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RESEARCH ARTICLE

INTRODUCTION TO THE DEVELOPMENT OF A HYDRAULIC ROAD BINDER BASED ON MINERAL COAL BOTTOM ASH

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Abstract

The use of natural aggregates with suitable characteristics for road construction presents in some regions a real problem of availability or cost related to transport. However, the resources in place, which are naturally unusable, can be used after treatment with Hydraulic Road Binders (HRB). In this study, we propose to valorize the mineral Coal Bottom Ash (CBA), a residue from the combustion of the SONICCHAR power station in Niger, as the main component of an HRB. After a physical, chemical and mineralogical characterization of the coal bottom ash, several proportions of the CBA powder and a cement type CEM I 42.5 were studied. Compression tests were carried out at 07, 28, 56 and 90 days to determine the class of the binder corresponding to the mixture selected. The performance of the HRB thus obtained was evaluated on two types of weakly clay soils ($IP \leq 12$, NF P 94-051), having an initially insufficient CBR. The 3% treatment of this product made the two aforementioned soils suitable for use as a base layer.

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Introduction:-

The high cost of road construction works in developing countries remains a major issue in socioeconomic development. In some countries, this reality is linked not only to the almost total import of coating materials, but also to the distance from the quarries of natural aggregates with geotechnical characteristics suitable for the implementation of the different layers of pavement. In sub-Saharan Africa, even more than ten years ago, the average unit cost per kilometer of paved road less than 50 km already exceeded US \$ 400,000 (Africon, 2008). However, this trend can be greatly improved through the use of materials in place or of deconstruction (involving a low cost of transport), originally unusable, but can be used after treatment with hydraulic road binders (HRB).

The objective of this study is to set up an HRB made from a majority component of mineral CBA associated with a cement of the CEM I 42.5 type. The coal bottom ash in question is the residue from the combustion of the coal collected at the SONICCHAR power station in the north-eastern of Niger. This, made up of 2 units of 18.8 megawatts, put into operation in 1981 and 1982 respectively, produces more than 75,000 m³ CBA per year (Djibo, 2014). Currently, the main use of SONICCHAR's CBA remains for backfilling the old quarry whose exploitation began in the 1980s.

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This operation was undertaken since 2010, and it follows the worsening of the landscape pollution of the mountains by the coal bottom ash as well as the agglomeration of their thin elements carried in the air coolers of the plant; the recovery in industrial quantities of this waste will then constitute a solution to an already thorny environmental problem.

General information on the CBA

Coal bottom ash is a *grayish* material with a heterogeneous character and very porous (67% porosity according to (Vinai and al., 2013)). It has a high amorphous phase and pozzolanic *properties, making* it a potential raw material for the cement industry. Its activity index is a function of the chemical composition, and therefore of the nature of the coal used. For example, TEFEREYRE CBA has a pozzolanic activity index of around 76% (Savadogo and al., 2015).

Physical Characteristics of the CBA:

Table 1:- Some physical parameters of the coal bottom ash.

Parameters	Values	Authors	Values	Authors	Values	Authors
Granulometry	0.08 to 20 mm	(Vinai and al., 2013)	0.01 to 10mm	(Consoli and al., 2007)	Gravelly sand	Rogbeck and Knutz 1996
Specific weight	1.8 to 2.2 t/m ³	Rogbeck and Knutz, 1996	2.31 t/m ³	(Savadogo and al., 2015)	1.39 t/m ³	Singh and Siddique, 2015
Bulk density	0.7t/m ³	(Vinai et al., 2013)	0.77 t/m ³	(Savadogo and al., 2015)	0.7 to 0.9 t/m ³	Rogbeck and Knutz, 1996

Chemical Characteristics of the CBA:

Table 2:- Major oxides in the coal bottom ash.

Major elements in%.	(Andrade and al., 2007)	(Vinai and al., 2013)	(Kumar and al., 2014)	(Hamzah and al., 2015)	(Jang et al., 2016)	(Mandal and Sinha, 2017)	(Pyo and Kim, 2017)
SiO ₂	50.46	62.32	68.0	68.9	44.2	66.32	48.0
Al ₂ O ₃	28.35	27.21	25.0	18.7	31.5	24.71	20.1
Fe ₂ O ₃ , Fe ₃ O ₄	10.69	3.57	2.18	6.5	8.9	3.71	8.77
CaO	2.07	0.50	1.66	1.61	2.0	3.3	7.11
TiO ₂	1.57	2.15	1.45	1.33	2.4	0.28	1.11

Materials and Methods:-

Materials

CBA of Sonichar

Particle size distribution

The coal bottom ash comes in the form of granules with dimensions ranging from 0 to 25 mm or slightly larger. However, slices larger than 6.30 mm are very friable and can therefore be considered as an agglomeration of smaller grain sizes. In the various tests, we mainly used ground CBA powders, passing through an 80-micron sieve. The granulometric analysis opposite (Figure 1), was carried out using a Laser Granulometer type MICROSEIZER 2000.

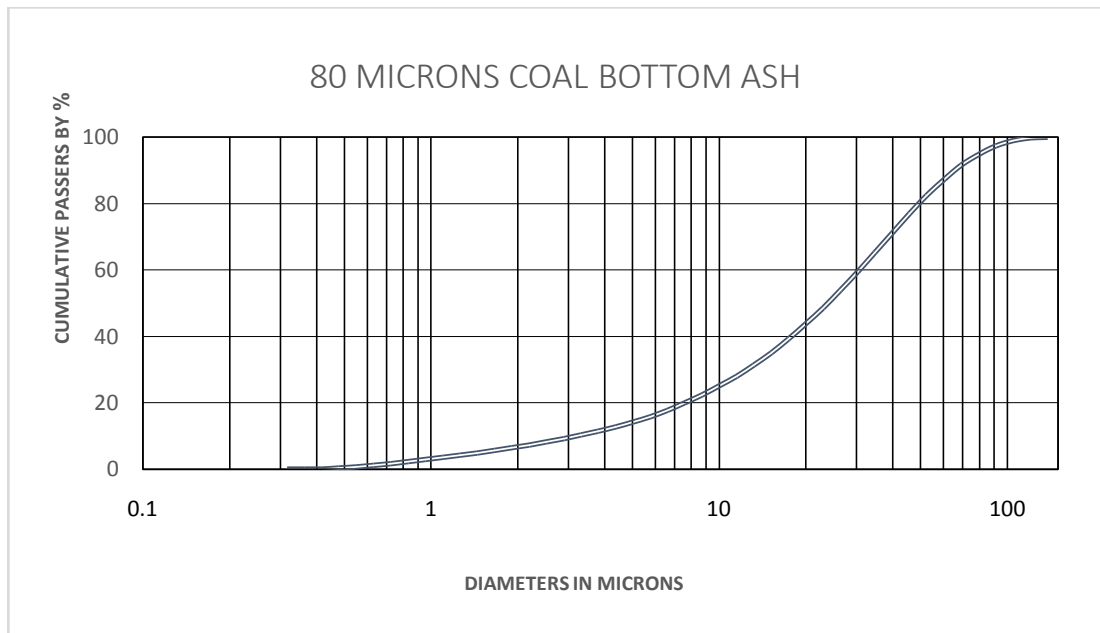


Figure 1:- Granulometric curve of the powder of the CBA.

Table 3:- Some characteristics of the granulometric curve of the coal bottom ash:

	d10	d20	d50	d80	d90
Diameter (μm)	3.185	7.581	23.906	49.066	64.844

For the CBA curve 80 μm , d_{90} = 64.84 microns. The latter is very similar to that found by Savadogo (Savadogo and al., 2015), also with a d_{90} of around 65 microns.



Figure 2:- CBA 0/2 mm on the left and 80 μm on the right.

Chemical and mineralogical characteristics

The X-ray diffraction performed on the powder of the coal bottom ash showed that it contains many amorphous elements, with the composition: Mullite 75%, Quartz 24% and Hematite less than 1%. The X-Ray Fluorescence gave the chemical composition described in Table 4, with a percentage of Silica and Alumina greater than 80%, and a low level of CaO (0.34%).

Table 4:- Chemical Composition of the coal bottom ash.

Result Fluorescence X on pearl (Integration of LOI) in %.

SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	TOTAL
55.72	1.82	24.42	5.34	0.01	0.47	0.34	0.04	1.86	0.05	8.35	98.43

The low proportion of CaO is quite common for coal bottom ash: 0.5% (Savadogo and al., 2015), 0.75% (Singh and Siddique, 2015), 0.99% (Kim, 2015), 1.61% (Jamaluddin and al., 2016) and 1.66% (Kumar et al., 2014).

Specific Gravity

Helium pycnometer measurements (NF EN ISO 8130-2 January 2011; FP-803-C-1) on the powder passing through the 80 μ m sieve gave average values of the order of 2.66 g/cm³, a little high compared to the usual values but lower than that of Mandal (Mandal and Sinha, 2017) which is 2.72 g/cm³.

The Cement

The cement used is CPA45/CEM I 42.5 according to the standard of NF P 15-301, manufactured by CIMTOGO.

Soils to be treated

For the analysis of the performance of the HRB, two laterites of different origins were used; the characteristics are described in the tables below.

Table 5:-Soils to be treated.

	Nature	Origin
SOIL A	Laterite	Maradi (University)
SOILS B AND R	Laterite	Niamey (Ouallam Road)

Table 6:- Granulometric characteristics of the soils.

	Granulometry			
	10mm	5mm	2mm	0,080mm
SOIL R	48.1	27.7	18.8	3.5
SOIL A	52.7	42.7	30	14.5
SOIL B	49.9	38.4	30	16.4

Table 7:- Atterberg limits and soil compaction characteristics.

	Limit		Proctor		CBR
	LL	IP	MDD	OMC	CBR to 95%OPM
SOIL R	19	11	1,82	12	35
SOIL A	21	8	2.13	5.3	46
SOIL B	25	12	2.06	7.3	40.5

MDD :Maximum Dry Density

OMC : Optimum Moisture Content

According to the NF P 94-078 standard, the CBR required for the creation of the form layers must be greater than or equal to 15. For subgrade and base, the NF EN 13286-47 standard recommends minimum values of 30 and 80 respectively. According to these specifications, soils A and B can only be used in form and foundation layers.

Methods: -

Formulation of the binder

Based on the principle of producing a binder with the maximum amount of clinker and the minimum amount of cement, we have produced (following the procedure of the normal EN 196-1 mortar) the mortars whose compositions are described in the table below. Prismatic 4x4x16 specimens from these mortars are crushed at 07, 28, 56 and 90 days.

Table 6:- Composition of the mortars.

Mortars	Proportions		
	CEM I 42.5 (%)	Coal bottom ash (%)	Report E/L

MC0100	100	0	0.5
MC5050	50	50	0.5
MC6040	40	60	0.5
MC7030	30	70	0.55
MC8020	20	80	0.6

HRB Dosage

In order to determine the optimal dosage of the HRB chosen, soil R was studied successively by treatment with 1% cement, 2% HRB and 3% HRB. The objective is also to verify the impact of the coal bottom ash powder on the increase in the value of the CBR in addition to the cement input.

Soil Treatment

Soils A and B are mixed with the percentage of binder retained, the materials thus obtained are subjected to the Proctor test (NF P 94-093) then the CBR test (NF P94-078).

Results And Discussion:-

Class of binder

According to the NF P 15-108 standard, the class of hydraulic road binder is defined according to the value of the compression resistance at 56 days as shown in the table below

Table 9:- Compressive strength of HRB classes according to NF P 15-108 standard.

Rc to 56 days (MPa)	Class		
	10	20	30
	≥ 10.0	≥ 20.0	≥ 30.0
	≤ 30.0	≤ 40.0	≤ 50.0

In our study, the crushing results of the prismatic test tubes gave the values in Table 10 and Figure 3.

Table 10:- Mortar compression resistance at 56 days (4x4x16 test tubes).

Mortars	Rc to 56 days (MPa)
MC0100	57.5
MC5050	36.88
MC6040	27.10
MC7030	15.4
MC8020	9.9

The specifications in Table 9 classify the MC7030, MC6040 and MC5050 mixes as class 10, 20 and 30 binders respectively. The binder MC7030 with the highest proportion of the CBA will then be selected for the soil treatment.

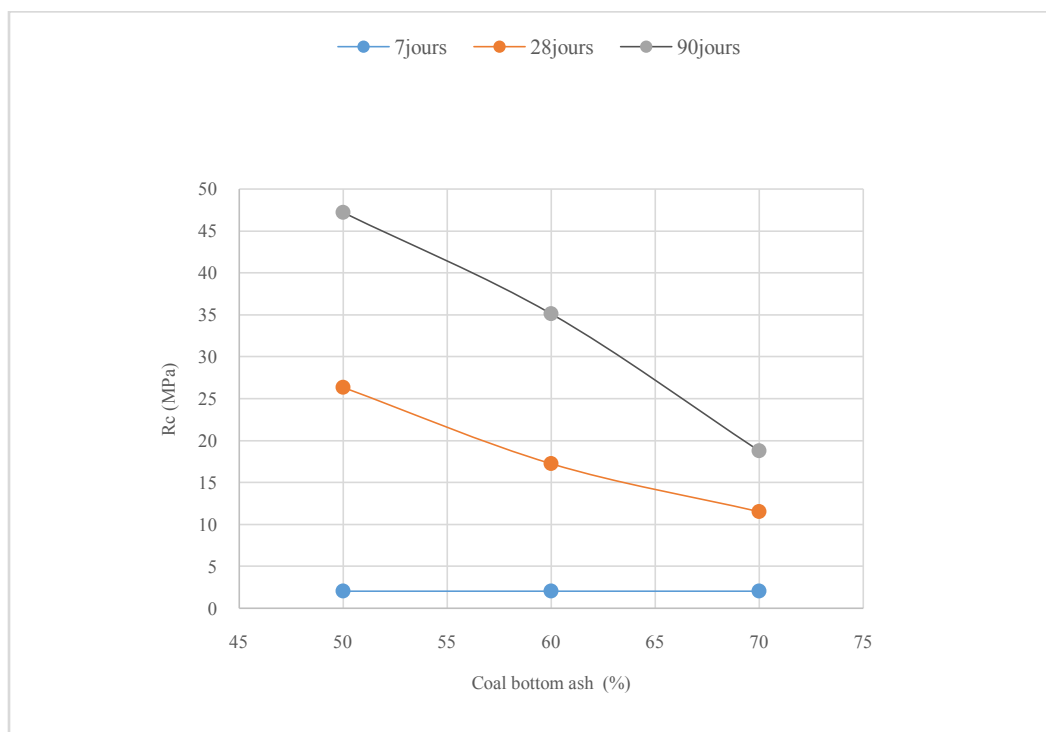


Figure3:- Mortar resistance by age and percentage of the coal bottom ash.

Mix of the HRB with MC7030

The results in Table 11 show that the 3% treatment of MC7030 (containing 0.9% cement) gives more interesting CBR values than the 1% cement treatment especially at 98% OPM. This implies that the pozzolanic activity of the bottom ash has a positive impact on the increase of the CBR index.

Although the literature quite often recommends values of 2% to 3% binder for soil improvements, the study of 4 to 5% MC7030 could be advantageous in the case of very low bearing capacity soils.

Table 11:- CBR Values based on binder percentage.

SOIL R	CBR		
	90%OPM	95%OPM	98%OPM
Untreated	20	35	52
1% Cement	30	58	65
2% HRB	25	48	65
3% HRB	33	59	78

Soil Treatment A and B at HRB MC7030

For soils A and B, Table 12 gives the new values of maximum dry density, optimum moisture content and the CBR (at 95% of OPM after imbibition).

Table 72:- CBR after 3% treatment of MC7030.

	Proctor		CBR
	γ_s	w	CBR at 95%OPM
SOIL A	2,10	4,9	102,7
SOIL B	2,04	6,9	86,9

Compared to Table 7, the CBR index increased more than 2-fold after improvement to the new HRB formulated. Dry density and optimal water content decreased slightly, suggesting the effects of quick-whitewash treatment in lateritious gravelly (CEBTP 1984). The A and B soils thus treated become suitable for use in base layers.

Conclusion:-

The development of a hydraulic road binder based on mineral coal bottom ash opens a great opportunity for the valorization of this industrial by-product, due to the importance of the quantities to be used in the context of road earthworks. This study has shown that, in addition to the low substitution of cement by the coal bottom ash in order to develop economical CEM II type binders, it is possible and easier to achieve the opposite; the precise nature of the soils suitable for improvement, the effect of the slow and prolonged hardening of bottom ash mortar and the environmental impact of the designed HRBs remain to be studied.

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