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Research Article

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Characterization of the Influence of Unconventional Fly Ash from the Bargny-Senegal Coal-Fired Power Plant on Hydraulic Concretes

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Abstract: In this work, we propose to valorize non-conventional fly ash from the Bargny coal-fired power plant (Senegal) in hydraulic concretes. Each year, the Bargny coal-fired power plant produces tons of fly ash considered as industrial waste, apart from that used by SOCOCIM, which must have a loss-on-ignition coefficient of less than 9%. As a result, the remainder, which is not used by SOCOCIM, is of no interest and causes a major storage problem. With this in mind, we proceeded to partially replace the cement in the concrete with different percentages of this fly ash: 10%, 15% and 20% in the concrete. After a laboratory study of the materials to be used in concrete formulation, physical tests were carried out on fresh and hardened concretes, and it was found that fly ash not only considerably improves the fluidity of concretes, since the higher the ash content, the greater the slump, but also makes concretes lighter by considerably reducing their density. With regard to the tensile and compressive strengths of the concretes, we found that at 28 days of age, the concretes with added fly ash had slightly higher strengths than those of the control concrete. Overall, the results show that even though fly ash has not undergone any testing to comply with [1], it can be of great interest in the construction field.

Keywords: Valorization - Fly ash - Coal-fired power plant - Bargny-hydraulic concrete.

1. 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. Although SOCOCIM uses fly ash from this plant, but only if the loss on ignition is less than 9%, this means that fly ash from boilers with a loss on ignition of over 9% poses a long-term storage problem, given the large quantities of ash produced. Reusing this ash would therefore be beneficial from all points of view:

Economically, the competitive price of using fly ash in cement-based matrices is a major advantage. Used judiciously, fly ash concrete is very cost-effective. It's quick and easy to install, and requires less material and manpower, which in some cases means shorter construction times.

Environmentally, in terms of reduced greenhouse gas emissions and lower energy consumption than clinker production. Technologically, it is recognized that the pozzolanic properties of fly ash can improve concrete properties, particularly in the hardened state. With this in mind, we focused our research on the possibility of using fly ash in hydraulic concrete. According to the literature, conventional fly ashes are reputed to improve the durability of concrete, so even if these ashes are not conventional, as they have not undergone chemical and physical tests apart from the loss on ignition test, they should be able to contribute something extra to hydraulic concretes.

The aim of the present study, entitled " The valorization of unconventional fly ash from the Bargny coal power plant in hydraulic concrete ", is to valorize non-conventional fly ash from the Bargny coal-fired power plant in hydraulic concretes, and to demonstrate that fly ash is an eco-material that does not degrade the structuring and durability properties of concretes. To this end, we will evaluate the contribution in terms of behavior and mechanical characteristics generated by the incorporation of fly ash at different percentages (10%, 15% and 20%) in concrete, then compare it with a control concrete without fly ash incorporation. To do this, we will begin the experimental study, starting with material characterization followed by theoretical concrete formulation using the DREUX GORISSE method [2], then present the results of the study.

2. Materials and Methods

Determination of specific gravity and bulk density

The specific weight of the materials was determined by hydrostatic weighing in accordance with [3]. The results give specific weights of 2.588 g/cm^3 and 2.611 g/cm^3 for fractions 3/8 and 8/16 respectively. The equipment used to determine bulk density consisted of a mold with a volume of 2103 cm^3 and a tare weight of 5069 g, a 30 kg capacity balance and a hand. The fall height of the material was set at 15 cm. The densities obtained as a function of concrete age are given in Table 4.

Tests on fresh concrete: Abrams cone slump

On fresh concrete, Abrams cone slump was measured in accordance with standard [4]. Test results are given in Table 3.

Compression test

The compressive strength of concrete is one of the fundamental parameters used to assess concrete quality. Compressive strength is often considered the most important property of concrete for several reasons [5]. Nine (9) molds were made for each type of concrete. Crushing was carried out at 7 and 28 days to define compressive strength in accordance with [6].

Tensile test

Concrete tensile strength is another important property for assessing concrete quality. In accordance with standard [7], this is measured by the indirect tensile strength test, also known as the Brazilian or splitting test. Although concretes are generally not designed to resist direct tension, knowing the tensile strength enables us to estimate the load under which cracking develops [5].

3. Concrete Formulation

Mass proportioning for 6 specimens of control concrete B.0

Concrete formulation is linked to a construction operation. We will consider the formulation of a material that will be used to manufacture structural elements inside a future residential building (category A) with exposure class XC1 [8].

- Characteristic 28-day cylinder compressive strength: f_{ck} = 25 MPa (class C25/30 concrete);
- Consistency required for placement: normally vibrated plastic concrete with a target slump of around 7.5 cm.

The characteristics of the materials available are:

- Cement CEM II 32.5R (commercial strength class) density 3.1;
- Clean rolled sand with absolute density ρ_s = 2500 kg.m^{-3};
- 3 good-quality crushed aggregates (8/16, 3/8, 0/3) with respective absolute densities $\boldsymbol{\rho_d}$ = 2940 kg.m^{-3}, 2780 kg.m-3, 2770 kg.m^{-3}
- Water

The proposed formulation method involves three phases:

- Obtaining the C/E ratio from the strength and therefore the quality of the target paste;
- Determining the quantity of C+E paste and the maximum granular skeleton compactness resulting from the desired workability;
- The balance of the quantities of each of the constituents (masses of cement, water, sand, 0/3, 3/8 and 8/16) and the theoretical density of the concrete $\boldsymbol{\rho_{th}}$.

The dosage of each component of control concrete B_0 for 6 specimens is shown in Table 1.

Table 1: Mass dosage for 6 specimens of B_0

Constituents	Mass (kg)
Cement	19.26
Aggregates 0/3	21.67
Sand	10.20
Aggregates 3.8	18.84
Aggregates 8/16	39.85
Water	10.43
Total weight	120.28

Mass proportioning for 6 specimens of concrete with fly ash

The mass of ash at different percentages is determined as a partial replacement of the cement mass for 6 specimens at different substitution rates (Table 2). The same W/C (Water/Cement) ratio is maintained for all formulations.

Table 2: Dosage of different percentages of fly ash

Type of Concrete	Substitution rate	Ash mass (kg)
B_1	10%	1,92
B_2	15%	2,89
B_3	20%	3,85

The foregoing has enabled us to determine the volume and mass dosage of each concrete component, i.e. water, aggregates and binders, which will enable us to produce concretes that meet the specifications.

4. Results and Discussion

Table 3 shows the results of Abrams cone slump tests for all concretes (B_0 to B_3).

Table 3: Slump of concretes

Type of Concrete	B_0	B_1	B_2	B_3
Settlement (cm)	7	7,9	8,6	9,1

The evolution of concrete slump as a function of ash dosage is shown in Figure 1.

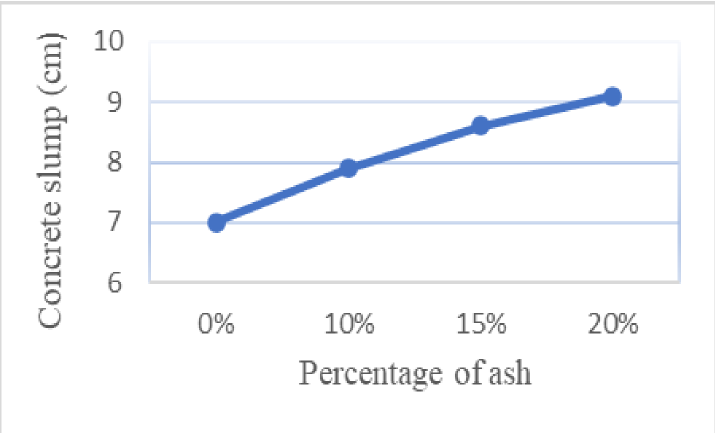

Figure 1: Variation in concrete slump as a function of ash dosage

To give a better idea of the trend in concrete slump as a function of ash dosage, we'll present them in the form of a histogram in Figure 2.

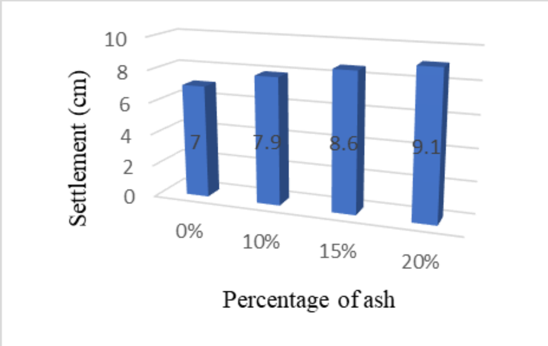

Figure 2: variation in concrete slump as a function of ash dosage

Concrete densities at different ages are given in Table 4.

Table 4: Concrete densities

Type of concrete	Concrete densities (T/m³)		
	7 days	14 days	28 days
B_0	2,573	2,572	2,570
B_1	2,510	2,508	2,503
B_2	2,489	2,486	2,484
B_3	2,342	2,339	2,336

The evolution of concrete densities as a function of ash dosage is shown in Figure 3.

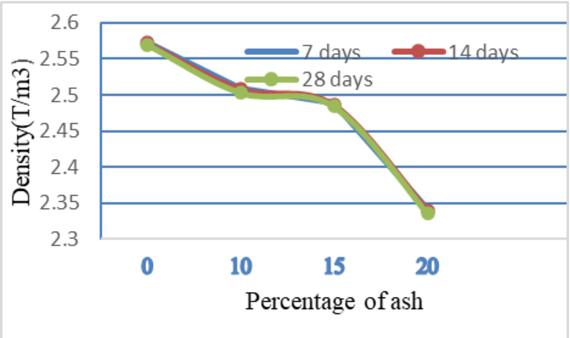

Figure 3: Evolution of concrete density as a function of ash dosage

For a better view of the trend in concrete density as a function of ash dosage, we'll present it in the form of a histogram (Figure 4).

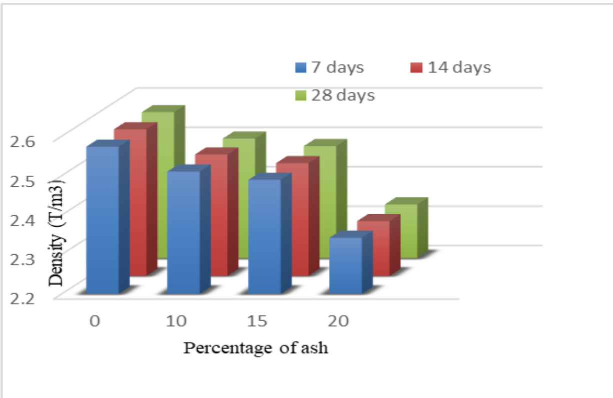

Figure 4: Evolution of concrete density as a function of ash dosage

The results of concrete compression tests at 28 days, 14 days and 7 days of age are shown in Table 5 below:

Table 5: Results of concrete compression tests

Types of concrete	Compressive strength of concrete (MPa)		
	7 days	14 days	28 days
B_0	15,51	19,35	24,43
B_1	14,62	19,11	24,67
B_2	14,54	19,18	24,88
B_3	14,36	19,26	25,06

The variation in compressive strength of concrete as a function of the number of days is shown in Figure 5.

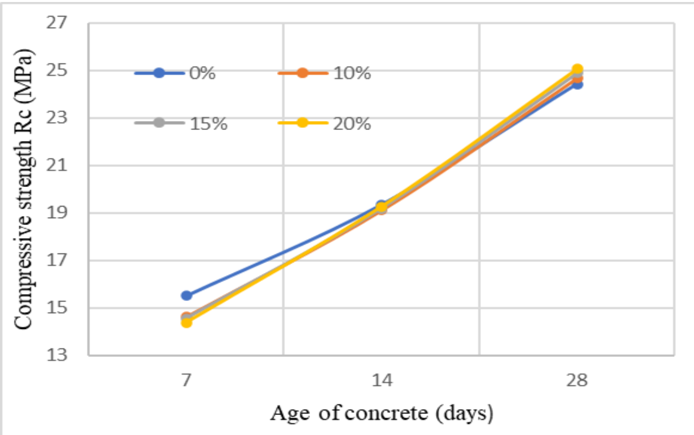

Figure 5: variation in compressive strength as a function of number of days

The trend in compressive strength variation for the different concretes is shown in the form of a histogram in Figure 6.

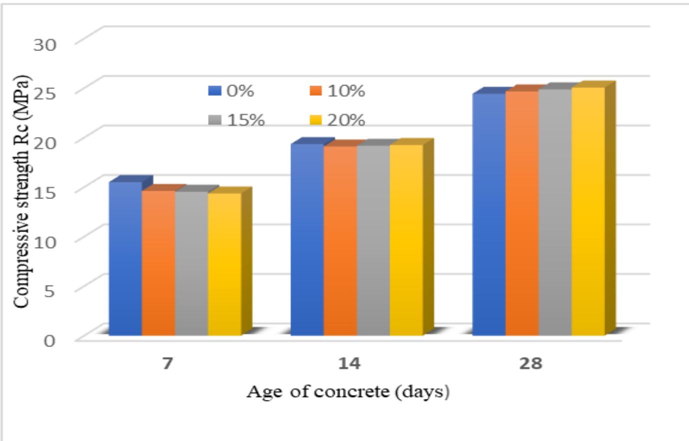

Figure 6: Variation in compressive strength as a function of number of days

In this way, we can calculate the variations in compressive strength of concrete compared to control concrete using the following formula:

$$\Delta = \frac{R_{CB0} - R_{CBC}}{R_{CB0}} x100 \qquad \text{(Eq. 1)}$$

With:

R_{cB0}: Compressive strength of control concrete at day-old.

R_{cBc}: Compressive strength of ash-treated concrete at day's age

Table 6 shows the variation in compressive strength of concrete with ash compared with concrete control.

Table 6: Variations in compressive strength of concrete with ash compared with control concrete

Type of concrete	% change		
	7 days	14 days	28 days
B_1	-5,73	-1,24	+0,98
B_2	-6,25	-0,87	+1,84
B_3	-7,41	-0,46	+2,57

Tensile test results for concrete at 7, 14 and 28 days of age are shown in Table 7:

Table 7: Results of tensile tests on concrete

Type of concrete	Concrete tensile strength (MPa)		
	7 days	14 days	28 days
B_0	2,09	2,64	2,72
B_1	1,87	2,57	2,78
B_2	1,82	2,53	2,82
B_3	1,76	2,48	2,87

The variation in tensile strength of concrete as a function of the number of days is shown in Figure 7.

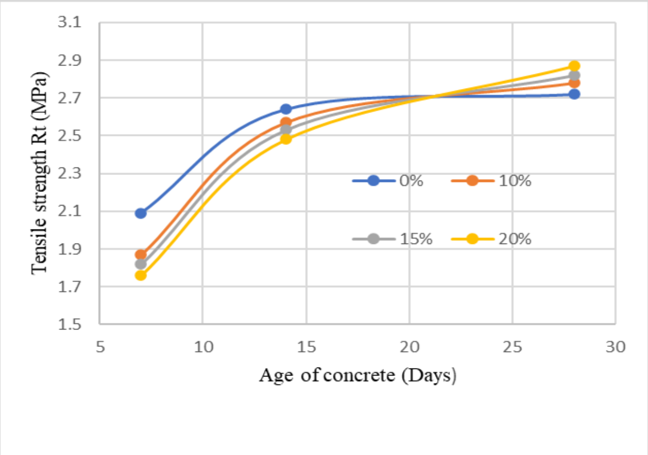

Figure 7: Variation in tensile strength of concretes B_0, B_1, B_2, B_3 as a function of the number of days.

To give a better idea of the variation in tensile strength of the different concretes, we'll present them in the form of a histogram (Figure 8).

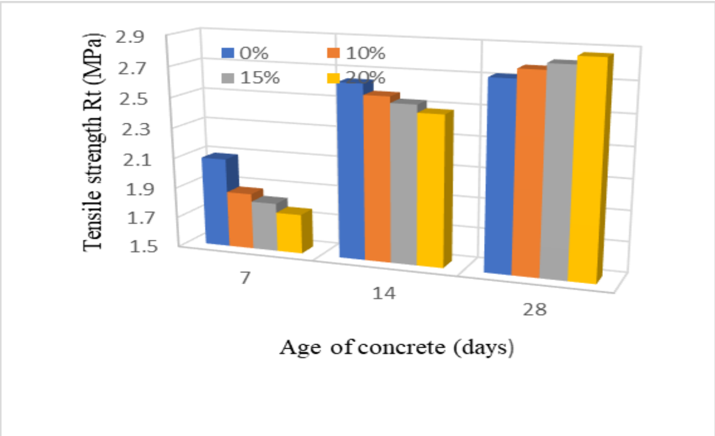

Figure 8: variation in tensile strength of concretes B_0 , B_1, B_2, B_3 as a function of the number of days.

Thus, the variations in tensile strength of concrete with ash added compared to control concrete can be calculated using the following formula:

$$\Delta = \frac{R_{tB0} - R_{tBC}}{R_{tB0}} x100 \qquad \text{(Eq. 2)}$$

With:

R_{tB0}: Tensile strength of control concrete at day-old

R_{tBc}: Tensile strength of concrete with ash after one day of age

Table 8 shows the variation in tensile strength of concrete with ash compared to control concrete.

Table 8: Variation in tensile strength of concrete with ash compared with control concrete

Type of concrete	Gap (%)		
	7 days	**14 days**	**28 days**
$\mathbf{B_1}$	-10,52	-2,65	+2,2
$\mathbf{B_2}$	-12,91	-4,16	+3,67
$\mathbf{B_3}$	-15,78	-6,06	+5,51

Figures 1 and 2 show that the workability, i.e. the slump of the concrete at the Abrams cone, increases with increasing ash dosage, since the slump of the control concrete is 7cm, rising to 7.9cm with 10% ash, then to 8.6cm with 15% ash and to 9.1cm with 20% ash added.

Fly ash therefore acts as a superplasticizer: as the percentage of ash increases, so does the workability of the concrete, enabling a considerable reduction in water content and consequently in the W/C ratio, which is likely to lead to an increase in concrete strength. Figures 3 4 show that, irrespective of age, concrete density decreases with increasing fly ash content. This can be explained by the low density (0.72 g/cm³) of ash compared to cement. In fact, concrete containing 100% cement has a higher density than those containing fly ash, so the density of concretes with ash decreases as the percentage of ash increases, i.e. concrete B1 has a higher density than B2 and the latter has a higher density than B3. Figures 5 and 6 show the difference in strength between concretes of different ages:

At 7 days, the compressive strength of the control concrete is approximately 1 MPa higher than that of the concrete containing fly ash. The variation in strength of B1, B2 and B3 concretes compared with the control concrete B0 is shown in Table 6. It can also be seen that compressive strength decreases with increasing ash content. It can be said that fly ash reduces the compressive strength of concrete at 7 days of age, i.e. at young age, and this can be explained by the fact that at 7 days the pozzolanic activity of the ash responsible for the strength gains has not yet begun. The main discrepancies in the literature concern the age at which the pozzolanic reaction begins, with results ranging from 3 to 28 days.

At 14 days, as at 7 days It can be seen that the compressive strength of the control concrete is higher than that of the concrete containing fly ash, but lower by around 0.2 MPa. The variation in strength of concretes B1, B2 and B3 compared with control concrete B0 is shown in Table 3. Here, unlike the 7-day concretes, we can see that between 7 and 14 days the gain in strength of the concretes with ash is higher than that without ash, although the latter still has a higher strength, so we can say that between 7 and 14 days we have the start of a pozzolanic reaction of the fly ash in the concrete.

At 28 days, the trend is reversed, i.e. concretes containing ash have slightly higher compressive strengths than the control concrete, of the order of around 0.5 MPa, so the pozzolanic reaction that began between 7 and 14 days is still evolving, giving concrete with ash higher strengths than the control concrete, even if the gain in strength is very minimal. As with compressive strengths, tensile strengths show the same trend whether at 7 days, 14 days or 28 days (Figures 7 and 8), i.e. at 7 days the tensile strength of fly ash concrete is lower than that of control concrete, and at 14 days, but at 28 days the tensile strength of concretes B.1, B.2 and B.3 becomes slightly higher than that of B0.

5. Conclusion

In this study, we presented the results of fresh and hardened tests on the various concretes we had formulated, and then proceeded to interpret them. The results were positive concerning the performance of concretes with added fly ash, especially those containing 20%. This work has shown us that concretes with added fly ash can present many advantages in the fresh state, by considerably improving the fluidity of the concretes, but also in the hardened state, by improving the density, compressive strength and tensile strength of the concretes. Results show that the optimum fly ash content is around 20% by weight of cement. It can therefore be said that the unconventional fly ash from the Bargny power plant can be valorized by incorporating it into hydraulic concretes, which will not only solve the storage problem caused by the ash, but also reduce the excessive production of greenhouse gases by reducing the quantity of cement used in concretes, thus impacting on total construction costs.

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