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Characterization of the Influence of Fly Ash on The Mechanical Behavior of Compressed Earth Bricks

Serigne DIOP[1], Oustasse Abdoulaye SALL[1], Diogoye DIOUF[1], Makhaly BA[2]

[1]Department of Civil Engineering, UFR SI-University of Thiès, Thiès, Senegal
[2]Department of Geotechnics, UFR SI-University of Thiès, Thiès, Senegal

Corresponding Author: Serigne DIOP

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ABSTRACT

The aim of this project was to valorize fly ash for use in compressed earth bricks. Indeed, fly ash from the bargny coal-fired power plant is renowned for its pozzolanic character and is used as an additive at various contents (5%, 10%, 15% and 20%) to earth for the production of compressed earth bricks (CEB). On the other hand, CEM II/B cement was used as a soil additive at different stabilizing contents (1%, 1.5% and 2%). A physico-chemical and geotechnical characterization of the materials used was carried out, followed by formulation and manufacture of bricks by dynamic compression of the optimum mix obtained using a press. Bricks were then pre-conditioned and mechanically characterized to determine compressive strengths at 14 and 28 days. The results showed that the mechanical performance of CEB decreases with increasing ash content and increases with increasing cement content.

Keywords: Valorization, Fly ash, Pozzolanic, CEB, Characterization, Strength

INTRODUCTION

In Senegal, there is potential for the valorization of as yet untapped by-products. This is particularly true of fly ash from the Bargny coal-fired power plant. In view of the large quantity of ash produced, there could be a long-term storage problem that could have a negative impact on the environment [1]. It is against this backdrop that we are working to reclaim fly ash for use in the production of compressed earth bricks (CEB). To achieve this, we will characterize the influence of fly ash on the mechanical properties of compressed earth bricks. To carry out this work, the soils were identified and then analyzed in the laboratory to determine their physico-chemical and geotechnical characteristics. The soil mixes were then formulated with the addition of fly ash at different levels (5%, 10%, 15% and 20%) and cement at different percentages (1%, 1.5% and 2%). Finally, test bodies were manufactured and pre-conditioned up to crushing days (14 and 28 days) to determine their mechanical properties.

MATERIALS AND METHODS

II-1 MATERIALS USED

In the compressed earth brick (CEB) manufacturing process, lateritic earth materials were used, with the addition of fly ash (5%, 10%, 15% and 20%) and cement (1%, 1.5% and 2%).

II-1-1 LATERITIC SOILS

The land used from Sindia (a locality in the Thiès region of Senegal) is defined as follows:

- Soil made up of fine grains (sample 1) with a sieve diameter of 4 mm or less and a natural water content of 1.74%;

- Soil made up of coarse grains (sample 2) with a sieve diameter greater than 4 mm and a natural water content equal to 2.48%.

The soil samples were taken at CEB's production site in Ngaparou, a locality in the Thiès region of Senegal.

II-1-2 FLY ASH

The fly ash used comes from the Bargny-Senegal coal-fired power plant, is siliceous in nature and spherical in shape. Their pozzolanic activity indices are equal to 77% and 96% respectively at 28 and 90 days according to the experimental procedure defined by the standard [2]. The physical characteristics are such that the specific surface area is 4126 cm^2/g using the Blaine method and 7.3 m^2/g using the BET method. The chemical composition of fly ash is given in Table 1 below.

Table 1: Chemical composition of fly ash used [3]

Chemical elements	Mass %		NF EN 450-1
Majority items	SiO_2	48,94	> 70% (SiO_2 + Al_2O_3 + Fe_2O_3 + CaO)
	Al_2O_3	29,65	
	Fe_2O_3	3,24	
	CaO	9,29	< 10%
	MgO	1,55	< 4%
	TiO_2	1,55	
	P_2O_5	2,19	< 5%
	Na_2O	0,1	< 5%
	K_2O	0,46	
	SO_3	2,67	< 3%
Minority interests	In mg/kg		-
	Mg	0	-
	Cd	0,08	-
	Pb	0,182	-
	S	2,24	-

II-1-3 CEMENT

The cement used is type CEM II/B 32.5 R from the DANGOTE cement works, whose physicochemical and mechanical characteristics are given in tables 2 to 4 below [4], [5], [6], [7], [8]

Table 2: Chemical composition of cement used (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	Na_2O	K_2O	SO_3	Cl
15,17	3,88	3,23	63,31	0,19	0,65	0,04	0,3	0,87	0,007

Table 3: Cement physical parameters

Reject 45 µm	Refuse 90 µm	BLAINE	Fire loss	IST	FST	E/C
%	%	cm^2/g	%	min	min	%
15	1,2	3910	13,03	320	360	24,6

Table 4: Compressive strength of CEMII/B 32.5 cement

Age	2 days	7 days	28 days
Resistances (MPa)	10,6	26,9	42,2

II-2 LAND IDENTIFICATION

For each sample (Figure 1), identification tests were carried out at LNR-BTP (formerly CEREEQ). These included granulometry, normal Proctor and Atterberg limit tests. In the same vein, mixes were identified as follows:

- A raw mixture, i.e. consisting solely of samples 1 and 2;
- A mixture of soil stabilized with cement (1%, 1.5% and 2%);
- A mixture of improved soils with fly ash at well-defined levels (5%, 10%, 15% and 20%).

Figure 1: Laterites used: a) sample 1 and b) sample 2

II-3 LAND CHARACTERIZATION

The lateritic earth materials used to make the bricks were subjected to chemical analysis using the X-ray fluorescence method at the Dangoté Cement laboratory, in order to determine the elemental chemical composition of the earth samples. The results are shown in Table 5.

Analysis of Table 5 shows a dominant presence of silica (SiO_2), alumina (Al_2O_3) and iron (Fe_2O_3) for both laterites. However, laterite 1 contains more silica but with a lower iron value (Fe_2O_3), unlike laterite 2, which has a high Fe_2O_3value and takes on a much redder color. The presence of lime with very low values was noted, as were other elements.

The water status of the soils (Table 6) was measured by means of Atterberg limit, natural water content, apparent specific weight and normal Proctor tests. These tests were carried out on two (02) types of raw soil samples (soils 1 and 2). The raw earth mixes were formulated as follows:

- ***M_1***: a mixture of 50% soil 1 (T1) and 50% soil 2 (T2);
- ***M_2***: a mixture of 60% soil 1 (T1) and 40% soil 2 (T2);
- ***M_3***: a mixture of 40% soil 1 (T1) and 60% soil 2 (T2).

Granulometric analysis was used to determine the texture of the soil, i.e. the distribution of grains according to the different granular classes. It was carried out in accordance with the standard [9]. Table 7 gives the percentages of 63 µm sieve rejects for the soils.

Table 5: Chemical analysis of Sindia laterites in %.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	Na_2O	K_2O	SO_3	CL
Lat 1	79,06	12,37	10,7	0,68	0,15	0,07	0,05	0,15	0,1	0,011
Lat 2	51,8	13,44	29,84	0,82	0,11	1,66	0,04	0,13	-0,02	0,013

Table 6: Parameters for identifying the consistency of lateritic soils

Parameters	T1	T2	M1	M2	M3
W (%)	2,15	1,81	1.98	2.01	1.95
WL (%)	24	26	23	25	26
WP (%)	15	14	12	15	15
IP (%)	9	12	11	10	11
CI (%)	2,4	2,02	1,91	2,2	2,19
$\gamma_{(h)}$ (T/m3)	1,396	1,826	-	-	-
$\gamma_{(d)}$ (T/m3)	1,366	1,793	-	-	-
$\gamma_{(dmax)}$ (T/m3)	2,007	2	2,003	1,94	1,93
$W_{(opt)}$ (%)	11	10	10,2	11,7	11,7

Table 7: Percentage of soil rejected by 63 µm sieve

Soils and soil mixtures	Screen reject 63 µm (%)
Earth 1	56,4
Earth 2	65,32
Mix M_1	68,82
Mix M_2	58.93
Mix M_3	68.06

II-4 BRICK FORMULATION

For the manufacture of compressed earth bricks, we first determined the water status of the M_1earth mixture sample using the normal Proctor and Atterberg limit tests (Table 6). Eight (08) cement- and fly ash-based formulations were selected to, respectively, stabilize and improve these formulas made up of M_1soil mixes (50% T1 and 50% T2) with fly ash added at 5%, 10%, 15% and 20% of the mass of soil used, as well as three (03) other formulas made up of M_1soil soil mixes at water contents corresponding to the Proctor optimum (Table 6). On the basis of these formulations (Table 8), we were able to identify one (01) control formula without addition and four (04) mixes with cement added at different proportions (1%, 1.5% and 2%).

Table 8: Formulation for CEB production

Designation	M_1+ 0%	M_1+1%	M_1+1,5%	M_1+2%	M_1+5%	M_1+10%	M_1+15%	M_1+20%
Wc	10,2%	8,20%	9,20%	9,90%	10,40%	11,90%	10,60%	12,00%
Wm (kg)	24	24	24	24	24	24	24	24
Wm.ad (kg)	0	0,024	0,026	0,048	1,7	2,4	3,6	4,8
wt (L)	2,4	2	2,2	2,4	2,49	2,85	2,54	2,88
wu (L)	3	3	3	3	3,2	3,5	4	4,3

II-5 BRICK MAKING

Bricks are obtained by mixing earths with or without additions at optimum water contents, and then mixing (dry and wet), followed by dynamic compression of the mixture using a wet press, followed by immediate demolding. The compression pressure exerted on the mold is calibrated at 90 bar (i.e. 9 N/mm^2, which corresponds to high pressure according to the standard [10]). They are parallelepipedic in shape, with dimensions of 14 cm x 9 cm x 29.5 cm. Once out of the mold (Figure 2), they are stored under natural curing conditions, followed by wetting until crushing at 14 and 28 days of age.

a) b)

Figure 2: a) Moulding with the press and b) bricks after demoulding

II-6 MECHANICAL CHARACTERIZATION OF CEB

After each curing period, the bricks were cut transversely by sawing into two equal parts (Figure 4a) in accordance with the standard [11], then the top and bottom surfaces of the two specimens thus obtained were measured and the smaller of the surfaces was used as the bearing surface (Sa). In fact, it was recommended to proceed as follows:

- Clean support and installation surfaces to remove any protruding roughness;
- Lightly dampen both laying surfaces to prevent water from migrating too quickly from the mortar into the two half-bricks;
- Apply a mortar bed no thicker than 10 mm on the entire face of the first half-brick;
- Lay the second half-brick, ensuring that the entire surface of the supporting face is filled with mortar;
- Check parallelism of test faces with a level;
- Allow to set for at least 24 h at room temperature.

After conditioning the prepared specimens, a load is applied continuously at a constant rate until the specimen breaks completely, as shown in Figures 3 and 4b [12]. The compressive strength (R) is obtained by dividing the value in Newtons of the brick's maximum breaking force (F) by the value in square millimeters of the brick's bearing surface (Sa).

$$R = \frac{F}{S_a} \qquad [1]$$

From the average strength obtained, the correspondence with the compressive strength category is determined in accordance with Table 9.

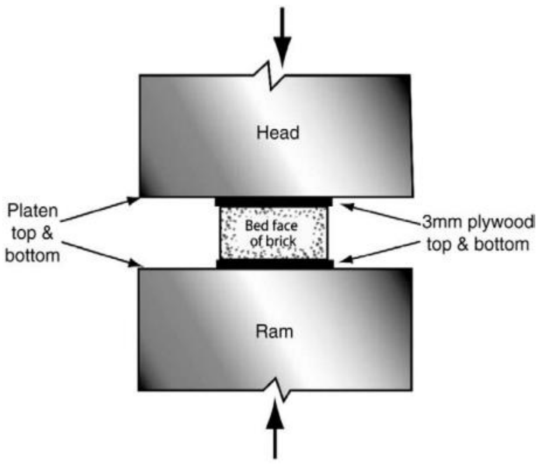

Figure 3: CEB compression test

Table 9: Compressive strength categories [11].

Category	**Average compressive strength of mud brick (MPa or N/mm2)**
Rc 0	< 1,00
Rc 1	≥ 1,00
Rc 2	≥ 2,00
Rc 3	≥ 3,00
Rc 4	≥ 4,00
Rc 5	≥ 5,00
Rc 6	≥ 6,00

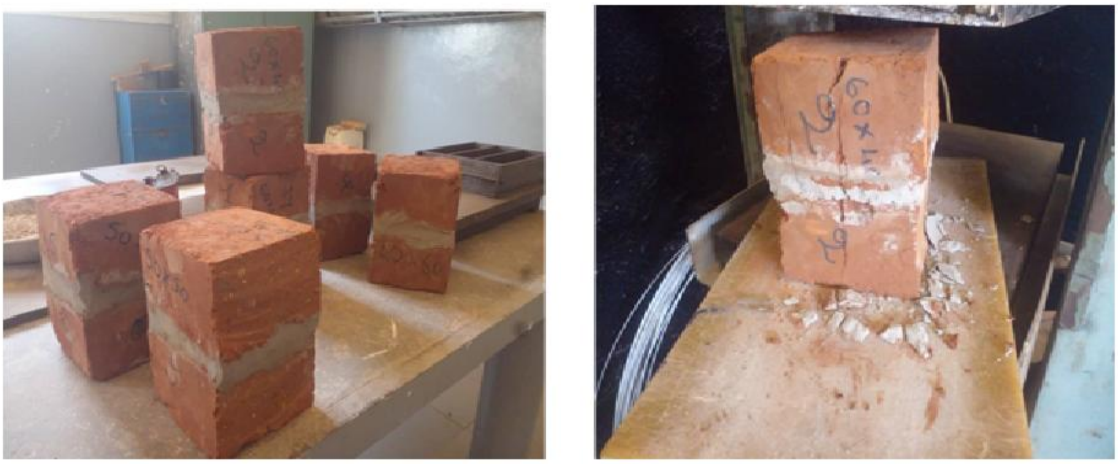

Figure 4: a) Superposition of the two half-bricks and b) State of the bricks after the compression test

RESULTS AND DISCUSSION

The effect of fly ash on the compressive strength of compressed earth bricks was studied and the results obtained are reported in Table 10. As part of this work, ash and cement were added to the soil mixtures at well-defined levels, as shown in Table 10.

Table 10: Compression results for cement and fly ash stabilized or improved CEBs

CEB	% addition	Compressive strength (MPa)	
		14 days	28 days
Fly ash	0%	0,91	0,79
	5%	0,54	0,61
	10%	0,48	0,54
	15%	0,36	0,42
	20%	0,3	0,36
Cement	1%	0,54	0,48
	1,50%	0,61	0,54
	2%	0,67	0,61

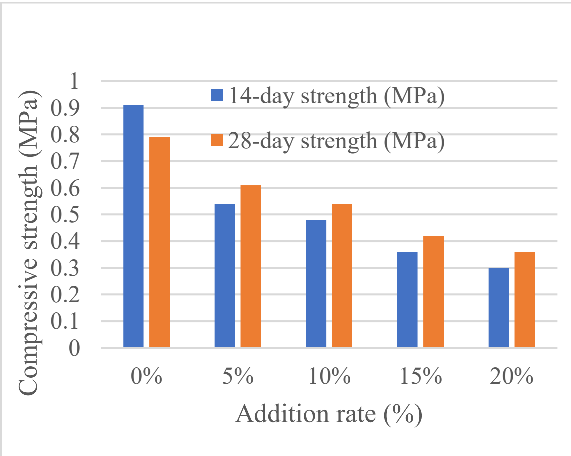

Figure 5: Compressive strength of CEB as a function of fly ash addition rate

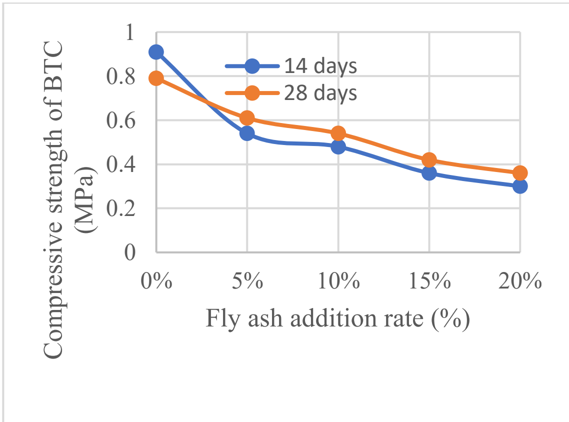

Figure 6: Compressive strength of CEB as a function of fly ash addition rate at different dates

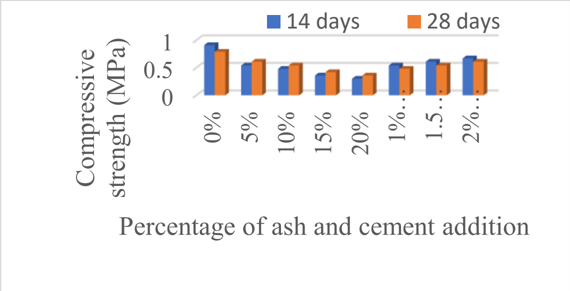

Figure 7: Compressive strength of CEB as a function of fly ash and cement addition rate

Figures 5 and 6 show the evolution of the compressive strength of CEB at 14 and 28 days as a function of the percentage of fly ash added. The analysis first shows a decrease in compressive strength as the percentage of fly ash increases. The strength becomes maximum for 0% ash addition, and mechanical performance at 14 days is better than at 28 days. And for the other percentages (5%, 10%, 15% and 20%), we see an increase in strength at 28 days compared with that obtained at 14 days.

Figure 7 shows the effects of adding fly ash and cement on the compressive strength of CEB at 14 and 28 days of curing. With the addition of cement, the analysis shows an increase in strength with the additive rate, and that maximum strengths are obtained at 14 days of curing, after which the strength decreases. This decrease in strength as a function of ash content and curing time could be explained by several factors:

- CEB cure conditions;
- The lack of binding properties of fly ash compared to cement;
- The increase in water content as the ash content rises (Table 8). In fact, water is a source of void creation when curing conditions are not appropriate or sufficient, which could lead to lower strengths at 28 days.

The increase in strength of fly-ash-improved CEBs when the curing period is extended from 14 to 28 days can be explained by the pozzolanic activity of fly ash over the long term [4]. From a mechanical point of view, according to the standard [11], the compressed earth bricks obtained are of category R_C0 (i.e. compressive strength less than 1MPa).

CONCLUSION

The valorization of industrial waste such as fly ash in the production of CEB not only has a positive effect on the environment, but also aims to promote eco-construction. The aim of this project was to characterize the influence of fly ash on the mechanical behavior of CEB for which ash and cement were added. To this end, bricks were manufactured and conditioned at 14 and 28 days of curing, before undergoing compression tests. The results showed that strengths with the addition of ash decreased as the ash content increased, and that strength increased with the age of the bricks. However, the strengths obtained at 14 days with the addition of cement remain higher.

Declaration by Authors

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