



## **Cement with SCBA as a stabilizer in compressed earth blocks**

Paula Gisele LAMEZON DE PÁDUA, Daniel MASKELL, Andrew HEATH, Pete WALKER

Article disponible dans les actes du colloque Terra 2016:

JOFFROY, Thierry, GUILLAUD, Hubert, SADOZAI, Chamsia (dir.) 2018, *Terra Lyon 2016: Articles sélectionnés pour publication en ligne / articles selected for on-line publication / artículos seleccionados para publicación en línea*. Villefontaine : CRAterre. ISBN 979-10-96446-12-4.

## ABSTRACT

The study outlined in this paper investigates the addition of Sugar Cane Bagasse Ash (SCBA) with cement to improve the mechanical and durability properties of compressed earth blocks. Initially, the chemical composition of the SCBA material was characterized by x-ray diffraction, particle size and morphology. Prototype compressed earth blocks were made using a variety of brick soils mixed with sand, cement and SCBA. These blocks were subjected to a variety of different tests to ascertain their mechanical and durability properties. The test results, outlined in the paper, indicate SCBA can be used together with cement as an effective stabilizer in compressed earth blocks. The blocks made with soil, 5% of the sand replacement by cement and SCBA obtained the best results in dry compressive strength at 7 and 28 days (112%; 159%), respectively when compared with the reference samples (soil and sand) and the values increased 25% when compared with the Brazilian Standard minimum performance requirements. In addition, the blocks had water absorption values 30% less than maximum values recommended by Brazilian Standard. The use of SCBA can reduce the environmental impact of masonry unit production, while meeting the current performance requirements.

## INTRODUCTION

Interest in the use of more sustainable construction materials has increased worldwide. In particular attention has turned to the greenhouse gases emitted in the production of cement and other building materials. Therefore, natural materials that have significantly lower emissions are gaining increasing popularity. Earthen construction is one of the oldest building materials and has been used throughout the world. The earth is a natural material, easy accessed and widely available. Earth is undoubtedly one of the most widely-used construction materials in the world, ever since humans learnt to build homes and cities around 10,000 years ago. Perhaps as many as 50% of the populations in developing countries still live in earth homes (Houben & Guillaud, 1994). Because of this there has been a growing awareness on the importance of this type of construction. Compressed earth bricks have gained some acceptance as an economically viable and sustainable construction material. Different stabilisation techniques are used to improve the mechanical and durability characteristics of earthen materials. As the largest sugar cane producer in the world Brazil produces large quantities of co-products derived from sugar and ethanol production. These co-products are used in concrete production to reduce the cement content; they could also be used within stabilised soil. Onchiri, R. *et al.* (2014) studied the use of SCBA as a partial replacement for cement to stabilize self-interlocking compressed earth blocks. The compressive strength results obtained at the age of 7 and 28 days were 2.1 MPa and 3.0 MPa, respectively to the 3.2% SCBA. This study aims to improve the mechanical property and the durability of bricks made of soil stabilized with cement that uses an additive derived from an agricultural residue, in this case, the sugar cane bagasse ash.

### 1. MATERIALS AND EXPERIMENTAL METHODS

A sandy silt soil, used for fired clay brick production supplied by Ibstock Brick Ltd (Bristol, UK), was used for this study. The soil was characterized previously for earth construction by Maskell (2014). In this study pre-air ashes (Blaine: 358m<sup>2</sup>/Kg), from sugar/alcohol plant located in the state of Minas Gerais, Brazil, were used. This is one of four types of ash produced by this company. Two types of sand, defined as finely and coarsely graded, were also used.

Cement produced by Lafarge Brazil was used in this study. It was made with 95% wt. of clinker and 5% wt. gypsum. These materials were ground together until obtaining a 513 m<sup>2</sup>/Kg (Blaine). Subsequently, a new type of cement was produced with the replacement 10% wt. of the cement with equivalent volume of the SCBA (Pádua, 2012). The aim of this research was to study the effectiveness of this new cement (SCBA) as a stabilizer for soil block production, not to evaluate the cement with CBCA, it has previously been proven by Pádua (2012). Because of this the block with soil-sand was used as reference in this study, instead of a block with soil-sand-cement. Moreover, the quantity of the ash used in the cement is small.

The materials (soil and sand) were initially oven dried to constant mass at 105°C and then left to cool to ambient condition (20°C) before mixing (according to BS EN772-1:2000). Blocks with different compositions were investigated (in total eleven variations). These preliminary test blocks were made to evaluate feasibility and determine the quantity of the water needed. All compressed blocks were made using a manual block press machine, producing units measuring 141 mm x 296 mm x 80 mm. After initial curing for 7 days in a controlled environment (20°C and 60% RH), the prototype blocks were tested to determine compressive strength. Compaction tests were undertaken on cylindrical samples made with soil-sand and soil-sand-cement (with SCBA) to establish the optimum mixture design and moisture content in accordance with BS 1377-4 (1990). Preliminary block and cylinder mixes are summarised in Table 1.

*Table 1- preliminary mixes investigated.*

Identification	Mix	Water addition (%)	Quantity of samples	Curing ages (days)
RB8	Block:50% soil+ 50% (coarse and fine sand mixture)	8	1	broken
RB9	Block:50% soil+ 50% (coarse and fine sand mixture)	9	1	7
RB10	Block:50% soil+ 50% (coarse and fine sand mixture)	10	1	7
RB11	Block:50% soil+ 50% (coarse and fine sand mixture)	11	1	7
RB12	Block:50% soil+ 50% (coarse and fine sand mixture)	12	1	7
5CB9	Block:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)	9	1	7
5CB10	Block:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)	10	1	7
5CB11	Block:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)	11	1	7
6CB9	Block:50% soil+ 44% (coarse and fine sand mixture)+6% cement with SCBA (10% wt. cement replacement by SCBA in volume)	9	1	7
6CB10	Block:50% soil+ 44% (coarse and fine sand mixture)+6% cement with SCBA (10% wt. cement replacement by SCBA in volume)	10	1	7
7CB12	Block:50% soil+ 43% (coarse and fine sand mixture)+7% cement with SCBA (10% wt. cement replacement by SCBA in volume)	12	1	7
RC9	cylinder:50% soil+ 50% (coarse and fine sand mixture)- Proctor test	9	1	
RC10	cylinder:50% soil+ 50% (coarse and fine sand mixture)- Proctor test	10	1	
RC11	cylinder:50% soil+ 50% (coarse and fine sand mixture)- Proctor test	11	1	
RC12	cylinder:50% soil+ 50% (coarse and fine sand mixture)- Proctor test	12	1	
5CC9	cylinder:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)- Proctor test	9	1	
5CC10	cylinder:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)- Proctor test	10	1	
5CC11	cylinder:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)- Proctor test	11	1	

Following preliminary tests mixtures were selected for further testing. Three specimens were made for each mixture (Reference block: 50% soil+ 50% coarse and fine sand; blocks made with: 50% soil+ 45% coarse and fine sand mixture+5% cement with SCBA-10% wt. cement replacement by SCBA in volume) with 9% water content by mass. The wet and dry compressive strengths were determined at 7 and 28 days. These blocks were designated: RB9W7, RB9D7, 5CB9D7, 5CB9W7, RB9W28, RB9D28, 5CB9D28 and 5CB9W28, as shown on Table 2.

Table 2 - mixes investigated.

Identification	Mix	Water addition (%)	Quantity of samples	Curing ages (days)
RB9D7	Block:50% soil+ 50% (coarse and fine sand mixture)- dry compressive strength	9	3	7
5CB9D7	Block:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)	9	3	7
RB9W7	Block:50% soil+ 50% (coarse and fine sand mixture)- wet compressive strength	9	3	7
5CB9W7	Block:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)- wet compressive strength	9	3	7
RB9D28	Block:50% soil+ 50% (coarse and fine sand mixture)- dry compressive strength	9	3	28
5CB9D28	Block:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)	9	3	28
RB9W28	Block:50% soil+ 50% (coarse and fine sand mixture)- wet compressive strength	9	3	28
5CB9W28	Block:50% soil+ 45% (coarse and fine sand mixture)+5% cement with SCBA (10% wt. cement replacement by SCBA in volume)- wet compressive strength	9	3	28

Durability test by water absorption test was also investigated at 28 days according to the Brazilian Standard (ABNT NBR 8492, 1984). Three samples with each mixture were measured.

## 2 . RESULTS AND DISCUSSION

Table 3 shows the chemical composition of the clinker and gypsum.

Table 3 –Chemical composition of the clinker and gypsum.

constituents	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	LOI*	CaO free	C <sub>3</sub> S	C <sub>2</sub> S	C <sub>3</sub> A	C <sub>4</sub> A F	IR**	AM**	BI***	Total
clinker (%)	21,17	5,91	3,90	65,51	0,89	0,78	0,046	0,999	0,20	1,04	54,71	19,08	9,08	11,85	0,10			
gypsum (%)	1,05	0,31	0,12	30,90	6,12	43,80		0,08	17,43							3,2	35,60	99,81

\*LOI:Loss on ignition\*\*IR: Insoluble residues\*\*\*AM: average moisture\*\*\*\*BI: Basicity index

The chemical composition of the SCBA studied is: silica (52.5%), aluminium oxide (11.4%), iron oxide (5.8%), calcium oxide (5.9%), magnesium oxide (3.5%), sulphur trioxide (2.4%), potassium oxide (12.0%), phosphorus pentoxide content (4.0%), with a high loss on ignition of 20%. The comparatively low silica content resulted from the incomplete combustion of bagasse, demonstrated further by a high content of loss of ignition. The X-ray diffraction pattern of the ash obtained from the pre-air region of the boiler has a medium to high level of crystallinity. There is a higher percentage of the quartz

and low percentage of the others crystalline phases (hematite, cristobalite and albite) in the sample.

The microscopy of SCBA (a,b) and cementitious composites with 10% the pre-air ash at 28 days of hydration (c,d) is shown in Fig. 1. It can be observed in photomicrograph (a,b) that the ash granulometry is irregular and has little porosity. In photomicrographs (c), (d) note that there is a very rough surface with some pores. Several poorly defined flat plates were also observed, indicating that Portlandite (1d), but does not have its usual well defined form.

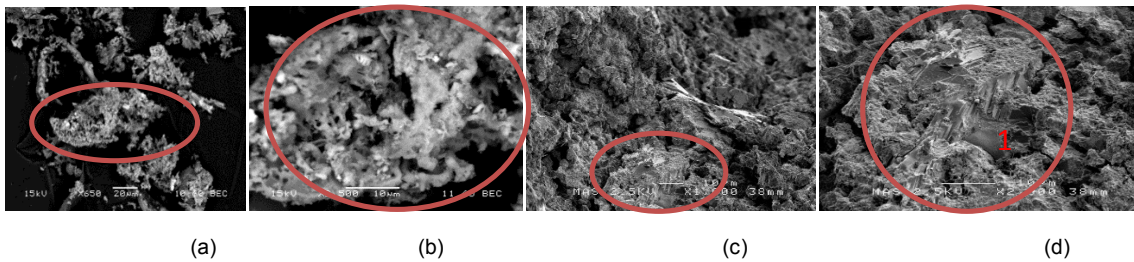


Figure 1. Photomicrographs of SCBA and composites with SCBA, images by SEM, increases: 650 (a), 2500 (b), 1000 (c) 2000 (d).

Fig. 2 shows the dry unit weight and optimum moisture content of the reference and 5% cement (SCBA)-soil-sand samples. The reference samples had values of  $19.9\text{kN/m}^3$  with an optimum moisture content of 9.3%, corresponding to mix in which 9% water was added. However, the 5% cement with ash samples had values of  $18.7\text{kN/m}^3$  with 9.0%, corresponding with the 10% water addition at mixing. This difference was attributed to the use of the cement and corresponding hydration reactions. However, the difference between the 9% and 10% cement stabilised mixes was not large. Therefore, to reduce the variables in the study, a consistent amount of water (9%) was added to all samples.

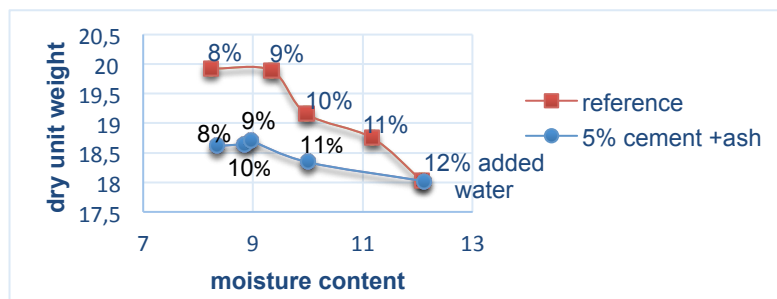


Figure 2. Optimum moisture content.

The blocks containing 9% water added to the mixture showed better compaction (Fig. 3a). For the other water contents the materials were less homogeneous and more friable (Fig. 3b,c). It was also noted that when mixed, the materials with higher water contents showed more pelletizing- little balls (Fig. 3d).



Figure 3. Blocks made with 5% cement+ SCBA with 9% (a), 10% (b) and 11% (c) water content added, respectively (5CB9, 5CB10 and 5CB11) and pelleted mixture in the small pan mixer (d).

Fig. 4(a) shows the preliminary test results for 7 days dry compressive strength blocks with varying mixtures and moisture content at compaction. Fig. 4(b) shows the effect of cement with ash on the 7 and 28 days compressive strength (dry and wet).

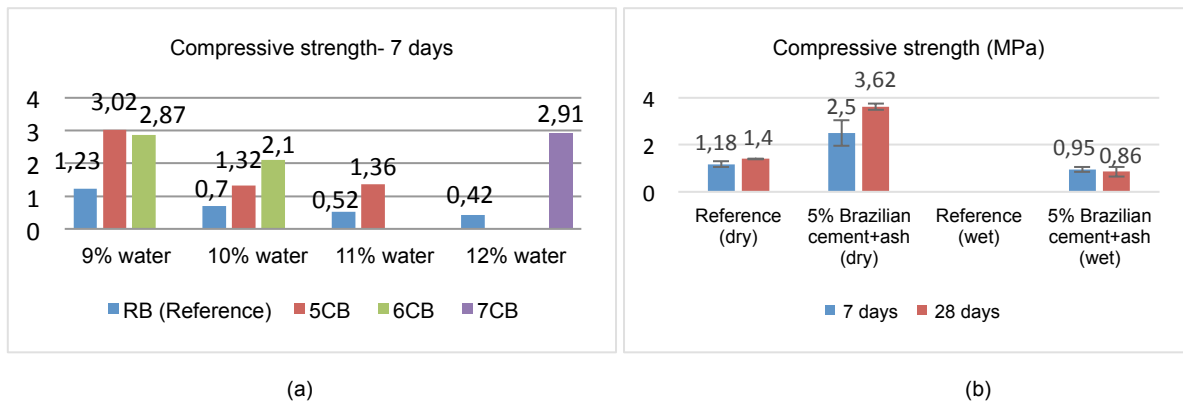


Figure 4. Compressive strength of blocks after 7 days of curing in controlled chamber (a). Compressive strength (dry and wet) of blocks (b).

As expected, all blocks containing cement had higher compressive strength results than the respective reference blocks. The best results were obtained with blocks made with 9% added water (5CB9, 6CB9). The most suitable moisture for blocks made with this mixture of soil-sand-cement (SCBA) was therefore 9%, in keeping with results obtained from the test Proctor. The block 5CB9 obtained compressive strength values of 145% more than the respective reference blocks. Block 6CB9, despite having higher cement content, did not have higher strength. Despite increasing the amount of water in the mixture, the compressive strength of the block decreased (about 26%) than the block with the same mixture with 9% added water (5CB9). The blocks 5CB9, 6CB9, 6CB10, 7CB12 achieved compressive strengths above that required by the Brazilian standard (1,7 MPa). In contrast to expectations, higher cement content did not directly result in higher compressive strength. The best result of the all samples was obtained by the blocks made with 5% cement-SCBA-soil-sand, 9% added water in the mixture (5CB9). These results are in accordance with those reported by Houben, H. & Guillard, H. (1994). As the objective of this study was the soil stabilization with the least amount of possible cement, further work focused on blocks made with 5% cement.

Blocks made with 5% cement and ash-soil-sand had better strength results compared to the reference blocks at 7 and 28 days. The compressive strength of the cement stabilised blocks were 112% and 159% higher respectively. In general the samples at 28 days showed improved compressive strength compared to 7 day performance, with exception of the samples tested for wet compressive strength, which achieved almost the same result. The dry compressive strength obtained at the age of 7 and 28 days for the samples with 5% cement with SCBA produced the highest strength, greater than that specified in the Brazilian Standard (ABNT NBR 8491, 1984). The samples made with 5% cement (SCBA)-soil-sand, obtained a 13.8% of water absorption after 28 days. This value is less than that specified in the Brazilian Standard (ABNT NBR 8492, 1984), which requires maximum 20% of average water absorption.

### 3 . CONCLUSIONS

The results from the experiments show that the moisture content of blocks at testing has a significant influence on the compressive strength. A higher compressive strength in the

preliminary test was obtained with cement and SCBA stabilisation (content 5%) with 9% water content (5CB9). Blocks with this composition showed higher dry compressive strength at 7 and 28 days than the reference samples and the Brazilian standard requirements. Samples containing 5% cement (SCBA)-soil-sand complied with the water absorption test requirement of the Brazilian Standard (NBR 8492, 1984). Blocks made with soil-sand-cement (SCBA) have improved durability and will reduce the environmental impact of masonry unit production, while meeting the current performance requirements.

#### 4 . ACKNOWLEDGMENTS

The authors are grateful to the financial support for this research by CAPES Foundation (Ministry of Education of Brazil), process nº 2591-13-8, to allow Paula G. L de Pádua to do her Post-Doctorate in University of Bath, UK. Lafarge Brasil, Destilaria Alpha Company and Ibstock Brick Ltd for supplying materials.

#### REFERENCES

- Houben, Hugo and Guillaud, Hubert (1994). *Earth construction. A comprehensive guide*. Intermediate Technology publication.
- Padua, P.G.L. (2012). *Desempenho de compósitos cimentícios fabricados com cimentos aditivados com cinzas de bagaço de cana-de-açúcar in natura e beneficiadas*. Theses of Doctorate in Structural Engineering, (Federal University of Minas Gerais).
- Onchiri, R., K. James, et al. (2014). "Use of sugarcane bagasse ash as a partial replacement in stabilization of self-interlocking earth blocks." *Journal Impact Factor* 5(10): 124-130.
- Maskell, Daniel. *Development of stabilized extruded earth masonry units*. Theses of Doctorate in Civil Engineering (University of Bath), 2013.
- BS 1377-4 (1990). *Soils for civil engineering purposes - Part 4: Compaction-related tests*. British Standards Institute (BSI).
- ABNT NBR 8492 (1984): *Tijolo maciço de solo-cimento- determinação da resistência à compressão e da absorção d'água*. ABNT (Technical Standards Brazilian Association), Rio de Janeiro.
- ABNT NBR 8491 (1984): *Tijolo maciço de solo-cimento*. ABNT (Technical Standards Brazilian Association), Rio de Janeiro.
- BS 5628 (2005)-1: *Code of practice for the use of masonry- Part 1: Structural use of unreinforced of masonry*. British Standards Institute (BSI).

#### BIOGRAPHY

**Dr. Paula Gisele Lamezon de Pádua:** Bachelor in Architecture and Urbanism. She obtained her MS in 2008, doctorate in Structural Engineering, both from the Federal University of Minas Gerais (2012) and Post-Doctorate in Civil Engineering at University of Bath (UK). She has experience in research on the following subjects: mechanical properties, concrete, cement, demolition and construction waste, sintering process, sugar cane bagasse ash (SCBA), SCBA-cement-soil blocks and rice husk ash.

**Dr. Daniel Maskel:** Researcher Associate in the Department of Architecture and Civil Engineering. His research interests are related to sustainable construction with a focus on natural and non-conventional building materials and methods. Daniel stayed within the department to undertake a URS funded PhD investigating the development of earthen construction techniques for mainstream use.

**Professor Andrew Heath:** Andrew Heath is a Professor in Geomaterials in the Department of Architecture & Civil Engineering at the University of Bath. His teaching and research are related to soils, transport infrastructure and sustainable construction. He obtained his MS in 2000 and PhD in 2002 in Civil and Environmental Engineering, both from the University of California at Berkeley. He joined the Department of Architecture and Civil Engineering at the University of Bath in 2003.

**Professor Pete Walker:** Pete Walker is a chartered civil engineer and a member of both the Institution of Engineers Australia and The Institution of Civil Engineers (UK). Having previously worked in Zimbabwe (University of Zimbabwe) and Australia (University of New England), Pete joined the University of Bath in 1998. He was promoted to Professor in 2006 on becoming Director of the newly formed BRE Centre for Innovative Construction Materials.