EFFECT OF RICE HUSK ASH PARTICLE SIZE IN LIME BASED MORTARS

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Abstract This paper presents some results achieved by a research program with the main objective of evaluating the effect of rice husk ash particle size in lime based mortars. A Portuguese commercial RHA used was sieved and grounded in laboratory to get different particle size distributions. The influence of the RHA particle size was evaluated on fresh and hardened properties of lime based mortars. The results show: the reactivity of the rice husk ash, the increasing of the pozzolanic reactivity with the reduction of the RHA particle size and the possibility of improving lime mortars properties.

Key-Words: lime mortar, rice husk ash, pozzolanic reactivity, particle size.

1 INTRODUCTION

Lime based mortars are presented as a compatible solution for the rehabilitation of ancient masonry. However, associated with them there are several characteristics that affect their application in this area. The main complexity concerns the difficulties presented by these local hardening in poor contact with the carbon dioxide in the atmosphere or in high humidity environments.

In this context, the lime mortar with added pozzolanic components seems to be an interesting alternative. The possibility of hardening of these mortars being to occur also by hydration reaction. Therefore, by controlling the amount of pozzolan and depending on the purpose, mortars can be made with different properties, bearing in mind the need for compatibility in mechanical, physical and chemical.

Considering the need to use the previously mentioned products and the adoption of solutions that may involve a reduction of energy consumption, several studies have been made on formulations of lime mortars with incorporation of industrial by-products with pozzolanic characteristics. The rice husk ash is presented as a material with enough potential in this context. It then becomes essential to understand the factors affecting the pozzolanic reactivity of the ashes, so as to maximize its potential use in the formulation of mortars.
Thus, this paper aims to study the pozzolanic action conferred by the addition of rice husk ash in lime mortars and evaluate the influence of its particle size in the performance of mortars.

2 EXPERIMENTAL SECTION

The aim of the present work is the study of the pozzolanic reactivity of rice husk ash in lime mortars and the evaluation of rice husk ash particle size effect in lime based mortars. For this purpose, four mortars were analyzed with three fixed parameters, namely the rice husk ash type (commercial brand), the ratio lime/ash (1:2) and the consistency (165 ± 5 mm). Firstly, the commercial rice husk ash was previously prepared in order to obtain samples with different particle sizes. As a reference, a pure lime mortar sample was also formulated. The latter was subjected to dry cure whereas the lime mortars with rice husk ash were subjected to saturated environments. Mortars characterization tests included: determination of consistence of fresh mortar, bulk density, exudation, water retention, flexural resistance, compressive resistance, ultrasonic propagation velocity, superficial hardness, capillarity water absorption, open porosity, karsten tube penetration test, dry test and carbonation depth.

2.1 Materials

For the production of mortars were used river sand, aerial hydrated lime in powder (CL90) and a Portuguese commercial rice husk ash. The rice husk ash was grounded and sieved in a laboratory in order to study the influence of its particle size.

2.2 Rice husk ash

When burned under controlled conditions (temperature, time and air flow) the rice husk ash, can be converted into an ash with a high percentage of amorphous silica (Metha, 1983). The pozzolanic reactivity is affected by several factors such as the type of pozzolan or the surface area. The latter is a relevant point to take into account in the pozzolanic reaction, since it happens between the amorphous silica of ash and the lime (calcium hydroxide). In fact, the reactivity will be greater with a larger surface area which, in general, is higher for smaller particle sizes. Some authors studied several mortars with addition of ashes with different particle sizes and they observed that smaller particle sizes led to higher values of mechanical strength (Almeida, 2008; Agarwal, 2004). Nevertheless, other authors (Payá, 2000) concluded that ashes with smaller particle sizes did not maximize the pozzolanic reactivity (Payá, 2000). In fact, according to other authors, the surface area of rice husk depends not only on particle size distribution but also on its roughness (Metha, 1983).
The pozzolanic reactivity can be assessed by two methods: mechanical and chemical. The first one considers that the addition of a pozzolan increases the mechanical strength of lime based mortars with pozzolanic materials. The second one assesses the evolution of consumption’s rate of Ca(OH)$_2$ reacted with pozzolan or measures the conductivity of the saturated Ca(OH)$_2$ solution added with pozzolan. Latter studies referred two methods to the analysis of the pozzolanic reactivity, however, it should be noticed that the referred methods, when used to evaluate the pozzolanic reactivity of the same material, might lead to different classifications (Velosa, 2006).

The rice husk ash studied throughout this work were provided by the Portuguese company CINCÁS. By the visual observation of ash, it was possible to identify a difference in tone in the recorded particles and also the presence of particles with different sizes. This occurs because the process used by the manufacturer to burn rice husk does not allow monitoring the thermal gradient and the air flow across the material. According to several authors, there is a correlation between the color of ashes and its chemical composition. The light shade of gray reveals evidence of a high percentage of silica concentration.

In order to reduce the use of the darker ashes and consequently minimize the use of ash with high carbon content, the commercial rice husk ash (C) was sieved through the sieve opening 500 $\mu$m for a 10 minutes period. At the end of this process it was obtained approximately 35% of ash (CP) retained on the sieve opening of 500 $\mu$m.

The sieved ash, CP, was then grounded in a Los Angeles mill to increase its fineness and consequently the specific surface. The process was made in two distinct phases: one from the minute zero to 45 minutes the milling was carried out using 6 balls of steel ($\approx$400g/ball), and another from 45 to 75 minutes using 10 balls. Comparative analysis of the ash before the milling process (CP) and the obtained at the end (CPm75) shows that this process has proved to be effective in reducing the size of the ash CP. In order to analyze the influence of fineness, by the mechanical characterization of mortars, the rice husk ash sieved and grounded (CM) was used with four different grading curves. Each curve was obtained by sieving the ash through the sieves meshes 500 $\mu$m, 250 $\mu$m, 125 $\mu$m and 75 $\mu$m leading to the synthesis of CM500, CM250, CM125 e CM75. Figure 1 and 2 shows the grading curves of commercial rice husk ash (C), ash sieved (CP). Figure 1 and 2 shows the grading curves of commercial rice husk ash (C), ash sieved (CP) and grounded and sieved through the sieves mentioned above.
2.3 Tests

To achieve the purpose of this research and taking into account the proposed on ASTM C593-06, the mortars with ash addition were formulated with 180g of hydrated lime, 360g of rice husk ash and 1480g of river sand (Ratio by weight 1:2:8 – lime:pozzolan:aggregate). The pure lime mortar was formulated with a lime/aggregate ratio by weight of 1:8. The amount of water used in the formulation of mortars was established in order to ensure a consistency of 165 ± 5 mm, measured according to EN 1015:3.

For each mortar, six prismatic specimens (40x40x160mm) were prepared in accordance with NP EN 196:1. Since the diffusion of carbon dioxide is slow in water, the carbonation reactions are reduced in saturated environments. Hence, the specimens of mortars made with ash were stored until their characterization under controlled conditions of 23±3°C and 95±5 % RH. In this way their hardening was mainly due to pozzolanic reactions. The specimens of lime mortar were stored at 23±3°C and 50±5 % RH. All the samples were demoulded 7 days after their preparation.

All tests performed were based on procedures described in international specifications or in several research works.
3 MECHANICAL AND PHYSICAL CHARACTERIZATION OF MORTARS

Table 1 shows the tested mortars, the type of ash used in each one, the ratio water/ (blinder mixture used in all mortars studied), values of consistence of fresh mortar, water retention, bulk density and blending.

Table 1 – Fresh state characterization.

<table>
<thead>
<tr>
<th>Mortar</th>
<th>Type of ash</th>
<th>water/ (lime+ash)</th>
<th>Consistence [mm]</th>
<th>Water retention [%]</th>
<th>Bulk density [kg/m³]</th>
<th>Blending [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAL</td>
<td>-</td>
<td>1,83</td>
<td>162</td>
<td>90,0</td>
<td>2080</td>
<td>2,6</td>
</tr>
<tr>
<td>A500</td>
<td>CM500</td>
<td>1,15</td>
<td>162</td>
<td>90,0</td>
<td>1870</td>
<td>1,5</td>
</tr>
<tr>
<td>A250</td>
<td>CM250</td>
<td>1,15</td>
<td>163</td>
<td>87,7</td>
<td>1890</td>
<td>1,3</td>
</tr>
<tr>
<td>A125</td>
<td>CM125</td>
<td>1,14</td>
<td>162</td>
<td>88,3</td>
<td>1890</td>
<td>2,1</td>
</tr>
<tr>
<td>A75</td>
<td>CM75</td>
<td>1,09</td>
<td>167</td>
<td>89,1</td>
<td>1930</td>
<td>2,1</td>
</tr>
</tbody>
</table>

When considering only the water / (mixed blenders) values and the values of the consistence of lime based mortar with rice husk ash, it appears that, the reduction of the maximum particle size of the ashes used is responsible for a lower amount of water required to obtain mortars with similar consistency (Figure 3 and 4).

Figure 3 – Water/(lime+ash) ratio for obtaining a consistence of 165±5mm.

Figure 4 – Relation between water/(lime+ash) ratio and maximum size of ash.
The values of water retention for reference mortar are higher when compared with the values of lime based mortar with ashes, Figure 5.

With the exception of A500, the presence of ash is responsible for a slight decrease in the water retention capacity of mortars when compared with the reference mortar. However, for mortar A250, A125 and A75, it shows that the value of the retention capacity of water has a slight tendency to increase with the increasing of the ash particles fineness.

The obtained water retention values for the mortars are satisfactory, allowing a good behavior of this type of mortar against the adverse weather conditions when applied on porous walls.

From the Figure 6, it can also be observed that all mortars made with rice husk ash have lower values of density, when compared to pure lime mortar. In relation to the lime mortar with the rice husk ash, it is clear that the increasing the fineness of the ash is accompanied by an increase in the bulk density of the different mortars. Whether this trend or the difference found between the reference mortar and the other mortars can be justified by the occupation of empty spaces by small particles of ash. It appears that the incorporation of fly ash in mortar causes a variation of exudation, especially for the values corresponding for mortar A500 and A250, where there is a reduction of exudation with the progressive decrease of the particle’s size.
Considering the mechanical strength values of mortars made with ashes against the lime mortar values, it can be concluded that the ash showed a considerable reactivity. In fact, this could be also noticed because the mortars made with ash have been subjected to a moist curing. In this way the hardening process and the values of mechanical strengths of these mortars are a consequence of the formation of hydrated compounds, like calcium silicates, resulting from the pozzolanic reactions.

Comparing the values of all the mechanical strength of mortars with 14 and 28 days old, it appears that the values obtained at an age of 28 days are higher, which leads to the conclusion that the ash of rice husk reveals a significant reactivity, especially A75 where the increase in the mechanical strength is higher. The mechanical characterization points out the influence of the
fineness of the ash used, since there was an increase of mechanical strength with the maximum size reduction of the ash used.

**Figure 8** – Specimen compressive tensile strength on the 14th and 28th days

**Figure 9** – Specimen flexural tensile strength on the 14th and 28th days

It can be observed that there is a growing trend in the propagation’s velocity of ultrasound for the mortars with the addition of rice husk ash. This indicates that this test was sensitive to the increase in pozzolanic reactivity manifested by a progressive increase of the fineness of the ash.

**Figure 10** – Prismatic specimens ultrasonic propagation velocity.

**Figure 11** – Capillarity water absorption.
By analyzing the different absorption curves, is identified in each of the mortars the existence of three sections with different rates of absorption, Figure 11. The first section is characterized by an absorption rate a lot higher than the others, and from this it can be determined the capillarity coefficient, mentioned above. (Rato, 2006) says that the initial velocity of this section depends mainly on the pore size, being higher in mortars with larger pores. The second section represents the transition between the absorption and initial stabilization phase. Finally, the third section corresponds to the stabilization phase and it is associated with a significantly reduced rate of absorption, since the samples are already close to its saturation. It is based on this last phase that determines the asymptotic value, which depends mainly on the open porosity of mortars.

Except for the reference mortar, CAL, the remaining mortars, particularly the A75, present coefficient of water absorption values by capillarity above the recommended bibliography at the mortars for plastering. (Veiga, 2003) states that these values should be between 0.13 and 0.20 kg/m².s⁰.⁵. It should be noticed that the low value obtained in the mortar CAL can be associated to the fact that it has only 28 days old, having a part of its hair structure filled with water.

![Figure 12](image1.png)  
**Figure 12** – Open porosity.  

![Figure 13](image2.png)  
**Figure 13** – Real and apparent density.
It can be verified that the reference mortar has a lower value of open porosity than all the mortar with the addition of rice husk ash, regardless of the particle size. Assessing only the lime based mortar with the addition of rice husk ash, the Figure 12 makes explicit the trend of porosity with the increasing fineness of the ash particles. A75 shows to be an exception.

It can also be observed that all mortars made with rice husk ash have higher values of porosity and consequently lower values of density, than when compared with pure lime mortar. This does not result from the addition of ash, but by the kind of environment in which they were submitted during their setting. (Almeida, 2008) after submitting a mortar made with rice husk ash to dry and saturated environments during their setting, he concludes that the latter environment was responsible for higher values of porosity. The same trend was found by other author (Faria-Rodrigues, 2004) in mortars made with different pozzolanic materials. The author explained this trend by the fact that in the saturated environment the mortar looses water slowly and when part of it is eliminated, the mortar is sufficiently hardened. Consequently the pores may have a larger size and lead to higher values of open porosity.

![Figure 14 – Karsten tube penetration test.](image1)

![Figure 15 – Cinetic of dry process.](image2)

Associated to the higher values of porosity, higher values of coefficient of water absorption are also observed.

It can be observed that the reference mortar has the higher initial capacity of absorption, represented by the steep slope of its absorption curve. From the analysis of mortars with addition of ashes, the A500 is the mortar that has the highest value of the initial capacity of absorption.
The behavior of mortars with incorporation of ashes in Karsten tube penetration test is consistent with results of open porosity test, since the water was easily penetrated in high porosity mortars. It is possible to conclude that the reference mortar shows a better performance in the drying test.

4 CONCLUSION

This paper showed that the workability of mortars is reduced with the incorporation of lower husk ash particle size. However, 10 minutes later after the mixing, the mortars showed greater consistency. It could be considered that for a period of higher mixing, consistency sought would be achieved with a smaller amount of water.

The used ashes, regardless of their finenesses, showed pozzolanic reactivity since the strength values of mortars made with ash was significantly increase compared to the values of lime mortar – the mechanical and flexural strength values of mortar A500 were ten times higher than lime mortar values. Since the mortars with rice husk ash had higher porosity values compared to the value of lime mortar, it can be concluded that the recorded increase is mostly due to the formation of hydrated compounds, like calcium silicates, and not because they have a more compact porous structure.

When only the mortars with rice husk ash were analyzed, it was found that the reduction of the rice husk ash particle size was responsible for the mechanical strength values increase. The latter values could be an indicator of a greater pozzolanic reactivity associated to an higher specific surface.

The addition of rice husk ash in lime based mortar resulted in an increase of open porosity in relation to the reference mortar. The fineness increase of the ash caused a downward trend in the porosity of the mortars with incorporation of ashes.

Taking into account some of the recommendations for old buildings (Rosário Veiga, et al., 2001), the addition of rice husk ash based on lime mortars should be performed in smaller proportions as the formulation used (1:2:8 by weight – lime: rice husk ash: sand) led to mortars with high values of mechanical strength.

This study allowed us to measure the great potential of using rice husk ash in lime mortars for old masonry use, contributing thus to the development of sustainable practices in the field of rehabilitation, through the incorporation of industrial by-products.
BIBLIOGRAPHY


