Revista ALCONPAT
www.revistaalconpat.org
eISSN 2007-6835
Revista de la Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de la Construcción

Characterization and feasibility of using vegetable biomass ash in mortar

C. F. Gonçalves[1], A. F. Soares[2], H. M. Paula[1]*
*Contact author: heberdepaula@hotmail.com
DOI: https://doi.org/10.21041/ra.v11i2.484

Reception: 17/03/2020 | Acceptance: 30/12/2021 | Publication: 01/05/2021

ABSTRACT

The present research aims to evaluate the incorporation of vegetable biomass ash, eucalyptus chips (ECA), sugarcane bagasse ash (SCBA) and rice husk ash (RHA), in mixed mortars of cement and lime, considering its properties and mechanical performance. The volume ratio was 1: 1: 6 for a partial replacement of Portland cement at a rate of 15 and 30%. The tests for the residues were a characterization of the particles and pozzolanic activity, while that of the mortars was an analyses in the fresh and hardened state. From the results, pretreatments (sieving and grinding) and lime added to the mixture improved the reactivity of the ashes and the best performance was presented for mortars with 15% substitution, mainly for those containing RHA.
Keywords: mortars; partial replacement of cement; supplementary cement materials; vegetable biomass ash.

Cite as: Gonçalves, C. F., Soares, A. F., Paula, H. M. (2021), "*Characterization and feasibility of using vegetable biomass ash in mortar*", Revista ALCONPAT, 11 (2), pp. 1 – 16, DOI: https://doi.org/10.21041/ra.v11i2.484

[1] Master's Degree in Civil Engineering, Faculty of Engineering, Federal University of Catalão, Catalão, Brazil.
[2] Department of Civil Engineering, Faculty of Engineering, Federal University of Goiás, Catalão, Brazil.

Contribution of each author
In this work, the author C. F. Gonçalves was responsible for the analysis, discussion of the results, writing and review of the paper. Author A. F. Soares developed the experimental methodology, carried out experiments and collected data. The author H. M. Paula contributed with the original idea, coordination of experiments, guidance and supervision of all activities.

Creative Commons License
Copyright 2021 by the authors. This work is an Open-Access article published under the terms and conditions of an International Creative Commons Attribution 4.0 International License (CC BY 4.0).

Discussions and subsequent corrections to the publication
Any dispute, including the replies of the authors, will be published in the second issue of 2022 provided that the information is received before the closing of the first issue of 2022.

Caracterização e viabilidade de utilização de cinzas de biomassa vegetal em argamassa

RESUMO

O presente trabalho tem como objetivo avaliar a incorporação de cinzas de biomassa vegetal, cavaco de eucalipto (ECA), bagaço de cana-de-açúcar (SCBA) e casca de arroz (RHA), em argamassas mistas de cimento e cal, considerando suas propriedades e desempenho mecânico. O traço em volume foi 1:1:6, para uma substituição parcial do cimento Portland a teores de 15 e 30%. Os ensaios para os resíduos foram de caracterização das partículas e atividade pozolânica, as argamassas foram submetidas a análises no estado fresco e endurecido. Dos resultados, os pré-tratamentos (peneiramento e moagem) e a cal adicionada a mistura melhoraram a reatividade das cinzas, o melhor desempenho foi apresentado para argamassas com 15% de substituição, principalmente para aquelas contendo RHA.

Palavras-chave: argamassas; substituição parcial do cimento; materiais cimentícios suplementares; cinza de biomassa vegetal.

Caracterización y viabilidad del uso de cenizas de biomasa vegetal en mortero

RESUMEN

El presente trabajo tiene como objetivo evaluar la incorporación de cenizas de biomasa vegetal, chips de eucalipto (ECA), bagazo de caña de azúcar (SCBA) y cáscaras de arroz (RHA), en morteros mixtos de cemento y cal, considerando sus propiedades y rendimiento mecánico. La mezcla por volumen fue 1: 1: 6, para un reemplazo parcial de cemento Portland de 15 y 30%. Las pruebas para los residuos fueron de caracterización de las partículas y actividad puzolánica, mientras que los morteros fueron sometidos a análisis en estado fresco y endurecido. De los resultados obtenidos, los pretratamientos (tamizado y molienda) y la cal añadida a la mezcla mejoraron la reactividad de las cenizas y el mejor comportamiento se presentó para los morteros con 15% de sustitución, principalmente para los que contienen RHA.

Palabras clave: morteros; reemplazo parcial de cemento; materiales de cemento suplementarios; cenizas de biomasa vegetal.

Legal Information

Revista ALCONPAT is a quarterly publication by the Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de la Construcción, Internacional, A.C., Km. 6 antigua carretera a Progreso, Mérida, Yucatán, 97310, Tel.5219997385893, alconpat.int@gmail.com, Website: www.alconpat.org

Reservation of journal title rights to exclusive use No.04-2013-011717330300-203, and ISSN 2007-6835, both granted by the Instituto Nacional de Derecho de Autor.

Responsible editor: Pedro Castro Borges, Ph.D. Responsible for the last update of this issue: Informatics Unit ALCONPAT, Ing. Elizabeth Sabido Maldonado.

The views of the authors do not necessarily reflect the position of the editor.

The total or partial reproduction of the contents and images of the publication is carried out in accordance with the COPE code and the CC BY 4.0 license of the Revista ALCONPAT.

1. INTRODUCTION

Civil construction is a segment that accounts for a high demand of raw materials, while releasing significant amounts of CO_2 into the atmosphere (Noor-ul-Amin, 2014; Berenguer et al., 2018). To minimize this problem, some agricultural residues have been incorporated by the construction industry (Chatveera and Lertwattanaruk, 2014). Moreover, much of this is because ash has pozzolanic properties, which plays a significant role when incorporated into cement (Hossain et al., 2016).

This property is identified in materials called pozzolanic that have silica or alumina in the state amorphous, which when in contact with water, react with the calcium oxide found in lime or in cement that give rise to a substance with cementicious properties (ASTM C 618-19; Farinha et al., 2018). To achieve this, in addition to a non-crystalline state, pozzolans must have a refinement of their particles, that is, they present a specific elevated surface area (Roselló et al., 2017).

The physical, chemical and mineralogical composition of these agro-industrial residues is varied, depending on the type of biomass, species, growth condition, harvest techniques, transport, storage, combustion process and many other conditions that can improve - or not - its content (Zajac et al., 2018). In general, it comprises aluminosilicates in the amorphous and crystalline phase, whereby silicon dioxide has the highest percentage in RHA and SCBA samples, as well as oxide of aluminum in ashes from wood origin (Farinha et al., 2018; Fernandes et al., 2016; Kazmi et al., 2017; Ukrainczyk et al., 2016).

Oxides of other metals are also present, such as iron, magnesium, calcium, and potassium.

In addition, there are carbonates and unburned carbon found in forest ash, such as ECA. Moreover, when applied in cementitious systems, they are responsible for a greater demand for water in the mixture, due to the high loss on ignition (Arif et al., 2016; Ban and Ramli, 2010; Garcia and Sousa-Coutinho, 2013; Ribeiro et al., 2017).

Despite this, the different levels of substitution can lead to an improvement of the properties of durability, resistance of the mortar, a decrease in the material cost in the construction (Hossain et al., 2016), good compaction and low evolution of the heat during hydration (Noor-ul-Amin, 2014). These are effective in controlling expansions of deterioration caused by alkali-aggregate reactions (Esteves et al., 2012) that can reduce the use of fossil fuels, form raw materials and generate income for workers involved in transportation, infrastructure, technological development processes and the application itself (Prasara-A and Gheewala, 2017).

Therefore, using ash as a partial substitute material for cement goes beyond sustainable issues, and encompasses economic and social issues (Prasara-A and Gheewala, 2017). However, commercializing waste and its application in construction is almost non-existent, even with the growing interest in supplementary cementitious materials from biomass in scientific research (Roselló et al., 2017), or with the possibility that new materials can improve the performance of buildings and materials, promoting greater quality control and minimizing the development of pathologies, for example. Therefore, further studies regarding the feasibility of using combustion residues in mortars and concrete should be conducted (Ukrainczyk et al., 2016).

These studies were developed because, in addition to the ashes showing good results when used as partial substitutes for Portland cement, they are by-products of cheap and abundant commodities worldwide, disposed of in landfills without any environmental concerns (Moraes et al., 2014; Zajac et al., 2018; Berenguer et al., 2018). In 2012, 34 million tons of RHA were discarded. In the following year, in the United States, it is estimated that 1.25 to 5.6 tons of SCBA were produced (Martirena and Monzó, 2017; Paris et al., 2016). The increased use of biomass for energy generation is one of the most important sources of renewable production and has projected growth for the future, also accounting for a greater availability of ash (Zajac et al., 2018).

There is confirmation that countries such as Brazil may have industries that may benefit from

biomass residues for applications in construction, as discussed in the study by Moraes et al. (2014) and Regô et al. (2015), for example. The former analyzed the possible uses of by-products of the rice chain, and the latter characterized the RHA produced in the country and its application in cementitious matrices. As a result, the two authors cited found the same advantages mentioned in the article previously. They also identified that the ash produced in Brazil has a chemical composition that does not vary much, and this makes the material easier to use as a component of mortars.
Taking this into account, the aim of the present work is to verify the technical feasibility of using different types of biomass ashes - ECA, SCBA and RHA -, at different percentages of substitution, as supplementary cementitious material in mixed mortars, which contain two agglomerates in their composition, i.e., cement and lime, aiming at the partial reduction of Portland cement.

2. MATERIALS AND METHODS

2.1 Materials and characterization

The reference mortar used is of the mixed type - Portland cement, hydrated lime, natural fine aggregate and treated water, such as those specified by NBR 13529 (ABNT, 2013). The cement is the high initial strength (CP - V ARI) or type III, for NBR 5733 (ABNT, 1991) and ASTM C 150M-20, respectively. The cement was chosen because it has few or no additions in its composition, providing a better investigation of the behavior of the material according to the incorporation of waste.
The lime used is the hydrated type with carbonates, classified as CH - III, according to NBR 7175 (ABNT, 2003) and ASTM C 206-3, giving the mixture greater plasticity, better workability and greater water retention, besides being traditionally used in the region and easy to obtain. Finally, the small aggregate is the dry natural sand, with commercial denomination of "medium" and specifications according to NBR 7211 (ABNT, 2009), without any kind of treatment such as sieving or washing. The sand was extracted by dredging it in the Veríssimo and Paranaíba rivers in the city of Catalão - GO.
The three types of vegetable biomass ash used are combustion by-products, used for heat and energy generation, classified as class C by ASTM C 618 and vegetable pozzolan for concrete use. The ECA was obtained from a mining and processing plant of niobium and phosphate, the residue comes from using eucalyptus chips in furnaces for heat generation to dry the phosphate rock, where temperatures reach between 1000 and 1100 º C. The SCBA, supplied by a sugar, ethanol and energy producing plant, is removed from boilers, where the sugarcane bagasse was burned for energy generation. RHA is a by-product of the food industry, which uses the bark for heat generation to process coffee. For RHA and SCBA, no information was made available regarding the process of obtaining the residues.
The chemical composition determined by Resende (2013), de Souza et al. (2014) and Berenguer et al. (2018) comprises ashes with similar particularities to those studied here. The X-ray fluorescence spectrometry technique was used and is presented in Table 1.

Table 1. Oxide concentration (% by mass) of the analyzed ashes.

Compound	ECA (Resende, 2013)	RHA (de Souza et al., 2014)	SCBA (Berenguer et al., 2018)
SiO_2	6.38	93.25	84.86
Al_2O_3	22.60	<0.1	1.91
Fe_2O_3	10.90	0.02	3.83
CaO	27.40	0.57	2.96
MgO	6.15	0.19	2.54
TiO_2	2.41	<0.1	0.75
P_20_5	2.75	0.51	0.38
Na_2O	0.28	-	0.47
K_2O	4.29	.18	1.38
MnO	0.41	0.25	0.19

2.2 Treatment of ashes

The biomass residues were submitted to pretreatments of sieving and milling ensuring an increase in the specific surface with particles of lesser granulometry, thus helping the occurrence of the pozzolanic activity. These procedures were suggested by Ramos et al. (2013), Matos and Sousa-Coutinho (2013), Salvo et al. (2015), Modolo (2015), Ataie and Riding (2016). Thus, the ashes were passed through the 50-mesh sieve (opening of 297 µm), eliminating coarse particles, mostly composed of inert material, such as soil and rock fragments. Then, they were ground in a ball mill for 30 min at a rotation of 30 rpm - for longer periods, the particles began to aggregate (Xu et al., 2015).

2.3 Standards and experimental trials

2.3.1 Particle characterization

The particle density test followed the methodology proposed by the Brazilian Agricultural and Research Company - EMBRAPA (2011) using the volumetric balloon method. The samples of 20 g, separated in containers of known mass, were placed in an oven to dry at 105 °C for 24 hours. Later, they were cooled in a desiRHAtor, weighed, and transferred to a 50 ml volumetric flask containing ethyl alcohol to remove the air or voids from the ashes and cement.

For the fineness index of ash, NBR 15894-3 (ABNT, 2010), 20 g of the sample were dispersed in 400 ml of 12.5 g/l sodium hexametaphosphate solution and sieved in a 45 µm mesh, nominal diameter of 200 mm, under a constant flow of 5 l/s flow water for 10 min. The retained material was transferred to a watch glass, placed in an oven to dry at 105 °C for 24 hours, thus determining its dry mass. The samples with 20% or more material retained in the 45 µm sieve can be classified as pozzolan, NBR 12653 (ABNT, 2014).

Regarding the fineness index of cement, NBR 11579 (ABNT, 1991), and adopting the manual method, the 75 µm sieve (number 200) was used. The test consists of sieving so that, initially, 50 g of the sample were weighed, and the process finished only when the passing material corresponded to a mass less than 0.05 g. This property can also be evaluated following the indications of NBR NM 76 (ABNT, 1998) or ASTM C 204-05 for the Blaine Method.

Gravimetry tests made it possible to determine the moisture content, NBR NM 24 (ABNT, 2003) and ASTM D 3173-73, where 1 g of each sample was weighed, dried in an oven at 105 ± 4 º C for 30 min, with subsequent periods of 10 min, until the mass reached was constant. The results determined should be less than or equal to 3 (three), as indicated in NBR 12653 (ABNT, 2014).

In loss on ignition, NBR NM 18 (ABNT, 2004) by Method nº 1, the ash samples were calcined in a muffle furnace - Bravac M2 Electric Stainless -, for 50 min at 900 ºC at a heating rate of 35 ºC/min. After firing, the crucibles were left for 5 (five) hours in the muffle furnace and later placed in a desiRHAtor for cooling and future weighing. The same procedure should be performed following the recommendations of ASTM D 7348 - 13, in a single step, at a maximum temperature of 900 ºC (Method B). To be classified as pozzolan, NBR 12653 (ABNT, 2014), the loss limits must be less than or equal to 6.

2.3.2 Proportioning, molding of specimens and curing

The influence of partial substitution of RHA, SCBA and ECA on the performance of mortar was studied by comparing the behavior of one trace taken as a reference, without residues, and another with the substitution of 15 and 30% by mass of Portland cement for each type of ash, Table 2. These substitution levels were defined, based on the best results presented in the research conducted by Paris et al. (2016), Hossain et al. (2016), Abbas et al. (2017), Izabelle et al. (2011), Resende (2013) and Ukrainczyk et al. (2016).

The volume was 1:1:6 (cement, lime and sand) and can be used as laying and coating mortar for ASTM C 270-19, mortar type N. Considering the analyses of Dubaj (2000) and Campos (2014), this proportion showed a better performance for mortar properties. The amount of water was determined through the consistency index, NBR 13276 (ABNT, 2016), fixed at 265 ± 5 mm.

The prismatic specimens with partial substitution of cement were identified with the acronym for each ash - RHA, ECA and SCBA - and with index 15, for those with 15% substitution, or 30, for those with 30% substitution. The specimens molded with the reference trace were identified with the acronym RS (reference specimen).

The mass proportioning used to prepare the mortar specimens was carried out so that the total dry material of the mixture was equal to 2.5 kg, Table 2. The mixture was prepared from the mass proportion used in the preparation of the mortar specimens was carried out so that the total dry material of the mixture was equal to 2.5 kg, Table 2. The mixture was prepared according to the method specified by NBR 16541 (ABNT, 2016), without a mechanical mixer. To reach the established consistency index, the consistency test was performed by the flow table, NBR 13276 (ABNT, 2016).

Table 2. Mass proportion (kg) of the materials used to produce mortars.

Sample	Cement	Lime	Dry sand	Ashes	Water
CPR	0.258	0.103	2.130	0.000	0.625
RHA15	0.219			0.039	0.750
RHA30	0.181			0.077	0.650
SCBA15	0.219			0.039	0.625
SCBA30	0.181			0.077	0.625
ECA15	0.219			0.039	0.670
ECA30	0.181			0.077	0.725

After the mixture was prepared, the specimens (CDP) were molded in a prismatic format, with dimensions of 4cm x 4cm x 16cm. Three specimens were produced by age for the reference mortar and for each type of ash with the two replacement strips, totaling 42 specimens (NBR 13279, 2005; BS EN 1015-11). After molding, the molds with the mixture were wrapped by film paper and subjected to dry curing in a laboratory environment, at a temperature of 23 ± 2 ºC and relative humidity of 60 ± 5%.

It is known that, with the loss of water and moisture during curing, the mechanical and water absorption properties will be compromised, hence the need for to be carried out within the standards established by ASTM C 309-19 and ASTM C 1315-19. However, the choice for a non-submerged cure reflects the character of the research in identifying the behavior of ashes in cementitious

systems, especially regarding their ability to interfere with the moisture needed to hydrate the cement.
After 48 hours, given the end of the curing period, the CDP were removed from the molds and wrapped again in film until carrying out the mechanical resistance tests.

2.3.1 Evaluation of mortars in the hardened state

The tensile tests in simple flexion and compression, NBR 13279 (ABNT, 2005) and BS EN 1015-11, were made in order to analyze the development of the mechanical strength of the mortar over the curing time at 14 and 28 days. The resistance analysis was performed only for these ages since the pozzolanic reaction occurs slowly and, therefore, according to Ataie and Riding (2016), for early ages, satisfactory results are not obtained.
The results found for compressive and tensile strength in flexion at 14 and 28 days were obtained by calculating the average strength of the six specimens tested for compression, and the three tested for flexural tensile strength, using the multiple analysis of means adopting the Tukey method at 5% ($p < 0.05$) of confidence level. In addition, the maximum absolute deviation value of 0.5 MPa was respected for the individual results achieved in compression and 0.3 MPa for those achieved in the flexural tensile test, NBR 13279 (ABNT, 2005).
The capillarity water absorption test was performed at 28 days, as prescribed by NBR 15259 (ABNT, 2005). Initially, the mass of each specimen that was still dry was determined, and then the samples were placed on a support inside a container with water in partial immersion for a constant water slide of 5 ± 1 mm. Finally, each sample was removed from the container, dried with a damp cloth, and weighed at 10 min and at 90 min given the start of the test.

3. RESULTS AND DISCUSSION

The physical and chemical characterization analyzed in this study, important for understanding the behavior of particles and their influence on pozzolanic reactions, was made from the results obtained for the particle density (PD), the fineness (F) of each element, water content (U) and loss on ignition (LOI). From the results shown in Table 3, it can be observed that the samples containing SCBA had a lower volume in their composition, as well as in the studies by Kazmi et al. (2017) as this quantity is inversely proportional to PD (Aprianti et al., 2016). Therefore, for ECA, the lowest PD value found, the volume is ten times greater than it would be if there were no substitution, according to Gluitz and Marafão (2013), and which will influence the strength of mortars as will be seen below.

Table 3. Physical characterization of the elements used

Sample	PD (g/cm³)	F	U	LF
Cement	2.73	3.14%	-	-
ECA	0.25	52.63%	6.59%	70.20%
RHA	0.55	78.67%	1.81%	5.79%
SCBA	0.84	31.72%	0.60%	11.65%

In addition, based on the PD, the process of accommodating the particles that make up the cementitious system can be understood. There is a better mechanical performance when they are strongly interlaced and where there are few voids. Thus, the best resistance results should be seen in the SCBA and RHA, because after being previously treated - ground and sieved - the samples showed a higher DP. Without this treatment for ECA, the strength or other property of the mortar

could be negatively affected, making the substitution of cement by ashes, for example, inept (Martirena and Monzó, 2017; Farinha et al., 2018).
However, knowing that the behavior of a mortar is governed by other properties, grinding and sieving could make the ashes highly reactive as observed by Roselló et al. (2017), and with the pozzolanic activity taking place, the mechanical performance of the system can be satisfactory. Therefore, analyzing the results for the fineness index and following the specifications of ASTM C 618-19, SCBA is in fact a pozzolana, the maximum content of material retained in the 45 µm sieve is 34%, compared to 31, 72% accumulated. For NBR 12653 (ABNT, 2014) none of the ashes would be a pozzolanic material; the maximum content is 20%.
However, even though they are not pozzolans within the limits established by current regulations, the smallest particles, that is, not much material going through the 45 µm sieve, are concentrated close to the aggregate interface and cement matrix, causing a filler effect. This can contribute to resistance gain in the hardened state (Khan et al., 2017; Aprianti et al., 2016; Resende, 2013). This phenomenon is the same as that observed in cementitious systems containing hydraulic lime.
While for fresh mortar, the fineness index reveals those of lesser value, in the SCBA case, there is no change in workability for any substitution range because particles larger than 45 µm affect the plasticity of the mixture (Netto, 2006). Similarly, for the RHA, there is a greater loss of workability, especially when the increase in cement replacement is from 15 to 30%. These are assertions that are equally proven by the consistency index, which are within the limits established by NBR 13276 (ABNT, 2016), Figure 1.

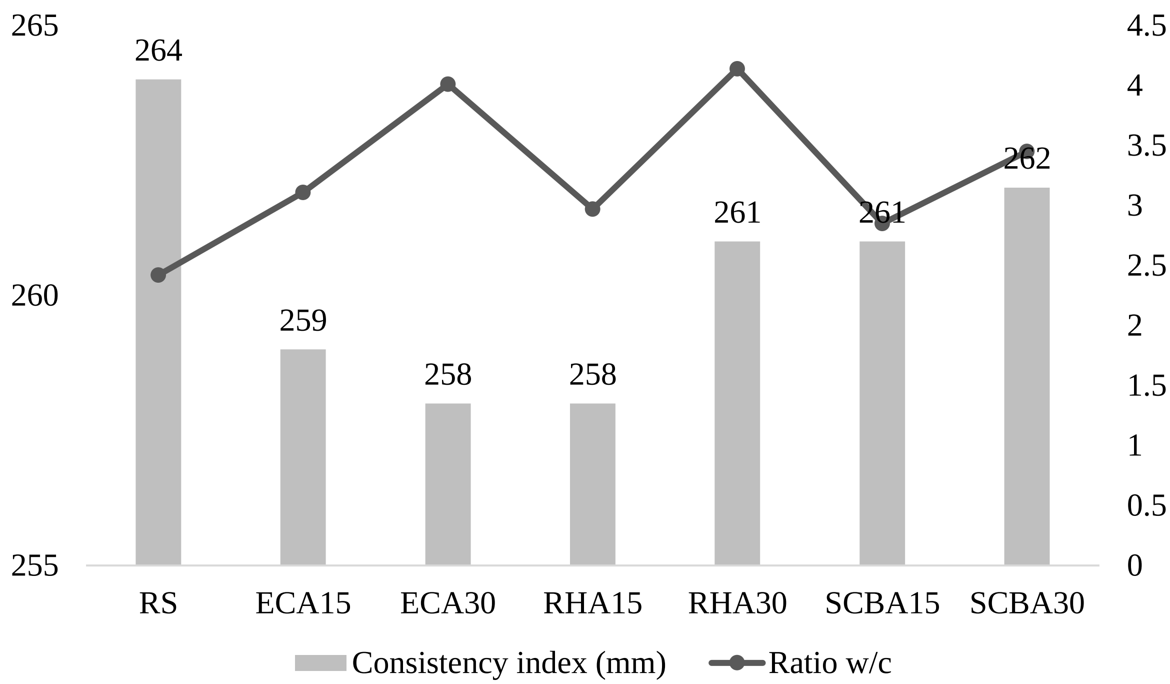

Figure 1. Chart results for consistency index and w/c ratio.

From the fineness index test, a visual analysis of the samples retained in the sieve was also performed. For the ECA, applying sodium hexametaphosphate, a dispersing chemical compound (Mauri et al., 2011), the presence of small crystals was noted. These particles account for the high-water content in the sample, Figure 1, due to the high absorption capacity (Netto, 2006). This explains not only the accentuated volume of water, which favors the maintenance of workability (Ataie, 2016), but also the humidity, which is satisfactory during the mortar curing (Rajamma et al., 2009).

Due to the hygroscopic nature of these crystalline elements, with more water released, there is a greater loss of mass of the ECA when subjected to the loss on ignition test, and for this reason there was a 70.20% loss, the largest among the analyzed ash. In addition, this occurrence is also due to the presence of unburned organic matter (Prasara-a, 2017), which during heating in a muffle, releases another portion of CO_2 and water.

Nevertheless, the presence of these crystals is not favorable to the properties of the mortar. For Aprianti et al. (2016), amorphous elements are more reactive. However, due to the fact that a large part of the retained material is crystalline and that its fineness reached a value of 52.63%, it is possible that the rest of the sample, through-pass and amorphous material, compensated for the reactivity of the ash. Thus, for ECA, the considerable gain in strength is a function of the volume of ash added to the mortar due to its low PD, as previously indicated.

Regarding the water demand in the samples, using the consistency index, Figure 1, in relation to the CPR, there is a high amount of water for mixtures containing ash in partial replacement for cement, except for SCBA. The largest amount required was for the RHA30 trace with 20% more when compared to CPR. According to Ukrainczyk et al. (2016), this occurs because of the irregular and bulky shape of the ashes. Berra et al. (2015) show the high specific surface area of ash compared to Portland cement, in addition to the porous nature of its particles, as suggested by Arif et al. (2016).

These characteristics are other factors that also account for greater water absorption. Another is the presence of a large amount of organic matter available for hydration during the mortar hardening, as identified by Rajamma et al. (2009) and previously confirmed by the loss on ignition test. It can be observed, therefore, that the workability decreased when there was the presence of ash in partial replacement to cement, corroborating the results obtained by Belviso (2018), Aprianti et al. (2016), Ukrainczyk et al. (2016) and those discussed here.

Despite this, the decrease found was 2.3% compared to the 34.4% cited in the literature. This difference was due to the size of the selected particles. Ukrainczyk et al. (2016), for example, used materials with particles up to 80 µm. In this study, we opted for those with max. 75 µm, a value considered satisfactory by Ataie and Riding (2016) to ensure reactivity, which is inversely proportional to the particle density, and therefore positively influence the mechanical properties of the mortar.

In general, considering the analyses for ECA, which are inverse to those observed in SCBA and RHA, and following the requirements of NBR 12653 (ABNT, 2014), only the last two can be classified as class N pozzolans, for content of water, moisture and loss on ignition. Both reached a moisture content of less than 3% and did not exceed 10% of the loss on ignition value. Moreover, adding the behavior of the ash before the properties of the mortar in the plastic state, workability and water absorption, a better reactivity is expected in samples containing RHA.

Therefore, regarding the results, there was no significant gain in compressive strength at 14 days for any of the samples, Figure 2, as shown in Paris et al. (2016) and Abbas et al. (2017). CPDs with a 15% cement replacement content achieved better mechanical performance, especially for ECA15. This is related to factors such as the lower rate of cement replacement (Garcia and Sousa-Coutinho, 2013; Carrasco et al., 2014; Ukrainczyk et al., 2016), the greater amount of reactive material, the better workability, when compared to CDP, and greater water absorption.

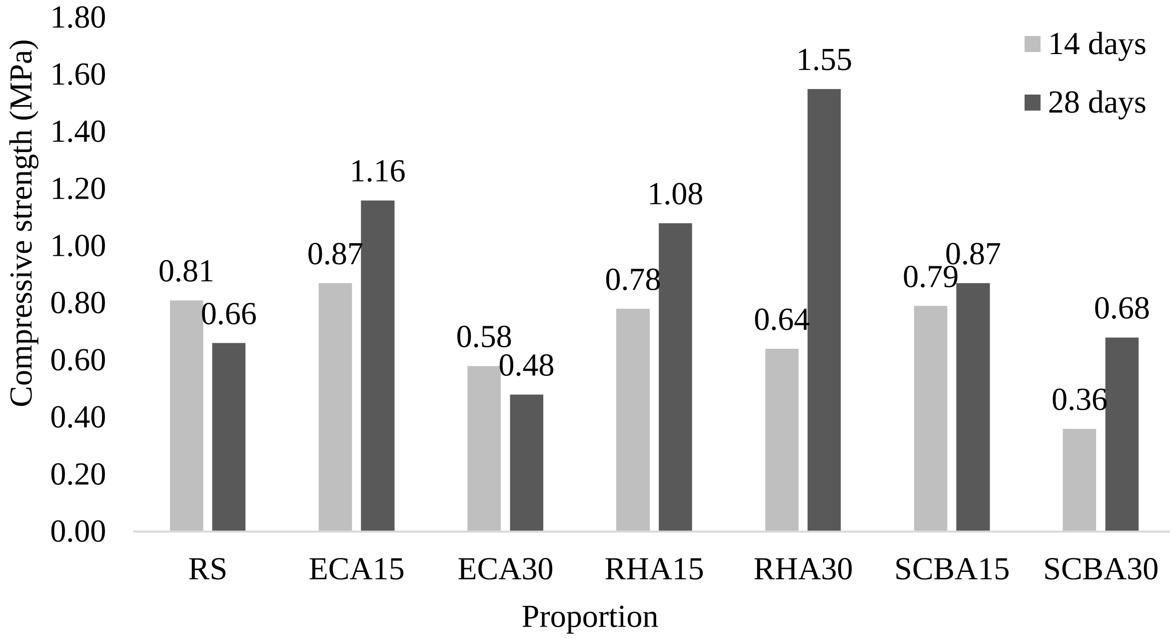

Figure 2. Bar chart showing a comparison between the average resistance achieved in the simple compression test for each trace at 14 and 28 days (Tukey method $p < 0.05$).

The cause of the poor performance of CPD is justified by the non-occurrence of the synergistic effect between cement hydration and the pozzolanic reaction, which directly influences the compression strength of the mortar (Isaia, 2003; Berra et al., 2015). On the one hand, the poor hydration action is possibly due to the use of wooden molds for molding the CDP, a material of a permeable nature, and little water retention during curing, as expected. On the other, the slow gray-cement reaction, Carrasco et al. (2014) and Rosales et al. (2017), suggest that long periods are necessary for there to be effects considered positive in resistance to compression.

At 28 days, the ECA30 did not show resistance gain as the causes are the same as those pointed out for the ECA15 at 14 days. This confirms that the ashes tend to contribute to the development of mechanical resistance due to their pozzolanicity and hydraulic activity, as in Berra et al. (2015). The best results were obtained for samples with a content of 15% and for RHA30. These were also identified by Rajamma et al. (2009) and Wang (2015). In RHA30, the sample with the greatest resistance gain is due to the high amount of silica in its composition (Fernandes et al., 2016), shown in Table 1, which can react more easily with the released CH, increasing the strength of mortars (Jamil et al., 2016).

Thus, it can be affirmed that, even without significant gain in compressive strength, the partial replacement of cement with biomass ash was considered acceptable for 15% by mass. The results identified in Figure 2 and those found by Rajamma et al. (2015), Garcia and Sousa-Coutinho (2013), Carrasco et al. (2014) and Ukrainczyk et al. (2016) point out that the resistance of samples containing ash is greater than that found in CPR for different curing times, that is, 28 days for those containing the biomass residue and 90 days for those without any additional cementitious material.

Analogously, analyzing the results obtained for flexural tensile strength, Figure 3, it was observed that only the SCBA30 and RHA30 traces did not exceed the CPR resistance and that for ECA30 the same value at 14 days was reached. For the age of 28 days, the traces containing ash obtained a better performance for tensile strength in flexion than for simple compression, confirming the delayed effect of gray-cement reactions, mainly for a 15% replacement.

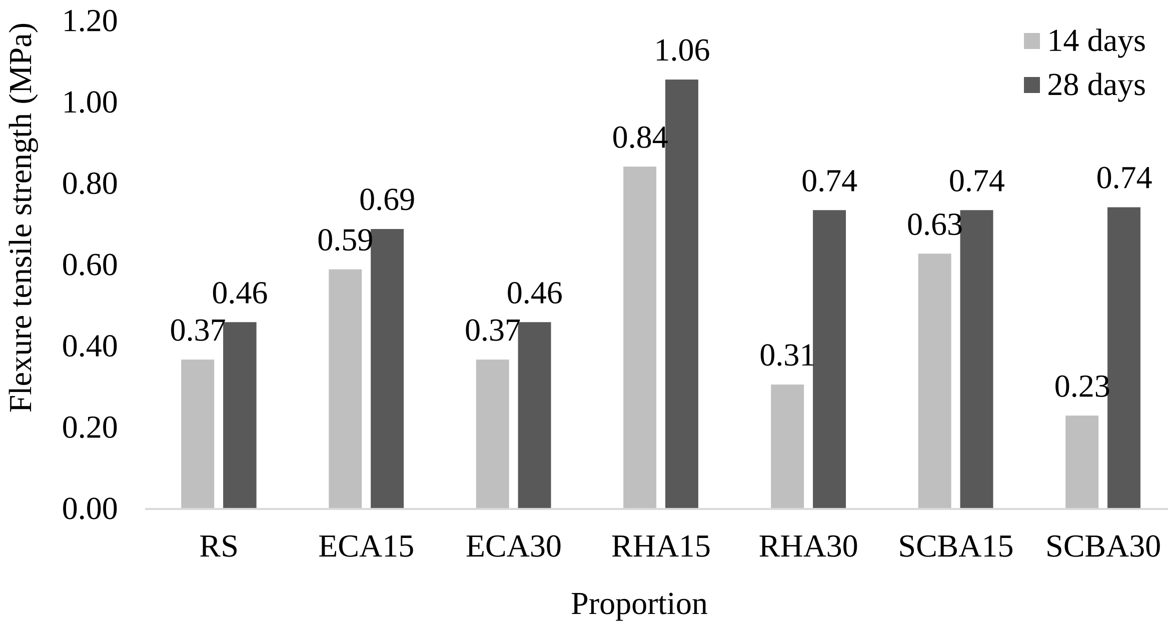

Figure 3. Comparison between the average resistance achieved in the flexural tensile test for each trace at 14 and 28 days (Tukey method p <0.05).

However, the results for flexion differ from those obtained by Rajamma et al. (2009), where there was a gradual reduction in resistance with the increase in the percentage of ash and, consequently, an increase in pozzolanic reactions, especially for replacement rates greater than 20% (Chowdhury et al., 2015). This phenomenon can be controlled by re-burning residues and grinding processes, as was done for the ashes studied here, confirming the need to submit them to these types of pretreatments, as indicated by Jamil et al. (2016).
Finally, to identify the water absorption phenomenon, the specifications presented by NBR 15259 (ABNT 2005) were followed. It states that the capillarity absorption index must be calculated as the average of the three specimens submitted to immersion in water for 10 min and 90 min, Figure 4.

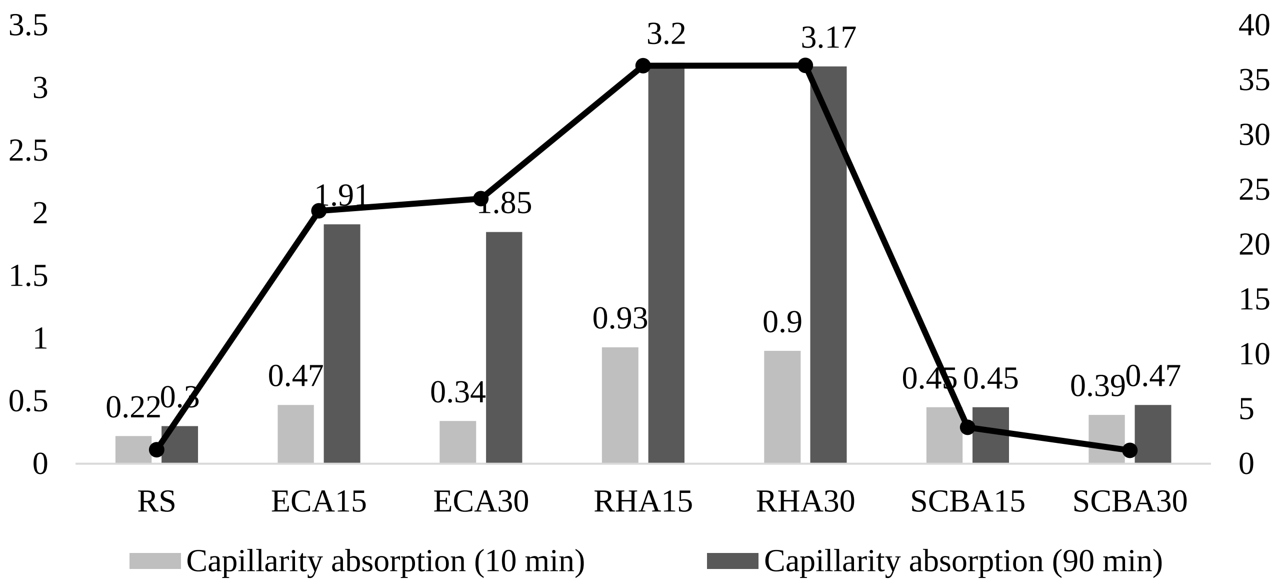

Figure 4. Absorption test at 28 days.

From the results found, the absorption rate decreases, even if expressively, as the cement replacement rate increases from 15 to 30%. Jamil et al. (2016) and Elinwa and Ejeh (2003) identified a reduction in water absorption when the mortar has 15% ash in its composition, at a rate of 0.8 to 1.25%. As a rule, it is accepted that this limit is less than or equal to 10%. However, it diverged from the studies by Chowdhury et al. (2015), in which the ash absorption and addition ratio is directly proportional.

For the highest values, ECA30 and ECA15, they occurred due to the presence of open pores in the structure, confirming the results for the granulometry and fineness index tests. In the presence of particles of different sizes, the water absorption capacity is increased. Therefore, due to the uniformity and fineness of the SCBA, the penetration of water in them has values close to those of the CPR. Thus, it is concluded that the absorption decreases as the amount of voids decreases, thus the SCBA can be used as filling material. It is also clear that, by increasing the ash percentages, the permeable voids will be filled, minimizing the absorption rate (Jamil et al., 2016; Rosales et al., 2017; Carrasco et al., 2014).

Concerning the cure, according to Aprianti et al. (2016), when incorporating fine material into cementitious systems, different procedures should be used to promote this concrete hydration. One option is to use superplasticizers (Ukrainczyk et al., 2016) to fix the w/c ratio and guarantee conditions of execution and performance (Carasek, 2010). For Ramos et al. (2013), Ataie and Riding (2016) the ideal value of the w/c ratio is equivalent to 0.4 and 0.45, respectively.

Given this, the ash with the greatest potential to improve the characteristics of mortar as a partial substitute for cement is RHA. Concerning ECA and SCBA, their potential as a filling material should be assessed, and a mortar that contains the three types together should be studied.

4. CONCLUSION

The use of ash as a component of mortar was clear. Materials that have this particularity are known as supplementary cementitious materials. All the data found in this research are also identified in the literature. The pretreatments reduced the granulometric variation of the ashes, increasing their specific surface, and the particles were better accommodated, showed greater reactivity. The content of unburned organic influenced the loss of ignition, but not enough to prevent better results in the hardened state when compared to the reference mortar.

It should be mentioned that from all the analyses made, mortars containing RHA achieved the best mechanical development. The behavior of ECA and SCBA suggests its application as a substitute for sand, for example, and may be the object of study in future research. The filling effect was identified by the resistance gain that occurred due to the behavior of the particles, like those of lime, occupying voids in the cement matrix. Using it as a substitute for cement should not be ruled out.

As for the substitution content, for the chosen bands, 15% is the ideal substitution content, however higher substitution contents may result in mortars with less mechanical resistance or more porous. The reference must therefore be the application of the mortar, whether laying or covering, whether external or internal area. Those studied here, due to their 1:1:6 trace and the results obtained, could be used for laying masonry or for ceramic tiles. However, the technical feasibility for these applications can only be proven by carrying out new studies.

Regarding water absorption, which was high for all ash contents, the mortar is highly porous. Ashes should be treated before being used (here they were ground and sieved). After doing this we suggest reburning the ash, that is, the residue needs to be ground, sieved and burnt. By doing this, the pozzolanic activity improves and voids that exist in the mortar will decrease. In addition, we suggest using an additive that will control the water-cement ratio.

5. ACKNOWLEDGEMENTS

The authors wish to thank the Brazilian National Council of Research and Development (CNPq) for financing this research (Project number 552118/2011-7).

6. REFERENCES

Abbas, S., Kazmi, S. M. S., Munir, M. J. (2017), *Potential of rice husk for mitigating the alkali-silica reaction in mortar bars incorporating reactive aggregates.* Construction and Building Materials. 132:61-70. https://doi.org/10.1016/j.conbuildmat.2016.11.126
Aprianti, E., Shafigh, P., Zawawi, R., Hassa, Z. F. A. (2016), *Introducing an effective curing method for mortar containing high volume cementitious materials.* Construction and Building Materials.107:365-377. https://doi.org/10.1016/j.conbuildmat.2015.12.100
Arif, E., Clark, M. W., Lake, N. (2016), *Sugar cane bagasse ash from a high efficiency co-generation boiler: Application in cement and mortar production.* Construction and Building Materials. 128:287-197. https://doi.org/10.1016/j.conbuildmat.2016.10.091
Associação Brasileira de Normas Técnicas. (1991). *NBR 11579: Cimento Portland – Determinação da finura por meio da peneira 75 µ (nº 200).* Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (1991). *NBR 5733: Cimento Portland com alta resistência inicial.* Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2003). *NBR 7175: Cal hidratada para argamassas – Requisitos.* Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2003). *NBR NM 24: Materiais pozolânicos – Determinação do teor de umidade.* Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2004). *NBR NM 18: Análise química – Determinação da perda ao fogo*. Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2005). *NBR 13279: Argamassa para assentamento e revestimento de paredes e tetos – Determinação da resistência à tração na flexão e à compressão*. Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2005). *NBR 15259: Argamassa para assentamento e revestimento de paredes e tetos – Determinação da absorção de água por capilaridade e do coeficiente de capilaridade.* Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2010). *NBR 15894-3: Agregados para concreto – Especificação.* Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2013). *NBR 13529: Revestimento de paredes e tetos de argamassas inorgânicas — Terminologia*. Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2014). *NBR 12653: Materiais pozolânicos - Requisitos.* Rio de Janeiro.
Associação Brasileira de Normas Técnicas. (2016). *NBR 13276: Argamassa para assentamento e revestimento de paredes e tetos – Determinação do índice de consistência.* Rio de Janeiro.
ASTM International. (2005). ASTM C 204-05 *Standard Test Method for Fineness of Hydraulic Cement by Air Permeability Apparatus.* https://doi.org/10.1520/10.1520/C0204-05
ASTM International. (2009). ASTM C 206-03 *Standard Specification for Finishing Hydrated Lime.* https://doi.org/10.1520/C0206-03R09
ASTM International. (2013). ASTM D 7348 – 13 *Standard Test Methods for Loss on Ignition (LOI) of Solid Combustion Residues.* https://doi.org/10.1520/D7348-13
ASTM International. (2017). ASTM D3173 / D3173M - 17a *Standard Test Method for Moisture in the Analysis Sample of Coal and Coke.* https://doi.org/10.1520/C0204-05
ASTM International. (2019). ASTM C 1315-19 *Standard Specification for Liquid Membrane-*

Forming Compounds Having Special Properties for Curing and Sealing Concrete. https://doi.org/10.1520/C1315-19
ASTM International. (2019). ASTM C 270-19ae1 *Standard Specification for Mortar for Unit Masonry*. https://doi.org/10.1520/C0270-19AE01
ASTM International. (2019). ASTM C 309-19 *Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete.* https://doi.org/10.1520/C0309-19
ASTM International. (2019). ASTM C 618-19 *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.* https://doi.org/10.1520/C0618-19
ASTM International. (2019). ASTM C 618-19 *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.* https://doi.org/10.1520/C0618-19
ASTM International. (2020). ASTM C 150M-20 *Standard Specification for Portland Cement.* https://doi.org/10.1520/C0150_C0150M-20
Ataie, F. F., Riding, K. A. (2016). *Influence of agricultural residue ash on early cement hydration and chemical admixtures adsorption.* Construction and Building Materials. 106:274-281. https://doi.org/10.1016/j.conbuildmat.2015.12.091
Belviso, C. (2018), *State-of-the-art applications of fly ash from coal and biomass: A focus on zeolite synthesis processes and issues.* Progress in Energy and Combustion Science. 65:109-135. https://doi.org/10.1016/j.pecs.2017.10.004
Berenguer, R. A., Silva, F. A. N., Torres, S. M., Monteiro, E. C. B., Helene, P., Neto, A. A. de M. (2018), A influência das cinzas de bagaço de cana-de-açúcar como substituição parcial do cimento na resistência à compressão de argamassa. Revista ALCONPAT. 8(1):30-37. https://doi.org/10.21041/ra.v8i1.187
Berra, M., Mangialardi, T., Paolini, A. E. (2015). *Reuse of woody biomass fly ash in cement-based materials*. Construction and Building Materials, 76:286-296. https://doi.org/10.1016/j.conbuildmat.2014.11.052
British Standard (2002). BS EN 1015-18 *Methods of test for mortar for masonry. Determination of water absorption coefficient due to capillary action of hardened mortar.*
British Standard (2019). BS EN 1015-11 *Methods of test for mortar for masonry. Determination of flexural and compressive strength of hardened mortar.*
Campos, M. O. (2014), "*Estudo da resistência de aderência à tração e ao cisalhamento de revestimentos de argamassa em substratos de concreto".* Dissertação Mestrado em Engenharia Civil, Universidade Federal de Goiás, p. 321.
Carasek, H. (2010), Argamassas. In: ISAIA, G. C. (Ed.). *"Materiais de Construção Civil e Princípios de Ciência e Engenharia de Materiais".* IBRACON, São Paulo, p.1-37.
Carrasco, B., Cruz, N., Terrados, J., Corpas, F. A., Pérez, L. (2014), *An evaluation of bottom ash from plant biomass as a replacement for cement in building blocks.* Fuel Processing Technology. 118:272-280. https://doi.org/10.1016/j.fuel.2013.10.077
Chatveera, B., Lertwattanaruk, P. (2014), *Evaluation of nitric and acetic acid resistance of cement mortars containing high-volume black rice husk ash.* Journal of Environmental Management. 133:365-373. https://doi.org/10.1016/j.jenvman.2013.12.010
Chowdhury, S., Mishra, M., Suganya, O. (2015), *The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: An overview.* Ain Shams Engineering Journal. 6 (2):429-437. https://doi.org/10.1016/j.asej.2014.11.005
de Souza, L. M. S., Fairbairn, E. M. R., Filho, R. D. T., Cordeiro, G. C. (2014), *Influence of initial* CaO/SiO_2 *ratio on the hydration of rice husk ash-*$Ca(OH)_2$ *and sugar cane bagasse ash-*$Ca(OH)_2$ *pastes.* Química Nova. 37 (10):1600-16605. http://dx.doi.org/10.5935/0100-4042.20140258
Dubaj, E. (2000), *"Estudo comparativo entre traços de argamassa de revestimento utilizadas em Porto Alegre"*. Dissertação Mestrado em Engenharia Civil, Universidade Federal do Rio Grande do Sul, p. 115.

Elinwa, A. U., Ejeh, S. P. (2003), *Effects of incorporation of sawdust incineration fly ash in cement pastes and mortars.* Asian Architecture Build Eng. 3:1-7. http://dx.doi.org/10.3130/jaabe.3.1

Esteves, T. C., Rajamma, R., Soares D., Silva, A. S., Ferreira, V. M., Labrincha, J. A. (2012), *Use of biomass fly ash for mitigation of alkali-silica reaction of cement mortars.* Construction and Building Materials. 26:687-693. https://doi.org/10.1016/j.conbuildmat.2011.06.075

Fernandes, I. J., Calheiro, D., Kieling, A. G., Moraes, C. A. M., Rocha, T. L. A. C., Brehm, F. A., Modolo, R. C. E. (2016), *Characterization of rice husk ash produced using different biomass combustion techniques for energy*. Fuel Processing Technology. 165:351-359. https://doi.org/10.1016/j.fuel.2015.10.086

Garcia, M. L., Sousa-Coutinho, J. (2013), *Strength and durability of cement with forest waste bottom ash.* Construction and Building Materials. 41:897–910. https://doi.org/10.1016/j.conbuildmat.2012.11.081

Gluitz, A. C., Marafão, D. (2013), "*Utilização da cinza da madeira de eucalipto na substituição parcial do cimento Portland em argamassa".* Trabalho de Conclusão de Curso, Universidade Tecnológica Federal do Paraná, p. 53.

Hossain, M. M., Karim, M. R., Hasan, M. K., Zain, M. F. M. (2016), *Durability of mortar and concrete made up of pozzolans as a partial replacement of cement: A review.* Construction and Building Materials. 116:128-140. https://doi.org/10.1016/j.conbuildmat.2016.04.147

Isaia, G. C., Gastaldini, A. L. G., Moraes, R. (2003), *Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete.* Cement and Concrete Composites. 25:69-76. https://doi.org/10.1016/S0958-9465(01)00057-9

Jamil, M., Khan, M. N. N., Karim, M. R., Kaish, A. B. M. A., Zain, M. F. M. (2016), *Physical and chemical contributions of Rice Husk Ash on the properties of mortar.* Construction and Building Materials. 128:185-198. https://doi.org/10.1016/j.conbuildmat.2016.10.029

Kazmi, S. M. S., Munir, M. J., Patnaikuni, I., Wu, F. (2017), *Pozzolanic reaction of sugarcane bagasse ash and tis role in controlling alkali silica reaction.* Construction and Building Materials. 148:231-240. https://doi.org/10.1016/j.conbuildmat.2017.05.025

Khan, M. N. N., Jamil, M., Karim, M. R., Zain, M. F. M., Kaish, A. B. M. A. (2017), *Filler Effect of Pozzolanic Materials on the Strength and Microstructure Development of Mortar.* Journal of Civil Engineering. 21:274-284. https://doi.org/10.1007/s12205-016-0737-5

Martirena, F., Monzó, J. (2017), *Vegetable ashes as Supplementary Cementitious Materials.* Cement and Concrete Research. https://doi.org/10.1016/j.cemconres.2017.08.015

Mauri, J., Ruiz, H. A., Raphael, B. A. F., Ker, J. C., Rezende, L. R. M. (2011), *Dispersantes químicos na análise granulométrica de latossolos.* Revista Brasileira de Ciência do Solo. 34:1277-1284. https://doi.org/10.1590/S0100-06832011000400021

Modolo, R. C. E., Silva, T., Senff, L., Tarelho, L. A. C., Labrincha, J. A., Ferreira, V. M., Silva, L. (2015), *Bottom ash from biomass combustion in BFB and its use in adhesive-mortars.* Fuel Processing Technology. 129:192-202. https://doi.org/10.1016/j.fuproc.2014.09.015

Netto, R. M. (2006), "*Materiais pozolânicos".* Dissertação Mestrado em Construção Civil, Universidade Federal de Minas Gerais, p.149.

Noor-Ul-Amin, S. (2014), *A multi-directional utilization of different ashes.* Royal Society of Chemistry Advances. 4(107):62769–62788. https://doi.org/10.1039/C4RA06568A

Prasara-a, J., Gheewala, S. H. (2017), *Sustainable utilization of rice husk ash from power plants: A review.* Journal of Cleaner Production. 167:1020-1028. https://doi.org/10.1016/j.jclepro.2016.11.042

Rajamma, R., Ball, R. J., Tarelho, L. A. C., Allen, G. C., Labrincha, J. A., Ferreira, V. M. (2009), *Characterization and use of biomass fly ash in cement-based materials.* Journal of Hazardous Materials. 172(2-3):1049-1060. https://doi.org/10.1016/j.jhazmat.2009.07.109

Rajamma, R., Senff, L., Ribeiro, J. A., Ball, R. J., Aleen, G. C., Ferreira, V. M. (2015), *Biomass* *fly ash effect on fresh and hardened state properties of cement-based materials".* Composites Part B: Engineering. 77:1-9. https://doi.org/10.1016/j.compositesb.2015.03.019

Ramos, T., Matos, A. M., Sousa-Coutinho, J. (2013), *Mortar with wood waste ash: Mechanical strength carbonation resistance and ASR expansion.* Construction and Building Materials. 49:343–351. https://doi.org/10.1016/j.conbuildmat.2013.08.026

Resende, D. S. (2013), "*Estudo do efeito da incorporação de cinzas de cavaco de eucalipto como material cimentício suplementar".* Tese Doutorado em Engenharia de Materiais, Universidade Federal de Ouro Preto, p. 168.

Rosales, J., Cabrera, M., Beltrán, M. G., López, M., Agrela, F. (2017), *Effects of treatments on biomass bottom ash applied to the manufacture of cement mortars*. Journal of Cleaner Production. 154:424-435. https://doi.org/10.1016/j.jclepro.2017.04.024

Roselló, J., Soriano, L., Santamarina, M. P., Akasaki, J.L., Monzó, J., Payá, J. (2017), *Rice straw ash: A potential pozzolanic supplementary material for cementing systems.* Industrial Crops and Products. 103:39-50. https://doi.org/10.1016/j.indcrop.2017.03.030

Salvo, M., Rizzo, M. C., Novajra, G., Canonico, F., Bianchi, M., Ferraris, M. (2015), *Biomass ash as supplementary cementitious material (SCM).* Advances in Applied Ceramics. 114:S3-S10. https://doi.org/10.1179/1743676115Y.0000000043

Ukrainczyk, N., Vrbos, N., Koenders, E. A. B. (2016), *Reuse of Woody Biomass Ash Waste in Cementitious Materials.* Chemical and Biochemical Engineering Quarterly. 30(2):137-148. http://dx.doi.org/10.15255/CABEQ.2015.2231

Wang, S. (2015), *Cofired biomass fly ashes in mortar: Reduction of Alkali Silica Reaction (ASR) expansion, pore solution chemistry and the effects on compressive strength.* Construction and Building Materials. 82:123-132. https://doi.org/10.1016/j.conbuildmat.2015.02.021

Xu, W., Lo, Y. T., Ouyang, D., Memon, A., Xing, F., Wang, W., Yuan, X. (2015), *Effect of rice husk ash fineness on porosity and hydration reaction of blended cement paste.* Construction and Building Materials. 89:90-101. https://doi.org/10.1016/j.conbuildmat.2015.04.030

Zajac, G., Szyszlak-Bargłowicz, J., Gołebiowski, W., Szczepanik, M. (2018), *Chemical Characteristics of Biomass Ashes.* Energies. 11(11):2-15. https://doi.org/10.3390/en11112885