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PRODUCTION AND UTILIZATION OF ACTIVE RICE HUSK ASH AS A SUBSTITUTE FOR CEMENT

By Yasuhiko YAMAMOTO and Shafi M. LAKHO***

1. INTRODUCTION

Rice husk ash (hereafter, this will be referred as RHA) is known to possess high potential of being utilized as a cementitious material for concrete because as high as 85 to 97% of the ash by weight is consisted of amorphous silica[1),2)]. Special interest has been given to the material in Asian countries mainly for three reasons, namely, abundance of rice husks, shortage of conventional Portland cement, and demand for low cost materials. During last 10 years, many workers worked on the material to increase the potential of its utilization both in the basic and applied fields, and there has been a worldwide race to devise better and cheaper ways of making quality RHA since 1974 when Mehta and Pitt[3)] published a paper which introduced a specially designed plant for mass producing active RHA. These efforts have confirmed that RHA, if produced properly, was a prospective silicious material not only for plastering but also for production of acid resistant high strength concrete[1),4),5)].

Mehta states that he obtained patents on his discovery that active RHA could be produced by maintaining the combustion temperature for prolonged period below 500°C under oxidizing conditions or, alternatively, combustion temperatures up to about 680°C may be used provided the hold time is short, viz., less than 1 min[4)]. However, as far as the authors know, none of his published papers includes any quantitative evidence to show how the discovery was made. In fact, lack of such information made many workers including Damer[6)], Paul[7)] and Malla[8)] fail to produce RHA of good quality although they burnt rice husks under very similar conditions to those suggested by Mehta. Ismail[9)] is another only worker who studied the optimum burning temperature of rice husks by means of differential thermal analysis and thermogravimetric curves and showed the results. But he could not use the results to explain the difference in activity of RHA actually obtained. Since useful RHA must be produced before its utilization, it is evident that factors involved for the production of active RHA need to be clarified.

In view of effective utilization of active RHA, it is essential that it be made on a mass scale and economically. The most simple and inexpensive way to mass produce RHA would be to burn rice husks in the open air. Cady and Groney[10)] and Ismail[9)] reported that RHA of good quality was obtained by burning conically shaped piles of husks in the open air, although their test results showed that their ashes were not so good as the one prepared by Mehta. Mehta and Pitt proposed an expensive plant type equipment for mass production of active RHA as mentioned previously and commented that, due to absence of temperature controls, silica in the field burnt RHA was generally in a relatively inactive crystalline form. However, it is undoubtedly desirable to produce active RHA without using sophisticated equipments or high capital investment, so that even the needs of indigent countries be met economically.

The present study was aimed at to seek clear understanding of the factors essential for the production of active RHA. Various ashes were prepared by changing the burning temperature of rice husks, time of burning, condition of air supply during burning, cooling rate of resulted hot ash and grinding time. They were then blended with hydrated lime and effect of each of the factors on the activity of RHA was evaluated by the degree of its contribution in raising the strength of lime-RHA mortars. Effective and simple way of producing active RHA on a mass scale was also studied by trial and error and a practical method was suggested.

* Member of JSCE, Dr. Eng., Ph. D., Assoc. Prof., Inst. of Structural Eng., Univ. of Tsukuba

** M. Eng., Assist. Engineer, Public Health Eng. Dept., Gov. of Sind, Pakistan

2. MATERIALS

(1) Rice Husks

Dirt free rice husks were obtained from a rice mill in Thailand. They were stored in plastic bags at their natural moisture content of about 20%. They were later burnt in a muffle furnace or in the open air to reduce to their ash under various conditions.

(2) Boiler Rice Husk Ash

Rice husk ash taken from a boiler of the same mill was also used in this work for comparative purpose. It is blackish grey in color and will be referred as boiler ash. It was also stored in plastic bags at its moisture content of about 10%.

(3) Lime

Lime used in this investigation was reagent grade calcium hydroxide. It was kept in air tight glass bottles to prevent its carbonation.

(4) Portland Cement

Portland cement conforming to ASTM Type I cement was used in the later parts of the work.

(5) Fine Aggregate

Natural river sand was used for making mortar. Its specific gravity, fineness modulus and water absorption were 2.60, 2.75 and 1.40, respectively. It was kept in plastic bags in moist condition and its free surface water was counted as a part of mixing water in designing the mix proportion of mortar.

(6) Mixing Water

Ordinary tap water was used throughout the experiments.

3. EXPERIMENTAL WORK

(1) Preparation of Rice Husk Ash

a) Preparation in Laboratory

A specially designed muffle furnace, which has a chimney installed, was used to burn rice husks under various conditions. Inside dimensions of the furnace are 20 cm wide, 12.5 cm heigh and 35 cm deep. Rice husks were placed in a steel tray and brought inside the furnace. About 100 g of ash was produced after each burning. A sufficient amount of ash was prepared beforehand for each series of test.

Control of air supply during the burning of rice husks was exercised by opening or closing the furnace door. Supply of air was considered to be restricted when the door was kept closed. When the door was moved to make an opening of about 2.5 cm so that fresh air could flow into the furnace continuously, the condition was defined as free air supply.

After the burning was completed, the ash was cooled to room temperature in three different ways. The first one was to leave the ash inside the furnace with the door closed after the furnace was switched off. The second one was to cool the ash also in the furnace but with the door opened. The third way of cooling was to cool the ash rapidly by sprinkling the hot ash quickly on a large steel plate. The last method brought the temperature of ash to room temperature within a few seconds. Quantitatively, the first method of cooling corresponds to a cooling rate of about 40°C/hr, the second one to 80°C/hr and the last one corresponds to instant cooling.

b) Production in Fields

Rice husks were burnt in large quantities in the fields under varying degrees of control. Three ways of burning were studied. The process of burning for all the cases was self-sustained and no fuel was used except at the time of starting fire which was made with the aid of a small amount of kerosene. No pre-drying of husks was done.

i) Open air burning

Husks were stacked in the shape of a cone. They were then put to fire from the top.

ii) Burning inside a ferrocement dome

A ferrocement dome of 1.5 m heigh and 2.1 m in diameter was used to burn husks inside of it. After a number of trials, five openings were made in the wall of the dome to produce ash of desired quality. The dimensions of the openings, one on the top and other four along the periphery, were approximately 15 × 15 cm each. The top opening was used to pour husks inside and to put them to fire. About 350 liters of husks were burnt inside the dome at a time. After the burning was completed, the dome was raised from the ground and the ash was spread to facilitate rapid cooling under atmospheric temperature.

iii) Burning inside a mud plastered cone

A cone of rice husks was plastered with 1-2 cm thick mud. Air vents of 13 mm diameter were made at about 30 cm center to center in all directions in the whole surface of the cone. Top 10 cm of the cone was truncated so as to provide an opening for starting fire. Later, a modification was made to install vertical masonry hollow shafts in the center of the cone. The ash produced was cooled in the same way as mentioned in ii).

c) Grinding

Grinding of ash was made in a 8.5 liter ball mill. About 300 g of ash was ground at one time.

(2) Mix Proportion of Mortars

RHA was blended with lime or Portland cement in a plastic bag until the mixture showed a uniform color. Sand-cement ratio of 2.75 by weight was maintained throughout the work.

In preparing the blended cement of lime and RHA, lime-RHA ratio was initially kept at 2.0 by weight. But it was changed to 0.5 in the later parts of the study after the latter was found to be the optimum. Water to lime plus RHA ratio was fixed at either 0.80, 0.65 or 0.60 depending on the purpose of the study. The proportion of RHA in the mixture of Portland cement and RHA was changed from 0 to 70% by weight. Mortars made from this mixture were designed for fixed consistency at (150 ± 5) expressed in flow. Water to Portland cement plus RHA ratio increased almost linearly as the proportion of RHA was increased.

(3) Mixing and Casting of Mortars

Mixing procedure adopted for mortars was as follows. First, blended cement and mixing water were placed in a bowl of a Hobart type mixer and mixed for 30 sec at a slow speed. Then fine aggregate was slowly added in the mixture over a period of 30 sec without stopping the mixer. The mixing operation was further continued at the same speed for additional 2.5 min to complete the mixing.

In a case where flow test was required, mortar used in the test was quickly brought back into the mixing bowl and entire mixture was remixed for another 15 sec.

The mixture was then cast in $5 \times 5 \times 5$ cm cube molds in two layers by tamping each layer 32 times, following the procedure described in ASTM C109.

(4) Curing and Testing of Specimens

Specimens were cured by either standard curing method or accelerated one.

Standard curing of mortar specimens was made in a fog room for initial 24 hrs. The specimens were then demolded and immersed in saturated lime water in a storage tank until the ages for their strength tests which were made at 3, 7 and 28 days.

The procedure for accelerated curing was as follows. A metal trough that was full of water and encased in a big plastic bag was placed in an oven. Then, molded specimens were placed beside the trough inside the plastic bag and the bag was made air tight by firmly tying its mouth. After closing the oven door, the specimens were kept in the oven set at 45 to 50°C. At the elapsed time of 12 hrs, the specimens were demolded and placed back again in the oven for their continued curing. They were taken out of the oven and tested at 1 day.

ASTM C109 was exactly followed for testing the compressive strength of the mortar specimens.

4. FACTORS AFFECTING THE ACTIVITY OF RICE HUSK ASH

(1) Effects of Burning Conditions and Cooling Rate

The activity of RHA is considered to be influenced by many factors. However, burning temperature and burning duration of rice husks, degree of air supply during the burning, and cooling rate of the resulted ash would be the most important ones among them as far as the intrinsic chemical activity of ash is concerned. The effects of these parameters were, therefore, studied step by step by examining the degree of contribution of each parameter in raising the strength of lime-RHA mortar. Ashes were used after grinding them for 30 min. Lime-RHA ratio was fixed at 2.0 after the work done by Cady and Groney[10] and water to lime plus RHA at 0.8. Mortar specimens were subjected to accelerated curing and tested at 1 day.

a) Burning Temperature and Duration

Rice husks were burnt at various temperatures for different time durations in the muffle furnace with the door closed. Ashes thus produced were then cooled in the furnace with its door open to room temperature. **Fig. 1** shows the results of compressive strength test of lime-RHA mortars in which these ashes were used.

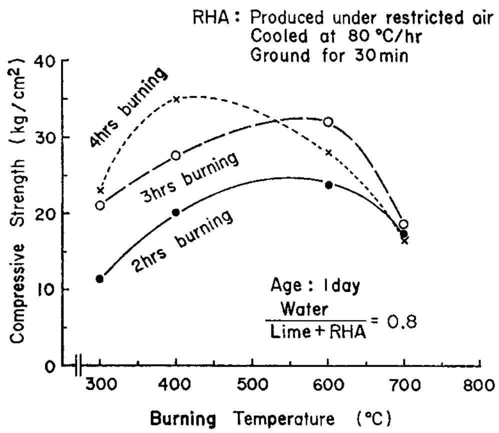


Fig. 1 Effects of Burning Temperature and Burning Time on Activity of Rice Husk Ash (To convert kg/cm² to MPa, multiply by 0.098).

It can be seen in the figure that there is an optimum temperature for each burning time, and burning at higher temperatures beyond a certain limit does not necessarily help to produce quality ash. The optimum temperatures are around 600°C for 2 or 3 hrs burning and 400°C for 4 hrs burning. Another noteworthy observation is that increase in burning time from 2 to 3 hrs improved the quality of ash considerably. However, 4 hrs burning resulted in some improvement over 3 hrs burning only in a low temperature range, and quality of ash was unaffected or adversely affected at temperatures more than 100°C above the optimum. These results are considered to suggest that activity of RHA decreases if rice husks are burnt at too high temperatures for too long time. Further discussions will be made on the effects of these parameters in later sections.

b) Cooling Rate

It is well known that a substance which has been formed by cooling rapidly and retains its high temperature configuration is unstable and, therefore, more susceptible to change at ordinary temperature compared with that of stable structure. This led to an expectation that the activity of RHA might differ depending on the cooling rate of RHA after burning. Based on the previous observation that 3 hrs burning at 600°C and 4 hrs burning at 400°C yielded the highest mortar strength, rice husks were burnt under these two conditions and the resulted ashes were cooled in three different ways. **Table 1** summarizes the strength test results of mortars that were made from these ashes.

As it was expected, higher cooling rate yielded a better ash. For instance, RHA that was cooled instantly from 400°C increased the strength of mortar by 17 or 41% compared with the case where ash was cooled at the rate of 80 or 40°C/hr, respectively. Another noteworthy result in **Table 1** is that the ashes produced at 400°C possess better quality at any cooling rate than those burnt at 600°C. This result will be considered to confirm the observation in the previous section that burning at a low temperature is preferable in view of the production of active RHA.

c) Air Supply During Burning

Rice husks were burnt in the furnace at 400°C for 4 hrs and at 600°C for 3 hrs keeping the door of the furnace open by about 2.5 cm so that enough air could be supplied during the burning. The ashes thus prepared were compared for their activity with those produced in a standard way of using furnace with the door closed. All the ashes used in this part were cooled instantly. **Fig. 2** (a) shows the results.

It can be seen that RHA produced under free air supply condition is apparently superior to that produced under restricted air regardless of burning temperature. It should be mentioned here that the former RHA when produced was found to consist of predominantly whitish grains except a layer of blackish grains in the bottom, whereas the latter consisted of predominantly blackish grains except a thin layer of whitish ones on the top. It is therefore conceivable that the whitish part of the ashes, which would be a product under enough air supply, contributed more to the strength development of mortar than the blackish one. In order to investigate this idea, the blackish and whitish parts of the ashes produced at 400°C were sorted out and were tested separately for their activity. The result

Table 1 Effect of Cooling Rate on Activity of Rice Husk Ash.

Burning Condition*		Compressive Strength** (kg/cm^2)		
		Cooling Rate		
Temp. (°C)	Time (hrs)	40°C/hr	80°C/hr	Instant
400	4	29	35	41
600	3	25	32	36

* Restricted air supply
** Strength of mortar at 1 day, lime/RHA=2.0, water/(lime+RHA)=0.8, grinding of ash: 30 min
Note: To convert kg/cm^2 to MPa, multiply by 0.098

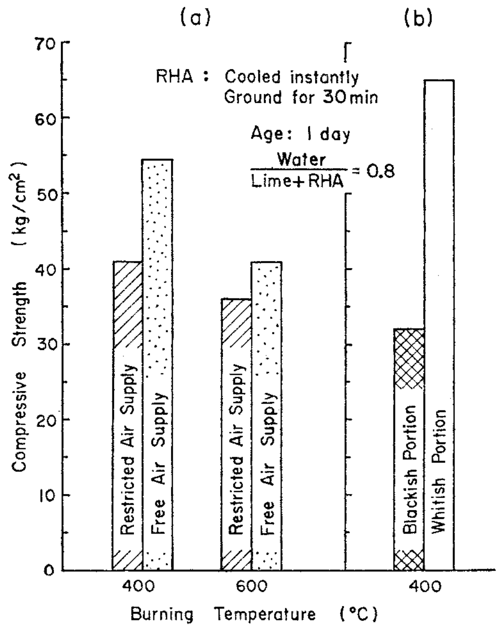


Fig. 2 Effect of Air Supply on Activity of Rice Husk Ash (To convert kg/cm^2 to MPa, multiply by 0.098).

indicated that the strength of mortar made from the whitish part was twice as strong as that of mortar in which the blackish one was used (See **Fig. 2** (b)) and the assumption was confirmed.

Fig. 2 (a) also shows that, when rice husks were burnt under restricted air supply condition, the ash produced at 400°C gave about 8% higher compressive strength to mortar than that produced at 600°C. The difference widened to 24% when the ashes were produced under enough air supply, indicating that the superior quality of RHA produced at 400°C is more enhanced under free air supply condition.

(2) Effect of Grinding Time

It should be noted that the maximum strength of lime-RHA mortar so far obtained is only 65 kg/cm^2 (6.37 MPa) after 1 day accelerated curing and will not be sufficient for structural concrete. Since one of the most effective and common methods to increase the activity of this kind of materials is to grind them finer, RHA which was produced by burning rice husks at 400°C for 4 hrs under free air supply and cooled instantly was ground in the ball mill for various time durations and the effect of grinding time was examined in both lime-RHA mortar and Portland cement-RHA mortar. Lime-RHA ratio of the former mortar was selected to be 0.5 instead of previously used ratio of 2.0 because the former ratio was found to be the optimum (See **Fig. 3**). Portland cement and RHA were mixed in the ratio of 7 : 3 in the latter mortar referring the work by Mehta and Pitt[1].

Fig. 4 shows the relations between grinding time of ash and compressive strength of these mortars. It can be noted in the figure that upto grinding time of about 90 min the strength of mortar increases sharply with the increase in grinding time as it was expected, whereas beyond 90 min further grinding contributes little to increase the strength. For instance, 90 min grinding increased the strength of both mortars by about 60% compared with the case where RHA was ground for 30 min.

The efficacy of longer grinding was further enhanced remarkably when Portland cement-RHA mortar was cured in a standard way as shown in **Fig. 5**. In this case, the strength of mortar was nearly tripled at 3 days and doubled at 28 days by the additional 60 min of grinding. These observations are considered to be due to the fact that the size of ash particles decreases noticeably as the grinding time is extended but not much so when the ash is ground for more than 90 min as can be seen in **Fig. 6**. Based on these results, ashes used for the rest of the work were ground for 100 min.

Another observation to be mentioned in **Fig. 5** is that the magnitude of strength and the manner

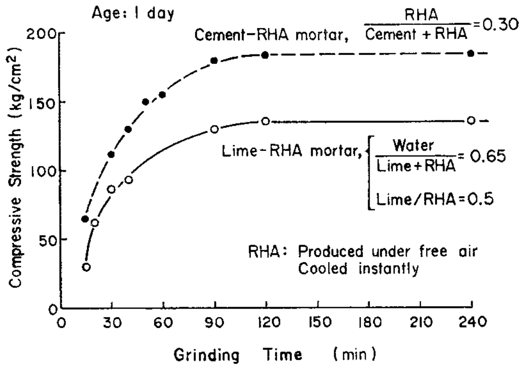


Fig. 4 Effect of Grinding Time of RHA on Strength of Mortar (To convert kg/cm^2 to MPa, multiply by 0.098).

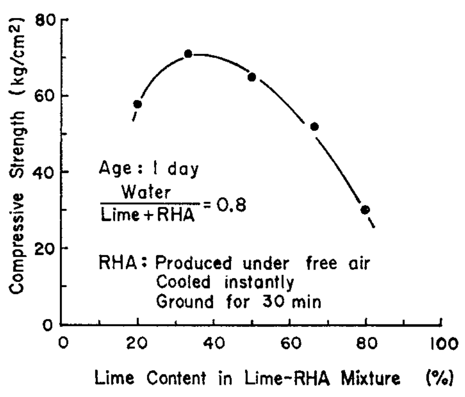


Fig. 3 Effect of Lime Content on Strength of Lime-RHA Mortar (To convert kg/cm^2 to MPa, multiply by 0.098).

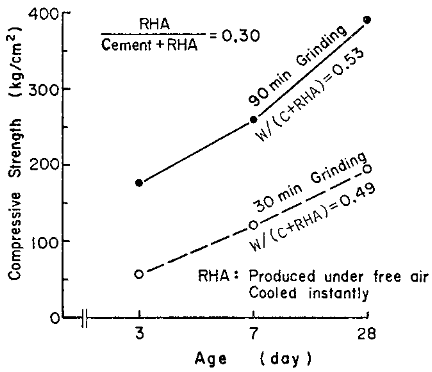


Fig. 5 Effect of Grinding Time of RHA on Strength of Standard-Cured Mortar (To convert kg/cm^2 to MPa, multiply by 0.098).

the strength develops in the case of 90 min grinding are quite similar to those of ordinary plain cement mortars. This would indicate that RHA, if produced properly, has a prospective potential of being used as an active silicious substitute for cement in making concrete for structural purpose.

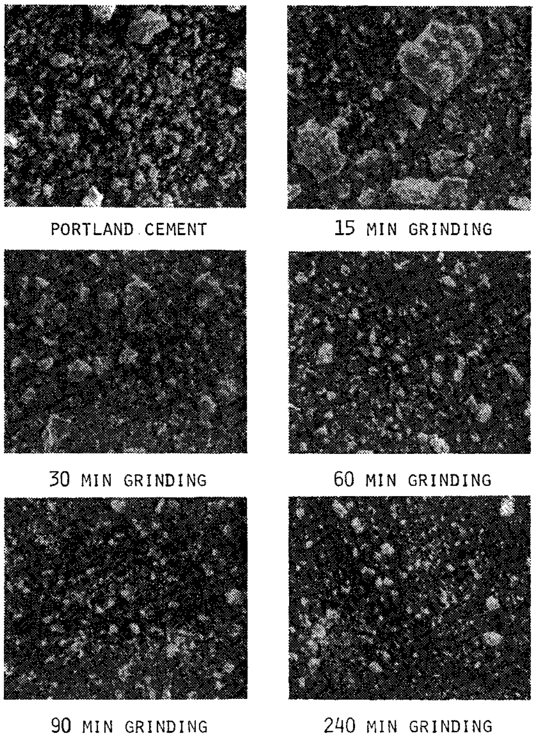


Fig. 6 Photomicrographs of Rice Husk Ash Powders Ground for Various Time Durations.

(3) Effects of Existence of Carbon

It was pointed out in **4(1)c)** that the blackish ash grains, which were sorted out from the ashes obtained by burning rice husks at 400°C for 4 hrs, had inferior quality compared with the companion whitish ones. Since the black color is considered to be due to the existence of carbon, a part of the inferior quality may be simply because the carbon is affecting adversely on the activity of the ash. In this connection, Ismail[9] reported that carbon content in RHA exceeding 10% reduced the overall activity of the ash. Mehta[1], who produced blackish ash, believed that the presence of some carbon in the silica ash helped rather than hurt the performance of the material. Since carbon, if existed in its free form, can be removed by complete combustion, the effect of the existence of carbon was examined by reburning the blackish portion of the ashes under free air supply condition at the same temperature for additional 1 hr. For a comparative purpose, the whitish portion of the ashes produced at 400°C, boiler ash, and black ash grains produced at 1000°C were subjected to similar treatment. **Table 2** summarizes the details of the treatment and the test results.

As shown in **Table 2**, the reburning process converted the blackish grains produced at 400°C into whitish ones and their quality was improved remarkably to reach the same level as that of the companion whitish portion. This result would indicate that the existence of carbon in RHA is not beneficial and it is possible, at least for the ash produced at 400°C, to remove the

Table 2 Effects of Reburning Treatment and Grinding Time on Activity of Rice Husk Ash.

Kind of Ash		Original Ash		Reburnt Ash				Grinding Time (min)	Water / Lime+RHA
		Color of Grains	Compressive Strength*1 (kg/cm²)	Reburning Conditions*2 Temp. (°C)	Reburning Conditions*2 Time (hrs)	Color of Grains	Compressive Strength*2 (kg/cm²)		
Ash Produced by Burning Husks at 400°C for 4 hrs	Blackish Portion	Mostly Black	68	400	1	Whitish Grey	118	100	0.6
			96				125	240	
	Whitish Portion	Whitish Grey	120	400	12	White	142	100	
			123				143	240	
Boiler Ash		Blackish Grey	17	400	4	Blackish Grey	22	100	0.8
				600	3		15		
			27	600	3		31	240	
Ash Produced by Burning*3 Husks at 1000°C for 90 Min		Mostly Black	17	400	12	Mostly Black	17	100	0.8
			24				26	240	

*1: 1 day strength of mortar (accelerated curing), lime/RHA=0.5
*2: Burnt under a free air supply condition
*3: Burnt under a restricted air supply condition
Note: To convert kg/cm² to MPa, multiply by 0.098

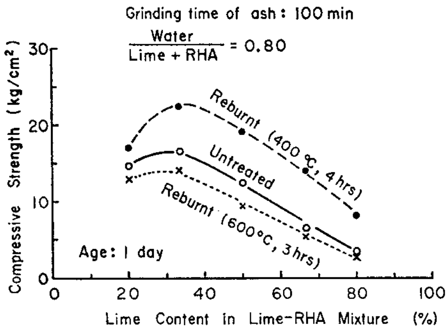


Fig. 7 Effect of Reburning Treatment of Activity of Boiler Rice Husk Ash (To convert kg/cm² to MPa, multiply by 0.098).

carbon by reburning treatment.

However, as also shown in **Table 2**, neither the removal of black color nor the remarkable improvement in the activity of ash grains could be attained by reburning process in the cases of boiler ash and the black RHA produced at 1 000 °C. A separate experiment in which lime-boiler ash ratio was changed widely also indicated negligible improvement in the activity of boiler ash through reburning treatment (See **Fig. 7**). A further experiment revealed that the black color of these ash grains could not be removed even when they were reburnt at 1000°C, probably indicating that carbon atoms in these ashes do not exist in their free form on the surface of ash grains. No further study was made on the state of carbon in these ashes. However, it is now obvious that the existence of carbon reduces the overall quality of RHA.

Another noteworthy result in **Table 2** is that the rate of increase in the activity of black or blackish ash due to additional grinding is considerable in all cases whereas almost no improvement can be observed in the case of white or whitish ash. This tendency may imply that a part of the reasons for the reduced activity of black or blackish ash is its low grindability.

All the test results so far shown indicated that the existence of carbon impairs the overall activity of RHA. Then, it would be natural to attempt to produce whiter ash of better quality, which would be possible only by extending the burning time of rice husks. However, investigation has revealed that attempting to do so was not only unpracticable but also uneconomical. For example, completely white ash was obtained by burning husks at 400°C for 10 hrs under free air supply condition. However, the 10 hrs of burning did not bring any remarkable improvement in the activity of RHA over 4 hrs burning

Table 3 Effect of Burning Time on Activity of Rice Husk Ash.

Burning Time*1 (hrs)	Compressive Strength of Mortar*2 (kg/cm²)
4	120
6	129
8	137
10	142
12	142

*1 Temp.=400°C, free air supply
*2 Strength at 1 day (accelerated curing), lime/RHA=0.5, water/(lime+RHA)=0.6
Note: To convert kg/cm² to MPa, multiple by 0.098

as shown in **Table 3**, although longer burning resulted in better ashes. Hence, it is evident that, instead of adopting longer burning time to obtain whiter ash, burning time should be just enough to get predominantly whitish ash since the latter saves time and energy without much affecting the activity of resulted RHA.

5. ACTIVITY OF RICE HUSK ASH PROPERLY PRODUCED

Based on the test results in the previous Chapter, RHA of good quality was prepared by burning rice husks under a free air supply condition at 400°C for 4 hrs, cooling the ash instantly and grinding it for about 100 min. The ash was then compared for its activity with that of ashes obtained by other workers, namely, Mehta[1] and Cook[11]. For this purpose, mortar specimens of various Portland cement-RHA ratios were prepared and cured in a standard way, and their compressive strengths were tested at 3, 7, and 28 days. **Table 4** shows the test results together with those by the workers.

Since sand and cement used, mix proportion of mortar selected, and possibly testing methods employed are different each other among these works, values of strength corresponding to a certain cement-RHA ratio are also different depending on the works and, therefore, direct comparison can not be made as can be seen in **Table 4**. However, if relative strength of each mortar to the strength of respective control mortar with no RHA is used for evaluating the activity of the ashes, it can be found that the ash prepared in this research is as active as that of Mehta which would be the best RHA so far made in the world, whereas the ash obtained by Cook is much inferior. A more significant result observed in **Table 4** is that, even when 70% of cement was replaced by RHA, mortar so made exhibited slightly higher strength than the control mortar at all ages. When 25% of cement was

Table 4 Comparison of Activity of Ash Produced in the Present Work with That of Other Workers.

RHA / (Cement+RHA) (%)	Compressive Strength of Mortar* (kg/cm²)							
	RHA Obtained in Present Work			RHA Obtained by P. K. Mehta			RHA Obtained by D. J. Cook	
	3 Days	7 Days	28 Days	3 Days	7 Days	28 Days	7 Days	28 Days
0	130 (100)	190 (100)	280 (100)	230 (100)	335 (100)	435 (100)	145 (100)	152 (100)
20	160 (123)	270 (142)	385 (138)	287 (125)	468 (140)	613 (141)	107 (74)	138 (91)
25	175 (135)	280 (147)	396 (141)	—	—	—	—	—
30	—	—	—	329 (143)	468 (140)	604 (139)	100 (69)	145 (95)
50	150 (115)	235 (124)	362 (129)	269 (117)	402 (120)	592 (136)	59 (41)	66 (43)
70	141 (108)	202 (106)	281 (100)	247 (107)	365 (109)	440 (101)	—	—

* Figure in parenthesis shows relative strength of cement-RHA mortar to the strength of respective control mortar with no RHA, expressed in percent.
Note: To convert kg/cm² to MPa, multiply by 0.098

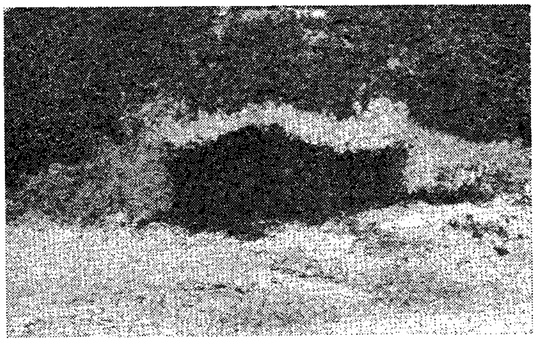
replaced by RHA, about 40% higher strength could be obtained compared with the case of control mortar. These results, therefore, would indicate that the RHA prepared in the present work is a quite active material.

6. MASS PRODUCTION OF ACTIVE RICE HUSK ASH

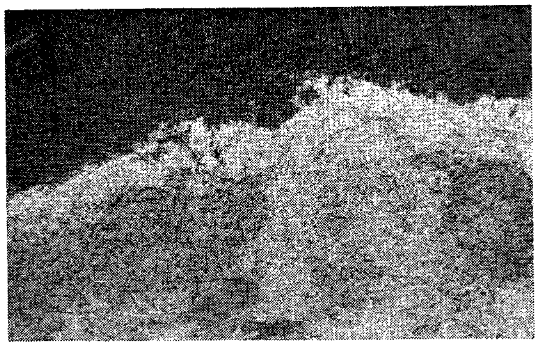
Through the experimental work so far made, factors affecting the activity of RHA have been clarified and the production of quality RHA has been succeeded in the muffle furnace. In view of utilizing RHA as a substitute for cement in making concrete, however, it must be produced in a large quantity and energy necessary for its production must be as low as possible so that it is much cheaper than cement and the worldwide demand for conserving energy can be met. Field experiments were, therefore, conducted to investigate the possibility of producing active RHA on such conditions.

To begin with, about 1 m heigh cone-shaped heap of rice husks was burnt in the open air utilizing only the self heat of burning. **Fig. 8** (a) shows the cross-sectional view of the resulted 25 cm heigh ash heap, which shows three different layers of ash. Underlying the semi burnt top layer of very small thickness are a layer of whitish ash and a thick core of blackish ash. The whitish and blackish parts were then examined for their activity. It was found that the whitish part possessed the same activity as that of the whitish part of RHA produced in the muffle furnace as shown in **Table 5**. The blackish part was observed to exhibit also similar activity to that of blackish RHA obtained in the furnace at 400°C.

Formation of above mentioned different zones may be explained as follows. The semi burnt top layer would have been produced because most of the heat of burning near the surface was absorbed into the atmosphere and heat required



(a) RHA PRODUCED UNDER UNCOVERED CONDITION



(b) RHA PRODUCED UNDER FERROCEMENT COVER

Fig. 8 Cross-Sectional Views of Heaps of Rice Husk Ash Produced in Fields.

for its complete combustion was not retained there. However, the surface layer, then acted as an insulating medium and sufficient heat was preserved for the rice husks in the second layer to attain their complete combustion in the presence of enough atmospheric oxygen, leaving the whitish zone. The inner blackish core which was in contact with the ground may be due to insufficient supply of air and/or too low temperature to

Table 5 Comparison of Activity of Ash Obtained by Burning Uncovered Heap of Husks with That of Ash Produced in the Furnace.

Kind of Ash		Grinding Time (min)	Comresssive Strength*1 (kg/cm²)
RHA Produced by Burning Uncovered Heap of Husks	Whitish Part	100	119
		240	122
	Blackish Part	100	70 (118)
		240	103 (121)
RHA Produced in the Furnance at 400°C*2	Whitish Part	100	120
		240	123
	Blackish Part	100	68 (118)
		240	96 (125)

*1: Strength of lime-RHA mortar at 1 day, lime/RHA=0.5, water/(lime+RHA)=0.6
Figure in parenthesis is the strength for a case where each ash was reburnt in the furnace at 400°C for 1 hr.
*2: The results for the ashes were taken from Table 2.
Note: To convert kg/cm² to MPa, multiply by 0.098

attain its complete burning.

To confirm the above discussion, rice husks were next hurnt under a cover of ferrocement dome with sufficient arrangement for air supply. The RHA produced was found to consist of all whitish ash except a semi burnt surface layer of very small thickness (See **Fig. 8** (b)). This may be because the ferrocement cover which has a relatively low thermal conductivity retained much of the heat of burning inside and heat required for the complete combustion of the inner layer was made available. The ash so produced was also examined for its activity by testing the compressive strength of mortar specimens of various cement-RHA ratios. **Table 6** summarizes the results. If the results are compared with those in **Table 4**, it is clearly seen that the ash produced in the dome is as active as the RHA prepared in the furnace. Therefore, the results in **Table 6** is considered to indicate that it is possible to attain efficient conversion of rice husks into active RHA in the field on a mass scale.

Such a cover as ferrocement dome may be relatively expensive, difficult to make, and unavailable in many areas in developing Asian countries even if rice husks are abundant. Therefore, some other simple and cheap means of preserving the heat were considered. Although there would be a number of choices, mud plastering method was studied in this work. As a first try, a cone-shaped heap of husks was plastered with mud and many air vents were made all arounr the surface. The ash produced under such a mud cover was whitish only near the surface and most of the remaining part was blackish. Therefore, a modification was made to insert vertical masonry hollow shafts in the center of the cone to its full depth for the aeration of the inner part. RHA obtained after such modification was found to be nearly all whitish (See **Fig. 9**) and of identical quality with that of active RHA produced inside the ferrocement cover. The modified mud plastering method, therefore, can be considered as one of the alternatives that can be employed in such areas where almost no capital fund is available but labor cost is low.

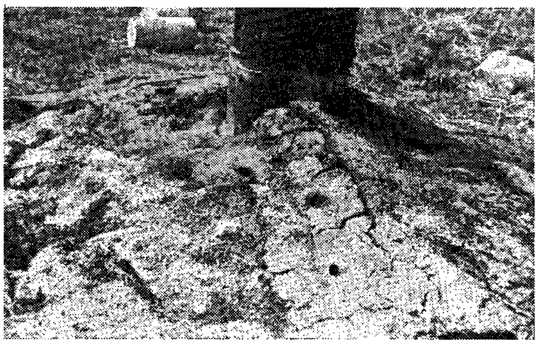


Fig. 9 Rice Husk Ash Produced under Mud Cover.

Table 6 Activity of Rice Husk Ash Produced under Ferrocement Cover.

RHA / Cement+RHA (%)	Compressive Strength of Mortar* (kg/cm²)			
	Standard Curing			Accelerated Curing
	3 Days	7 Days	28 Days	1 Day
0	128 (100)	198 (100)	285 (100)	144 (100)
20	161 (126)	259 (131)	374 (131)	190 (132)
30	172 (134)	280 (141)	401 (141)	202 (140)
50	166 (130)	268 (135)	382 (134)	201 (140)
70	130 (102)	205 (104)	295 (104)	150 (104)

* Figure in parenthesis shows relative strength of each mortar to the strength of respective control mortar with no RHA, expressed in percent.
Flow of mortar: 150±5
Note: To convert kg/cm² to MPa, multiply by 0.098

7. CONCLUSIONS

Factors affecting the activity of RHA were examined using a specially designed muffle furnace and possibility of producing active RHA on a mass scale was sought. Within the limits of the experiments, the following conclusions can be made.

(1) Inherent activity of RHA is also dependent on the cooling rate of resulted hot ash in addition to the previously reported factors such as burning temperature and burning time of rice husks and air supply during the burning. Rapid cooling is required for the production of more active RHA.

(2) RHA of good activity can be obtained by burning rice husks at 400°C for 4 hrs or more under enough air supply condition and cooling the resulted ash rapidly. Burning of rice husks at a higher temperature than 600°C for a prolonged period reduces the activity of RHA.

(3) It is possible to mass produce active RHA at a low cost utilizing only the self heat of burning. For this purpose, rice husks must be burnt under such conditions that a sufficient amount of heat is retained for the burning of inner rice husks and enough air is supplied during the burning.

(4) When RHA grains of good activity are ground to a proper extent, as high as 70% of cement can be replaced by the RHA without impairing the strength of mortar at both 3 days and 28 days.

(5) Existence of carbonized ash grains reduces the overall activity of RHA. They can be converted into active ones by their reburning if both the initial burning and reburning are made at a low temperature, e.g., 400°C, under enough air supply condition.

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