

# Physical and Mechanical Performance of Mortars with Ashes from Straw and Bagasse Sugarcane

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**Abstract**—The objective of this study was to identify the optimal level of partial replacement of Portland cement by the ashes originating from burning straw and bagasse from sugar cane (ASB). Order to this end, were made five series of flat plates and cylindrical bodies: control and others with the partial replacement in 20, 30, 40 and 50% of ASB in relation to the mass of the Ordinary Portland cement, and conducted a mechanical testing of simple axial compression (cylindrical bodies) and the four-point bending (flat plates) and determined water absorption (WA), bulk density (BD) and apparent void volume (AVV) on both types of specimens. Based on the data obtained, it may be noted that the control treatment containing only Portland cement, obtained the best results. However, the cylindrical bodies with 20% ashes showed better results compared to the other treatments. And in the formulations plates, the treatment which showed the best results was 30% cement replacement by ashes.

**Keywords**—Modulus of rupture, simple axial compression, waste.

## I. INTRODUCTION

THE production of cement generates various environmental and social impacts, therefore, a concern in this sector with the improvement of modern technologies that minimize or avoid some of those impacts.

The cement business is prepared to face the challenge of investing heavily in Brazil's infrastructure, construction of which is still only beginning.

This challenge is still in progress with the commitment of sustainable practices. Again, the cement industry shows a pioneer in the field studying the development of a new initiative: the development of a mapping on the CO<sub>2</sub> emissions of the sector in Brazil, projected to 2050, and their reduction alternatives [1].

The cane sugar after being processed in the mills generates numerous wastes such as straw and bagasse, for example, they can be burned for energy generation in the industry itself and the ashes generated are normally used as fertilizer on crops. However, the soil can become saturated with the constant use as fertilizer of the ashes. An alternative is the use of ashes as an additive for cement [2]-[4].

One line of research with a lot of perspective on the world is the recycling of agro-industrial wastes such as minerals for

the preparation of cement-based materials (pastes, mortars, concretes and fibercement) as substitutes for traditional mineral additives such as fly ash and natural pozzolan additions.

Is known the pozzolanic potential of certain agro-industrial wastes when calcined under controlled conditions in the laboratory as for example, bagasse from sugarcane and rice husk [5], [6].

The cane bagasse ashes has a large amount of silicon dioxide usually above 60% by weight in this manner can be used as pozzolan in the manufacture of cement. The silica present in the ashes is derived mainly from epidermis of plant cells. Another possible source of silica for the ash is the sand (quartz), derived from farming, which is not completely removed during the washing step in the processing of cane sugar [4].

So with the above, the objective of this study was to identify the optimal level of partial replacement of Portland cement by the ashes originating from burning straw and bagasse from sugar cane.

## II. MATERIALS AND METHODS

### A. Raw Materials

The raw materials used for this study are outlined below:

#### Portland Cement

Portland cement used for this work was the CP-V ARI (Caue brand) packed in paper bags "Kraft" of 50 kg, produced according to the technical specifications of ASTM C150 [7].

Portland cement was purchased and placed in plastic bags to prevent moisture due to humidity.

#### Sand

The sand used is from the construction trade. In accordance with the NBR 7214 [8], the sand was sifted for testing Portland cement. We opted for the use of coarse medium sand.

#### Ashes Straw and Bagasse from Sugar Cane

The ashes of straw and bagasse from sugar cane (BSA) were acquired from the production process of cogeneration by burning straw and bagasse, the Abengoa Bioenergy Brazil group company located in Pirassununga (São Paulo, Brazil). The ashes initially was re-burned in a muffle furnace (Jung brand / model 10010) with a heating ramp of 10°C/min, at 400°C for 1 h, and then cooled naturally. The reason for the re-burn is in the homogenization of the material and also in the reduction of organic matter.

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### B. Mortars

The production and physical and mechanical characterizations of the formulations occurred in two types of bodies-specimens: Cylindrical and flat plates. The composition of the mortars is showed in Table I.

TABLE I  
COMPOSITION OF MORTARS

	Portland cement (%)	Sand (%)	ASB (%)
Mortar 1	25	75	---
Mortar 2	20	75	5
Mortar 3	17,5	75	7,5
Mortar 4	15	75	10
Mortar 5	12,5	75	12,5

#### Cylindrical Bodies

The mixture of these materials was done in a planetary mixer (Cairo Metal brand/model AG5) with a tank capacity of 5 L, and low speed of  $62 \pm 5$  rpm. To prepare the bodies (cylindrical geometry), the mortar was poured in cylindrical molds of 25mm diameter 50mm height and was compacted by vibration for 4 min, using a vibrating table with flat surface, set in motion by a motor of 3 kW and with vibration frequency of 2200 rpm.

After the bodies were molded, they were placed in a tray completely sealed with plastic for two days. Then, curing was performed, in which the bodies of each formulation was immersed in water for 26 days, curing total of 28 days.

#### Flat Plates

The mixture of these materials was done in a planetary mixer (Cairo Metal brand/model AG5) with a tank capacity of 5 L, and low speed of  $62 \pm 5$  rpm. To prepare the plates (square geometry), the mortar was poured in a wooden frame with metallic background with was compacted by vibration for 4 min, using a vibrating table with flat surface, set in motion by a motor of 3 kW and with vibration frequency of 2200 rpm.

After the plates were molded, they were placed in a tray completely sealed with plastic for two days. Then, curing was performed, in which the plates of each formulation was immersed in water for 26 days, of each formulation, curing total of 28 days.

### C. Mechanical Tests

#### Cylindrical Bodies

For the test of simple axial compression [9] of cylindrical bodies was used a universal testing machine (EMIC brand / model DL-30000), with 50kN load cell. The calculated stress was obtained by dividing the load at failure (N) from the area of the body of the specimen (square meter) section, then obtaining the average of the replications.

#### Flat Plates

The plates of 28 days old were cut into circular saw cooled by water, with diamond disk, ensuring the integrity of the test specimens, used in the nominal dimension of 160 mm x 40 mm x 14 mm and tested in saturated water condition, due to the curing process adopted; before the bending test the excess

of water was removed from the surfaces of the plate with a cloth.

The mechanical tests were performed on a universal testing machine (EMIC brand/model DL-30000), according to RILEM [10].

The configuration used was the one at four points bending, with the span between lower supports equal to 135 mm and with equal distance between higher supports equal to 45 mm, with a load cell of 5 kN and deflectometer of EMIC brand, EE05-ESP model, for measuring the deformation in mm. The rate of load application was 1.5 mm/min.

The specific deformation was calculated based on the values of the deformation obtained by deflectometer, divided by the distance between lower supports.

In the mechanical tests, the following properties were obtained: modulus of rupture (MOR), limit of proportionality (LOP) and modulus of elasticity (MOE), as procedure quoted by [11].

$$MOR = [3 \cdot P_{max} \cdot (L_{inf} - L_{sup})] / [2 \cdot W \cdot B^2] \quad (1)$$

$$LOP = [3 \cdot P_{lop} \cdot (L_{inf} - L_{sup})] / [2 \cdot W \cdot B^2] \quad (2)$$

$$MOE = [(276 \cdot L_{inf}^3) / (1296 \cdot W \cdot B^3)] \cdot [P / \delta] \quad (3)$$

where P is load,  $P_{max}$  is the maximum load,  $P_{lop}$  is the load at the upper point of the linear portion of the load vs specific deflection curve (before the first cracking point),  $L_{inf}$  and  $L_{sup}$  are the inferior and superior span length, equal to 135 mm and 45 mm respectively,  $\delta$  is the displacement registered by the deflectometer, B and W are the specimen thickness and depth (width) respectively.

#### D. Physical Tests

The specimens by formulation were subjected to physical tests for determination of water absorption (WA), bulk density (BD) and apparent void volume (AVV) according to ASTM C-948-81[12].

It has been determined firstly in the mass of bodies immersed in water saturated test. Then dried superficially with a cloth to remove excess water and saturated determine the mass and after that, they were kept in an oven with air circulation at apparent 105°C for 48 hours to determine the dry mass.

For statistical analysis of physical and mechanical tests, it was used a completely randomized design to compare the means and the Tukey test at a confidence level of 95% ( $P < 0.05$ ) [13].

For each of the mechanical and physical testing eight samples were used.

### III. RESULTS AND DISCUSSION

This part comprehends the physical and mechanical results of the mortars.

Fig. 1 shows the mean values and standard deviations of the maximum stress achieved in the mechanical testing of simple axial compression in the cylindrical bodies.

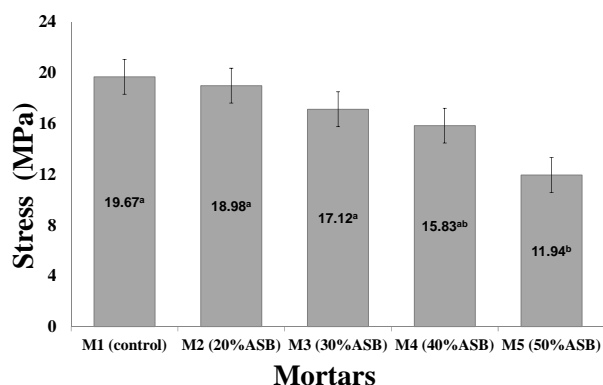


Fig. 1 Maximum stress achieved in the mechanical testing of simple axial compression

One notes that the M1 treatment had the best result. This result was expected, since it is the control treatment, with only Portland cement. But based on these results, it is observed that the mortar 1, 2, 3 and 4 did not differ statistically.

In Table II, the mean values of the mechanical tests (Tukey test,  $P < 0.05$ ) performed on flat plates are presented.

Mortars	LOP (MPa)	MOE (MPa)
1 (control)	9405.3 <sup>a</sup>	4.29 <sup>ab</sup>
2 (20%ASB)	8909.0 <sup>a</sup>	4.45 <sup>ab</sup>
3 (30%ASB)	8968.3 <sup>a</sup>	5.03 <sup>a</sup>
4 (40%ASB)	6126.0 <sup>b</sup>	2.60 <sup>c</sup>
5 (50%ASB)	5989.5 <sup>b</sup>	2.44 <sup>c</sup>

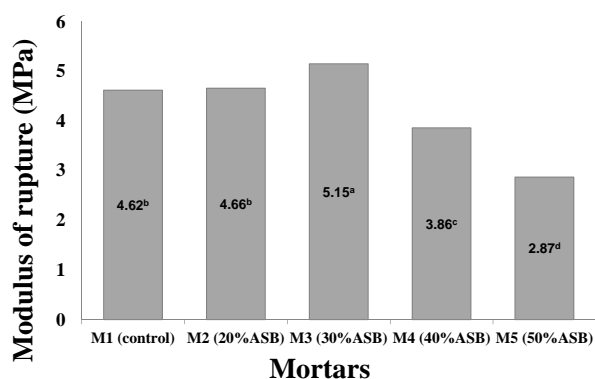


Fig. 2 Modulus of rupture in flat plates

According to Table II and Fig. 2, treatment with 30% ashes (M3) has the largest value of the modulus of rupture (MOR), modulus of elasticity (MOE) and a better result than the control treatment (M1), only the limit of proportionality treatment with 30% ash has a lower result to the control, but not statistically significantly different.

In Table III, the mean values of the physical tests (Tukey test,  $P < 0.05$ ) performed on cylindrical bodies are presented.

TABLE III  
RESULTS OF PHYSICAL TESTS IN CYLINDRICAL BODIES

Mortars	BD (mg/cm <sup>3</sup> )	AVV (%)
1 (control)	1.92 <sup>a</sup>	23.35 <sup>c</sup>
2 (20%ASB)	1.88 <sup>ab</sup>	24.72 <sup>b</sup>
3 (30%ASB)	1.87 <sup>ab</sup>	24.70 <sup>b</sup>
4 (40%ASB)	1.86 <sup>b</sup>	24.63 <sup>b</sup>
5 (50%ASB)	1.81 <sup>c</sup>	25.99 <sup>a</sup>

Note in Table III that an increase in the amount of ashes introduced mortars resulted in a decrease in bulk density of the bodies, which was expected due to the density of ashes [14]. In relation to apparent porosity can note that the insertion of the ash leads to increased porosity, inversely proportional.

Fig. 3 shows the mean values and standard deviations of the water absorption in the physical testing in the cylindrical bodies.

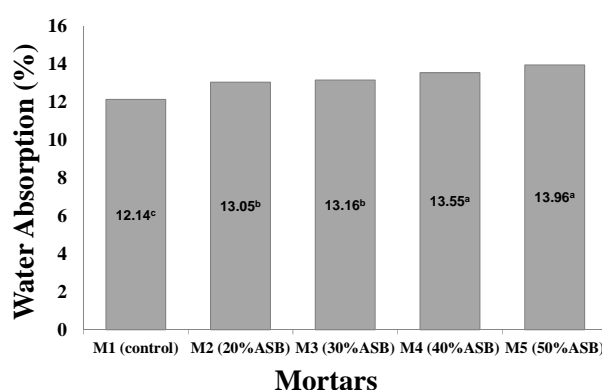


Fig. 3 Water absorption in cylindrical bodies

It is observed that the increase in rates of cement replacement by the ashes has led to increased water absorption by the bodies, that due to the higher percentage of ashes in mortar. In Table IV, the mean values of the physical tests (Tukey test,  $P < 0.05$ ) performed on flat plates are presented.

Mortars	BD (mg/cm <sup>3</sup> )	AVV (%)	WA (%)
1 (control)	1.89 <sup>a</sup>	21.17 <sup>d</sup>	11.18 <sup>c</sup>
2 (20%ASB)	1.87 <sup>a</sup>	24.15 <sup>c</sup>	12.89 <sup>d</sup>
3 (30%ASB)	1.90 <sup>a</sup>	24.00 <sup>c</sup>	12.64 <sup>b</sup>
4 (40%ASB)	1.88 <sup>a</sup>	24.83 <sup>b</sup>	13.20 <sup>d</sup>
5 (50%ASB)	1.83 <sup>b</sup>	25.87 <sup>a</sup>	14.12 <sup>a</sup>

The results of physical tests obtained for flat plates corroborate those obtained by cylindrical bodies. That is, the insertion of ashes the bulk density decreases and inversely behaves apparent porosity, and ratio of water absorption, this increases with the addition of ashes.

#### IV. CONCLUSIONS

The physical and mechanical results for flat plates and cylindrical bodies demonstrated that the ashes of straw and bagasse cane sugar added in mortars have good performance,

which leads to possible application of this waste in cementitious materials.

#### ACKNOWLEDGMENT

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#### REFERENCES

- [1] Nation a Union of the Cement Industry. Annual Report 2012. Available at: <<http://www.snica.org.br>>. Accessed January 2014.
- [2] J. F. M. Hernández, B. Middeendorf, M. Gehrke, H. Budelmann, "Use of wastes of the sugar industry as pozzolana in lime-pozzolana binders: study of the reaction". *Cem Concr Res* 1998;28(11):1525-36.
- [3] J. Payá, J. Monzó, M. V. Borrachero, L. M. Ordóñez, "Sugar-cane bagasse ash (SCBA): studies on its properties for reusing in concrete production" *J. Chem Technol Biotechnol* 2002; 77(1):321-5.
- [4] G. C. Cordeiro, R. D. Toledo Filho, L. M. Tavares, E. M. R. Fairbairn, "Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete" *Cement and Concrete Research*, v.39, p. 110-115, 2009.
- [5] M. Frías, M. E. Villar, M. I. S. Rojas, E. Valencia, "The effect that different pozzolanic activity methods has on the kinetic constants of the pozzolanic reaction in sugar cane straw ash/lime systems: Application of a kinetic-diffusive model." *Cement and Concrete research*, 35, 2137-2142, 2005.
- [6] M. Frías, C. Villar., H. Savastano Jr., "Brazilian sugar bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture". *Cement and Concrete Composites*, 33(4)490-496, 2011.
- [7] ASTM C150/C150M-11. Standard. Standard Specification for Portland Cement; 2011.
- [8] ABNT Brazilian Association of Technical Standards. NBR 7214: Standard sand for testing cement. Rio de Janeiro, 1982.
- [9] ABNT Brazilian Association of Technical Standards. NBR 7215: Portland cement: Determination of compression strength. Rio de Janeiro, 1996.
- [10] RILEM Technical Committee 49 - TFR Draft Recommendations. *Matériaux et Constructions*, Paris, v.17, n.102, p.441-456, 1984.
- [11] G. H. D. Tonoli, A. P. Joaquim, M. A. Arsène, K. Bilba, H. Savastano Jr., "Performance and durability of cement based composites reinforced with refined sisal pulp." *Materials and Manufacturing Processes*, v.22, p.149-156, 2007.
- [12] ASTM C 948-81. Standard. Dry and wet bulk density, water absorption and apparent porosity of thin sections of glass-fiber reinforced concrete; 2009.
- [13] SAS Institute. SAS OnlineDoc® 9.1.3. Cary, 2006.
- [14] D. C. G. Oliveira, M. S. Rodrigues, S. F. Santos, H. Savastano Jr., "Characterization and use of swine deep bedding ashes in cementitious composites." *Eng. Agríc.* 2012, vol.32, n.5, pp. 810-821.