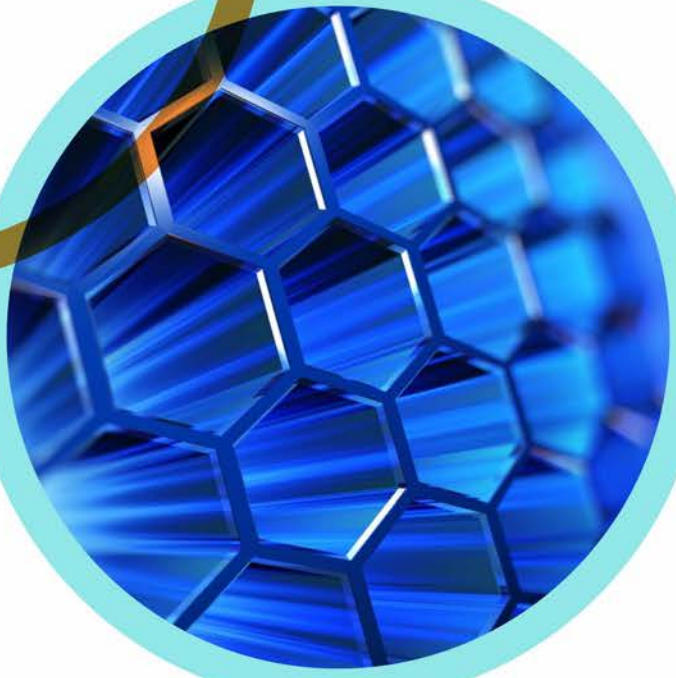

Asian Journal of
Materials Science

ansinet
Asian Network for Scientific Information

OPEN ACCESS Asian Journal of Materials Science

ISSN 1996-3394
DOI: 10.3923/ajmskr.2020.1.8

Research Article
Comparative Study of the Effect of Ashes from Rice Husk, Sugarcane Bagasse and Corn Cob on Mortar Properties

[1]Kenneth Marizane, [1]Arão Manhique and [1,2]Carvalho Madivate

[1]Deprtment of Chemistry, Faculty of Sciences, Eduardo Mondlane University, Avenida Julius Nyerere, Nº 3453, P.O. Box 257, Campus Principal, Maputo, Mozambique
[2]Higher Institute of Science and Technology of Mozambique-ISCTEM, 1394 Street, Facim Zone, Maputo, Mozambique

Abstract

Background and Objectives: Agro-industrial waste has a potential to be used as partial replacement of cement in mortars. Corn cob is the most abundant agricultural residue in countries where maize meal is the main corn. In this study the comparison of rice husk, sugarcane bagasse, corn cob ashes is carried out as replacement of cement in mortars was investigated. **Materials and Methods:** The mortars were prepared using ashes partially replacing Portland cement. The ashes were characterized by X-ray diffraction for mineralogical analysis and amorphous content. The mortars performance was determined by flexural and compressive strength. **Results:** Mineralogical analysis indicate the predominance of silica (quartz) in rice husk ashes, while in other ashes was present not in a dominant position. The mortars produced with rice husks showed the best performance with additions up to 15%, with mechanical properties surpassing those of the reference material, at 28 days of curing age. Corn cob ashes showed a good development of properties at earlier ages, 2 and 7 days with no further improvement in later ages. Sugarcane bagasse ash showed an intermediate performance, between rice husk and corn cob ashes. **Conclusion:** The study indicates that corn cob ashes did not likely perform as the other two residues. Results indicate for corn cob ashes a filler effect rather than the pozzolanic effect.

Key words: Corn cob ash, rice husk ash, sugarcane, bagasse ash, mortar properties

Citation: Kenneth Marizane, Arão Manhique and Carvalho Madivate, 2020. Comparative study of the effect of ashes from rice husk, sugarcane bagasse and corn cob on mortar properties. Asian J. Mater. Sci., 12: 1-8.

Corresponding Author: Arão Manhique, Department of Chemistry, Faculty of Sciences, Eduardo Mondlane University, Avenida Julius Nyerere, Nº 3453, P.O. Box 257, Campus Principal, Maputo, Mozambique Tel/Fax: +258 21 493377

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Due to their pozzolanic activity, ashes from agro-industrial waste are used for the partial replacement of cement as well as to partially replace fine aggregates used in the production of mortars[1]. Ash composition and mineralogy and its effect on mortar properties is mainly affected by burning conditions. Studies carried out by Ribeiro and Morelli[2] show that at 500°C formation of calcium silicates and aluminates has not yet begun; at 600°C the highest levels are recorded at 700°C a slight decrease of the acidic oxides responsible for the pozzolanic activity of the ashes is noted. Cordeiro *et al.*[3] worked also with sugarcane bagasse at temperatures in the range of 400-800°C, with increments of 100°C and a burning time of 3 h. The results obtained by Cordeiro *et al.*[3] show at 400°C a completely amorphous material while indicating that crystallization initiates at 500°C.

Arum *et al.*[4] studied the effect of ash from rice husk (RHA) and coconut husk, in the range of zero to 15% and showed a maximum increase on the compressive strength at 10% RHA, while the bark ash of coconut showed a continuous growth up to 15% of ash content in the tested samples. Bie *et al.*[5] produced RHA at 600-700°C and burning times of 1-2 h. The results of Bie *et al.*[5] show some crystallization in samples prepared at 700°C and some deterioration of their compressive strength compared to values obtained with ash prepared at 600°C. The best results were obtained with 10% additive, burning for 1 or 2 h. The values obtained are comparable or even slightly higher than those of conventional mortar.

Jamil *et al.*[6] start by the calculation of the ideal amount of ashes, based on the stoichiometry of the pozzolanic reaction between amorphous silica and $Ca(OH)_2$, an approach that do not consider the filler effect (physical component of pozzolanic activity) and lead therefore to an optimal ash content different from the value obtained experimentally.

Non conventional mortars show low values of compressive strength for the lower curing times. These results can be explained by a slower development of the mechanical resistance of mortars with addition of pozzolanic materials, when compared to reference mortars[7]. According to Shatat[8], in lower curing ages, materials show a greater filler effect, whereas for higher curing ages, greater pozzolanic activity of these materials is registered.

Although there is a general evidence of this trend, the results obtained by Moraes *et al.*[9] with sugarcane bagasse ash (SCBA), show, even for curing ages of 3 and 7 days, comparable values of the compressive strength of reference mortars and mortars with ash addition. This may be evidence that results obtained depend from other variables like the ratio of the different components, viscosity, consistency and decanting time of mortars[10], but also the areas where a certain product was cultivated, as evidenced by X-ray diffraction results obtained with RHA from different regions[11].

In the present study, a comparative study of the effect of the ashes from rice husk, sugarcane bagasse and corn cob was carried out. The water/binder ratio was kept constant, with all the limitations that this entails in the work ability of some compositions, which in some cases limited the maximum content of ash added.

MATERIALS AND METHODS

Present research encompassed the following phases: Ash production from the 3 samples and the determination of the amount of amorphous phase in each ash sample, the production of mortars; and the performance of the compressive and flexural strength after 2, 7 and 28 days curing age.

Study area: This study was conducted in Maputo Mozambique as part of the research project at the University Eduardo Mondlane, from February, 2016 to December, 2017. The agricultural material was obtained in local villages from peasants, for corn cob, rice ask was obtained from a agricultural farm in the north of Maputo (Inácio de Sousa, Lda.). Sugarcane bagasse was obtained from a local sugar mill company, namely Companhia Açucareira de Xinavane.

Ashes production: The ashes were prepared by burning the material (corn cob, rice husk and sugarcane bagasse) on a kitchen stove using aluminium pots. The samples were grinded for 30 min using a porcelain ball mill, to facilitate calcination. The pulverized material was transferred into a nickel crucible and placed in a muffle at preset temperature.

The optimization process for the three selected materials followed the experience described in the literature[3,5,12]. Selected temperatures ranged from 550-800°C with 50°C intervals and burning times ranging from 1-4 h with 1 h intervals. The test specimens were prepared using ash produced under optimal conditions.

Mineralogical analysis as well as the amorphous content determination in the ashes were done by XRD using a panalytical Empyrean diffractometer.

Table 1: Amounts of different components of the mortars used in the preparation of test specimens

Cement (g)	Ash content: Percentage	Ash content: Gram	Sand (g)	Water (mL)
450.0	0	0.0	1350	225
427.5	5	22.5		
405.0	10	45.0		
382.5	15	67.5		
360.0	20	90.0		
337.5	25	112.5		
315.0	30	135.0		

Preparation of the mortar specimens: The preparation of the test specimens and the performance of the compressive and bending stress tests after 2, 7 and 28 days of cure, followed the methodology described in Macie *et al.*[13], which is based on ASTM standard[14] 91977, norms NM[15] NP 197-1: 2000 and NBR[16] 9778. For this purpose, mortar compositions were formulated, keeping the contents of the components constant, varying only the percentage of cement, which was replaced by varying amounts of ash of the 3 materials.

For mortars preparation a local Portland cement 42.5 N was used, produced by *Cimentos de Moçambique* and sand from Corrumana, a dam located in the District of Moamba-Maputo Province. The sand was manually washed to reduce dust and other impurities, dried, milled and sieved for the production of 6 classes of fine aggregate according to standardized process[17].

Preparation of the mortars for test specimens followed norm[18] NP EN 196-1:2006 the amount of sand (1350 g) and water (225 mL = 225 g) was kept constant, while cement was partially replaced by quantities of ash in different percentages as shown in Table 1. The ratio of cement (plus ash): Sand was kept constant(1:3) corresponding to 25% cement to 75% sand in each mortar and with a ratio of 225/450 g (water/cement), making a trace of 1:3:0.5 (cement:sand:water), according to norm[18] NP EN 196-1:2006. Bending and compressive stress tests were conducted in a Controls press.

RESULTS

Optimization of the ash production process: Figure 1a-c show the results of the amorphous content in the samples of RHA, SCBA and corn cob ash (CCA), calcined at different temperatures (550, 600, 650, 700 and 750°C) and different calcinations time (2-4 h).

A uniform behaviour, with amorphous content in the order of 99% for the different calcination times tested and in the temperature range of 550-750°C, is observed in Fig. 1a (RHA). Similar behaviour is observed with SCBA for 2 and 3 h, while at 4 h a different behaviour is observed (Fig. 1b). A slight reduction in amorphous content is observed at 650°C. The amorphous contents were below 50%. The CCA curves showed no regular behaviour (Fig. 1c), especially at 2 and 3 h burning.

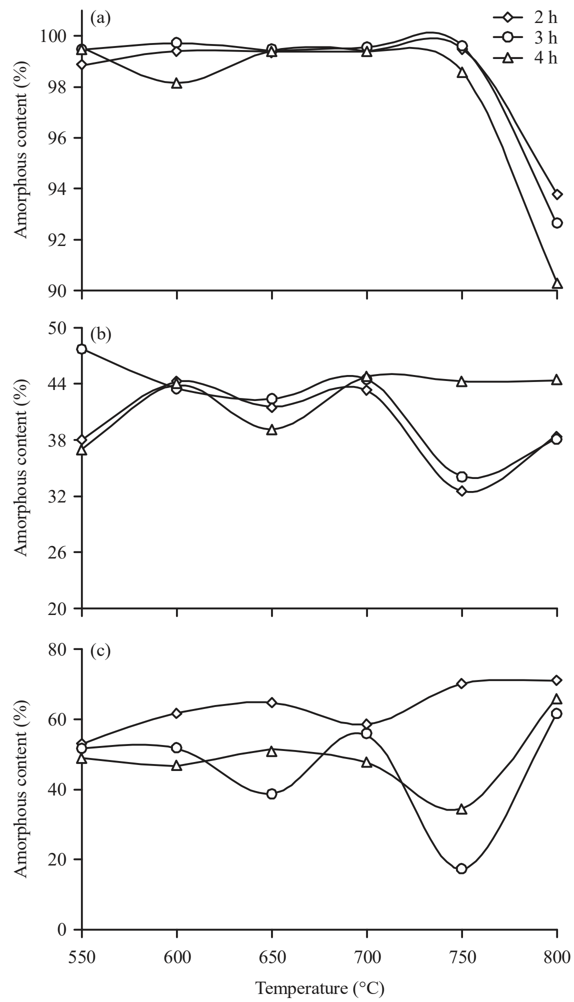

Fig. 1(a-c): Amorphous content in (a) Rice husk (b) Sugarcane bagasse and (c) Corn cob ashes as function firing temperature and time

The overall X-ray diffraction tests for the different temperatures the results are presented in Fig. 2-4. Heat treatment did not produce significant changes in the mineralogy of RHA, mainly composed by quartz and cristobalite, neither the heating time have produced (Fig. 2). The SCBA XRD patterns show the presence of quartz (SiO_2), albite ($NaAlSi_3O_8$) and microcline ($KAlSi_3O_8$). Quantitative results (Fig. 1) show a slight increase in crystalline content as the heating temperature increases. Increasing the heating time favours crystalline content. The CCA patterns show the presence of cloritoide ($(Fe, Mg, Mn)_2$, $Al_4Si_2O_{10}(OH)_4$), jasmundite ($Ca_{11}(SiO_4)_4SO_2$) and quartz (SiO_2).

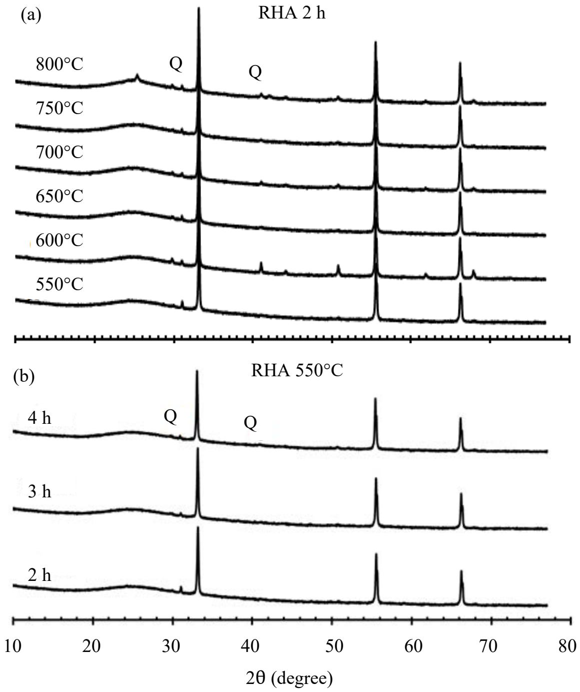

Fig. 2(a-b): XRD patterns of rice husk ashes (RHA) (a) Effect of temperature and (b) Effect of firing tim

Q: Quartz (SiO_2)

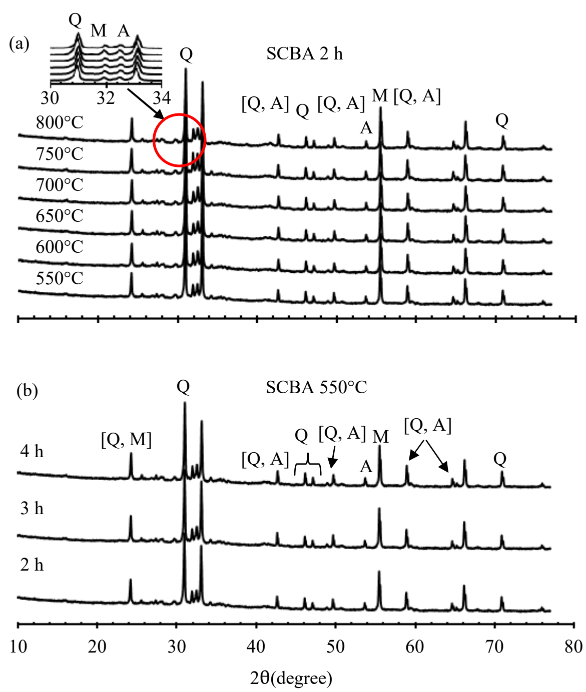

Fig. 3(a-b): XRD patterns of sugarcane bagasse ashes (SCBA) (a) Effect of temperature, (b) Effect of calcination time

Q: Quartz (SiO_2), A: Albite ($NaAlSi_3O_8$), Mcr: Microcline ($KAlSi_3O_8$)

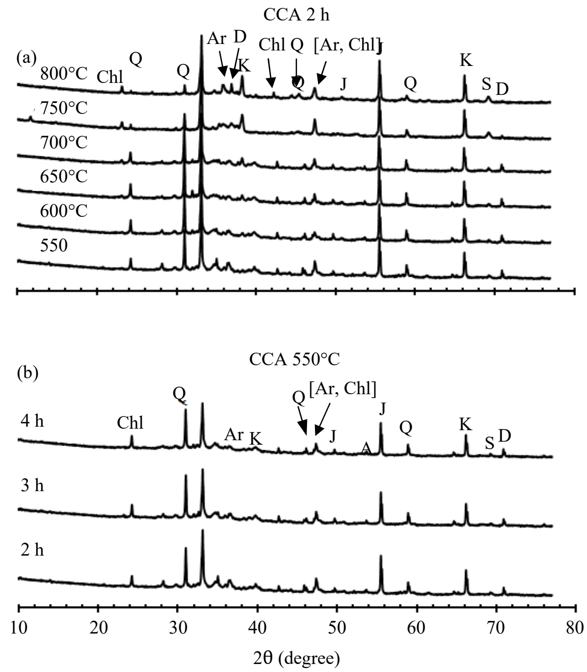

Fig. 4(a-b): XRD patterns of corn cob ashes (a) Effect of temperature and (b) Effect of calcination time

Ar: Arcanite (K_2SO_4), Chl: Cloritoide ($(Fe, Mg, Mn)_2Al_4Si_2O_{10}(OH)_4$), Q: Quartz ($SiO_2$), K: Kalicinite ($KHCO_3$), J: Jasmundite ($Ca_{11}(SiO_4)_4SO_2$), D: Dolomite ($CaMg(CO_3)_2$))

Compressive strength of mortars: Figure 5a and b present results of the compressive strength of mortars with various ash contents. To facilitate comparison, the value of the compressive strength of the reference mortar (mortar with 100% cement) and the minimum value of the compressive strength were introduced in Fig. 5a and b. With RHA and CCA mixtures with 20 and 25% of ash content were not performed do to difficulties in work ability of the mixtures.

Results indicate that after 2 days of curing all samples performed above the threshold value of compressive strength, 10 MPa (Fig. 5a).

At 28 days of curing time only mortars with 5, 10 and 15% of RHA showed values of compressive strength higher than 42.5 MPa, the threshold value indicated by the norm NM NP EN 197-1:2005 (Fig. 5b).

Flexural strength of mortars: Although it is not a decision-making value for assessing the feasibility of using a given material, good performance in this parameter may contribute to the acceptance of the material. These results are graphically presented in Fig. 6a and b.

The results of the flexural strength after 2 days curing age show, only for the CCA and only for the 5% additive, flexural strength values higher than the conventional mortar. From

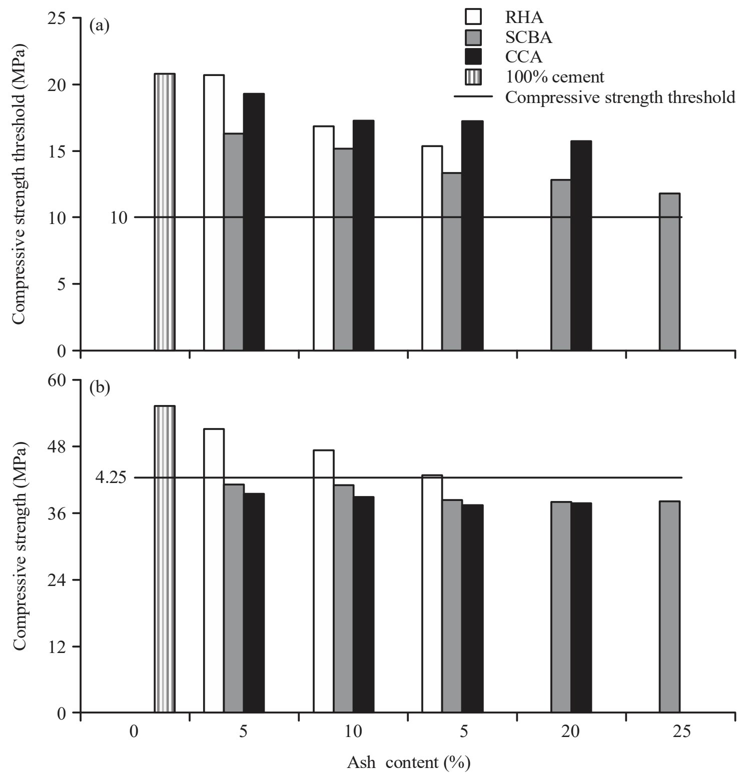

Fig. 5(a-b): Compressive strength of cement mortars with different ash contents at (a) 2 days and (b) 28 days curing age
RHA: Rice husk ash, CCA: Corn cob ash, SCBA: Sugarcane bagasse ash

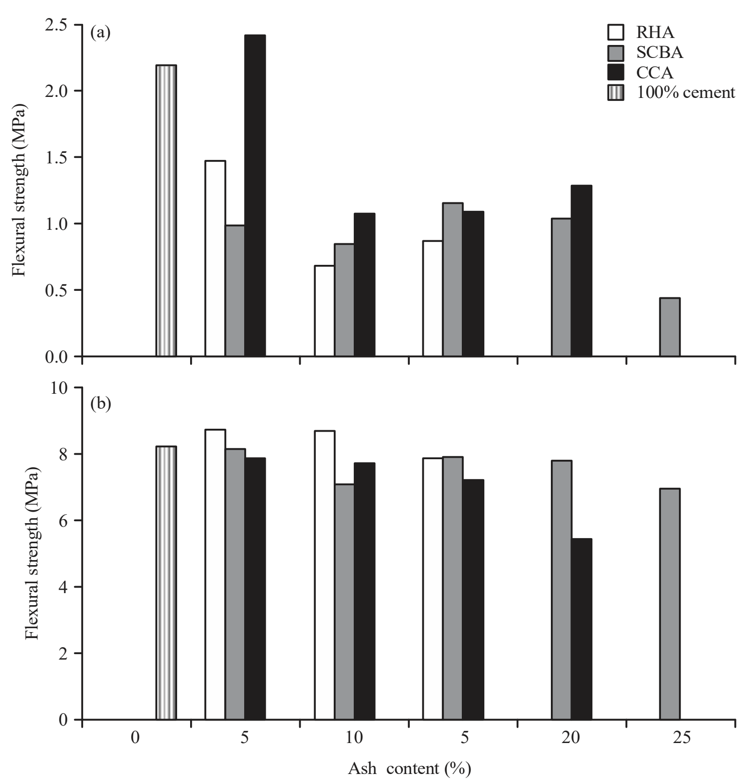

Fig. 6(a-b): Flexural strength of cement mortars with different ash contents at (a) 2 days and (b) 28 days of curing age
RHA: Rice ask ash, CCA: Corn cob ash, SCBA: Sugarcane bagasse ash

2-7 days curing age, there is a significant increase in the flexural strength of RHA and SCBA, with all the 3 types of ashes showing flexural strength values higher than those of conventional mortar at 5% additive, with RHA exhibiting the highest values. The RHA and CCA show higher values for 5 and 10% additive, while SCBA show values higher than reference mortar only for 5% additive.

At 28 days the RHA showed values higher than the reference mortar at 5 and 10%, SCBA showed a value comparable to that of conventional mortar at 5%, while that of CCA showed a lower value in the entire additive contents tested. At 15% the RHA and SCBA show a value that amounts to 96% of the value of the conventional mortar.

The results show a remarkable development of the pozzolanic activity of CCA in early curing ages, as evidenced by the results of the flexural strength (Fig. 6a, b), but the development of the pozzolanic activity of these ashes is then supplanted by the ashes of RHA and SCBA, in later stages of curing (Fig. 6b).

DISCUSSION

The evaluation of the content of amorphous material of ashes prepared from the 3 samples shows for RHA a content of amorphous material of 99%, for temperatures up to 700°C, results consistent with those obtained by Bahurudeen and Santhanam[19] and Bié *et al.*[5]. Ashes from sugarcane bagasse and corncob show lower values, in the order of 40-45 and 55-60%, respectively. Although the amorphous material content is used as an indication of the pozzolanicity of the material, its use must be done with some care, because the fraction of the only acidic oxides (SiO_2 and Al_2O_3) are responsible for the pozzolanic reaction with $Ca(OH)_2$. The amorphous material in these ashes includes other components, which do not necessarily contribute for the pozzolanic activity.

Comparison of the X-ray diffraction diagrams basically shows the following results:

- The RHA does not show major changes with the heat treatment. They have few crystalline phases (quartz and cristobalite) and high levels of amorphous material (<1% of crystalline material)
- The SCBA also had little variation of the composition, with 3 crystalline phases (albite, quartz and microcline) and amorphous material content in the order of 40%
- The CCA show a significant increase in the content of crystalline phases with temperature and a more complex composition (greater number of crystalline phases), with a content of amorphous between 50 and 70%

Table 2: Chemical composition of rice husk, sugarcane bagasse and corn cob

Component	Rice husk (%)	Sugarcane bagasse (%)	Corn cob (%)
Cellulose	50.00	35.20	40-44
Hemicellulose	31.17	24.50	31-33
Lignin	25-30	22.20	16-18
Silica	15-20	-	-
Ashes	-	20.90	2.88

Source: Rezende *et al.*[21], Pointner *et al.*[22], Ummah *et al.*[23]

According to Ribeiro and Moreli[2], Benassi *et al.*[11] and Safiuddin *et al.*[20], RHA should give ashes free from crystalline material. The presence of crystalline material may be caused by the way these wastes were processed prior to their burning. According to Ribeiro and Moreli[2], adequate washing of the residue of bagasse, prior to its burning, should lead to the production of ashes free from crystallines phases.

A look at the approximate chemical composition of rice husk, sugarcane bagasse and corn cob (Table 2) shows.

- Presence of silica in rice husks only
- Significant ash content in sugarcane and corn cob
- Considerable contents of lignin, cellulose and hemicellulose in all the 3 samples

Results in Table 2 show that the amorphous material in studied samples is not necessarily attributed to the presence of silica, but to other components, for instance lignin which is present in form of an amorphous three-dimensional macromolecule, which can form amorphous phases but do not show the pozzolanic reaction with $Ca(OH)_2$. Use of more objective methods is required; those better quantify and separate the chemical and physical components of the pozzolanic activity of ashes.

The RHA shows the best performance, with values of compressive strength comparable to that of conventional mortars, at 5% of additive and values of compressive strength equal to or above the minimum value prescribed in the standards, up to 15% of the additive and for the cure time of 28 days.

The pozzolanic activity index, assessed from compressive strength results, show a different behaviour for the three samples. The RHA show a slow development of pozzolanic activity at early curing ages (2 and 7 days) but increased at 28 days, results in agreement with Antiohos *et al.*[1] and Khan *et al.*[24]. The SCBA show an increase of pozzolanic activity with increasing curing ages in the interval 15-25%, results which are in agreement with Pereira *et al.*[25]. Corn cob presents a significant early development at curing age 2 days but decreasing at 7 and 28 days curing ages.

CONCLUSION

Ashes from rice husk, sugarcane bagasse and corn cob show promising results for partial replacement of cement in mortars. Sugarcane bagasse and rice husk ashes showed the most promising results with additions up to 15% of ashes replacing cement. Corn cob ashes showed a good earlier development of the properties at the curing age of 2 and 7 days and not showing a significant further improvement after this. The poor performance of corn cob ashes can be explained by the fact of the optimization parameters for ashes production was only concerned to the temperature. Another reason could be the lower content of silica in these ashes.

SIGNIFICANCE STATEMENT

This study discovers the use of corn cob residue in the production of ashes with potential to be used as cement additives could help reducing environmental burden of the cement industry, as well lowering construction costs. This study will help the researchers to uncover the mortar properties of corn cub which many researchers were not able to explore.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Fundo Italiano de Ajuda Multisectorial (FIAM) for the financial support and to the Laboratório Engenharia de Moçambique (LEM) for the technical contribution and support.

REFERENCES

1. Antiohos, S.K., V.G. Papadakis and S. Tsimas, 2014. Rice Husk Ash (RHA) effectiveness in cement and concrete as a function of reactive silica and fineness. Cement Concrete Res., 61: 20-27.
2. Ribeiro, D.V. and M.R. Morelli, 2014. Effect of calcination temperature on the pozzolanic activity of Brazilian Sugar Cane Bagasse Ash (SCBA). Mater. Res., 17: 974-981.
3. Cordeiro, G.C., R.D.T. Filho and E.M.R. Fairbairn, 2009. Effect of calcination temperature on the pozzolanic activity of sugar cane bagasse ash. Constr. Build. Mater., 23: 3301-3303.
4. Arum, C., C.M. Ikumapayi and G.O. Aralepo, 2013. Ashes of biogenic wastes-Pozzolanicity, prospects for use and effects on some engineering properties of concrete. Mater. Sci. Applic., 4: 521-527.
5. Bie, R.S., X.F. Song, Q.Q. Liu, X.Y. Ji and P. Chen, 2015. Studies on effects of burning conditions and Rice Husk Ash (RHA) blending amount on the mechanical behavior of cement. Cement Concrete Comp., 55: 162-168.
6. Jamil, M., A.B.M.A. Kaish, S.N. Raman and M.F.M. Zain, 2013. Pozzolanic contribution of rice husk ash in cementitious system. Constr. Build. Mater., 47: 588-593.
7. Dwivedia, V.N., N.P. Singhb, S.S. Dasa and N.B. Singha, 2006. A new pozzolanic material for cement industry: Bamboo leaf ash. Int. J. Phys. Sci., 1: 106-111.
8. Shatat, M.R., 2016. Hydration behavior and mechanical properties of blended cement containing various amounts of rice husk ash in presence of metakaolin. Arabian J. Chem., 9: S1869-S1874.
9. Moraes, J.C.B., J.L. Akasaki, J.L.P. Melges, J. Monzó and M.V. Borrachero *et al*., 2015. Assessment of Sugar Cane Straw Ash (SCSA) as pozzolanic material in blended Portland cement: Microstructural characterization of pastes and mechanical strength of mortars. Constr. Build. Mater., 94: 670-677.
10. Karim, M., M. Hossain, M. Khan, M. Zain, M. Jamil and F. Lai, 2014. On the utilization of pozzolanic wastes as an alternative resource of cement. Materials, 7: 7809-7827.
11. Benassi, L., A. Bosio, R. Dalipi, L. Borgese and N. Rodella *et al*., 2015. Comparison between rice husk ash grown in different regions for stabilizing fly ash from a solid waste incinerator. J. Environ. Manage., 159: 128-134.
12. Chindaprasirt, P., P. Kanchanda, A. Sathonsaowaphak and H.T. Cao, 2007. Sulfate resistance of blended cements containing fly ash and rice husk ash. Constr. Build. Mater., 21: 1356-1361.
13. Macie, C., A. Manhique, R. Manjate and C. Madivate, 2016. Effect of the mineralogical composition of limestone on the properties of mortars. J. Mater. Sci. Chem. Eng., 4: 16-24.
14. ASTM., 1977. Concrete and mineral aggregates-part 14. ASTM 91977, American Society for Testing Materials, Philadelphia, USA.
15. NMNP., 2000. Métodos de ensaios de cimentos. Parte 1: Determinação da resistência mecânica. NM NP EN 197-1, (In Portuguese).
16. NBR., 1987. Argamassa e concreto endurecido-Determinação da absorção de água por imersão-Índice de vazios e massa específica. NBR 9778, (In Portuguese).
17. LNEC., 1979. Cimentos-determinação da resistência mecânica (Documentação normativa). Laboratório Nacional de Engenharia Civil, Lisboa, (In Portuguese).
18. NPEN., 2006. Métodos de ensaio de cimentos. Parte 1: Determinação das resistências mecânicas. NP EN 196-1, (In Portuguese).
19. Bahurudeen, A. and M. Santhanam, 2015. Influence of different processing methods on the pozzolanic performance of sugarcane bagasse ash. Cement Concrete Comp., 56: 32-45.

20. Safiuddin, M., J.S. West and K.A. Soudki, 2012. Properties of freshly mixed self-consolidating concretes incorporating rice husk ash as a supplementary cementing material. Constr. Build. Mater., 30: 833-842.
21. Rezende, C.A., M.A. de Lima, P. Maziero, E.R. deAzevedo, W. Garcia and I. Polikarpov, 2011. Chemical and morphological characterization of sugarcane bagasse submitted to a delignification process for enhanced enzymatic digestibility. Biotechnol. Biofuels, Vol. 4, No. 1.
22. Pointner, M., P. Kuttner, T. Obrlik, A. Jager and H. Kahr, 2014. Composition of corncobs as a substrate for fermentation of biofuels. Agron. Res., 12, 391-396.
23. Ummah, H., D.A. Suriamihardja, M. Selintung and A.W. Wahab, 2015. Analysis of chemical composition of rice husk used as absorber plates sea water into clean water. ARPN J. Eng. Applied Sci., 10, 6046-6050.
24. Khan, R., A. Jabbar, I. Ahmad, W. Khan, A.N. Khan and J. Mirza, 2012. Reduction in environmental problems using rice-husk ash in concrete. Constr. Build. Mater., 30: 360-365.
25. Pereira, A.M., J.C.B. Moraes, M.J.B. Moraes, J.L. Akasaki and M.M. Tashima *et al*., 2018. Valorisation of sugarcane bagasse ash (SCBA) with high quartz content as pozzolanic material in Portland cement mixtures. Mater. Constr., Vol. 68, No. 330 10.3989/mc.2018.00617.