INFLUENCE OF LIGHT AND NOT-COMBUSTED PARTICLES ON THE MECHANICAL AND DURABILITY MORTARS MADE WITH BIOMASS BOTTOM ASH

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Abtract

In the last years, power generation of energy from biomass combustion is increasing substantially. Biomass for this type of power generation plants consists essentially of olive residues and other residues from the agricultural industry. However, the combustion of this type of waste produced ashes which must be transported to landfill for deposition.

In Andalusia (Spain) there are a large number of power plants from biomass due to the significance of the agricultural industry of the region, which is generator a lot of ash from biomass.

According to the efficiency of combustion in the boiler, not combusted particles and light particles can be obtained in the bottom ash biomass. For this reason, the BBA may contain high amounts of the organic matter content, reducing their physical and chemical properties and considerably reducing the possibilities of reuse.

Therefore, this paper aims to study the mechanical and durability properties of mortars containing BBA, applying different methods of processing. Nine mortars were made by applying a 30% replacement of cement by BBA and performing several processing methods (grinding, removal of light particles and calcination). To determine their influence, compressive and flexural tests on several days to cure, density and porosity test, and shrinkage test were applied.

The results have made significant improvements in the mechanical and durability properties in mortars with processes of extraction of light particles, calcination and grinding, thus allowing optimize the use of this type of waste in the manufacture of mortars and concretes with low technical requirements.

Keywords: recycled aggregates, organic matter content, mortar, durability, biomass

1. Introduction

The use of renewable energy as substitutes for conventional energy sources for electricity production, is growing in recent years due to the increase of the environmental awareness. Solar and wind energy are the two most worldwide common types of renewable energy. However, other types of energy are applied in order to reuse the waste generated by other industries. In Andalusia (Spain) there is an important industry focused on the agrifood sector. Specifically, industrial production derived from olive oil generates residues as olive prunings and other elements, which are used in power generation from combustion. This waste is known as biomass.

Power generation from biomass produces two types of waste: Biomass Fly Ash (BFA), which are used in the sector of food industry for its fertilizing power [1] and Biomass Bottom Ash (BBA), which are not well-known [1]. However, some investigations were conducted to study the mechanical properties of BBA and its possible use in the construction sector. Hinojosa al (2014) [2] studied the chemical properties of BBA. Cabrera et al (2014) [3] studied the physical properties of BBA and its possible use on roads. Beltran et al (2014) [4] conducted an investigation related to the application of BBA for non-structural concrete made with recycled aggregates. On the other hand, Cuenca et al (2013) [1] applied BFA in self-compacting concrete.

Regarding the application of waste mortars, other investigations were made using fine recycled concrete aggregates, mixed aggregates or fly ash from the steel industry as substitutes of natural sand and cement

2. Materials and methods

2.1 Materials

Cement

Ordinary Portland Cement type CEM-I 52.5 with rapid hardening and a characteristic strength of 52.5 MPa were used in this work, according to ASTM C150. This cement is pure clinker grey cement without additions which is resistant to chemical attack by sulphates. Its properties are summarized in Table 1.

Table 1. Properties of cement

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Granul. 45µm	Granul. 32µm	Blaine E. S.	Loss of ignition
%	%	%	%	%	%	%	%	%	%	cm^2/g	%
20.18	4.14	4.51	63.75	0.91	3.24	0.75	0.31	6.2	16.1	3701	1.44

Recycled and natural aggregates

A standard natural sand (SNS) was applied as natural aggregate for the manufacture of mortars.

The characteristics of this type of sand are in accordance with the specifications required by the standard DIN 196-1 and its properties are summarized in Table 2. This type of sand presents a maximum value of 2mm in grain size distribution (Fig. 1).

Biomass Bottom Ashes (BBA) from the thermal plant located in Puente Genil, Córdoba (Spain) was used as a substitute for CEM. They are obtained from the combustion of several agricultural wastes as olive pruning and other plant compounds, called biomass. First, Biomass is introduced into a chamber and then, is combusted at a temperature of 405 °C to generate steam that flows through a closed-loop system. BBA is the non-combusted waste generated. Its properties are exposed in Table 2.

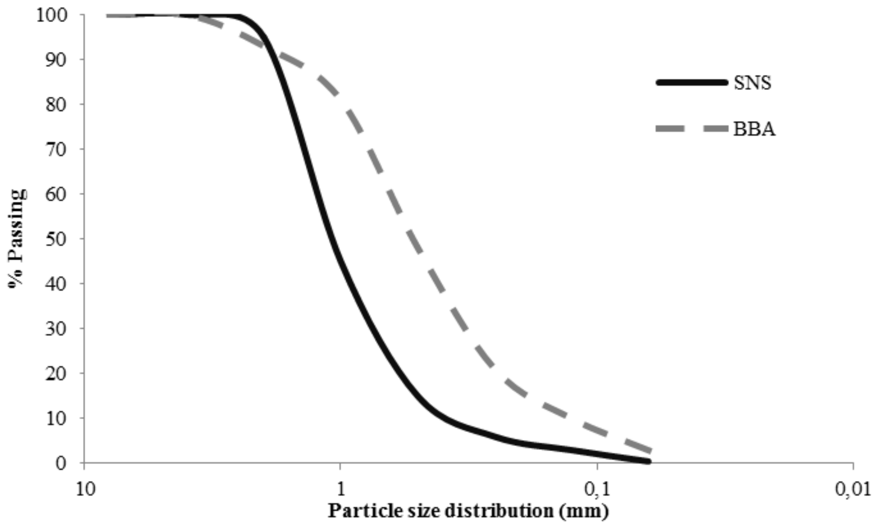


Figure 1 Particle size distribution

Table 2. Properties of recycled and natural aggregates

		BBA	SNS	EHE-08
Size (mm)	EN 933-1	0-4	0-2	-
Density (kg/dm^3)	EN-1097-6	2.02	2.6	-
Absorption (%)		18.1	1.15	5%
Los Angeles (%)	EN-1097-2	-	-	40
Friability ratio (%)	EN-83-115	34	10	40
Sulphur content (%)	EN-1744-1 EN-1744-1	0.31	<0.01	1
Soluble sulphate (%SO_3)	EN-1744-1	0.45	<0.01	0.8
Chlorides (%)	EN-1744-1	0.21	<0.01	0.05
Organic matter content (%)	EN 1744-1	4.57	<0.01	1

As it is showed in Table 2, BBA presented a low density compared to SNS (2.02 kg/dm3). Respect to water absorption capacity, BBA obtained a high value (18.1%). The value of this property is out of range allowed by the Spanish Concrete Instruction (EHE-08). However, the friability values was higher in BBA respect to SNS. These values were below the limit set by the EHE-08. Regarding chemical properties, it is highlighted the high organic content (4.57%) and chloride content (0.21%). The limits set by the EHE-08 were lower than the values obtained.

However, the particle size distribution of BBA was continuous and similar to natural sand (Figure 1), allowing an appropriate particle size distribution.

2.2 Mix proportions and manufacture of mortars

Two groups of mortars were manufactured according to the particle size distribution of BBA. The first group of BBA presented a similar granulometry to natural sand. The second group was manufactured applying crushed BBA (C), which presented a similar granulometry to filler. Each group consisted of 4 types of mortars according to the process system of BBA: unprocessed mortars (BBA), mortars with BBA without light particles (NL), combusted mortars (CO) and combusted mortars without light particles (CO- NL). To perform a comparison of results, a Control mixture of mortar was added (CONTROL). In Table 3 the nomenclature of mixtures is described.

Table 3. Nomenclature

MORTAR	DESCRIPTION
CONTROL	Reference mortar
M/BBA-C	Mortar with crushed BBA
M/BBA-C-NL	Mortar with crushed BBA (without light particles)
M/BBA-C-CO	Mortar with crushed and combusted BBA
M/BBA-C-CO-NL	Mortar with crushed and combusted BBA (without light particles)
M/BBA	Mortar with BBA
M/BBA-NL	Mortar with BBA (without light particles)
M/BBA-CO	Mortar with combusted BBA
M/BBA-CO-NL	Mortar with combusted BBA (without light particles)

The replacement rate of CEM by BBA was 30% by weight in all cases. Moreover, saturation water was added to compensate for the high absorption of BBA (18%). In Table 4 mixing ratios by weight are exposed.

Table 4. Mortar mix proportions

	CONTROL	M/BBA-C	M/BBA-C-NL	M/BBA-C-CO	M/BBA-C-CO-NL	M/BBA	M/BBA-NL	M/BBA-CO	M/BBA-CO-NL
Cement	450	315	315	315	315	315	315	315	315
SNS	1350	1350	1350	1350	1350	1350	1350	1350	1350
BBA	135	135	135	135	135	135	135	135	135
Water	225	225	225	225	225	225	225	225	225
Additive	0	3.1	4.2	4.5	4	4.6	5.3	5.6	5.9

Manufacturing process of mortars was conducted following the guidelines set by the UNE-EN 196-1. The materials were introduced into a mixer with low rotation speed (280 rev per min). First, mixing and saturation water and superplasticizer were gradually added to the mixer followed by the cement. Second, SNS and BBA were added. The mixing process lasted 3 minutes.

The slump was measured for all batches using a shaking table, as described in the UNE-EN 1015-3. Then the moulds were filled and vibrated into two layers using a vibrating table to homogenize the fresh mortar specimens. Then the moulds were taken to a curing chamber with a humidity of 50% and a temperature of 20°C for 24 hours. After 24 hours, the moulds were immersed in a water tank.

3. Experimental methods and results

Several properties of each mortar manufactured were measured for this work.

3.1 Slump

Consistency of fresh mortar was obtained after the manufacture of each mortar. To measure the consistency, a shaking table was used according to the UNE-EN 1015-3. Similar consistency to the Control mortar mixture was obtained from all, because a super-plasticizer additive was added. For this, preliminary tests were conducted using various amounts of additive in each mortar.

In Table 5 are presented the results for this test.

Table 5. Test results

	Day	CONTROL	M/BBA	M/BBA-NL	M/BBA-CO	M/BBA-NL-CO	M/BBA-C	M/BBA-C-NL	M/BBA-C-CO	M/BBA-C-CO-NL
Slump (mm)	**0**	220	218	219	220	221	221	218	219	221
Compressive Strength (Mpa)	28	60.1	20.6	23.8	27.6	30.4	32.6	36.9	40.1	47.2
Flexural Strength (Mpa)	28	10.3	6.4	6.5	6.7	7.3	7	7.4	7.8	8.8
Density (Kg/dm^3)	28	2.32	2.14	2.15	2.17	2.18	2.15	2.15	2.18	2.19
Absorption (%)	28	3.4	6.4	6.3	6.1	6	5.9	5.6	5.5	5.3

3.2 Density and porosity

The density of mortar and porosity were determined at 28 days of age by applying prismatic specimens of dimensions 40 x 40 x 160 mm according to UNE-EN 1015-10. The results obtained are showed in Table 5.

Because of the reduced density of BBA, lower densities were obtained for all additions of BBA mortars respect to the Control mixture. Comparing the two sets of mortars, similar density values were obtained according to the BBA crushing (Figure 2). Therefore, the density of mortars was not increased with crushing BBA. However, the density was increased applying the extraction of light particles and the elimination of organic matter for both series, as expected. However, density increases were not significant.

In contrast, the porosity of mortar with incorporations of BBA increased respecting the control Mixture. This is due to the high porosity of the particles of BBA. On the other hand, porosity was lower in mortar with crushed BBA.

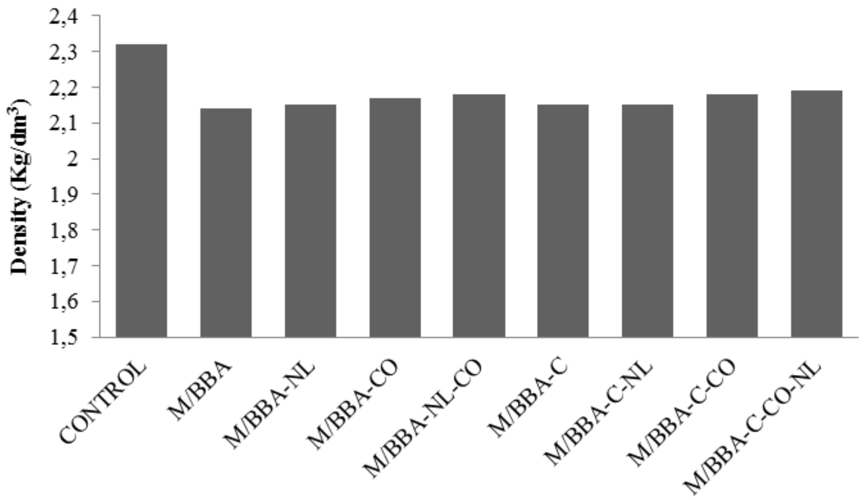


Figure 2 Density of mortars

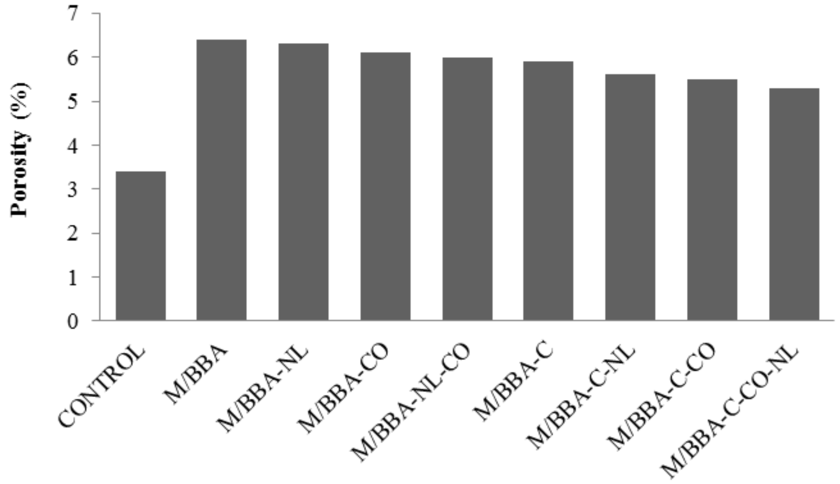


Figure 3 Porosity of mortars.

Moreover, the porosity was reduced in mortars where BBA processed was applied (extraction of light particles and combustion), because the high content of light particles and organic matter is the cause of the porosity and the low density in mortars made with BBA.

As with compressive and flexural strengths, as discussed later, density and porosity of mortars improved with BBA processed. This indicates that it is necessary to perform this type of processing in order to obtain an adequate BBA for use in mortars.

3.2 Compressive strength

The compressive strength was measured at 1, 7, 28 and 90 days according to UNE-EN 196-1. The results at 28 days are presented in Table 5 and the evolution of compressive strength over time is showed in Figures 4 and 5.

Overall, despite all mortars with incorporation of BBA obtained lower compressive strength respect to CONTROL. Better results were obtained in a mortar with crushed BBA respect to BBA mortars with BBA but without crushing (Figures 4-5).

On the other hand, mortars containing BBA processed improved their mechanical behaviour respect to mixtures where BBA unprocessed were applied.

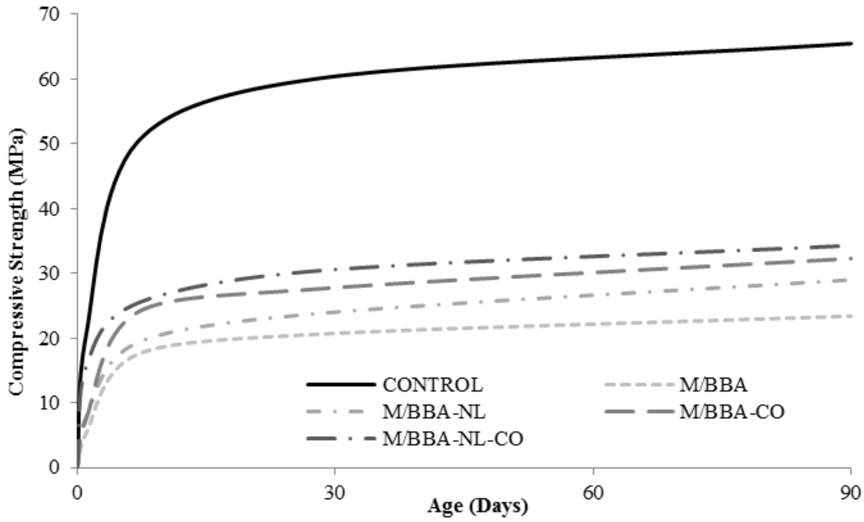


Figure 4 Evolution of compressive strength. Mortars with BBA

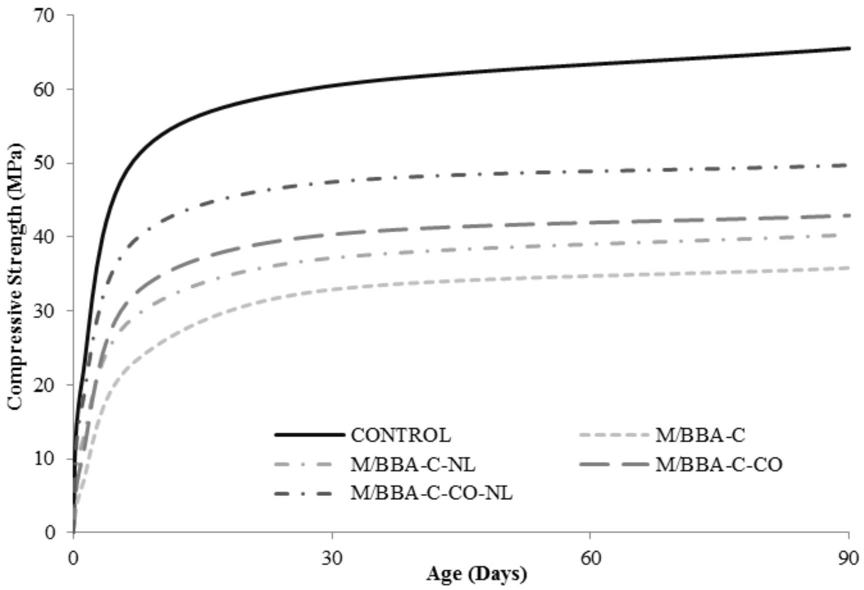


Figure 5 Evolution of flexural strength. Mortars with crushed BBA

The loss of compressive strength for M/BBA was 66%, while the loss of compressive strength was 60, 54, and 49% for M/BBA-NL, M/BBA-CO and M/BBA-NL respectively. For mortars with crushed BBA, the loss of compressive strength was 46-39% for M/ BBA-C and M/BBA-NL-C, and 33-21% for M/BBA-C-CO and M / BBA-C-CO-NL.

This indicates that the extraction of light particles and removal of organic matter from combustion improves significantly compressive strength.

3.3 Flexural strength

According to UNE-EN 196-1, the flexural strength was measured at different ages (1, 7, 28 and 90 days). The values of flexural at 28 days are shown in Table 5, and its evolution for all ages is showed in Figures 6-7.

As happened with the compressive strength, flexural strength presented lower values than the Control Mixture for all mortars containing BBA, being obtained higher values in mortars with crushed BBA. However, the flexural strength losses were less significant than compressive strength losses.

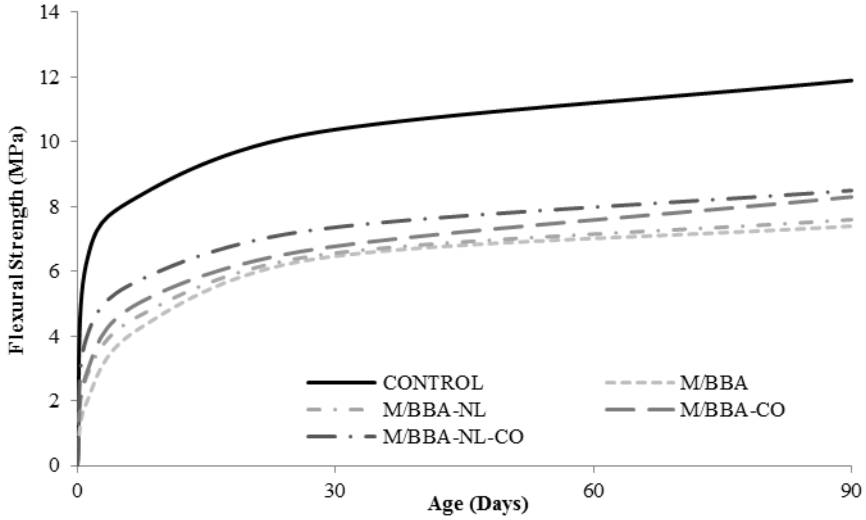


Figure 6 Evolution of flexural strength. Mortars with crushed BBA

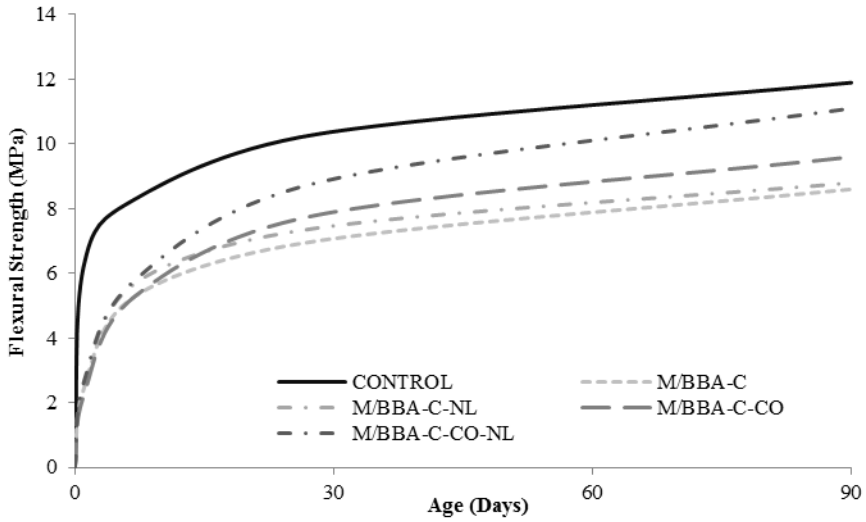


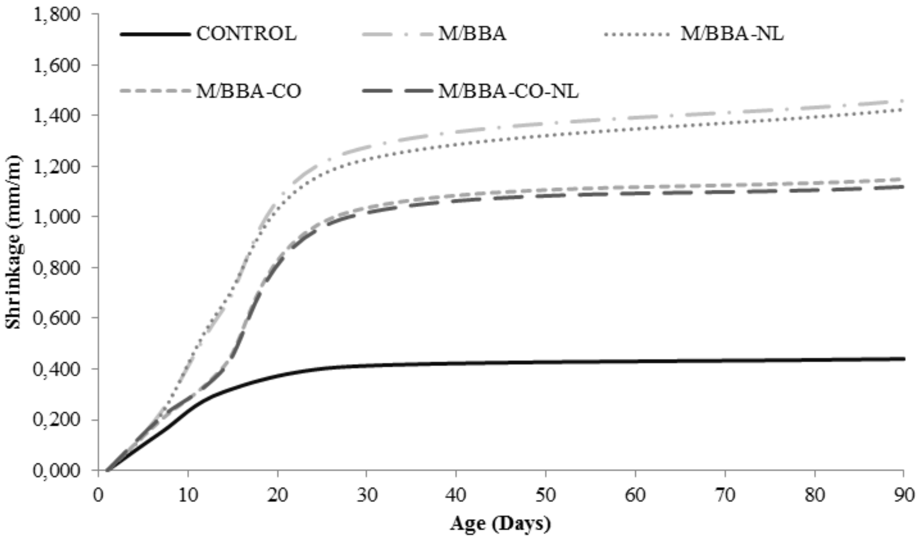
Figure 7 Evolution of flexural strength. Mortars with crushed BBA

As we observed in fig. 6-7, for mortars containing BBA without crushed, strength losses were about 37% for M/BBA and M/BBA-NL respectively, and between 35% and 29% for M/BBA-CO and M/BBA-CO-NL respectively.

For mortars with crushed BBA, flexural losses were lower compared to Control Mixture: over 32%-28% for M/BBA-C and M/BBA-C-NL respectively, and 24%-15% for M/BBA-C-CO and M/BBA-C-CO-NL respectively.

3.5 Shrinkage

Shrinkage was measured at 1, 7, 14, 28 and 90 days according to UNE 83831. Shrinkage was higher for all mortars with additions of BBA respect to the Control Mixutre for all ages and measurement.



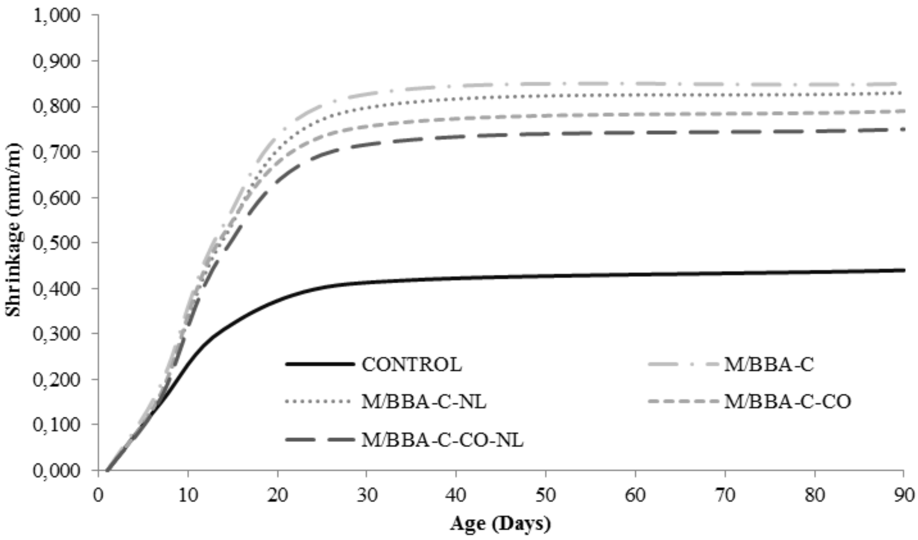


Figure 8 Shrinkage of the mortar as a function of age in days

As can be seen in Fig.8 in mortars made with a degree of substitution of BBA were obtained values above the mortar shrinkage control. The BBA that was processed by calcination presented more controlled shrinkage values, reducing their values if the BBA had been combusted and light particles removed.

5. Conclusions

The following conclusions were obtained:

Incorporating 30% of BBA reduces mechanical properties of the manufactured mortars. However, lower values in behavior in compressive strength and flexural strength were obtained in mortar mixtures with BBA-C substitutions. In turn, lower values of density and higher porosity values are obtained due to the low density and high porosity of BBA.

Similarly, by replacing CEM by BBA the durability properties of mortar mixtures are reduced. These reductions are less significant if BBA-C is replaced in mortars. Therefore, BBA-C improves its properties in general, recommending to be crushed for use in mortars.

Moreover, for all manufactured mortars, light particles extraction and removal of organic matter by burning improve considerably the mechanical and dimensional behaviour regarding mortars without processing. Therefore, mortars with additions of BBA-C-NL are technically assumable, and it is possible to be used in low incorporation rates.

Therefore, it is recommended the use of BBA as a substitute for cement in mortar mixtures whenever a crushing processing, extraction of light particles and removal of organic matter is performed.

Acknowledgments

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