid. It is then filtered through a weighed glass fibre filter and then washed with demineralised water. The filter is then dried in an oven at 105 °C (whole night) and weighed again. The weight change will be the weight of insoluble SiO_2 (total silica, both crystalline and amorphous).

2.2.2. Soluble fraction of silica

Rice husk ash samples are taken, weighed in an analytical balance and boiled in 100 ml of 2.5 N (10%) NaOH. The solution is then filtered through a filter paper and washed with demineralised water. This filter is dried in an oven at 800 °C, cooled and weighed to get the weight of the insoluble silica. Soluble silica remained as dissolved in the solution.

2.2.3. Pozzolanicity

The variation of electrical conductivity of a saturated solution of calcium hydroxide on dispersing with the RHA samples can be taken as a measure of the pozzolanic activity of the samples [8]. Initially the conductivity of calcium hydroxide saturated solution (200 ml, 40 °C) is measured. To this 5 gm of RHA sample is added. The electrical conductivity is measured after 2 min of continuous stirring. The difference between the initial and the final conductivities is calculated as a measure of pozzolanicity. This is identified as a rapid method to evaluate the pozzolanic effect of rice husk ash [10,15,19].

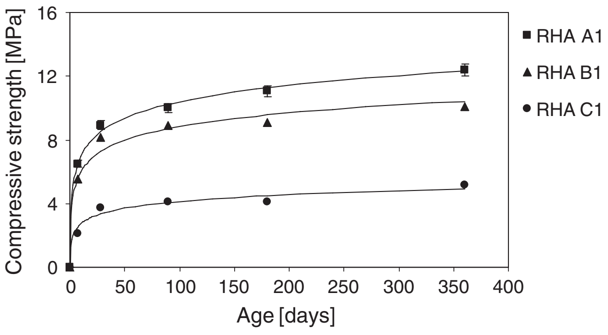

Fig. 8. Long term compressive strength of lime–RHA mortar [1:1:6].

Table 3
BET surface area of different RHA samples

RHA samples	BET surface area in m^2/g
RHA.A	63 ± 1
RHA.B	65 ± 1
RHA.C	43 ± 1
RHA.D	115 ± 1

Table 1 gives the properties of the different RHA samples. The reference sample (RHA D) has the highest value of pozzolanicity and waste ash (RHA E) has the lowest value. Among the field samples RHA A has the highest value of pozzolanicity.

2.3. X-ray Diffraction Analysis (XRD)

XRD analysis was performed on a Philips PW 3710 X-ray diffraction system having a copper tube and a nickel filter. Only cristobalite could be detected in RHA A. Where as the XRD of RHA B, C, D and E (Figs. 4–6) showed the peaks of Quartz also. Also the XRD pattern of RHA C and E verifies the presence of crystalline silica in excess of other RHA samples.

Higher percentage of loss on ignition and XRD pattern of RHA E itself are sufficient to prove the inferiority of RHA samples produced from uncontrolled burning. Therefore RHA E has not been subjected for further tests other than compressive strength.

2.4. Particle size analysis by laser diffraction with the Malvern Mastersizer S

Table 2 and Fig. 7 give the details of particle size analysis. These measurements were done with a Mastersizer S, 300RF lens, and the sample presentation unit. The ash samples were made wet with a non-ionic surfactant and dispersed in demineralised water. They stayed stable for several minutes. When ultrasonic effect is applied, the distribution became much smaller.

Table 4
Lime reactivity of different RHA samples

Sample	Mix♣ lime–ash–sand	Average compressive strength in 8 days N/mm^2
RHA-A	1:3:12	10.97
RHA-B	1:3:12	7.76
RHA-C	1:3:12	5.35
RHA-D	1:3:12	13.35

♣ Water content in percentage by weight of lime and ash is 0.76.

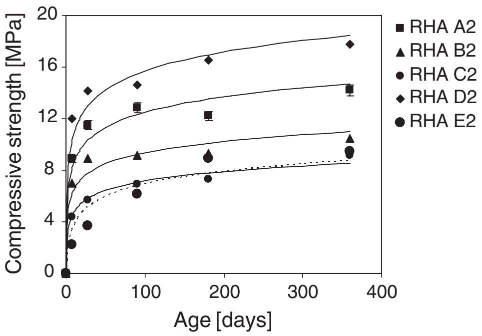

Fig. 9. Long term compressive strength of lime–RHA mortar [1:3:12].

Among the four samples subjected for particle size analysis RHA D showed higher percentage of finer particles. Within the field samples particle size was increasing from RHA A to C (A<B<C).

2.5. Specific surface area, BET (Brunauer, Emmett and Teller) analysis

The specific surface areas of the RHA samples were determined by nitrogen adsorption using the Quanta chrome Autosorb-6B analyser. The BET method provides a combined surface area value for both inter-particle area and intra-particle area; surface inside pores of the structure and outer surface of the particles. Table 3 shows the specific surface area of different RHA samples. The reference sample (D) has the highest surface area compared to field burnt samples.

2.6. Lime reactivity test

This test has been recognised as a standard method by I.S.1727-1967 [9] for determining the reactivity of the pozzolanic material (RHA) with hydrated lime, as represented by the compressive strength of standard mortar test cubes prepared and tested under specific conditions. The dry materials of standard test mortar of lime–pozzolana–sand in the different proportions (by weight) is tested. Lime and ash is weighed and inter-ground in a ball mill (for 60 min) just before making the mortar. Cube specimens of 40 mm size[2] are moulded according to I.S 1727-1967 specifications. After covering the surface of the specimen in the mould with a smooth and greased glass plate, it is kept in a moist room with a temperature of 21 °C for 48 h. Then the specimens are removed from the mould and cured at 90% to 100% relative humidity for a period of 8 days at 50±2 °C in an incubator. The specimens after curing for 8 days were taken out of the oven and tested for compressive strength after they reached room temperature. Since the specimens were kept exposed only for a short duration, chances of carbonation are meagre.

Table 5
Compressive strength of lime-RHA mortar

RHA-lime mortar	Water content in percentage by weight of lime and ash	Compressive strength for different durations in MPa				
		7 days	28 days	3 months	6 months	1 year
RHA A1(1:1:6)	0.76	6.5	8.93	10	11.06	12.37
RHHA B1	0.76	5.56	8.15	8.9	9.08	10.08
RHA C1	0.76	2.1	3.75	4.13	4.09	5.17
RHAA2(1:3:12)	0.76	8.91	11.5	12.81	12.21	14.21
RHHA B2	0.76	6.97	8.96	9.19	9.32	10.45
RHA C2	0.76	4.35	5.69	6.96	7.29	9.19
RHA D2	0.76	12	14.13	14.59	16.6	
RHA E2	0.76	2.23	3.69	6.15	8.96	
RHAA3(3:1:12)	0.76	2.6	5.53	6.23	5.4	7.51
RHHA B3	0.76	2.83	4.52	5.42	6.29	7.19
RHA C3	0.76	1.17	2.6	2.61	2.25	3.36

Table 4 gives the eight days average compressive strength of different RHA specimen as an indication of their reactivity. RHA D was giving the higher strength mortar among the tested samples and was showing a variation of compressive strengths for different mortars in the order of RHA D>RHA A>RHA B>RHA C.

2.7. Long term compressive strength

Lime–RHA and cement–RHA mortars in 1:3 proportions (by weight) were prepared for different proportions of lime–RHA and cement–RHA combinations. 40 mm cube specimens were prepared in the same manner as that of lime reactivity test and compressive strength was measured after a curing period of seven days to one year according to ASTM C 311-71 standards.

X_1, $X_{2,}$ X_3 and X_4 series corresponds to 1:1:6, 1:3:12, 3:1:12 and 2:1:9 proportions of RHA pozzolana with lime and cement mortar. Figs. 8 and 9 show the evolution of the compressive strength of different lime–RHA mortars during a period of one year. In all the mortars, a gain in strength with time can be seen (Tables 5 and 6). Percentage of rice husk ash in the total powder

Table 6
Compressive strength of cement–RHA mortar

RHA–cement mortar	Water content in percentage by weight of lime and ash	Compressive strength for different durations in MPa				
		7 days	28 days	90 days	180 days	360 days
RHAA2(1:3:12)	0.79	7.88	10.42	12.67	12.65	14.70
RHHA B2	0.80	10.08	10.19	11.36	14.63	16.24
RHA C2	0.61	7.6	18.06	20	20.46	24.35
RHA D2	0.70	9.59	11.21	13.77	14.96	
RHAA3(3:1:12)	0.53	33.4	53.15	49.19	53.36	68.54
RHHA B3	0.53	37.69	48.94	51.61	59.25	80.8
RHA C3	0.43	37.9	46.77	52.46	65.79	70.52
RHA D3	0.50	41.23	55.53	61.55	64.61	
RHA E3	0.53	29.65	44.29	46.17	61.83	
RHA A4(2:1:9)	0.53	23.31	26.13	51.88	60.2	–
RHHA B4	0.54	25.25	44.83	53.06	55.44	68.76
RHA C4	0.50	30.17	44.38	42.63	64.06	70.02

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[2] The test specimens used are 40 mm cubes instead of the 50 mm cubes as specified by I.S.1727-1967.

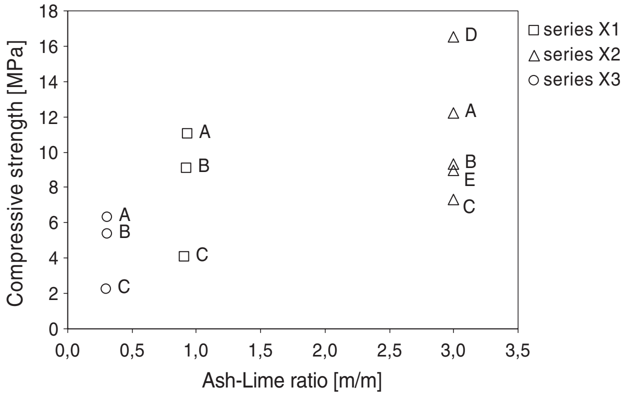

Fig. 10. Influence of ash content on the compressive strength (180 days) of Lime–RHA mortars of different proportions.

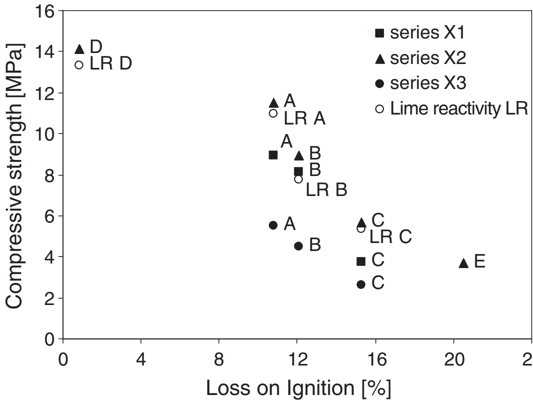

Fig. 12. Influence of carbon on the 28 day compressive strength of different lime–RHA mortars.

(ash + lime or cement) has also a significant influence in the strength of the mortar. Fig. 10 illustrates this.

3. Results and discussion

3.1. Chemical analysis

Table 1 and Fig. 11 give the variation of soluble silica and carbon content in different RHA samples. The influence of different heating arrangements and burning duration can be discussed based on the results of chemical analysis.

Among the field samples RHA A from the annular oven gave better results with minimum carbon content (LOI) and maximum percentage of soluble silica. LOI was ranging from A to C in the order of A < B < C and soluble silica as A > B > C. In both cases RHA C gave inferior results compared to RHA A and B. This variation in amorphous silica and carbon content can be due to the longer duration of burning and limited air flow in the case of pit burning compared to the other two arrangements. Figs. 12 and 13 shows the variation in compressive strength of different lime–RHA samples (with the same water–binder ratio −0.76) with loss on ignition and total silica in the ash. It confirms the detrimental effect of carbon in the compressive strength of corresponding mortars for three different mix compositions of the field samples. The quick burning and plenty air flow in the case of annular enclosure due to its peculiar shape and bottom firing favored better results of RHA A. This factor can be confirmed from the case of RHA E with uncontrolled burning. It had a lower percentage of soluble silica and highest percentage of LOI. On the contrary the reference sample RHA D, produced from the controlled conditions in the lab showed the results of least carbon content among the samples and higher percentage of amorphous silica compared to RHA C and E. The color of the samples also gives an indication of carbon content.

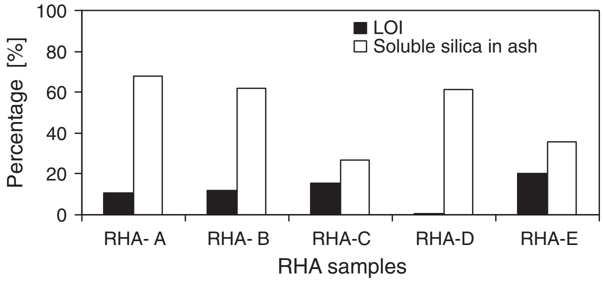

Fig. 11. Percentage of soluble silica fraction and loss on ignition in different RHA samples.

3.2. Pozzolanicity

The variation in electrical conductivity of saturated calcium hydroxide solution on adding the pozzolanic material can be taken as a quick measure of the pozzolanic activity of RHA samples. It is based on the concept that the active constituents of the pozzolanic material will react with calcium hydroxide leading to a decrease in concentration of Ca^{2+} and hence to a decrease in electrical conductivity. Table 1 gives the different properties of RHA samples. Among the tested RHA samples, pozzolanicity decreases from D to E (D > A > B > C > E) as the carbon content (Fig. 14). The field samples showed a variation in the reactivity in the same order as that of soluble silica and LOI from RHA A to C. However, RHA D showed a higher value of pozzolanicity than RHA A and B, even though it had a lower percentage of amorphous silica (Fig. 15). This can be

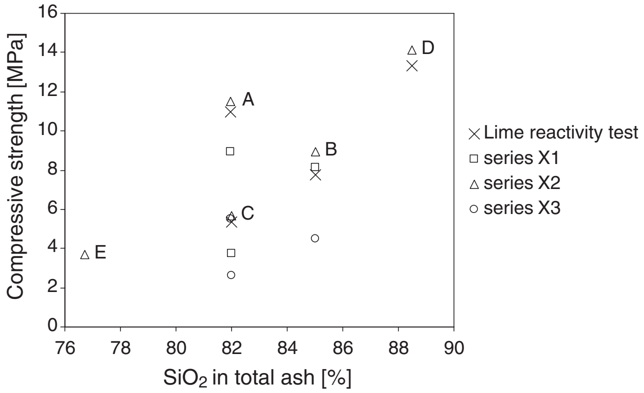

Fig. 13. Influence of soluble silica in the ash on the 28 day compressive strength of different lime–RHA mortars.

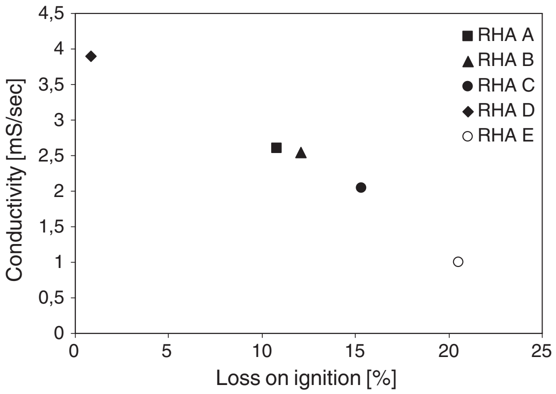

Fig. 14. Influence of loss on ignition on the pozzolanicity of different RHA samples.

attributed to the extremely low value of loss on ignition of RHA D. The same influence could also be noticed in the cases of RHA C and E. Even though both amorphous silica and carbon content are deciding factors on the reactivity of RHA pozzolana, these results show the significance of carbon content in the pozzolanic activity.

Pozzolonic activity of RHA samples explained by the variation in electrical conductivity gives a clear correlation of the variation in compressive strength of different mortars (Fig. 16).

3.3. X-ray diffraction analysis

XRD analysis also shows consistent results with chemical analysis. The degree of amorphousness of RHA samples can be judged by the intensity or average height of the diffused band between 15° and 26° values of 2θ, using X-rays generated from a copper target and nickel filter [2]. XRD patterns of RHA A and RHA B shows the amorphous nature of samples, whereas the peaks of quartz could be detected in the other samples. The presence of quartz shown by the XRD of RHA C can be due to the longer duration burning or can also be attributed to the contamination of sand particles from the pit. The uncontrolled burning of waste ash caused the crystallinity of RHA E.

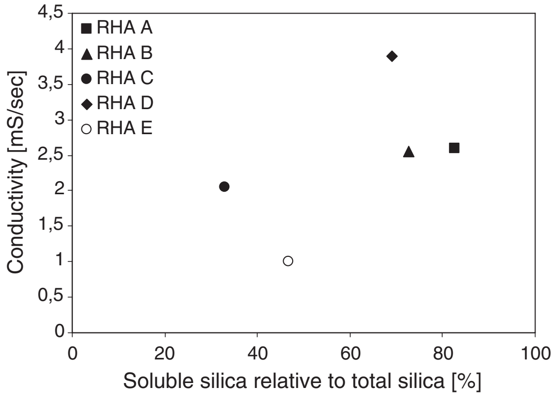

Fig. 15. Influence of soluble silica on the pozzolanicity of different RHA samples.

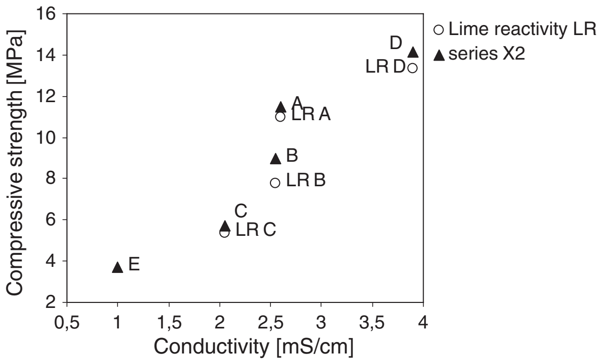

Fig. 16. Relation between conductivity and compressive strength.

3.4. Particle size analysis

Table 2 gives the percentage of different size of particles in the tested RHA samples. It was also showing the same variation as that of pozzolanicity from RHA D to C with RHA D having the higher percentage of smaller particles. The percentage of large particles was less in RHA D compared to A and B, whereas RHA C showed higher percentage of coarse particles (with D90 = 320 μm, i.e. 90% of particles smaller than 320 μm). Fig. 7 shows the particle size distribution of different samples. Unimodal distribution of A, B and D samples corresponds to the homogeneity of ashes whereas the bimodal distribution of RHA C shows the heterogeneous nature of RHA C. Also the particle size distribution clarifies the presence of coarse particles (D90 = 320 μm) in RHA C compared to RHA B (D90 = 171 μm) and RHA A (D90 = 152 μm). Higher concentration of comparatively smaller particles in RHA D (D90 = 60.7 μm) explains the higher reactivity of the reference sample. Also the field samples showed consistent results in the particle size with the reactivity of ash samples. These results also confirm the excellence of annular enclosure (RHA A) compared to the other two field arrangements.

3.5. BET analysis for surface area

The BET results of all the samples varies in the same order as that of pozzolanicity as expected. Fig. 17 shows the

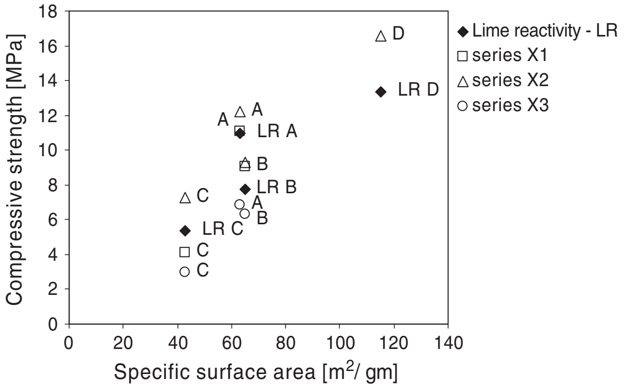

Fig. 17. Influence of Specific surface area on the long term (180 day) compressive strength of different lime–RHA mortars.

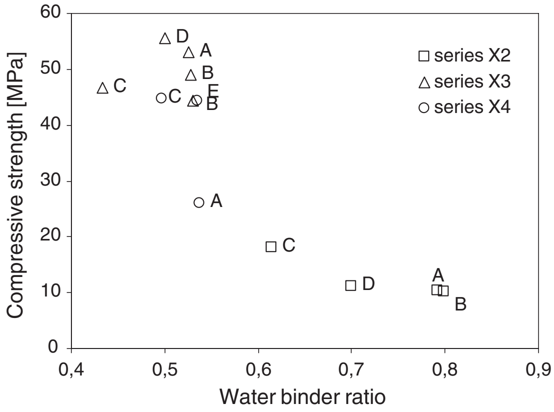

Fig. 18. Influence of water binder ratio on the compressive strength (28 day) of different cement–RHA mortars.

influence of specific surface area on the 180 day compressive strength of different lime–RHA samples with the same water–binder ratio (0.76). RHA D having the higher specific area gave the highest value of compressive strength in 1:3:12 proportion of lime–RHA mortar and it showed a variation in the other samples in the same way as that of specific surface area from A to C.

Since all the samples are subjected to grinding with the same conditions, the higher surface area of RHA D can be attributed to the controlled conditions of burning. The higher surface area of RHA increases its pozzolanic activity [16]. Hence the higher surface area of the RHA D compared to other samples can also attribute to the higher strength gain. According to James and Rao temperature and duration of incineration are important parameters which influence the specific surface area [5]. The annular oven took only a comparatively shorter duration of burning and cooling of the RHA samples compared to the other two field arrangements. This can be attributed to the variation in specific surface area of the field samples (RHA A>RHA B>RHA C) and the corresponding variation in the compressive strength of mortars (Fig. 17). Hence the grinding efficiency is apparently not the same for different ashes with different particle size and surface area (Tables 2 and 3). Also the specific surface area of rice husk ash is mainly controlled by pore volume and hence collapse of pore structure will result in decrease in surface area. Therefore, grinding of RHA could not influence the BET values until it reaches certain fineness [10].

3.6. Lime reactivity and compressive strength

Lime reactivity test is considered as a quick measure of the reactivity of RHA pozzolanas. The tested RHA samples were showing a decrease in strength from RHA D to RHA C in the order of D>A>B>C. Similar variation could also be noticed in the compressive strength of RHA–lime mortar. According to Paya et al the reactivity of RHA with lime depends on a combination of two factors, i.e. its non-crystalline silica content and specific surface area [12]. But the variation in compressive strength of RHA–lime pozzolanas in different proportions also confirms the influence of carbon content (with RHA D giving higher strength) along with the other two parameters. All the mixes showed a strength gain during the period of one year. Field burnt samples showed a variation in strength from A to C with RHA A having a higher value with lime mortar.

However the variation in the compressive strengths of cement–RHA mortars from different ashes were not that consistent as in lime–RHA mortars. This can be mainly due to the different water/binder ratios. This variation in water content in different mortars was guided by the loss on ignition of the corresponding RHA samples and ash content. The influence of water/binder ratio in the compressive strength of cement-RHA mortar can be well explained by Fig. 18. In addition to this, the higher strength of RHA C pozzolanas can be due to its non-homogeneous nature rather than the pozzolanic activity. The coarse nature of large sized particles of RHA C provides a satisfactory gradation of fine particles and leads to a dense mix. The filler effect of smaller particles in the mix dominates the pozzolanic effects in this case [14].

4. Conclusions

The comparisons of the properties of ashes from different field ovens confirm the significance of annular enclosure over the other two field ovens. These results also show that rice husk ash samples with lower values of loss on ignition and higher specific surface area can result in the production of relatively higher strength pozzolana (RHA D). Presence of un-burnt carbon can adversely affect the reactivity even though it is rich in amorphous silica. Hence the duration and type of incineration are important parameters, influencing the reactivity of RHA pozzolanas. The presence of ample oxygen during incineration is also an important factor necessary for reducing the carbon content of ashes (RHA C). For rural building applications, sophisticated ovens and techniques are not feasible and affordable to attain the above criteria. This research was carried out to identify an affordable incinerator to produce reactive pozzolana for rural building applications in Kerala. We came to the following conclusions.

i. RHA A samples from the annular enclosure produced better results in all the mix compositions compared with RHA samples from other field ovens. Therefore the annular type of oven can be suggested as an affordable and simple option for the small-scale production of RHA in rural areas. A modification of the annular enclosure with bricks instead of weld meshes can be suggested as a long-term solution.
ii. RHA B pozzolanas from the brick ovens also gave reasonably good strengths with lime and cement in different proportions even though those were lower than RHA A. The lower strength values of RHA C from the pit burning compared to the other samples can be due to longer period of incineration and slow cooling rate. Reducing the depth of the pit can modify this arrangement to ease air movement and result in better ash.
iii. Type of kindling can also affect the duration of incineration. RHA A samples were produced by firing the

oven from the bottom, whereas in other two cases husk samples were fired from the top. Bottom kindling can accelerate the burning process and ease natural cooling.

iv. Waste ash (RHA E) from the parboiling operations or other sources where rice husk is used as fuel can also be utilized in the production of RHA pozzolanas of lower strengths.

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