ISSN: 0976-3376

Available Online at http://www.journalajst.com

ASIAN JOURNAL OF
SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 15, Issue, 10, pp. 13120-13125, Octoberr, 2024

RESEARCH ARTICLE

RECYCLING OF UNCONVENTIONAL FLY ASH FROM THE BARGNY COAL-FIRED POWER PLANT IN SENEGAL FOR THE PRODUCTION OF HYDRAULI BINDERS

Serigne DIOP*, Oustasse Abdoulaye Sall, Déthié SARR and Makhaly BA

Laboratoire de Mécanique et Modélisation (L2M), Université Iba Der Thiam, Thiès, Sénégal

ARTICLE INFO

Article History:
Received 27th July, 2024
Received in revised form
17th August, 2024
Accepted 11th September, 2024
Published online 23rd October, 2024

Keywords:

Valorization; Fly ash; Coal-fired power plant; Bargny; Hydraulic binders; Mortars; Clinker-DANGOTE.

ABSTRACT

The aim of the work is to valorize the unconventional fly ash from the Bargny coal-fired power plant, in order to address issues related to the durability of concrete structures, as well as to provide economic and environmental solutions linked to the storage of industrial waste. To this end, a physico-chemical, mineralogical and mechanical characterization of hydraulic binders was carried out at the DANGOTE cement plant laboratory. Firstly, CEM II/B 32.5 R cement from the said plant was substituted with fly ash at different substitution rates (0%, 5%, 10%, 20% and 30%). Subsequently, a cement, with limestone, clinker, phosphogypsum and ash as raw materials substituting clinker at different tenements (5%, 10% and 20%), was designed and produced. After formulation and considering the results obtained, we can say that, on the one hand, the use of fly ash as a substitute product increases the Blaine specific surface area of the cement produced, and therefore its workability, and on the other hand that the mechanical strengths at 2 days and 28 days are within the limits acceptable under NF EN 196-1 regulations for a substitution rate of up to 20%.

Citation: Serigne DIOP, Oustasse Abdoulaye Sall, Déthié SARR and Makhaly BA 2024. "Recycling of Unconventional fly ash from the bargny coal-fired power plant in Senegal for the production of Hydrauli Binders", *Asian Journal of Science and Technology*, 15, (10), 13120-13125.

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. Given the large quantity of ash produced, there will be a long-term storage problem, which could have a negative impact on the environment. In this context, reuse of this ash would be beneficial from all points of view. That's why we've focused our research on the possibility of using this ash in the cement manufacturing process, by substituting clinker at different percentages. According to the literature, conventional fly ashes are reputed to improve the durability of concrete, so even if they are not conventional, as they have not undergone chemical and physical tests apart from the loss on ignition test, these ashes should be able to contribute something extra to the production of hydraulic binders. To achieve this, we will be characterizing the materials used to determine their physico-chemical, mineralogical and mechanical parameters, and to measure their durability and reactivity. The materials to be characterized are:

- Cement produced by DANGOTE;
- Cement synthesized in the laboratory using raw materials such as limestone, clinker, phosphogypsum and ash as a clinker substitute;

A procedural method will be used to characterize each type of cement according to NF EN 197-1 (2012) based on the substitution rate.

MATERIALS AND METHODS

Laboratory cement formulation: The cement designed and manufactured in the laboratory is the result of raw materials (Figure 1) such as clinker, limestone, fly ash and phosphogypsum. The mass composition of this cement is 28% limestone, 3.2% phosphogypsum and 68.8% clinker for a total cement mass of 5kg (Table 1). For the purpose of this work, four types of cement (Figure 2) were formulated according to the percentage of clinker substitution by ash (0%, 5%, 10% and 20%). The grinding time was set at 35 minutes, followed by sieving with a 1mm diameter sieve.

These materials (Figure 1) used in the composition of cements have been identified and described as follows:

- ***Clinker:*** a material available in sufficient quantities in the DANGOTE CEMENT plant, it is obtained from the optimal mixture of limestone (80%) and clay (20%) followed by a high-temperature firing at around 1,450°.
- ***Limestone:*** a material very rich in lime carbonate ($CaCO_2$), extracted from the quarry 7 km from the cement plant.
- ***Phosphogypsum:*** A by-product of gypsum (H_2 SO_4), phosphogypsum is a waste product from Senegal's chemical industry (ICS) and acts as a setting regulator.

Fly ash: An industrial waste from the Bargny-Sendou coal-fired power plant in Senegal, characterized by its pozzolanic power, i.e. its content of mineral elements such as silica (SiO_2), alumina (Al_2O_3) and ferrite oxide (Fe_2O_3).The formulation of these four types of cement is given in Table 1 and Figures 1 and 2 below.

****Corresponding Author: Serigne DIOP,***
Laboratoire de Mécanique et Modélisation (L2M), Université Iba Der Thiam, Thiès, Sénégal

Table 1. Formulation of manufactured cements

Nature	Clinker (kg)	Gypsum (kg)	Limestone (kg)	Ash (kg)
0%	3,44	0,16	1,4	0
5%	3,19	0,16	1,4	0,25
10%	2,94	0,16	1,4	0,5
20%	1,952	0,128	1,12	0,8

Figure 1. Raw materials used to manufacture laboratory cement

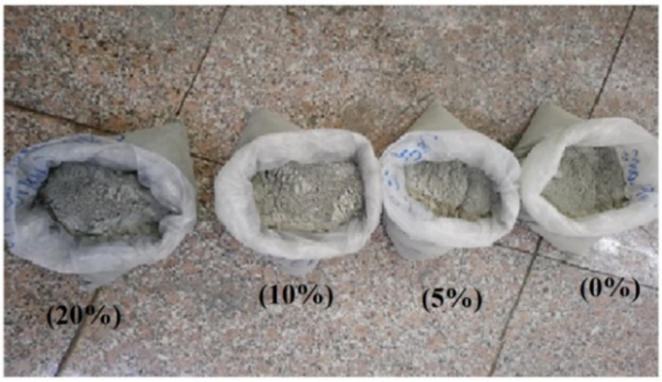


Figure 2. Cement obtained after grinding and passing through a 1mm diameter sieve for different ash contents (0%, 5%, 10%, 20%).

The characteristics of the cements resulting from this work will be compared with those of the hydraulic binder type CEM II/B 32.5 R from DANGOTE CEMENT, which will be considered as the control cement.

Cement Characterization

Mechanical Characterization: To determine the cement's mechanical properties, prismatic mortar specimens measuring 40x40x160mm were made using the mass ratios of a conventional standardized mortar (m_{sable} = 3x m_{liant} and m_{liant} = 2x m_{eau}). An electric mixer with a capacity of ***5 l*** was used to make the mortars according to the following procedure (NF EN 196-1):

- The water is completely introduced into the mixer,
- The binder is poured into the water;
- Mixing starts immediately at low speed for 30 seconds;
- Without stopping the mixer, sand is gradually added for 30 seconds;
- Mixing continues for 30s at high speed;
- The 90s pause is performed where manual scraping is done in the first 15 seconds;
- Restart mixing at high speed for 60 sec.

The molds are filled in 3 layers using a standardized impact table. The specimens are stored in a humid room (RH>96%) where the temperature is regulated at 20°C. Twenty-four hours after manufacture, the specimens are demolded and stored in water in a room at 20° (±1°C) until the day of crushing (Figure 3). The results of the crushing tests will be compared with the mechanical specifications in Table 2.

Table 2. Strength values by strength class (NF EN 196-1)

Designation class	Compressive strength (MPa)			
	Short-term resistance		Current resistance	
	at 2 days	at 7 days	at 28 days	
32,5 N	-	≥ 16	≥ 32,5	≤ 52,5
32,5 R	≥ 10	-		
42,5 N	≥ 10	-	≥ 42,5	≤ 62,5
42,5 R	≥ 20	-		
52,5 N	≥ 20	-	≥ 52,5	-
52,5 R	≥ 30	-		

Figure 3. a) Test tubes, b) Crush test

Fire loss measurement: The test consists in drying a ***1g*** sample of cement at 105°C, which is then introduced into a kiln following the heating curve of the fired aggregates. At the end of the firing process, the mass of the sintered aggregates is determined. The loss of mass on firing is obtained by the following equation.

$$LOI = \frac{m_1 - m_2}{m_1} x100 \qquad \text{………….(Eq.1)}$$

Setting time measurement: It is determined by the moment when the Vicat needle - a needle with a cross-section of 1 mm2 and weighing 300 g - no longer sinks to the bottom of a pellet of pure cement paste. The test procedures are described in standard NF EN 196-3. Depending on the type of cement, the setting time must be greater than 45 minutes or 1 hour.

Blaine fineness: It is used to measure the fineness of grind of a cement. It is characterized by the specific surface or total developed surface of all the grains contained in one gram of cement (standard NF EN196-6). It is expressed in cm^2 /g and its value is generally between 2,800 and 5,000 cm2/g, depending on the type of cement.

Control cement study

Chemical and physical characterization: The cement used in this study is CEM II/B 32.5 R hydraulic binder from DANGOTE CEMENT (Senegal). A chemical, mineralogical, physical and mechanical characterization of the cement was carried out. The chemical composition of the control cement is given in Table 3. The physical characteristics of cement are given in Table 4.

Mechanical Characterization: To determine the strength of cements, the first step is to prepare mortar specimens with standardized sand, which are kept in an immersion room until the day of crushing (Figure 3). The results of the crushing tests are given in Table 5 below. In the same vein, a mortar formulation in which cement was substituted by fly ash at different substitution rates (5%, 10%, 20% and 30%) was carried out. Data and results relating to this formulation are reported in Tables 6 and 7 below.

Table 3. Chemical composition of control cement

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	Na O_2	K O_2	SO_3	Cl
%	%	%	%	%	%	%	%	%	%
15,17	3,88	3,23	63,31	0,19	0,65	0,04	0,3	0,87	0,007

Table 4. Physical parameters of cement

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

Table 5. Compressive strength of cement CMII/B 32.5

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

Table 6. Mortar formulation using fly ash instead of cement

Designation	Indicator	CVCP			
	0%	5%	10%	20%	30%
Cement (g)	450	427,5	405	360	315
Standardized sand (g)	1350	1350	1350	1350	1350
Water (g)	225	225	225	225	225
Ash (g)	0	22,5	45	90	135

Table 7. Compressive strength with and without substitution of ash for control cement

Substitution rate	Compressive strength of mortar (MPa)		
	2 days	28 days	90 days
0%	10,6	42,2	55,3
5%	11,2	45,4	59,5
10%	9,6	40,2	56,7
20%	7,9	34,1	52,9
30%	4,9	26	41,2

Table 8. Cement formulation

Substitution rate	Clinker	Gypsum	Calcareous % (%)	Ash % (%)
0%	68,8	3,2	28	0
5%	63,8	3,2	28	5
10%	58,8	3,2	28	10
20%	48,8	3,2	28	20

Table 9. Chemical composition of cements with different substitution rates

Substitution rate	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	P_2O_5 (%)	NaO_2 (%)	KO_2 (%)	SO_3 (%)	Cl (%)
0%	17,5	5,02	3,39	60,26	0,63	0,66	0,16	0,36	1,07	0,008
5% CV	16,25	4,39	3.5	61,62	0,61	0,65	0,1	0,3	1,31	0,009
10% CV	18,24	5,78	3,39	57,76	0,68	0,7	0,15	0,33	1,28	0,009
20% CV	20,96	7,65	3,89	51,78	0,77	0,72	0,2	0,39	1,3	0,011

Table 10. Physical parameters of cements

Substitution rate	Blaine (cm^2 /g)	Refusal 45 (%)	Refusal 90 (%)	Fire loss (%)
0%	4809	-	4,7	12,16
5% CV	5757	-	3,8	13,77
10% CV	6003	12,7	1,2	12,92
20% CV	6619	9,4	2,2	14,66

Table 11. Compressive strength of cements manufactured at different rates of clinker/ash substitution (MPa)

Clinker substitution rate	Compressive strength of mortar (MPa)		
	2 days	28 days	90 days
0%	8,8	37,1	48,7
5%	8,4	36	47,6
10%	7,9	41,4	49,8
20%	5,9	36,2	44,3

Cement designed and manufactured using ash instead of clinker

Formulation and chemical composition: Following characterization of the control cement, we set about producing cements by substituting clinker with fly ash at different percentages, the formulation and chemical composition of which are given in Tables 8 and 9 below. The chemical composition of the cements manufactured and their constituents are determined by X-ray diffraction (XRD) analysis. Chemical analysis of cements is carried out in accordance with standard EN 196-2.

Physical and mechanical characterization: Blaine specific surface area is an important parameter for characterizing cement fineness. Other physical parameters were also determined, such as: percentage of rejects at sieves 45 and 90, loss on ignition, setting start and end times (Table 10). Cements are divided into three strength classes 32.5, 42.5 and 52.5, defined by the cement's strength value. Cement strength corresponds to the mechanical compressive strength measured at 28 days in accordance with EN 196-1 and expressed in MPa. It is measured on normal mortar specimens and is used to determine the cement strength class as specified in Table 2. For the purposes of this study, the test results are given in Table 11 below.

RESULTS AND DISCUSSION

To characterize the materials involved, cement of type CEM II/B 32.5 R from the DANGOTE cement plant was initially substituted with fly ash at different substitution levels (0%, 5%, 10%, 20% and 30%). Subsequently, a cement, with limestone, clinker, phosphogypsum and ash as raw materials substituting clinker at different strengths (0%, 5%, 10% and 20%), was synthesized**.** The results of the physicochemical, mineralogical and mechanical characterization of the materials are shown in the following Figures 4 to 16.

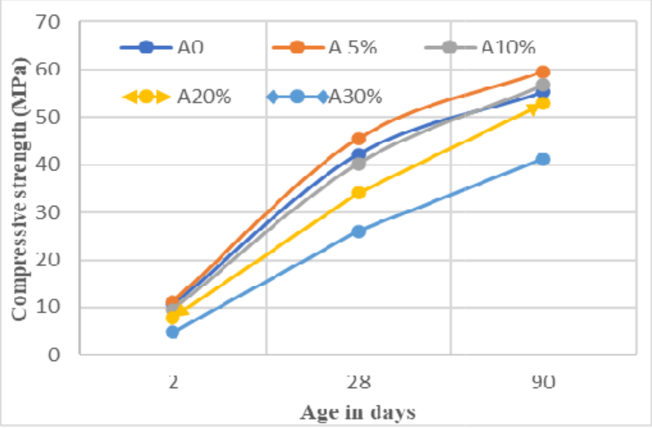


Figure 4. Compressive strength of DANGOTE cement at different substitution rates

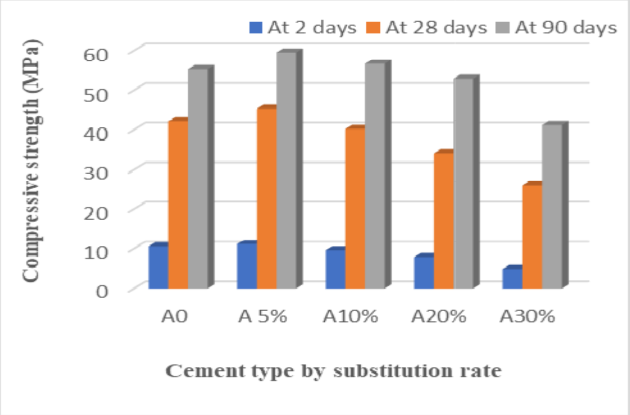


Figure 5. Compressive strength of cement at day as a function of substitution rate

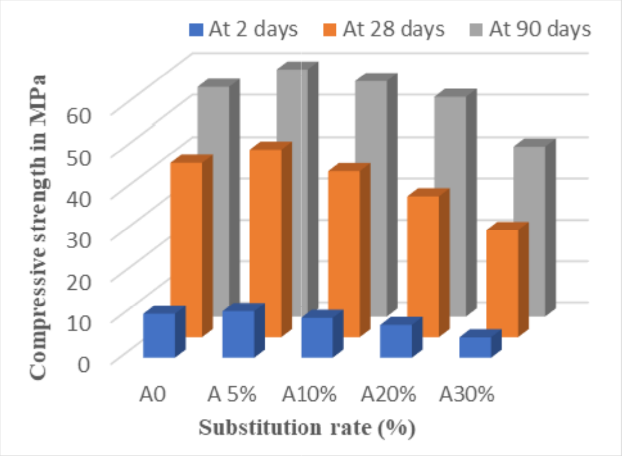


Figure 6. Compressive strength of cement at different substitution rates

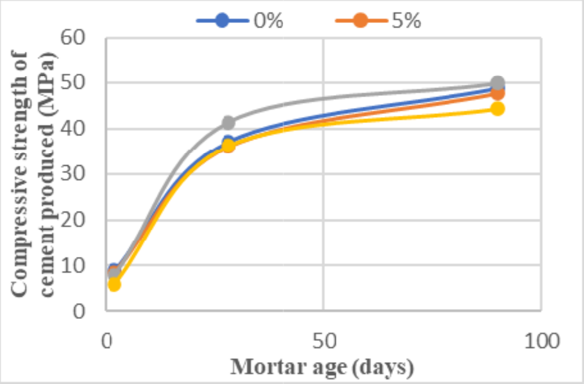


Figure 7. Compressive strength of cement obtained by substituting fly ash for clinker

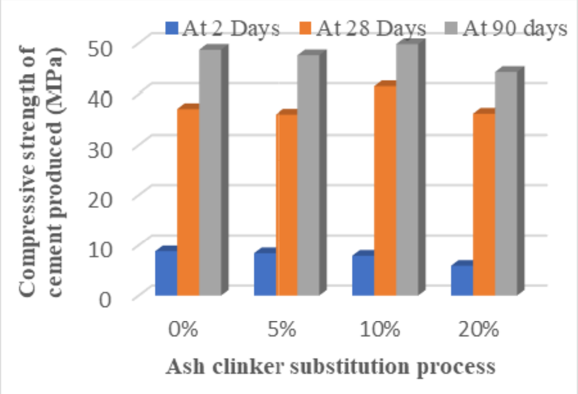


Figure 8. Compressive strength of cement obtained by substituting fly ash for clinker

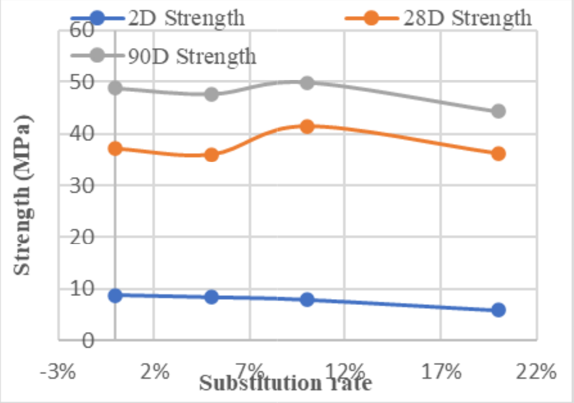


Figure 9. Compressive strength of cement obtained by substituting fly ash for clinker at different days of age

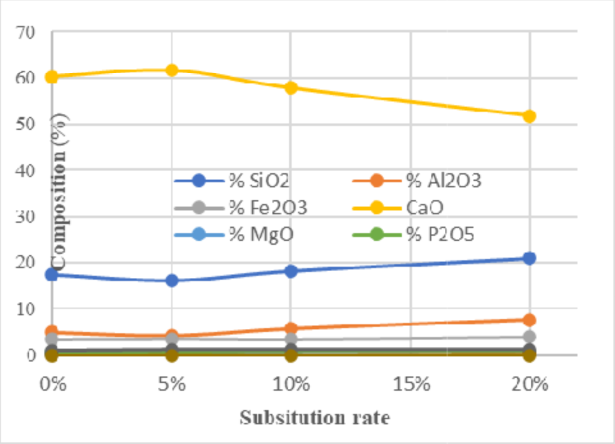


Figure 10. Chemical composition of cement obtained by substituting fly ash for clinker

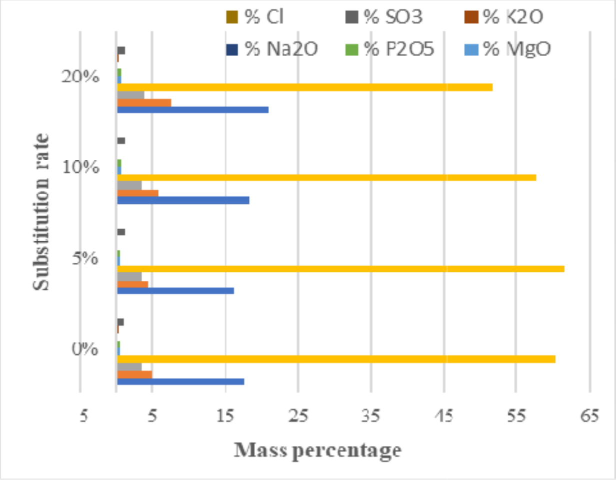


Figure 11. Chemical composition of cement obtained by substituting fly ash for clinker

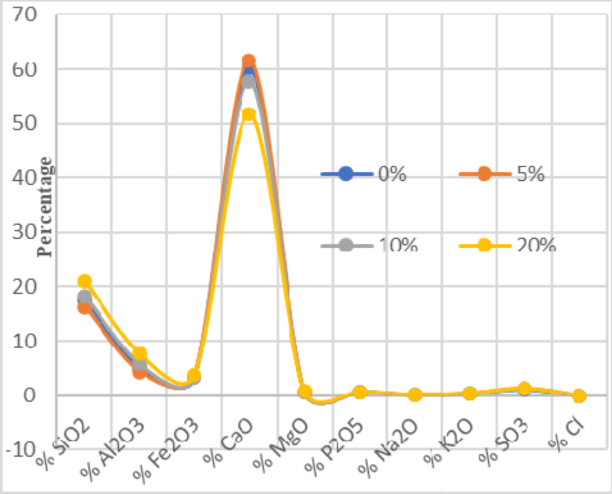


Figure 12. Chemical composition of cement obtained by substituting fly ash for clinker

The results obtained show that the Blaine specific surface area increases with the percentage of clinker substituted by ash (Table 10, Figure 13). This is in line with results found in the literature, which show that the Blaine specific surface area of ash is greater than that of cement. This gives the ash a pozzolanic power with an activity index ***I*** of between **0.67** and **1** according to ASTM C618. Overall, these results show that increasing the specific Blaine surface area of cement gincreases the workability of concrete or mortar, which in turn reduces the time and labor involved in placing them.

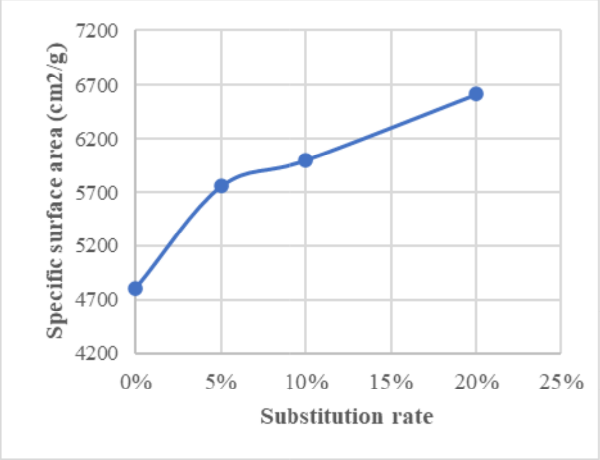


Figure 13. Evolution of the specific surface area of the cement obtained as a function of the rate of clinker substitution by fly ash

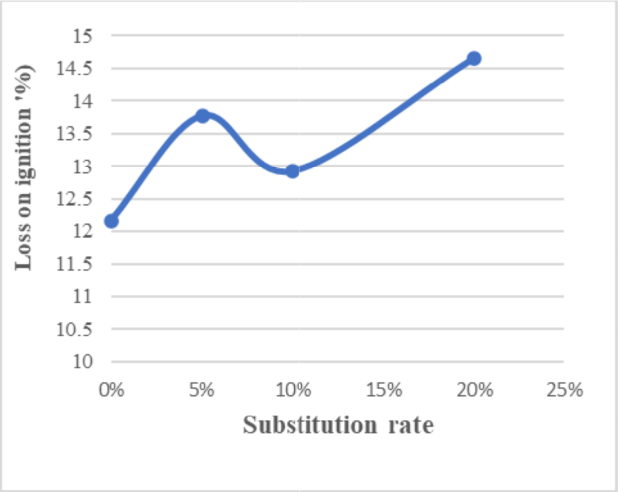


Figure 14. Loss on ignition of cement produced as a function of the rate of substitution of clinker by fly ash

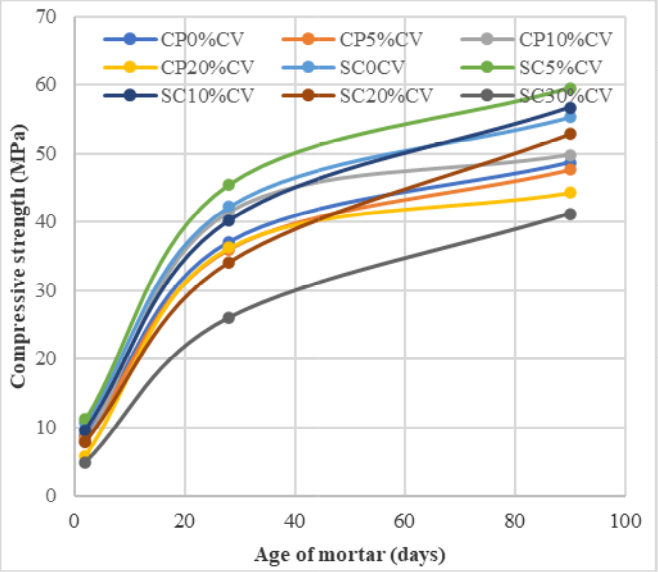
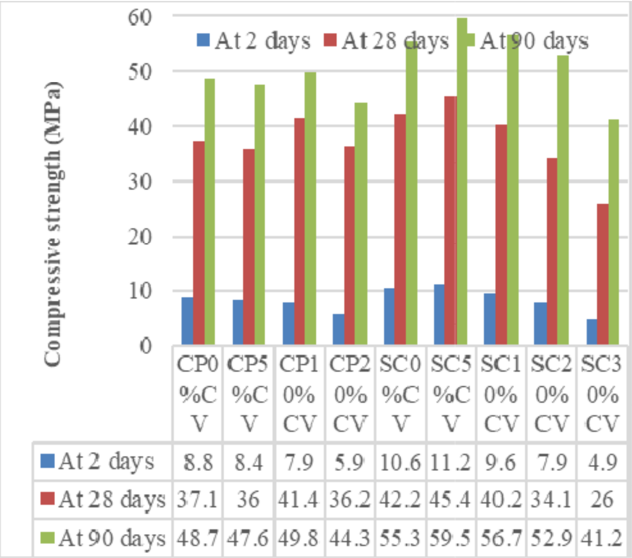


Figure 15. Comparison of cement performance with fly ash-substituted CEM II/B 32.5 R

Figures 4 to 8 show that the compressive strengths of cement produced with or without ash substitution for clinker are higher than the target 28-day strength of 32.5 MPa. The results also show that 2-day strengths remain below the target, which must be greater than or equal to 10 MPa, while 90-day strengths increase by around 10 MPa compared with those obtained after 28 days of curing.



	CP0%CV	CP5%CV	CP10%CV	CP20%CV	SC0%CV	SC5%CV	SC10%CV	SC20%CV	SC30%CV
At 2 days	8.8	8.4	7.9	5.9	10.6	11.2	9.6	7.9	4.9
At 28 days	37.1	36	41.4	36.2	42.2	45.4	40.2	34.1	26
At 90 days	48.7	47.6	49.8	44.3	55.3	59.5	56.7	52.9	41.2

Figure 16. Histogram of cement performance and that of CEM II/B 32.5 R substituted with fly ash

The strength of the cement manufactured in the course of this work increases at 28 days and 90 days for a clinker substitution rate of 10% by fly ash. By contrast, it decreases for substitutions of 5% and 20% at all curing times (2 days, 28 days and 90 days) compared with that obtained with the control test (0% fly ash). The compressive strengths at 2 days and 28 days for the two types of cement in the study exceed the limit values accepted by standard EN 196-1 (Table 2) up to 20% of the substitution ratio of cement and clinker (Figures 15 and 16). Figure 16 shows that the mechanical performances found with clinker substitution by ash are better than those found with direct cement substitution by ash. Chemical analysis (Figures 10 and 11) correlated with compressive strength at 5% clinker substitution shows that mechanical performance increases with the amount of lime (C_a O) present in the product. Overall, the results obtained show that the use of fly ash as a substitute for cement and/or clinker is a beneficial recovery route from the point of view of mechanical, economic and environmental performance.

CONCLUSION

The aim of this work was to propose ways of valorizing non-conventional fly ash from the Bargny-Sendou coal-fired power plant, with a view to its use in the construction industry in general as a by-product to replace cement and/or clinker. To carry out this work, cement of type CEM II/B 32.5 R from the DANGOTE cement plant was initially substituted with fly ash at different substitution levels (0%, 5%, 10%, 20% and 30%). Subsequently, a cement, with limestone, clinker, phosphogypsum and ash as raw materials substituting clinker at different strengths (0%, 5%, 10% and 20%), was synthesized. And finally, a physicochemical, mineralogical and mechanical characterization of the products obtained was carried out. The results showed:

- An increase in Blaine's specific surface area for synthesized cements.
- Good mechanical performance corresponding to the acceptable limits of NF EN 196-1 regulations for the substitution of cement and clinker by ash up to 20%.

The results obtained have shown that the use of fly ash as a substitute for cement and/or clinker is a beneficial recovery route from a mechanical, economic and environmental point of view.

REFERENCES

ASTM Standard, C618-08a (2008), Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, West Conshohocken, PA: Annual Book of ASTM Standards, ASTM Interna
common cements-38 pages
NF EN 196-1 (2016), Test methods for cements - Part 1: determination of strengths, 35 pages
NF EN 196-2 (2013), Cement test methods - Part 2: chemical analysis of cements - 80 pages
NF EN 196-3 (2017), Cement test methods - Part 3: Determination of setting time and stability- 15 pages
NF EN 197-1 (2012), Cement - Part 1: composition, specifications and conformity criteria
NF EN196-6 (2018), Cement test methods - Determination of fineness - 19 pages

****