THE INFLUENCE OF THE INCINERATION TEMPERTURE OF RICE HUSK ON THE MECHANICAL BEHAVIOUR OF MIXES OF SANDY SOIL WITH RICE HUSK ASH AND LIME

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ABSTRACT

The paper reports the results of a study on the influence of rice husk burning temperature on the properties of rice husk ash (RHA) and soil-RHA-lime mixes, with paving purposes. The stabilized soil was sedimentary sand from Uruguay. Residual RHA produced in a furnace without temperature control and RHA generated by laboratory burning at controlled temperatures of 500°C, 650°C, 800°C and 900°C were used. All types of RHA were tested to X-ray diffraction; chemical analyses of organic matter content were also carried out. Specimens of sandy soil-residual RHA-lime mixes, cured by 7, 14, 28 and 56 days were also submitted to X-ray diffraction and unconfined compressive strength tests. Residual RHA was used in two contents (15% and 20%) together with 5% or 10% of lime. Other specimens were made of sandy soil, 15% of RHA burnt at controlled temperatures varying from 650°C to 800°C and 5% of lime, cured by 28 days. It was shown that controlling the burning temperature of rice husk increases RHA reactivity to lime comparing to that of the residual RHA, providing significant increases of the strength and stiffness. It was concluded that the optimal burning temperature to produce the most active RHA ranges between 650°C and 800°C.

KEY WORDS

RICE HUSK ASH / LIME / TREATMENT / PAVEMENT

1. INTRODUCTION

Rice milling generates a by product known as husk. This husk contains about 80% organic volatile matter and water, and the balance 20% of the weight of this husk converted into ash during the firing process is known as rice husk ash (RHA) (Juliano, 1985). The RHA is a new by product and its final disposition is a great problem. RHA contains around 90% amorphous silica (Juliano, 1985), and its use as soil stabilizer agent, along with the lime, with paving purposes has been widely investigated. It has been shown that this pozzolan is cost-effective and environmentally friendly.

The properties of the RHA significantly depended on the burning process of the husk (Houstin, 1972). The RHA quality depends on the temperature, incinerating time, cooling time and milling conditions (James and Rao, 1986). The silica in the ash suffers structural transformations according to temperature conditions, affecting the reactions between the RHA and lime and the properties of the soil-RHA-lime mixtures (James and Rao, 1986).
Behak and Núñez (2008) researched the effects of the stabilization with RHA and lime of a sedimentary sandy soil in Uruguay. RHA burned in an oven without temperature control

and RHA burned in a laboratory mufla to different controlled temperatures were used with the purpose of evaluating the effects of the temperature control in RHA properties and the influence in the mixtures of sandy soil with RHA and lime.

2. RICE HUSK ASH AS SOILS STABILIZERS

The rice plant is one with higher concentration of silica (Boateng and Skeete, 1990). Much of the silica is concentrated in the husk, constituting a very resistant structure to environmental conditions, being capable of protecting the rice grain itself. Rice husk is typically composed by cellulose (40-45%), lignin (25-30%), ash (15-20%) and water (8-15%).

Metha (1975) developed a process for producing cements based on RHA. It is possible to obtain considerable improvements in the behaviour of the sedimentary clays when is adding RHA and lime (Lazaro and Moh, 1970). In countries where rice husk is abundant, soil stabilization by addition of RHA and lime or cement for pavement constructing is particularly attractive, because it leads to cheaper construction and disposal costs, reduces environmental damages and conserves the most highly qualified materials for priority uses (Ali et al., 1992). The stabilization of sandy-silty soils with RHA and cement reduces construction costs, particularly in the rural counties of developing countries (Basha et al., 2005).

Houstin (1972) proposed to classify RHA according to the burning conditions in high-carbon char (black), low-carbon ash (gray) and free-carbon ash (pink or white). The colours are associated with the evolution degree of the combustion process and with the structural changes of the silica in the ash (Boateng and Skeete, 1990). The white colour indicates the total oxidation of the carbon in the ash, while very high temperatures and long periods of incineration produce pink ashes typical of crystalline silica.

The type of ash suitable for the pozzolanic activity is amorphous rather than crystalline (James and Rao, 1986). Rice husk incineration at temperature ranging from 550 to 700ºC has been found to produce amorphous silica, while temperatures in excess of 900ºC produce unwanted crystalline structures. However, Smith and Kamwanja (1986) observed formation of crystalline silica in small proportions for temperatures of about 800ºC maintained for 12h.

The structural changes at several temperatures affect the reactivity of the RHA since the larger the specific surface of the silica the greater the extent of the chemical reactions with lime (Boateng and Skeete, 1990). The X-ray diffraction is a useful tool in determining qualitatively the degree of crystallinity of the silica in the ash (Boateng and Skeete, 1990).

The technologies of ash production vary from open-heap burning to specially designed incinerators (Metha, 1979). When the rice husk is burned in open-heap or conventional oven crystalline ash with low reactivity index is produced, while when is incinerated in an oven with controlled temperatures, the residue is a highly reactivity white ash that mixture with lime change in a cement structurally as good as Portland cement (Metha, 1975).

The rice husk incinerated in oven at controlled temperature conditions between 800ºC and 900ºC verified a high reactivity of the ash in comparison with the ash resulting of the open-heap burning (Boateng and Skeete, 1990).

Organic matter influences the stabilization process, retarding the reactions and producing low increases of strength. The avidity of the organic matter by the calcium ions interfere the reactions between calcium ions and amorphous silica (Petry and Glazier, 2005). According to these authors, lime stabilization of soils with 6% of organic matter is economically impracticable. A remaining organic matter less than 3% was measured in a RHA obtained by burning in an oven with controlled temperature to 800ºC in Nigeria (Rahman, 1987).

3. MATERIALS

3.1. Soil

A sandy soil with low content of fines was collected from a quarry placed 24km west of Montevideo, Uruguay capital. The soil was constituted by 1% of gravel, 92% of sand, 1% of silt and 6% of clay, classifying as well graded silty sand (SW-SM) by the Unified Soil Classification System, and as A-1-b (0) soil by the AASHTO classification system. The dominant mineral of the sandy fraction is quartz, while the main components in the clay fraction are kaolinite and montmorillonite.

3.2. Residual Ash Rice Husk

Rice husk ash residual (RHAr) of the husk incineration in an oven without temperature control was used in the investigation. The residual ash and rice husks for laboratory controlled temperature incineration were collected in a plant of rice parboilization sited in Treinta y Tres province, Northeastern Uruguay.

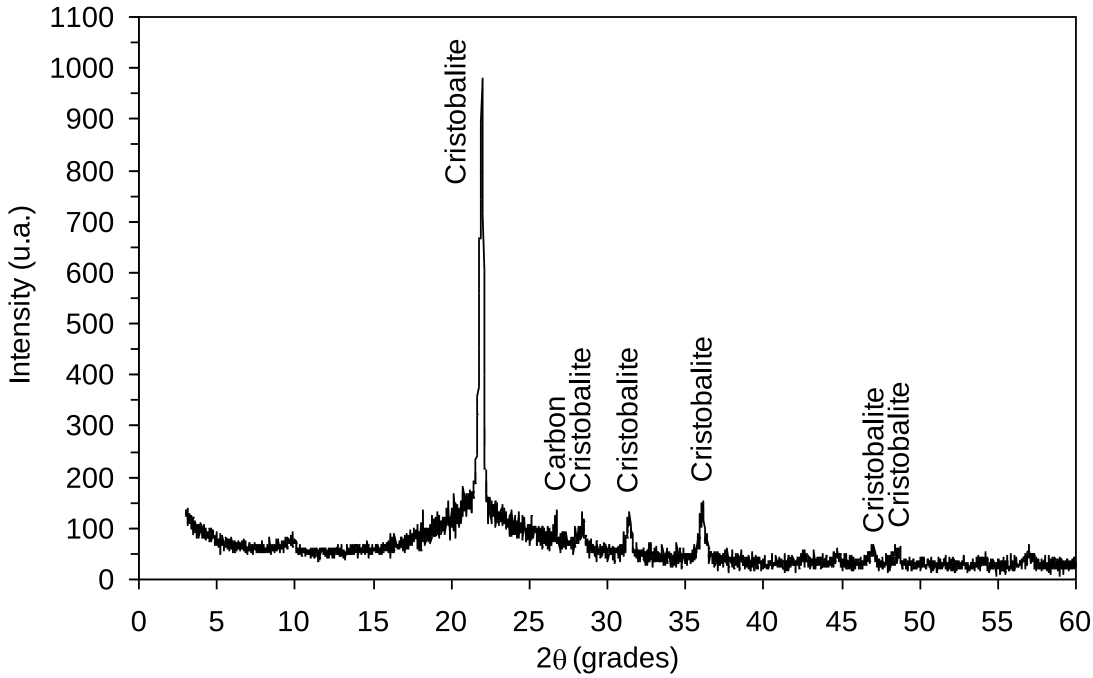

Figure 1- X-ray Diffractograph of Residual Rice Husk Ash

Residual rice husk ash (RHAr) has a leafy form and black colour, being classifyied as high-carbon ash (Houstin, 1972). The presence of incompletely burnt rice husk and the ash colour are both due to the variability of incineration temperature (low to very low), and the insufficient incinerating time to allow for the complete combustion of organic matter. The result is a RHAr with heterogeneous characteristics and low pozzolanic activity. The RHAr was coarse-sized, with 88.2% of the weigh retained on #200 sieve and 11% of the fines greater than 2 μm. By lost ignition analysis to 1000°C, a quite high content of organic matter of 18.7% was verified.

Figure 1 shows the X-ray diffractograph of the RHAr. Peaks characteristics of cristobalite (a type of silica) are identified. The peaks indicate that the silica is in crystalline state. Other peak shows presence of carbon (C), a product of the crystallization of the organic matter.

3.3. Lime

A commercial lime manufactured in Uruguay was used. The lime was constituted by 66.0% of calcium oxide, 5.3% of magnesium oxide and others elements like silica and ferric oxide. It was a fine lime with 92.9% of passing the #200 sieve. 100% of the coarse fraction pass the #10 sieve, whereas 91.2% is grater than 2 μm.

4. METHODS

4.1. Rice husk Incineration at Controlled Temperature

The rice husk was incinerated into a mufla to controlled temperatures of 500°C, 650°C, 800°C and 900°C (denoted as RHA_{CT500}, RHA_{CT650}, RHA_{CT800}, RHA_{CT900}, respectively). Due to the low volume capacity of the mufla and the low specific density of the rice husk, 30g to 40g of rice husk were placed in a porcelain vessel and burnt during 4h both. The produced ash was then air-cooled.

4.2. Test Mixtures

Three different mixtures of soil with RHAr and lime were considered: soil+15%RHAr+5%lime; soil+20%RHAr+5%lime; soil+20%RHAr+10%lime. Only one mixture of soil with 15% of controlled temperature RHA (RHA_{CT}) and 5% of lime (soil+15%RHA_{CT}+5%Lime) was evaluated, due the difficulties of producing high volumes of the RHA_{CT} in the mufla.

The mixtures were manually homogenized and immediately afterwards the specimens were moulded. The specimens were cured in plastic bags to ambient temperature.

4.3. X-Ray Diffractions

X-ray diffraction tests were performed on samples of the soil, RHAr, RHA_{CT} and mixtures of soil with RHA and lime cured 28 days, using a dusty diffractometer, with CuKalfa radiation and wavelength 1.5418 Å. Specimens of every mixture were tested to unconfined compression strength. Immediately after each test, samples were obtained by milling the specimen into a mortar to reduce its grain size to less than 0.075 mm (#200 sieve).

4.4. Chemical Analysis of Organic Matter

The organic matter content of both RHAr and RHA_{CT} were evaluated by matter organic loss tests due to calcination at 1000°C.

4.5. Unconfined Compression Strength

Unconfined compression strength tests were conducted in specimens of soil, mixtures of soil with RHAr and lime with 7, 14, 28 and 56 cured days and the mixture of soil with RHA_{CT} and lime cured by 28 days in accordance to the AASHTO Standard T208. The specimens were statically compacted in three layers, at the optimum compacting parameters of Proctor test (Normal energy) of the mixture of soil with 20% of RHAr and 10% of lime (maximum dry unit weight of 13.6 kN/m^3 and optimum moisture content of 8.5%). Triplicate specimens were compacted in trisplit metallic moulds 7.65 cm high with 3.72cm internal diameter. The controlled strain tests were performed in a press with 50 kN maximum capacity, at a strain rate of 0.25mm/min and conducted to raise peak strength.

5. TESTS RESULTS AND DISCUSSION

5.1. Characteristics of the Rice Husk Ashes at Controlled Temperature

Figure 2 shows weight loss, expressed by the ash weight to husk weight ratio, as a function of the incineration temperature of the husk. The ash weight – husk weight ratios are in the range of 15% to 20%. The loss on ignition decreases when the incineration temperature increases up to 650°C. Further on, the ash weight – husk weight ratio tend to become constant.

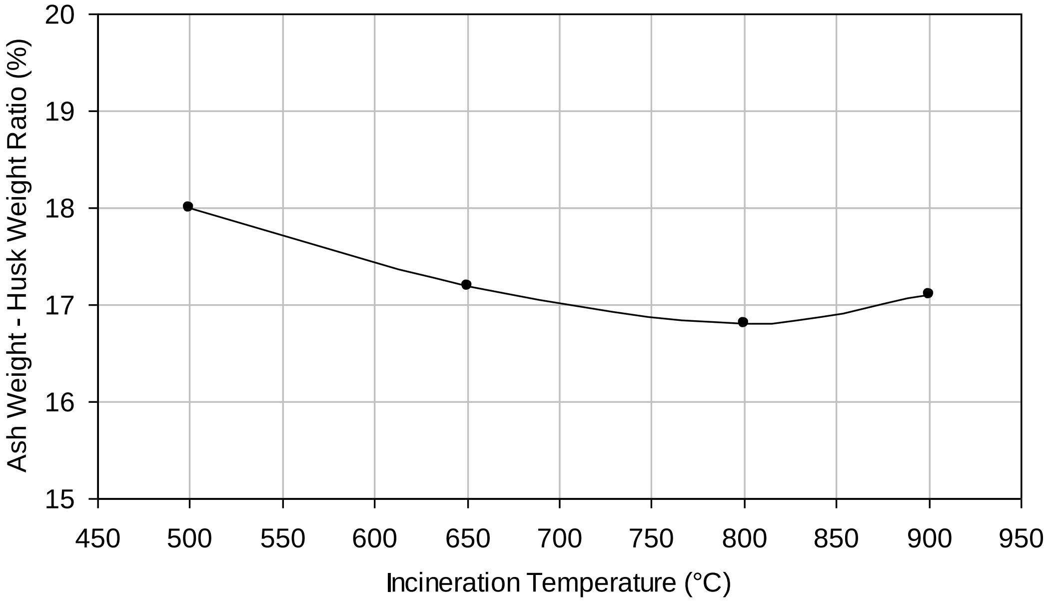

Figure 2 - RHA weight to rice husk weight ratio in function of the incineration temperature

Ashes colours changed with incineration temperature. The RHA_{CT500} was gray with black points and the RHA_{CT650} presented a white gray colour with pinked tone. The RHA_{CT800} and the RHA_{CT900} were white with pinked tones more intense than in the RHA_{CT650}. According Houstin (1972) the RHA_{CT500} and RHA_{CT650} may be classified as low-carbon ashes, while the RHA_{CT800} and the RHA_{CT900} are free-carbon ashes.

The X-ray diffractographs of the RHAr and the different RHA_{cT} are showed in Figure 3. The X-ray diffractographs of the RHA_{CT500}, RHA_{CT650}, and RHA_{CT800} are very similar; without peaks, indicating that these ashes have amorphous structures. The RHA_{CT900} presents a peak of high intensity at diffraction angles (2θ) of 22° and other smaller peak at 36.35°, both indicate cristobalite (a crystalline type of silica). Silica crystallization begins between the 800°C and the 900°C when the incineration time is 4h.

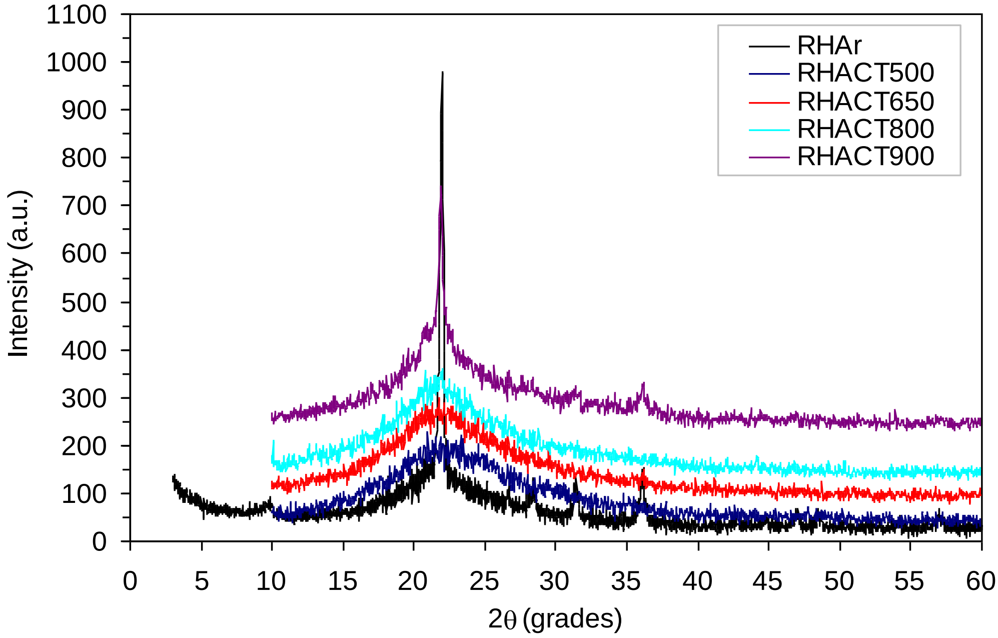

Figure 3 - X-ray diffractogrphs of the RHAr and differents RHA_{CT}

Figure 4 shows the organic matter content of the RHA_{CT} - expressed in ashes weight loss by calcination to 1000°C - as a function of husk incineration temperature. The organic matter content linearly decreases with the increase of the incineration temperature. A remarkable difference in organic matter contents is observed between the RHAr and the RHA_{CT}. The control of the temperature and the method of the incineration are of paramount importance, when the objective is to produce RHA with high pozzolanic activity.

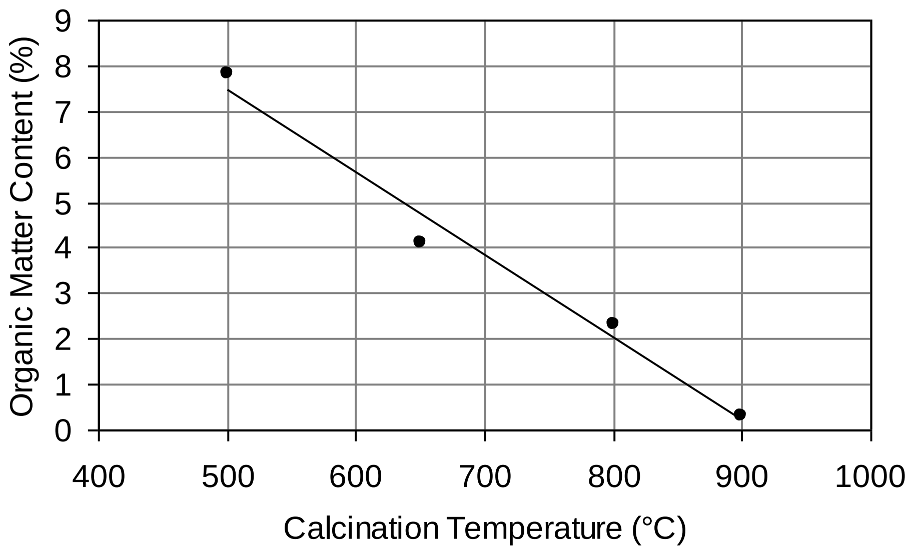

Figure 4 – RHA organic matter content in function of husk incineration temperature

The organic matter content of the RHA_{CT500} is relatively high for the stabilization purpose (7.8%) and this is similar for the RHA_{CT650} (4.1%). On the other hand, the organic matter content of the RHA_{CT800} (2.3%) may be acceptable. Therefore, in order to prevent the effects of the organic matter on the pozzolanic reactions, it might be recommendable to burn RHA at temperatures above 650°C.

The optimum range of incineration temperatures, for the studied ashes, for soil stabilization might be 650°C-800°C. In this controlled temperature range ashes of optimum pozzolanic activity are produced, with highly reactive amorphous structures and negligible contents of organic matter and.

5.2. X-ray Diffraction of the Mixtures

The x-ray diffractographs of the soil and the mixtures of the soil with RHAr or RHA_{CT} and lime, 28 days-cured, are showed in Figure 5. As expected, in the x-ray diffractograph of the soil shows peaks characteristic of quartz. The mineralogy of both mixtures of soil with RHA_{CT} and lime is similar. The peaks of quartz of the soil remain in the mixtures, while new peaks of albite are observed. The presence of the albite, a calcium aluminium silicate, proves that the pozzolanic reactions between the amorphous silica of the RHA and the calcium ions of the lime occurred after 28 days of curing. The similarity among the x-ray diffractographs shows that the pozzolanic activity of the RHA is independent of the controlled incineration temperatures in the range of 650°C-800°C.

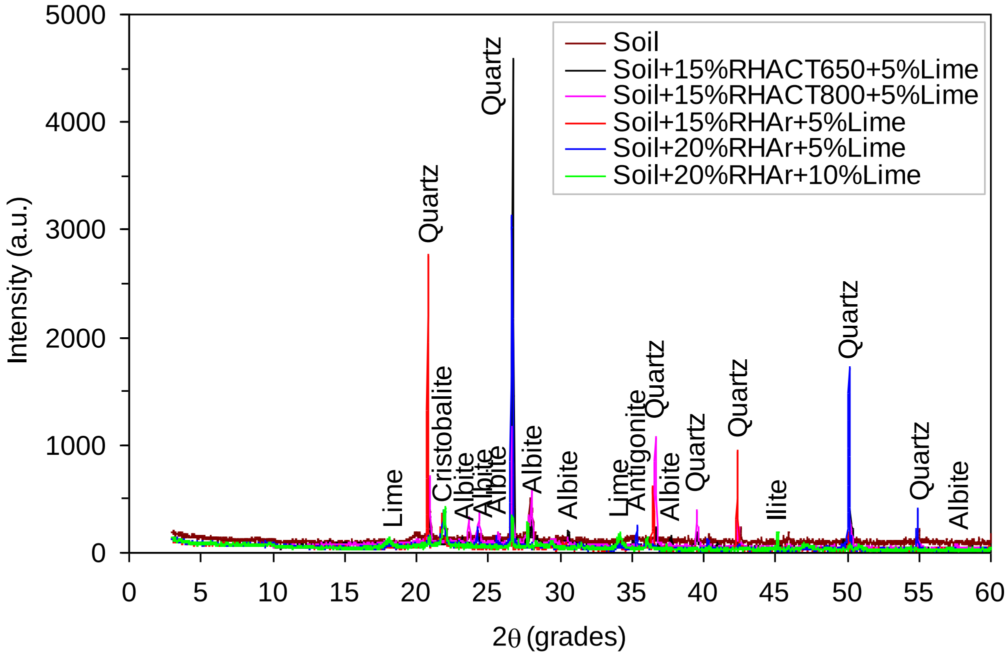

Figure 5 - X-ray diffractographs of the soil and mixtures of soil with RHAr or RHA_{CT} and lime.

The mixtures of soil-RHAr-lime present new peaks of pozzolanic products (antigonite, portlandite). The presence of lime in the mixture of the soil with 20% of RHAr and 10% of lime would be due to exceeding lime that did not reacted before 28 days of curing. However, the difficult identification of pozzolanic products in the mixtures of soil with RHAr and lime indicates that the pozzolanic activity of the RHA_{CT} is much higher than that of thee RHAr produced without temperature control (especially in the range of controlled temperatures of 650°C–800°C). RHA contents to obtain similar reactions are less in those produced to controlled temperature than in the residual ones. The use of RHA incinerated at controlled temperature between 650°C and 800°C is more efficient and economic for stabilizing sandy soils.

5.3. Unconfined Compression Strength

Figure 6 shows the unconfined compression strength (UCS) of mixtures of soil with RHAr (15% or 20%) and lime (5% or 10%) and mixtures of soil with 15% of RHA_{CT} (650°C or

800°C) and 5% of lime, in function of curing time. A remarkable increase of the UCS of mixtures with RHA_{CT} in comparison to mixtures with RHAr may be observed.

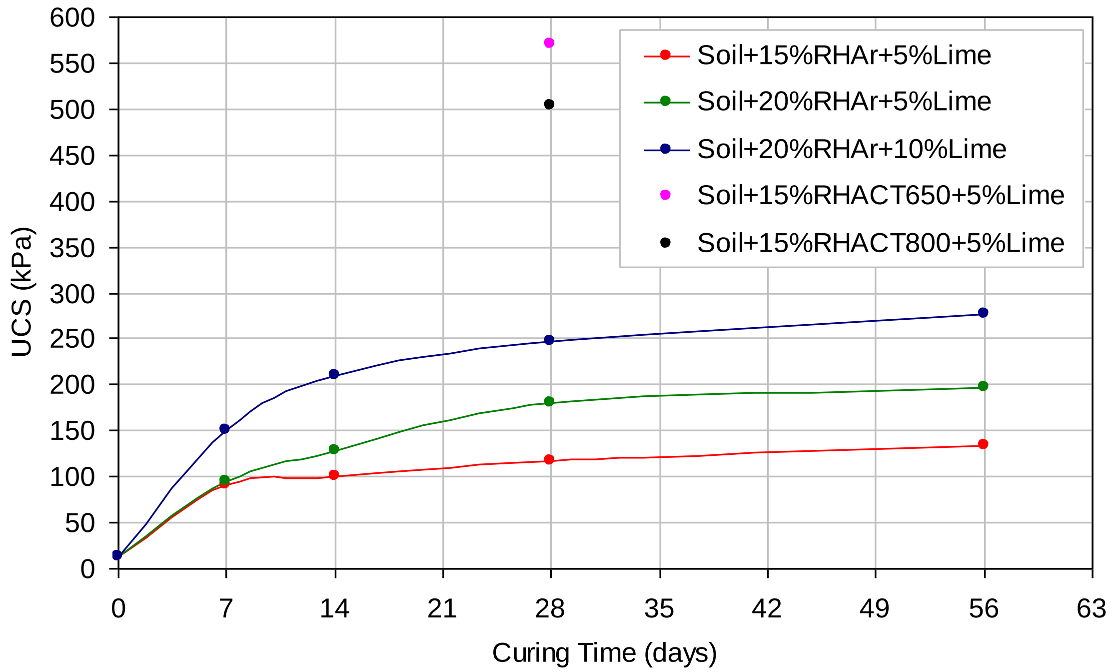

Figure 6 – Soil-RHA-lime unconfined compression strength asfunction of curing time, RHA type and RHA and lime contents.

The UCS of the mixture of soil with 15% RHA_{CT650} and 5% of lime is 4.8 times higher than the UCS of the mixture of soil with 15% of RHAr and 5% of lime, after 28 days of curing. For the mixture of soil with 15% RHA_{CT800} and 5% of lime, the UCS was 4.3 times higherr than the same mixture of soil with RHAr and lime, after the same curing time.

The UCS of the mixtures with RHA_{CT650} and RHA_{CT800} are respectively 2.3 and 2 times higher than that of the mixture with 20% of RHAr and 10% of lime tested after 28 days curing. If the UCS values of the same mixture of soil with 20% of RHAr and 10%of lime, but cured for 56 days, are considered, the UCS of the mixtures with RHA_{CT650} and RHA_{CT800} after 28 days curing are respectively 2.1 and 1.8 times greater.

The higher UCS obtained for the mixtures with RHA_{CT} in the temperature range of 650°C-800°C demonstrates the more intense pozzolanic activity of RHA_{CT} comparing to that of RHAr. The strength increase ratios are higher when the RHA_{CT} are used in the sandy soil stabilization. It is expected that the UCS will continue growing beyond 28 days of cure. Lower contents of lime and RHA are necessary to reach greater UCS when RHA_{CT} are used, therefore constituting a more economical alternative.

The UCS of the mixtures with RHA_{CT} are quite alike, evidencing similar pozzolanic activities for both incineration temperatures. The UCS of the mixtures of soil with RHA_{CT} and lime cured for 28 days is independent of the incineration temperature in the range of 650°C-800°C.

6. CONCLUSIONS

The following conclusions can be drawn on basis of the results obtained.

- For purpose of stabilization of sandy soils, the optimum range of incineration temperatures of rice husk is of 650°C-800°C. This temperature range produces ashes with maximal pozzolanic activity.

- The mineralogy of the mixtures of soil with RHA_{CT} and lime after 28 curing days are quite similar; then the pozzolanic activity of the RHA_{CT} is independent of the controlled incineration temperatures in the range of 650°C-800°C. The pozzolanic activity of the RHA_{CT} in the range of 650°C – 800°C is much higher than that of the residual RHAr produced without temperature control.

- The pozzolanic activity of the ashes produced by controlled incineration is independent in the temperature range of 650°C-800°C, and don't affect the unconfined compression strength of the mixtures of sandy soil with RHA_{CT} and lime, cured for 28 days.

- The unconfined compression strengths of the mixtures of sandy soil with RHA_{CT} and lime were greater than the mixtures of sandy soil with RHAr and lime, including those tested after 56 days. Higher strengths were obtained with less RHA_{CT} and lime. The use of RHA_{CT} incinerated at the temperature range of 650°C-800°C is an economical alternative.

The control of the rice husk incineration allows the production of more active ashes than those residuals made in a uncontrolled process, providing remarkable strength increases. The optimal range of incineration temperature is of 650°C-800°C. As in this temperature range the produced ashes presents similar pozzolanic activity, rice husk incineration to temperatures slightly higher than 650°C may be most suitable due to economical and environmental advantages, deriving of the less energetic consume.

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