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Influence of fly ash from the Bargny-Senegal coal-fired power plant on the mechanical performance of hydraulic concrete

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ABSTRACT: The aim of this project is to reclaim fly ash from the Bargny coal-fired power plant for use in the production of hydraulic concrete, and also to provide economic and environmental solutions for the storage of industrial waste. To achieve this, the materials used were first characterized, in particular cement, fly ash and aggregates (sand, basalt, flint and limestone), in order to determine their physical and physico-chemical characteristics. Next, a campaign to formulate hydraulic concretes and manufacture 16x32cm cylindrical test bodies was carried out, in which cement was substituted by fly ash at different contents (0%, 5%, 10% and 20%). After conditioning in water, the specimens were progressively crushed at 7, 14 and 28 days of curing. The results showed an increase in compressive strength with increasing curing time for a given substitution rate. However, a decrease in compressive strength was observed for all formulated concretes as the fly ash content increased. On the other hand, the strengths obtained with basalt are higher than the target strength at 28 days (25 MPa), even up to 20% cement substitution.

KEYWORDS: Strength; Fly ash; Coal-fired power plant; Hydraulic concrete; Formulation.

1 INTRODUCTION

In Senegal, there is considerable potential for the valorization of as yet untapped by-products. This is particularly true of fly ash from the Bargny coal-fired power plant. Given the large quantity of ash produced, there will be a long-term problem of storage, which could have a negative impact on the environment. In this context, the reuse of this ash would be beneficial from all points of view. For this reason, work focused on the possibility of using fly ash in the manufacture of hydraulic concrete by simply substituting cement with fly ash at different percentages (0%, 5%, 10% and 20%). According to the literature [1], [2], [3], conventional fly ash is known to improve the durability of concrete. Within the framework of this work, a characterization of the materials used, notably cement, fly ash and aggregates (sand, basalt, flint and limestone), will first be carried out to determine the physico-chemical and geotechnical parameters of these materials. Then, a hydraulic concrete formulation will be designed using the Dreux-Gorisse method [4]. Next, 16x32cm cylindrical specimens will be made and then crushed to determine the mechanical characteristics of the concretes. Finally, the results obtained will be presented and discussed.

2 MATERIALS AND METHODS

2.1 CHARACTERIZATION OF AGGREGATES USED

The aggregates used in this work are local, available in Senegal and obtained by crushing at various quarries. They include sand (0/3), basalt (0/3, 3/8 and 8/16), flint (0/3, 3/8 and 8/16) and limestone (0/3, 3/8 and 8/16).

2.1.1 SAND

The dune sand comes from the Makha quarry at Taïba Ndiaye in the department of Tivaoune (Senegal). This dune sand is used as a raw material in the manufacture of concrete. Its characteristics include a fineness modulus.

of less than 2.2, with a sand equivalent of 39%. Its specific weight and apparent density are 2.398 and 1.485 g/cm^3 respectively. However, the sand was corrected with 0/3 aggregates (basalt, flint and limestone) to obtain a fineness modulus between 2.2 and 2.8.

2.1.2 OTHER AGGREGATES (BASALT, FLINT, LIMESTONE)

Natural crushed aggregates (classes 0/3, 3/8 and 8/16) were used in the composition of hydraulic concretes (Figure 1), both for control concretes and for concretes in which cement was substituted by fly ash. These are:

- Basalt;
- Flint;
- Limestone.

Fig. 1. Aggregates used in hydraulic concrete formulations

The basalt used is a volcanic rock from the Talix Mine Grand Lefebvre quarry in the Ngoudiane area (Thiès region, Senegal). The flint used is a siliceous sedimentary rock from the SOCOBEG quarry in the Taïba Ndiaye area (located in the Thiès region of Senegal). Limestone is a sedimentary rock used as a raw material in the manufacture of hydraulic concrete and cement. It comes from the quarry “Le sable de Allou Kagne” a few kilometers from the city of Thiès (Senegal). The complete identification of these aggregates was carried out at the LNR-BTP Laboratory, ex-CEREEQ, and the results obtained are reported in Tables 1 to 3 below.

Table 1. Geotechnical parameters of basalt

Basalt	0/3	3/8	8/16
Flattening (%)	-	27,22	15,12
MD (%)	-	9,6 - 9,2	7,4 - 7
LA (%)	-	14,2	8,8
Specific weight	2,809	1,464	1,479
Bulk density (g/cm3)	1,623	1,568	1,647
ES control	74	-	-
ES (mel.50x50(%))	46	-	-

Table 2. Geotechnical parameters of flint

Flint	0/3	3/8	8/16
Flattening (%)	-	35.9	14.52
MD (%)	-	12.2 - 12.6	8,4 - 7.8
LA (%)	-	28.4	34.52
Specific weight	2,304	1,221	1,252
Bulk density (g/cm3)	1,204	1,240	1,376
ES control	74	-	-
ES (mel.50x50(%))	31	-	-

Table 3. Geotechnical parameters of limestone

Limestone	0/3	3/8	8/16
Flattening (%)	-	8.53	6.53
MD (%)	-	62.2 - 57.8	59.2 - 58.8
LA (%)	-	47.34	44.74
Specific weight	2,398	1,192	1,195
Bulk density (g/cm3)	1,363	1,279	1,257
ES control	32	-	-
ES (mel.50x50(%))	46	-	-

2.2 BINDER CHARACTERIZATION

The binders used are hydraulic binders composed of cement and fly ash as a cement substitute at different percentages (5%, 10% and 20%).

2.2.1 CEMENT

The cement used is type CEM II/B 32.5 R from the DANGOTE cement works, whose physico-chemical and mechanical characteristics are given in tables 4, 5 and 6 below [5], [6], [7], [8], [9].

Table 4. Chemical composition of cement used (%)

SiO2	Al2O3	Fe2O3	CaO	MgO	P_2O5	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 5. Cement physical parameters

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

Table 6. Compressive strength of CEMII/B 32.5 cement

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

2.2.2 THE CASE OF FLY ASH

The fly ash used, from the Bargny-Senegal coal-fired power plant, is siliceous in nature and mostly spherical in shape. Its pozzolanic activity indices are equal to 77% and 96% respectively for 28-day and 90-day maturities, in accordance with the standard [10]. Its physical characteristics [11] are such that its Blaine specific surface is equal to 4126 cm^2/g and that of the BET method is equal to 7.3 m^2/g. Its chemical composition is given in the following table 7.

Table 7. Chemical composition of the fly ash used

Chemical elements		Mass %	NF EN 450-1
Majority items	**SiO_2**	**48,94**	
	Al_2O_3	**29,65**	**> 70%**
	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	-

2.3 FORMULATING HYDRAULIC CONCRETES

For the concrete study, three types of formulations were selected for the different natural aggregates (basalt, flint and limestone) according to the Dreux-Gorisse method [4] (the target conditions are given in Table 8). Depending on the degree of substitution of cement by fly ash (5%, 10% and 20%), twelve (12) hydraulic concrete formulas were designed (Figure 2). The optimum mix for the concrete composition was calculated using LOBOWIN software, then each component of the mix was weighed and placed in the concrete mixer. Depending on the amount of water poured into the mixer, the consistency of the concrete is checked by measuring the slump with an Abrams cone (Figure 2a). After each slump check, the density of the fresh concrete is determined by simply weighing the 16x16x16 cm cubic test specimen with steel reinforcement, and the operation is carried out according to the formulas of suitability. Figure 3 shows the test bodies of concrete after one day's curing in an immersion room.

a) b)

Fig. 2. a) slump measurement and b) measurement of concrete density

Table 8. Target conditions for formulating XC1 concretes [12]

Consistency	Mini resistance	Minimum binder content (kg/m^3)	Type of sand	Ratio W/Binder max
Normally S2 vibrated plastic concrete (50 to 90mm)	Class C25/30	400	Clean rolled sand	0,65

Fig. 3. Improved hydraulic concrete specimens, just after demolding

For each type of aggregate, four (04) formulation types were selected: one formula for the control concrete and 3 formulas for concretes in which cement is substituted by fly ash at different levels (5%, 10% and 20%). The following codifications were adopted:

- **CB**: basalt-based concrete
- **CF**: flint-based concrete
- **CL**: limestone-based concrete

The various formulations are shown in Tables 9 to 11 below:

Table 9. Formulation of basalt-based concretes

Concrete	AB1 8/16 (kg)	AB2 3/8 (kg)	M (50% S and 50% AB3 0/3) (kg)	Cement (kg)	Ash (kg)	Water (L)	Target size (cm)	Subsidence obtained (cm)	Effective water (L)	W/BINDER
CB0	49,3	30	39,6	26	0	15	7,5	7,5	14,8	0,569
CB5	49,3	30	39,6	24,7	1,3	15	7,5	7,2	12,4	0,477
CB10	49,3	30	39,6	23,4	2,6	15	7,5	7,5	12,8	0,492
CB20	49,3	30	39,6	20,8	5,2	15	7,5	7,5	14,9	0,573

Table 10. Formulation of flint-based concretes

Concrete	AF1 8/16 (kg)	AF2 3/8 (kg)	M (50% S and 50% AF3 0/3) (kg)	Cement (kg)	Ash (kg)	Water (L)	Target size (cm)	Subsidence obtained (cm)	Water used (L)
CF0	38,2	22,3	32,3	26	0	21,5	7,5	7,5	16,4
CF5	38,2	22,3	32,3	24,7	1,3	21,5	7,5	**7,5**	16
CF10	38,2	22,3	32,3	23,4	2,6	21,5	7,5	7,5	17
CF20	38,2	22,3	32,3	20,8	5,2	21,5	7,5	7,5	17,1

Table 11. Formulation of limestone-based concretes

Concrete	AL1 8/16 (kg)	AL2 3/8 (kg)	M (50% S and 50% AL3 0/3) (kg)	Cement (kg)	Ashes (kg)	Water (L)	Target size (cm)	Subsidence obtained (cm)	Water used (L)
CL0	37.1	24	32.1	26	0	18.2	7,5	7,4	17.10
CL5	38,2	22,3	32,3	24,7	1,3	18.2	7,5	7.5	16
CL10	38,2	22,3	32,3	23,4	2,6	18.2	7,5	7,5	17
CL20	38,2	22,3	32,3	20.8	5,2	18.2	7,5	7.5	17.2

3 Results And Discussion

After the hydraulic concrete had been formulated, with the cement replaced by fly ash at different substitution rates, cylindrical test bodies 16x32cm were made and crushed at 7 days, 14 days and 28 days. The results obtained are shown in Tables 12 to 14 and Figures 4 to 6 below.

Table 12. Compressive strength of basalt-based concrete with ash-substituted cement at d days

Ages	CB 0%	CB 5%	CB 10%	CB 20%
7 days	22	14	12	10
14 days	31	22	20	17
28 days	39	33	26	25

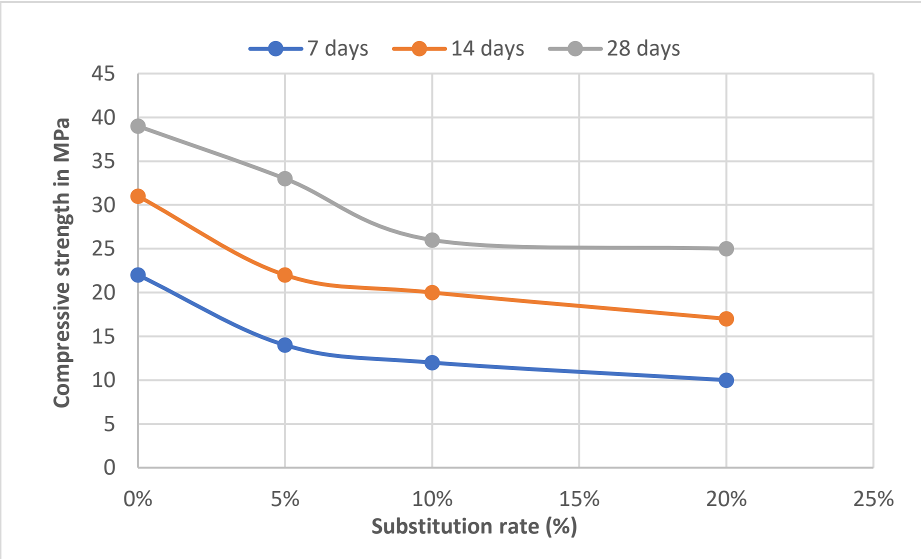

Fig. 4. Compressive strength of basalt-based concrete at different substitution rates

Table 13. Compressive strength of ash-substituted cement-based concrete

Ages	CF 0%	CF 5%	CF 10%	CF 20%
7 days	11	8	8	7
14 days	17	12	11	10
28 days	20	18	16	13

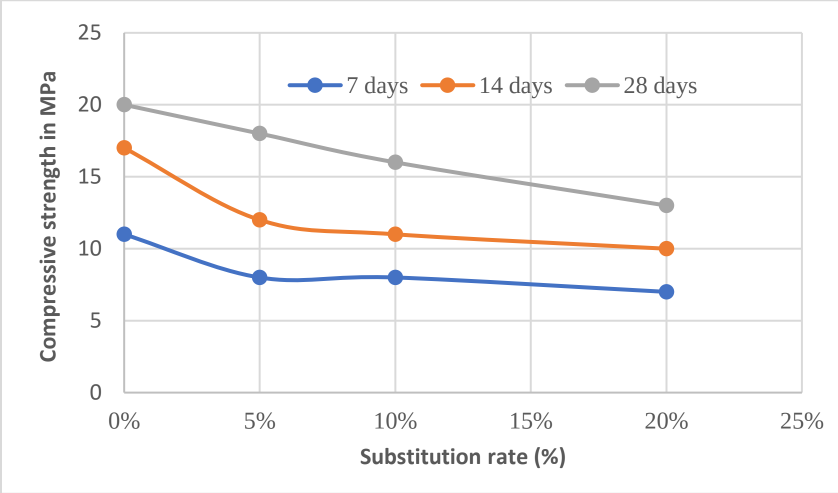

Fig. 5. Compressive strength of flint-based concrete at different substitution rates

Table 14. Compressive strengths of limestone-based concrete with ash-substituted cement at d days

Ages	CL 0%	CL 5%	CL 10%	CL 20%
7 days	10	9	9	8
14 days	16	15	15	12
28 days	19	17	16	14

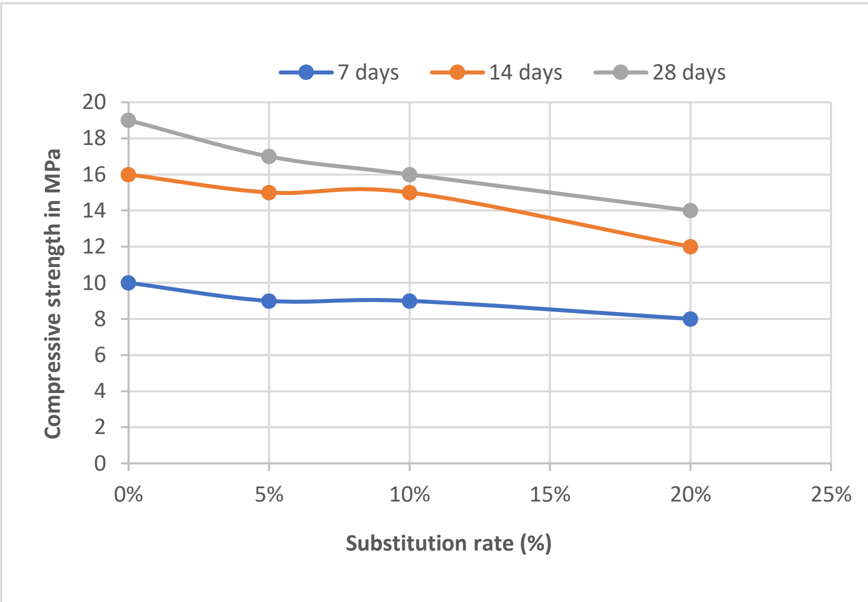

Fig. 6. Compressive strength of limestone-based concrete at different substitution rates

For basalt, the results showed that the strength obtained at 28 days is greater than or equal to the target strength at 28 days (25MPa) for a substitution rate of up to 20%, and that strength decreases as the percentage of ash increases compared with control concretes (Figure 4). The results also show that for the same substitution rate, strength increases with concrete age (Table 12).

Table 13 gives the compressive strengths of flint-based concrete in which the cement has been substituted by fly ash at different contents (0%, 5%, 10% and 20%) at the given curing date ***d*** (with d = 7 days, 14 days or 28 days). The results (Figure 5) obtained showed the existence of two evolutionary phenomena:

- An increase in compressive strength as a function of maturity for all substitution rates;
- A decrease in compressive strength as the rate of substitution of cement by ash increases.

Nevertheless, the strengths obtained at 28 days remain below the target strength at the same date, which is 25 MPa.

For limestone-based concrete, analysis of Table 14 and Figure 6 reveals an increase in the compressive strength of concrete made with limestone aggregate as a function of the curing time of the concrete at different times (7 days, 14 days and 28 days). However, for a given curing time, a decrease in strength is observed as the rate of substitution of cement by fly ash increases. As in the case of flint-based concrete, strengths at 28 days are lower than the strength (25MPa) the concrete would have had at the same time.

4 Conclusion

The aim of this work was to propose ways of valorizing fly ash from the Bargny-Sendou coal-fired power plant for use in the construction industry in general, and in the production of hydraulic concrete in particular, as a substitute for cement at different rates (5%, 10%, 20% and 30%). To carry out this work, first a characterization of the materials was carried out, including the complete identification of the aggregates, then a hydraulic concrete formulation campaign was carried out to produce 16x32cm cylindrical test bodies. Finally, crushing tests were carried out on these test bodies at different times (7 days, 14 days and 28 days) to determine the mechanical characteristics of the different types of concrete. The results showed:

- The strength obtained at 28 days with basalt-based concrete is higher than the target strength at 28 days (25MPa) for a substitution rate of up to 20%, and strength decreases as the percentage of ash increases compared with control concretes (0% ash).
- Resistances obtained at 28 days with flint and limestone-based concrete are lower than those that would be obtained at the same time (25MPa).

Overall, the results obtained showed that the use of fly ash as a substitute for cement is a valuable option from a mechanical, economic and environmental point of view for the production of hydraulic concretes, particularly basalt-based concretes.

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