Bottom ash from biomass combustion as aggregate for mortars

R.C.E. Modolo[1], V.M. Ferreira[1], L.A. Tarelho[2], J.A. Labrincha.[3], D.F.R. Silva[2]

[1] Dpt. Civil Engineering/CICECO, University of Aveiro , Aveiro, Portugal, regina.modolo@ua.pt
[2] Dpt. of Environment and Planningt, University of Aveiro , Aveiro, Portugal
[3] Dpt. Ceramics and Glass Engineering/CICECO, University of Aveiro , Aveiro, Portugal

Abstract

The quality of mortars depends firstly on the characteristics of raw materials. Criteria are defined and controlled to guaranty the final product established specifications. Bottom ash from eucalyptus bark combustion in a bubbling fluidized bed was tested in partial substitution of the standard aggregate (granulometric calibrated sand) used in industrial mortars. The relevant characteristics of the new mortars were then evaluated and compared with those of the reference (ash-free formulations). Results revealed that bottom ash has potential to be recycled in these products, but pre-treatment operations are needed to the ash, particularly to remove soluble salts.

Keywords: Biomass, bottom ash, fluidized bed combustion, mortars.

INTRODUCTION

The solid biomass combustion is a proven technology for heat and power generation, and fluidized bed and grate furnace equipments are the most common [1; 2]. Fluidized bed combustion (FBC) has been used due its economic and environmental benefits in burning low-grade coals, biomass and organic wastes, and thereby mixtures of them [1; 3]. These furnaces have been applied since 1960 for combustion of municipal solid wastes and industrial wastes. Since 1980, more than eight hundred commercial circulating fluidised bed boilers have been put into operation in China [4]. In Portugal, the first installation started running 20 years ago, in pulp and paper producing industries and also to burn tires [3]. Nowadays, Portugal has several plants operating with the fluidized bed technology and the future scenario predicts the construction of more units [5]. As a consequence, the amount of ashes generated from the process will increase considerably. The high level of inert material (soil and little stones from the forest) fed together with the biomass in the Portuguese BFBC plants [6] implies a relatively high frequency of bottom bed discharge.

The production of industrial pre-mixed mortars exceeds one million tons in Portugal, consuming then a huge amount of natural pre-treated raw materials (e.g. quarried sand) as aggregates. This activity can be looked as a target for the incorporation of ashes, as currently happens with the fly ashes from the coal combustion in concrete [7].

In this work, the coarse sand fraction used in mortars formulations was (partially and completely) substituted by the bottom ash produced during fluidized (bubbling) bed combustion of biomass. The ash was used in two conditions: (i) as collected and just sieved to obtain a compatible grain size distribution; (ii) and pre-washed (to diminish the amount of chlorides) and then sieved. The leaching of chlorides from the components of mortar mixes is mandatory, since they cause deleterious effects [8; 9; 10]. The control of grain size distribution of the aggregates is crucial to adjust the fresh (e.g. workability) and hardened (e.g. mechanical strength) properties of the mortars.

METHODOLOGY

Material

The ordinary Portland cement used was CEM I 42.5 R, while the bottom-ashes were collected in an industrial fluidized (bubbling) bed combustor using biomassa as fuel in a paper-pulp producer (BA – sieved and used as collected) or BAT pre-treated –The industrial leaching was performed in continuous and under typical conditions used in an industry that makes treatment of natural sand for the construction industry. The leaching procedure includes a continuous shower like process using a L/S (liquid to solid) ratio equal to 2, and a processing capacity of 10 ton/h; the process includes treatment of the leaching solution by sedimentation in order to reuse the liquid solution on the leaching process.The chemical composition of ashes was analyzed for some chemical elements using X-Ray Fluorescence Spectroscopy –XRF (using a Panalytical Axios spectrometer) and the results are expressed in terms of metal oxides, while the crystalline phases were detected by X-ray diffraction – DRX (equipment RIGAKU-Geiger flex diffractometer). Results are presented in Table 1. The grain size distribution was determined by sieving according to NP EN 933:1/2000. The fine grain sand fraction (S1) has particles between 63 and to 250 µm, while the coarse fraction (S2) is constituted by larger particles, as shown in Figure 1; in the figure it is also presented the grain size distribution of BA and BAT. Finally, the Limestone Filler (LSF) has particles between 0.41 to 19.50 µm, as determined by laser interference (Coulter LS230 – measurement interval of 0.04; 2000mm).

Table 1. Raw materials chemical and mineralogical analysis.

Parameters	Raw material					
	BA	BAT	S1	S2	LSF	CEM 42,5 I
SiO_2 (%)	72,17	85,00	99,43	97,53	0,60	20,16
CaO (%)	17,16	8,60	0,07	0,28	56,37	59,91
Na_2O (%)	0,88	1,00	0,04	0,07	0,05	0,17
Cl (%)	0,12	0,04	0,00	0,00	0,04	0,02
L.O.I (%)	1,97	0,60	0,09	0,24	41,26	2,26
Mineralogy (by DRX)	Quartz, Calcite, Larnite and Microcline	Quartz, Calcite and Larnite	Quartz and Microcline	Quartz and Microcline	Calcite	NQ*

*Not Quantified

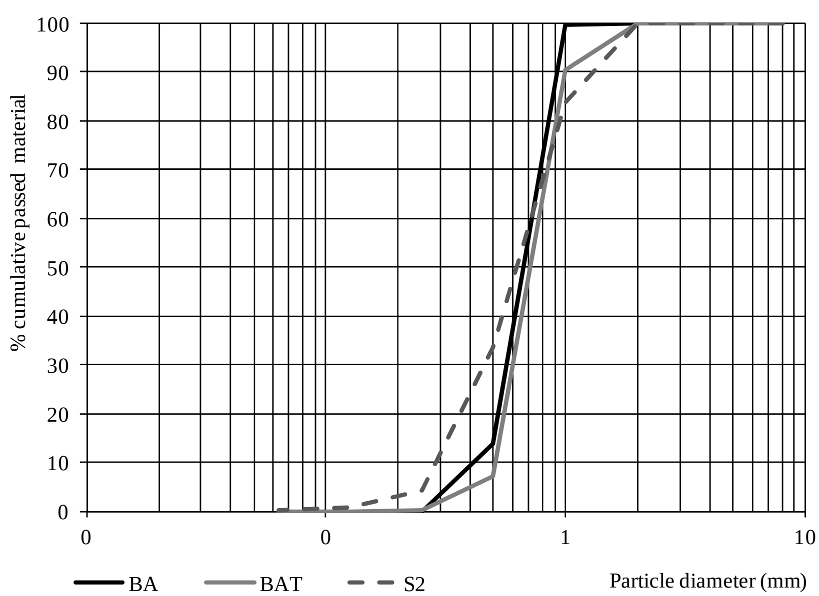

Figure 1. Grain size distribution of BA, BAT and S2, determined according to EN 933:1/2000.

Mortars formulations and characterization

Specific rendering mortars with different amounts of BA and BAT (0, 25, 50 and 100%) were produced and tested. BA and BAT were introduced replacing in the formulations the coarser sand (S2). Portland

cement (type I 42.5R) was used as binder and the binder to aggregates mass ratio was kept at 1:6. The amount of water for mixing was fixed (16.5% of total mass).
The particle size distribution of powdered and dried mortars (dust) was controlled according to EN 933-1:2000 standard [11]. The preparation of samples included: (i) water weighting and addition to the solids; (ii) mixing for 30s at a low rotation speed (60 rpm); (iii) stopping for 1 min; (iv) mixing again for 1 min at the same low speed and, (v) keep the mixture in stand by for 10 minutes before testing. Fresh state properties were also assessed. Workability was evaluated by the spread diameter on the flow table (according to EN 1015-3:1999) [12] and setting time was measured according to EN 196-3:2005 standard [13] (Vicamatic - Automatic Recording Vicat Apparatus). Regarding the hardened state mortar properties, specimens with 40×40×160 mm were produced and tested after 7 and 28 days of curing, according to EN 1015-11:1999 [14]. Compressive and flexural strength were evaluated with these samples. Table 2 gives the basic requirements for a suitable rendering mortar.

Table 2. Rendering mortars specific requirements.

State	Characteristics		Minimum	Maximum
Dust	Grain size distribution (%)	1.600 mm	0.0	0.0
		1.250 mm	0.0	1.0
		0.630 mm	9.0	17.00
		0.315 mm	16.0	43.0
		0.160 mm	12.0	35.0
		0.080 mm	2.0	15.0
		< 0.080 mm	23.0	33.0
Fresh	Water/Cement (%)		1.1	1.2
	Density (g/cm3)		1.65	1.80
	Flow table (mm)		150	180
	Setting time (min)	Beggining	300	450
		End	400	550
Hardened at 28 days	Flexural Strength (MPa)		1.5	--
	Compressive Strength (MPa)		3.5	--

RESULTS AND DISCUSSION

The decrease of Cl^- content in BAT ashes (see Table 1), when compared to BA, reveals the efficiency of the washing process. In particular, the reduction of chlorides (about 60%) is very important for this application. Their presence usually has an effect of anticipation of setting time, but deleterious effects are mostly observed on hardened bodies.
Table **3** gives the particle size distributions of the prepared formulations, obviously related with the size distribution of each single component (Figure 1).
S2 aggregate present a broader size distribution: below 0.1 mm and up to 1.25 mm, with 50 vol. % of particles comprised in the 0.5 mm upper fraction. By contrast, BA has a narrower distribution (~90 vol. % between the 1mm and 0,5 mm fractions). The washing process seems to destroy some agglomerates of BA, and then BAT contains more particles below 0.5 mm. Its distribution approaches that of S2 size distribution. The control of particle size is crucial to define the compactness of the mixtures, then affecting physical and hydration behaviour of cementitious mortars.

In

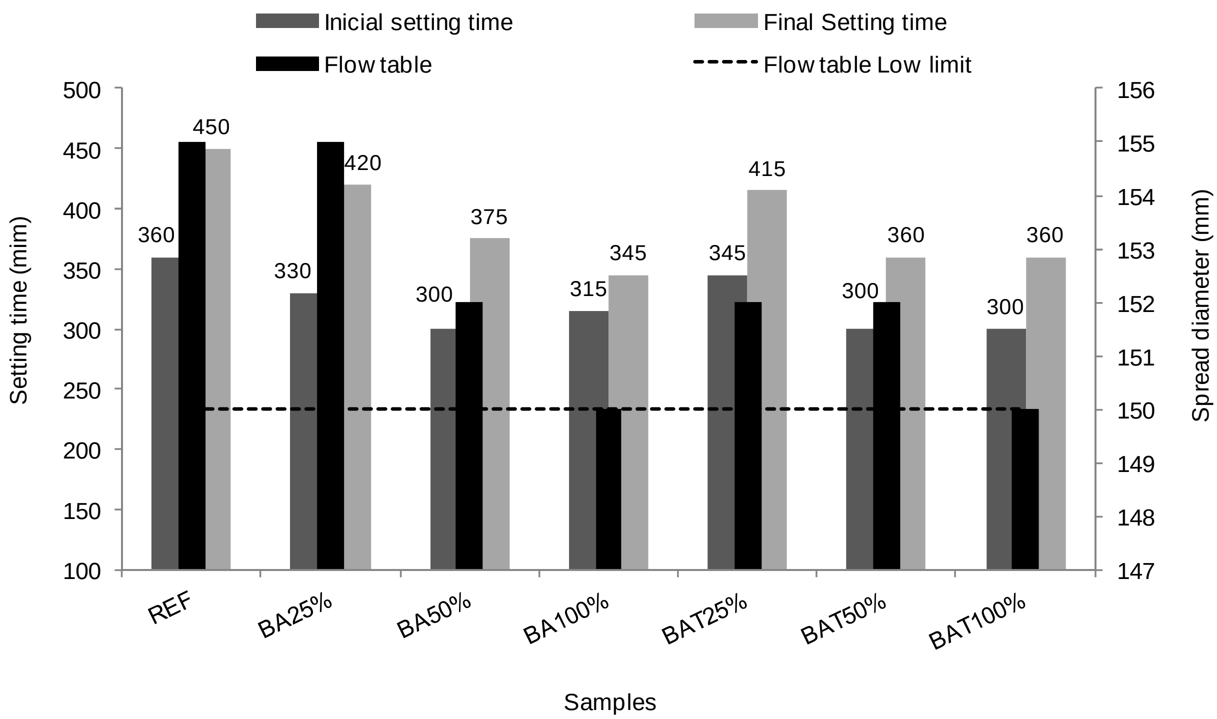

Figure 2 it is shown the setting time and values of spread diameter on the flow table for the mixtures. According to the requirements (see Table 2), the minimum limit for the initial setting time is 300 min. The use of BA and BAT tends to diminish setting time, as a possible consequence of the presence of chlorides in the ash. This effect is more pronounced with the use of BA since it has more chlorides.

Table 3. Rendering mortars mixtures grain size distribution.

mesh	% retained material								
(mm)	REF	BA25%	BA50%	BA100%	BAT25%	BAT50%	BAT100%	Low limit	High limit
1,6	0	0	0	0	0	0	0	*0*	*0*
1,25	1	0	0	0	0	1	0	*0*	*1*
0,63	10	9	13	15	11	13	15	*9*	*17*
0,315	40	37	35	33	35	33	34	*16*	*43*
0,16	16	19	17	17	20	19	17	*12*	*35*
0,08	9	9	9	9	9	9	9	*2*	*15*
Bottom	25	25	25	26	25	25	24	*23*	*33*

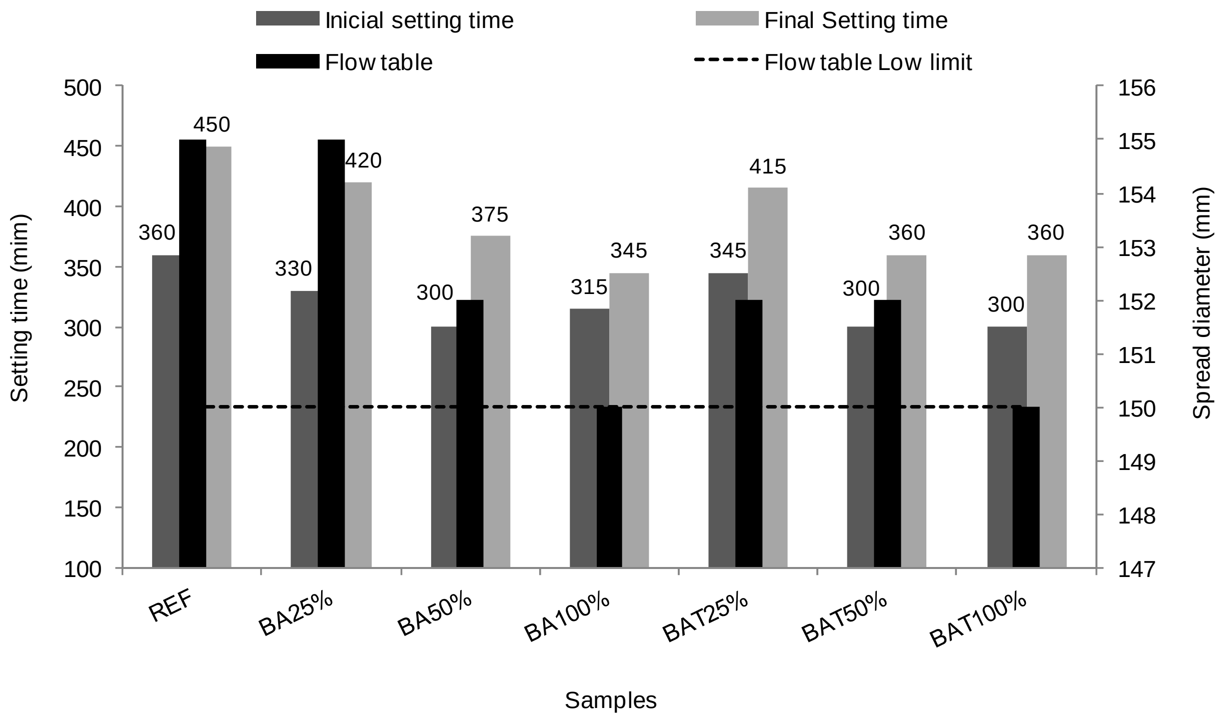

Figure 2. Setting time and spread diameter (flow table) of prepared mortars.

The workability of the mortars also tend to diminish when the ash is used (the spread diameter is lower) and mortars in which the S2 aggregate was fully replaced by BA or BAT, workability reached the lower limit. Specifications recommend spread diameters between 150 and 180 mm. The lack of fluidity in ash-containing samples might also result from a poor particles arrangement and a need for kneading water content adjustment.

Figure 3 gives the mechanical strength of mortars cured for 7 and 28 days. All samples show values well above the required limits: 1.5 and 3.5 MPa, respectively on flexion and compression strength. Differences between distinct compositions are not relevant and the replacement of S2 by ashes did not degrade the mechanical behavior.

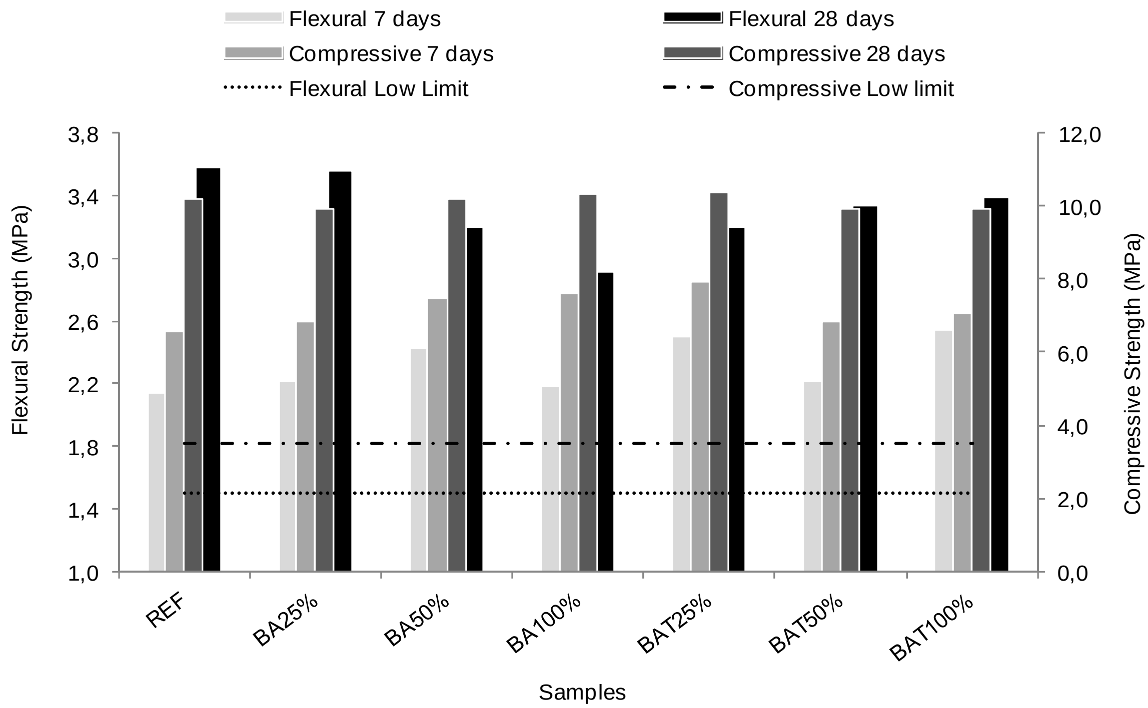

Figure 3. Rendering mortars mechanical strength results at 7 and 28 days.

CONCLUSIONS

Apart the concern about the presence of chlorides in the ashes, this study suggests that the use of the waste in the formulation of rendering mortars, as a substitute of sand, is promising. Workability and mechanical strength in mortar containing ashes could be controlled and kept on the range for required values for conventional mortars. However, further tests should be conducted to prove the sustainability of the proposed solution. Long-term or durability tests are also recommended.

ACKNOWLEDGMENTS

The authors want to acknowledge the financial support by Fundação para a Ciência e a Tecnologia (FCT), Portugal, through the project with reference PTDC/AAC-AMB/098112/2008 (Bias-to-soil - Biomass ash: Characteristics in relation to its origin, treatment and application to soil) and SFRH/BD/75182/2010.

REFERENCES

[1] Van Loo, S., J. Koppejan, *Handbook of Biomass Combustion and Co-firing*, Twente University Press, The Netherlands, 2003.

[2] Yin C., Rosendahl LA., Kaer S.K., Grate-firing of biomass fort heat and power production, Progress in Energy and Combustion Science 34 (2008) 725–754.

[3] Tarelho LAC., (2001). Controlo de emissões gasosas poluentes resultantes da combustão de carvão em leito fluidizado, Dissertação de Doutoramento, Departamento de Ambiente e Ordenamento, Universidade de Aveiro, Portugal.

[4] Van Loo, S., Koppejan, J. *The Handbook of Biomass Combustion and Co-firing, Earthscan*, London, 2008.

[5] Coelho AMSL. Management of ashes produced in thermoelectric and cogeneration plants operated with biomass. MSc Thesis in Environmental Engineering (in Portuguese) University of Aveiro, Aveiro, Portugal, 2010.

[6] Tarelho LAC, Coelho AMSL, Teixeira ER, Rajamma R, Ferreira VM. Characteristics of ashes from two Portuguese biomass co-generation plants. Proceedings of the 19th European Biomass Conference & Exhibition, 6-10 June 2011, Berlin, Germany, pg 1041-1053.
[7] Silva L, Modolo R, Ferreira VM, Labrincha JA, Sequeira P. Utilização e Valorização de Resíduos de Areias de Leito Fluidizado e de Lamas de Corte de Pedra em Argamassas. Exemplos de Aplicação. 1º Congresso Nacional de Argamassas de Construção, pesquisa de 14/10/2009. ,www.apfac.pt
[8] Goudie, A.; Viles, H. Salt Weathering Hazard. Chichester, John Wiley & Sons, 1997.
[9] Harris, S.Y. Building pathology. New York, John Wiley & Sons, 2001.
[10] Scherer, G.W. Internal stress and cracking in stone and masonry. In Measuring, Monitoring and Modeling Concrete Properties, Proc. 16th European Conf. Fracture. Konsta-Gdoutos MS (ed.). Springer: Berlin, 2006, 669–673.
[11] NP EN 933-1: 2000. Tests for geometrical properties of aggregates, Part 1: Determination of particle size distribution, Sieving method.
[12] EN 1015-3:2007. Methods of test for mortar for masonry: determination of consistence of fresh mortar (by flow table).
[13] NP EN 196-3: 2005. Methods of testing cement. Determination of setting times and soundness.
[14] EN 1015-11:1999. Methods of test for mortar for masonry – Part 11: Determination of flexural and compressive strength of hardened mortar