International Journal of Environment and Climate Change

Volume 14, Issue 12, Page 104-114, 2024; Article no.IJECC.127299
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Sustainable Use of Recycled Plastic and Coal Bottom Ash in the Development of Construction Material

Saley Mahamadou [a*], Abass Saley Abdoulatif [a], Kailou djibo Abdou [b], Mahaman Lawali S. Nourou [a] and Zakari Mahamadou Mounir [c]

[a] *Ecole des Mines, de l'Industrie et de la Géologie (EMIG), BP 732, Niamey, Niger.*
[b] *Ecole Africaine des Métiers de l'Architecture et de l'Urbanisme, BP 2067, Lomé, Togo.*
[c] *Laboratoire Écologie et Gestion de la Biodiversité Saharienne, Université André Salifou, BP 656, Zinder, Niger.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijecc/2024/v14i124610

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/127299

Original Research Article

Received: 25/09/2024
Accepted: 27/11/2024
Published: 04/12/2024

ABSTRACT

Mineral coal bottom ash (CBA) is a by-product of coal combustion in power plants. Its potential use in building materials has attracted interest due to its beneficial properties and environmental implications. The aim of this study is to assess the feasibility of using mineral coal slag from the Anou Araren coal company in Niger (Sonichar), in combination with plastic waste, in various construction applications. In this case, the focus is on compressive strength and slip potential for floor coverings. Following a technical characterization of the various elements involved in the

**Corresponding author: E-mail: madou111@gmail.com;*

Cite as: *Mahamadou, Saley, Abass Saley Abdoulatif, Kailou djibo Abdou, Mahaman Lawali S. Nourou, and Zakari Mahamadou Mounir. 2024. "Sustainable Use of Recycled Plastic and Coal Bottom Ash in the Development of Construction Material". International Journal of Environment and Climate Change 14 (12):104-14. https://doi.org/10.9734/ijecc/2024/v14i124610.*

production of the proposed material, 02 firing methods are described, with the advantages and disadvantages of each. Mixtures with varying proportions of plastic waste and bottom ash (30%/70%, 40%/70% and 50%/50%) were studied. For the mix selected, the results show that the CBA/plastic waste material has good compressive strength and low slip potential, making it suitable for use in a variety of construction applications.

Keywords: Coal bottom ash; plastic waste; recycling; environment; circular economy; Niger.

1. INTRODUCTION

The collection, management, and recycling of plastic waste remain a major issue in the development of African cities in general, and those of Niger in particular. Recycling this environmentally harmful waste, with other bulky by-products of local industry, will undoubtedly improve urban hygiene and beautify our cities. This is all the more important because the depletion of raw materials makes it more difficult to continue producing them. Today, recycling our waste can be seen as a sustainable solution for reconciling production, consumption, and environmental protection. Indeed, the preservation of the environment and its many socio-economic issues occupy an important place in the challenges of this century.

The relentless growth in production is leading to declining levels of natural reserves of raw materials and generating large quantities of waste (Ndiaye, 2006). Waste is both a risk and a resource. If not carefully disposed of, it can damage landscapes, pollute the environment, and expose people to nuisances and dangers, some of which can be very serious (Desachy, 2001). On the other hand, this waste can be recycled and reused to create a circular economy. The latter is the purpose of the present work, to recycle the mineral coal bottom ash in the building industry. SONICHAR's bottom ash potential (the plant has been operating in northeastern Niger since 1981) exceeds 3.5 million cubic meters of reserves (Omar 2022).

This study aims to formulate a construction material composed of mineral coal bottom ash from the Nigerien Coal Company of Anou Araren combined with melted plastic waste recovered from the city of Niamey (Niger), to make a composite material suitable for floor coverings (tiles and pavers), various decorations, masonry work, and urban development. The specificity of the proposed material lies in the fact that, unlike many studies which use CBA as aggregates in concrete and mortar, the method employed consists in fusing the plastics to form the matrix without the use of cement.

2. MATERIALS AND METHODS

2.1 Coal Bottom Ash (CBA)

Coal bottom ash is a greyish, heterogeneous, and highly porous material (67% porosity (Vinai et al. 2013)). It has a high amorphous phase and pozzolanic properties, making it a potential raw material for the cement industry. Its activity index depends on its chemical composition and the nature of the coal used. By way of example, TEFEREYRE (SONICHAR) bottom ash in Niger has a pozzolanic activity index of around 76% (Savadogo et al. 2015). It is an aggregate in the form of grains of varying dimensions. Fig. 1 provides information on a range of grain sizes from the bibliography. For this study, only 02 mm sieve passings are used.

Depending on the source, coal type, and plant technology, mineral coal bottom ash has a variety of chemical compositions. The oxides encountered in most cases are silica SiO_2, alumina Al_2O_3, iron oxide Fe_2O_3, lime CaO, magnesia MgO, sodium oxide Na_2O, potassium oxide K_2O, titanium oxide TiO_2, phosphorus oxide P_2O_5, sulfuric anhydride SO_3. Table 1 shows a selection of compositions found in the literature. The literature describes various physical characteristics of mineral coal slag, but the most relevant include specific weight, fineness modulus, and water absorption coefficient. Table 2 gives some examples.

Niger's mineral coal bottom ash (Fig. 3a) comes from the SONICHAR power plant (Anou- Araren). This power plant exploits the Anou Araren mineral coal deposit located 75 km northwest of the city of Agadez in the Republic of Niger. Fig. 2 shows the particle size distribution of SONICHAR's coal bottom ash. Tables 3 and 4 give the percentage composition of major oxides (determined by XRF) and the physical characteristics of the mineral coal slag studied.

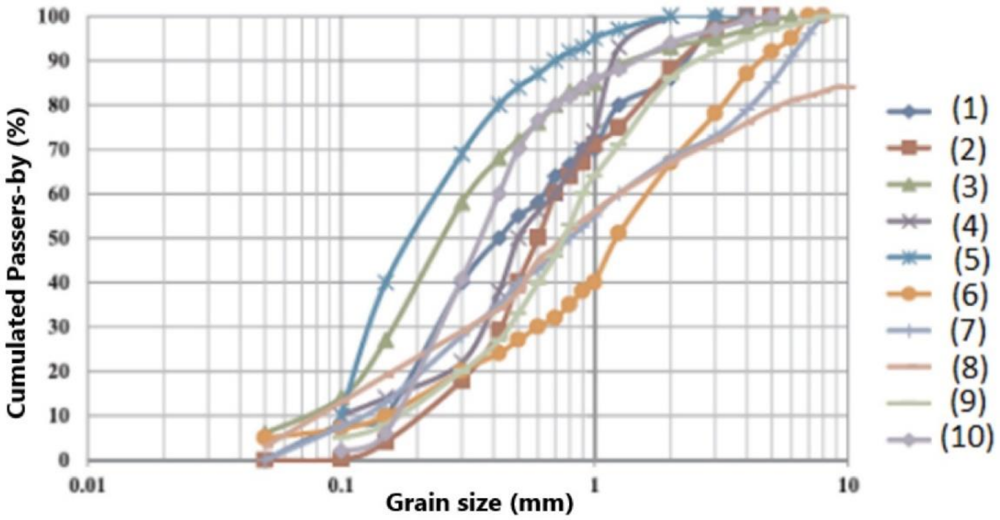

Fig. 1. Granulometry of coal bottom ash in literature (Singh et al. 2018)
(1) Syahrul et al. 2010, (2) Sanjith J, Kiran B M, Chethan G 2015, (3) Andrade et al. 2008, (4) Kim, Lee 2011, (5) Singh, Siddique 2013, (6) Rafieizonooz et al. 2016, (7) Press 2007, (8) Zainal Abidin et al. 2014, (9) Kasemchaisiri, Tangtermsirikul 2008, (10) Siddique et al. 2012

Table 1. Chemical composition of CBA

Authors	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	P_2O_5	SO_3
Men, Argiz 2021	52.2	27.5	6	5.9	1.7		0.57	1.53	0.74	0.13
Wie, Lee 2020	62.33	25.52	4.16	1.00	0.94	0.08	3.25	0.84	0.12	-
Singh, Bhardwaj 2020	65.02	19.18	6.86	1.76	2.00	0.85	-	0.93	0.04	-
Hashemi et al. 2019	50.49	27.56	10.93	4.19	1.24	0.57	0.82	2.23	0.24	0.10
Mangi et al. 2018	52.5	17.65	8.30	4.72	0.58	-	-	2.17	-	0.84
Ge et al. 2018	59.82	27.76	3.77	1.86	0.70	1.61	0.33	-	-	1.39
Sigvardsen, Ottosen 2018	47.1	23.1	5.7	7.8	1.5	0.7	5.3	1.2		1.5
Argiz et al. 2017	52.2	27.5	6.0	5.9	1.7	-	0.6	1.53	0.74	0.13
Oruji et al. 2017	58.7	20.1	6.2	9.5	1.6	0.1	1.0	-	1.0	0.4
Shahbaz et al. 2017	44.10	9.21	24.30	13.00	1.88	–	1.25	–	–	–

Table 2. Physical characteristics of CBA

Reference	Specific weight	Thinness module	Water absorption (%)
Majhi, Nayak 2019	2.45	2.14	8.50
Kuan et al. 2017	2.20	2.55	25.20
Baite et al. 2016	2.20	2.71	20.15
Kim et al. 2016	2.08	3.43	18.30
Zhang, Poon 2015	2.21	3.3	11.17
Onprom et al. 2015	2.10	2.10	6.80
Cadersa et al. 2014	2.88	3.70	25.70

Table 3. Chemical composition (% by weight) of SONICHAR CBA

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Sum
55.72	1.82	24.42	5.34	0.01	0.47	0.34	0.04	1.86	0.05	8.35	98.43

Table 4. Physical parameters of SONICHAR coal bottom ash

Parameter	Value
Specific Mass (g/cm^3)	2.66
Thinness module	3.45
Water absorption (%)	20

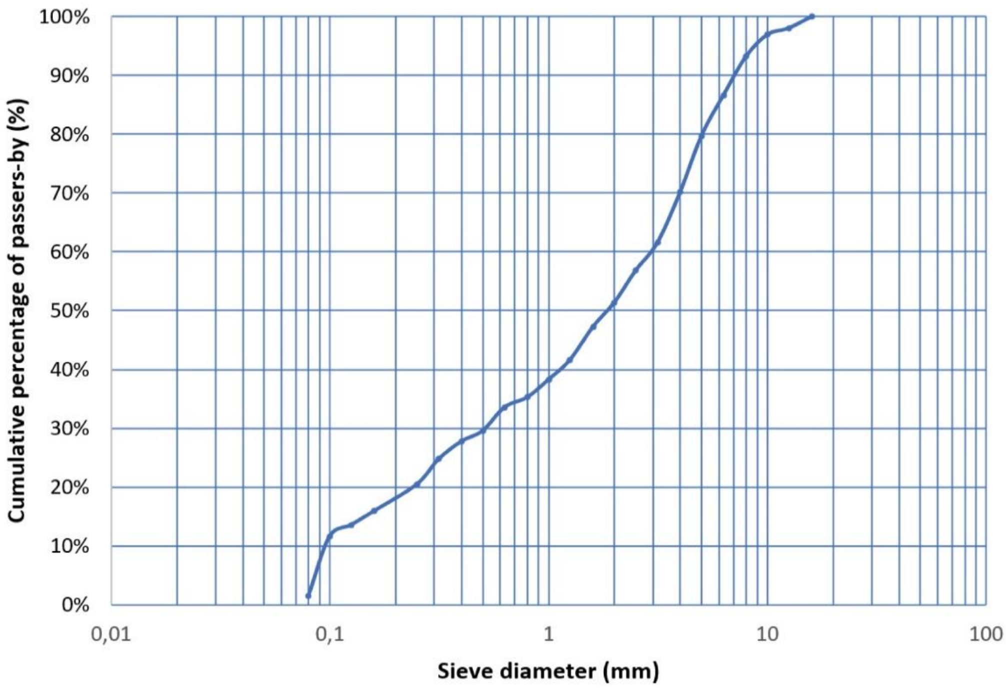

Fig. 2. Granulometric curve for CBA

2.2 Plastic Waste

The plastics used come from household waste such as bags and cans (Fig. 3b) from the city of Niamey in Niger. After washing and drying, sorting is carried out to retain only polyethene PE (high and low density). Plastic waste preparation involves sorting, cleaning and drying plastic bags. Sorting enables plastics to be identified and classified according to their nature, to avoid the problem of disparity in melting points. When tested with a flame, the selected packaging bags, leak and give off paraffin-like odours; these are polyethene-type plastics. Cleaning involves removing any remaining contents from the bags and washing them with water. The plastic waste then, needs to be crushed and compacted, dried and stored in a dry place.

2.3 Methodology

For the study of the CBA-plastic waste material, we propose to produce test tubes in the form of 4 x 4 x 16 cm prismatic specimens by melting plastic waste into which CBA with a grain size of 0/2 mm is introduced. Three types of CBA-Plastic Waste mixtures (M-DP1, M-DP2, M-DP3) will be produced in the weight proportions described in Table 5.

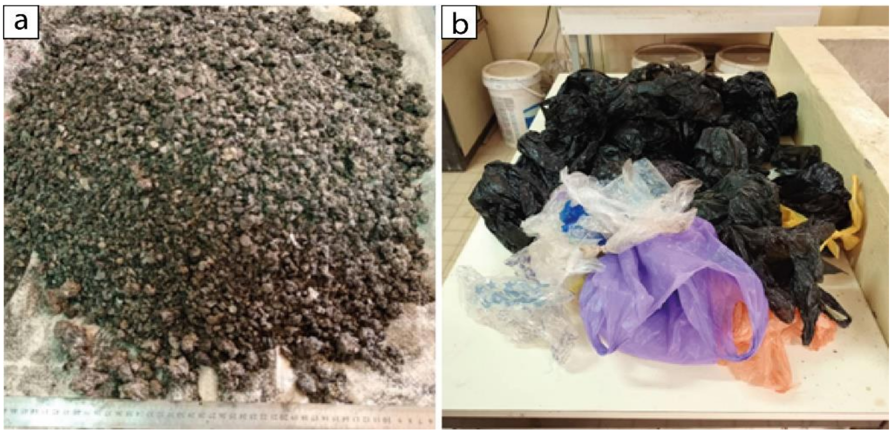

Fig. 3. Raw materials for briquette production

The aim of these different compositions is to determine the mix that will contain the maximum amount of CBA, while remaining homogeneous, compact and crack-free. To achieve this, the plastics are melted in two (2) ways: by means of a hot plate maintained at 250°C until the plastic waste melts, and by flame. Whichever melting method is used, briquette processing follows the main stages of the process described in the flow chart in Fig. 4.

Table 5. Input dosage

Mixture	Proportion (%)	
	Plastic	**CBA**
M-DP1	30	70
M-DP2	40	60
M-DP3	50	50

For hot-plate melting (Fig. 5a), the equipment used consists of a hot plate with a range greater than or equal to 250°C, a metal can with a diameter greater than 16 cm, an extraction hood, a mixing tool, and a cutting saw. For flame melting (Fig. 5b), the equipment consists of a metal vessel, a traditional hearth (coal or wood-fired), a mixing tool, a small shovel or large ladle, a formwork for prismatic specimens and a small hand-held tamper.

For the manufacture of M-DP specimens, the following procedure was used for melting and mixing: the plastic bags are heated until melted, and then the CBA is introduced into the vat before the mixture is mixed: for the hot plate method, the CBA is preheated in an oven maintained at 250°C for two (2) hours, and the flame method (Fig. 5c), preheating is optional.

For casting, cooling and demolding using the hot-plate method: the metal box forms, both the melting tank and the formwork. At the end of the process, the can is destroyed to remove the resulting material, which is then cut into 4x4x16 (cm) test tubes using a chainsaw. Cooling is carried out slowly in ambient air. Following the flame method, the mixture is poured into the formwork and compacted by hand (Fig. 5d). Here, cooling takes place more rapidly in water (Fig. 5e). In both (2) cases, demolding (Fig. 5f) takes place after the specimens have cooled completely.

Tests and measurements on CBA and plastic waste specimens relating to physical properties and strength mainly concern the visual appearance of the material obtained, density, compressive strength and flexural strength. Density measurements were carried out on prismatic specimens measuring 4 cm x 4 cm x 16 cm (a volume of 256 cm3). The uniaxial compression test on the specimens was preceded by a bending test to divide each specimen in two (2).

The SRT pendulum test method is commonly used to assess surface properties (slipperiness), as specified in European standard EN 13036-4. This establishes the slip resistance classification for all flooring products, in both dry and wet conditions, by determining slip and the level of potential risk of injury.

3. RESULTS

3.1. Visual Appearance of Specimens

Production of the M1 mix was complex, due to the difficulty of mixing because of the insufficient quantity of plastic; the fluidity and compactness of the resulting mortar left much to be desired, and this mix should be abandoned (Fig. 6a). The M-DP2 mix is more fluid and compact than the M-DP1 mix but shows a few small cracks after cooling (Fig. 6b). Mix M3 is fairly easy to produce, thanks to a sufficient quantity of plastic; the fluidity and compactness of the resulting mortar are quite interesting, so this mix should be retained for the rest of the study (Fig. 6c).

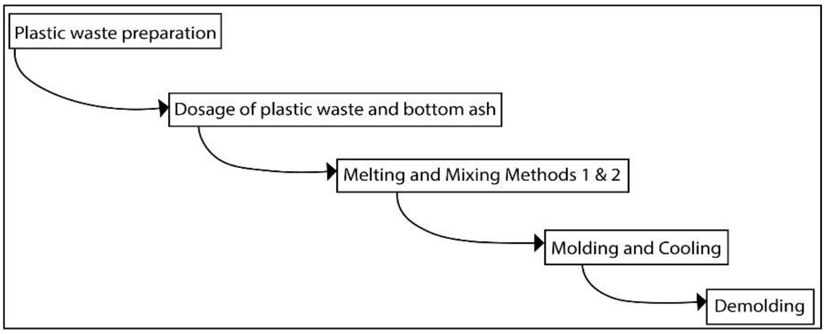

Fig. 4. Briquette manufacturing process

Fig. 5. Some used equipment to manufacture briquettes

Fig. 6. The visual appearance of mixtures

3.2 Mixture Density

Table 6 shows the density values for the three types of mixtures. These results show that the M-DP3 blend is the densest.

3.3 Compressive Strength

Table 7 shows the tensile stress values for samples M-DP2 and M-DP3 (M-DP1 is excluded due to its low compactness). Fig. 7a shows details of the stresses and strains of the M-DP3 mixture (plate method), which corresponds to the strongest sample (Table 7); its bending results are shown in Fig. 7b.

3.4 Slip Test

Table 8 shows the slip test results carried out on the M-DP3 mix. The average of 52 obtained over the five (5) tests allows us to deduce from Table 9 that the potential slip level is low (1/1,000,000).

Table 6. Density of M-DP specimens

Mixture	Test tube n°	Test tube Mass (g)	Volumic Mass (g/cm^3)
M-DP1	1	319	1.23
	2	313	
M-DP2	1	341	1.32
	2	334	
M-DP3	1	397	1.54
	2	390	

Table 7. Compressive strength of M-DP specimens

Mixture	Fusion method	Test tube n°	Breaking stress (MPa)	Mean Breaking stress (MPa)
M-DP3	Hot plate	1. a	19.47	19.42
		1. b	19.15	
		2. a	19.71	
		2. b	19.33	
M-DP3	Flame	1.a	18.04	17.89
		1. b	17.96	
		2. a	17.81	
		2. b	17.75	
M-DP2	Flame	1.a	14.69	14.06
		1. b	14.38	
		2. a	13.75	
		2. b	13.44	

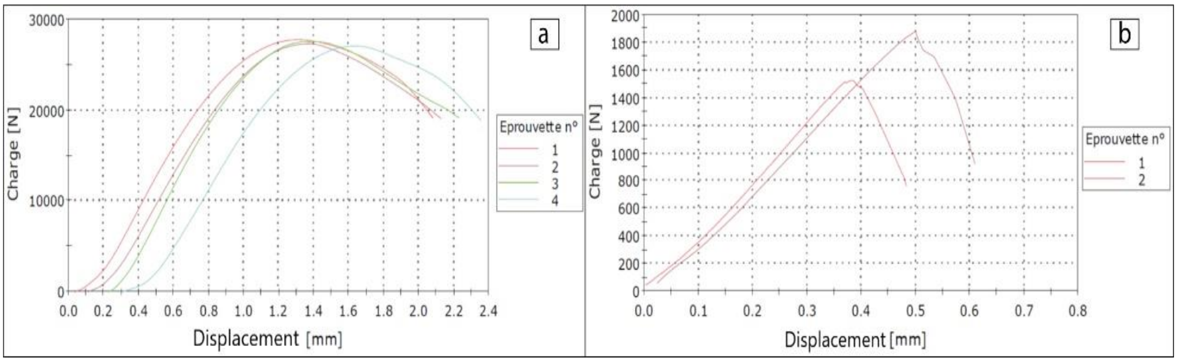

Fig. 7. Stress-strain diagrams and bending test on M-DP3

Table 8. M-DP M3 blend PTV values

Sample	Test	PTV value	Mean
M-DP3	1	55	52
	2	53	
	3	49	
	4	50	
	5	53	

Table 9. PTV values and corresponding slip levels (Dennison 2019)

Potential slip level	Rating	Probability of slipping
High	0-24 PTV	Up to 1 in 20
Moderate	25-35 PTV	1 out of 100,000
Low	+ de 36 PTV	1 out of 1,000,000
Extremely low	+ de 75 PTV	Less than 1 in 1,000,000

4. DISCUSSION

The use of plastic waste melted with CBA as a construction material is not very common in the literature. However, these 02 resources are used together as recycling aggregates, as in the case of (Kumar Gupta et al. 2021) who worked on the use of waste plastic aggregates and coal residues as a replacement for natural aggregates.

The literature more frequently refers to plastic waste/sand or gravel mixes for the production of sustainable mortars and concretes. Due to the low density of clinker, the constraints associated with the use of plastic-waste clinker are quite different from those of sand/plastic mixtures. However, the highest compressive strengths obtained at a plastic ratio of 50% corroborate the results of (Saïfoullah et al. 2020) and (Rijalalaina et al. 2014) for sand/plastic pavers and sand/plastic tiles respectively. On the other hand, contradictory results were obtained for another manufacturing method (with demolding after 72 hours) used by (Ndepete et al. 2022).

In the case of our study, test results on M-DP specimens show:

- A low density (1.54) compared with conventional building materials, coupled with an interesting compressive strength (19.42 MPa), which could make this material a structural or filling element;
- And a low slip potential, making it ideal for use as floor coverings (tiles or pavers) in buildings.

These results prove that M-DP panels can be used in various parts of buildings, including infill walls, floor tiles and decoration. Fig. 8 shows a computer-generated image of a possible application.

Fig. 8. Floor and wall covering in M-DP panels

5. CONCLUSION

A study of the different mixtures of bottom ash and plastic waste reveals the great potential for using bottom ash in masonry, cladding and decoration. M-DP mixes have the advantage of being both light and strong. Their compressive strength is close to that of conventional concretes, making them ideal for use in fillers, structures, decorations and slabs of all kinds. As for its low slip potential, this bodes well for floor coverings.

However, the use of masonry elements or cladding incorporating plastic and exposed to a variety of environments requires further study as to its durability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

ACKNOWLEDGEMENTS

The authors expressed their gratitude to all those who helped make this work a success.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Andrade, L. B., Rocha, J. C., & Cheriaf, M. (2008). Influence of coal bottom ash as fine aggregate on fresh properties of concrete. *Construction and Building Materials, 23*(2), 609-614. https://doi.org/10.1016/j.conbuildmat.2008.05.003

Argiz, C., Sanjuán, M. Á., & Menéndez, E. (2017). Coal bottom ash for Portland cement production. *Advances in Materials Science and Engineering, 2017*. https://doi.org/10.1155/2017/6068286

Baite, E., Messan, A., Hannawi, K., Tsobnang, F., & Prince, W. (2016). Physical and transfer properties of mortar containing coal bottom ash aggregates from Tefereyre (Niger). *Construction and Building Materials, 125*, 919-926. https://doi.org/10.1016/j.conbuildmat.2016.08.117

Cadersa, A. S., Seeborun, A. K., Chan, A., & YUK, C. (2014). Use of coal bottom ash as mechanical stabiliser in subgrade soil. *Hindawi Publishing Corporation Journal of Engineering, 2014*, 6. https://doi.org/10.1155/2014/234512

Dennison, A. (2019). 5.5: Norme EN 13036-4 Méthode de mesure de la résistance à la glissance - dérapage d'une surface. *Bulletin*.

Desachy, C. (2001). *Les déchets: Sensibilisation à une gestion écologique*. Tec & Doc.

Ge, X., Zhou, M., Wang, H., Liu, Z., Wu, H., & Chen, X. (2018). Preparation and characterization of ceramic foams from chromium slag and coal bottom ash. *Ceramics International, 44*(10), 11888-11891. https://doi.org/10.1016/j.ceramint.2018.03.122

Gupta, B., Kapoor, K., Nazeer, M., & Kaur, M. (2021). Waste plastic aggregates as a replacement of natural aggregates. In *Sustainable Environment and Infrastructure* (pp. 249-258). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-51354-2

Hashemi, S. S. G., Mahmud, H. B., Ghuan, T. C., Chin, A. B., Kuenzel, C., & Ranjbar, N. (2019). Safe disposal of coal bottom ash by solidification and stabilization techniques. *Construction and Building Materials, 197*, 705-715. https://doi.org/10.1016/j.conbuildmat.2018.11.123

Hichri, Y. (2018). *Adhérence des chaussées contaminées par des particules*. Brétagne Loire. Retrieved from file:///Users/cpt3270/Documents/Library.papers3/Articles/2011/Unknown/2011.pdf%5Cnpapers3://publication/uuid/0D99B4F2-5594-43C2-8F1C-E906FFDF777F

Kasemchaisiri, R., & Tangtermsirikul, S. (2008). Properties of self-compacting concrete incorporating bottom ash as a partial replacement of fine aggregate. *ScienceAsia, 34*, 87-95. https://doi.org/10.2306/scienceasia1513-1874.2008.34.087

Kim, H. K., & Lee, H. K. (2011). Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete. *Construction and Building Materials, 25*(2), 1115-1122. https://doi.org/10.1016/j.conbuildmat.2010.06.065

Kim, H. K., Ha, K. A., & Lee, H. K. (2016). Internal-curing efficiency of cold-bonded coal bottom ash aggregate for high-strength mortar. *Construction and Building Materials, 126*, 1-8. https://doi.org/10.1016/j.conbuildmat.2016.08.125

Kuan, S., Kim, O., Mo, H., & Alengaram, U. J. (2017). Valorization of wastes from power plant, steel-making and palm oil industries as partial sand substitute in concrete. *Waste and Biomass Valorization, 8*, 993-1003. https://doi.org/10.1007/s12649-017-9937-6

Majhi, R. K., & Nayak, A. N. (2019). Properties of concrete incorporating coal fly ash and coal bottom ash. *Journal of The Institution of Engineers (India): Series A, 100*(3), 459-469. https://doi.org/10.1007/s40030-019-00374-y

Mangi, S. A., Wan Ibrahim, M. H., Jamaluddin, N., Arshad, M. F., & Putra Jaya, R. (2018). Short-term effects of sulphate and chloride on the concrete containing coal bottom ash as a supplementary cementitious material. *Engineering Science and Technology, an International Journal, 22*(2), 515-522. https://doi.org/10.1016/j.jestch.2018.09.001

Men, E., & Argiz, C. (2021). Reactivity of ground coal bottom ash to be used in Portland cement. *Multidisciplinary Scientific Journal, 8*(4), 223-232.

Ndepete, C. P., Zaguy-Guerembo, R., Gbongo, A. M. D., Regakouzou, L. M.-P., Namndouta, V. O. N., & Kpeou-Kolengue, J. (2022). Valorisation des déchets plastiques en matériaux de construction. *European Scientific Journal, 18*(21), 320. https://doi.org/10.19044/esj.2022.v18n21p320

Ndiaye, M. B. (2006). *Le recyclage de métaux d'origine industrielle au Sénégal* (Thesis). Ecole Doctorale Matériaux de Lyon (France) et Ecole Supérieure Polytechnique (Sénégal).

Omar, Y. B. (2022). *Caractérisation et valorisation des mâchefers du charbon minéral de la Sonichar* (Mémoire d'ingénieur). Ecole des Mines, de l'Industrie et de la Géologie.

Onprom, P., Chaimoon, K., & Cheerarot, R. (2015). Influence of bottom ash replacements as fine aggregate on the property of cellular concrete with various foam contents. *Advances in Materials Science and Engineering, 2015*, Article 381704. https://doi.org/10.1155/2015/381704

Oruji, S., Brake, N. A., Nalluri, L., & Guduru, R. K. (2017). Strength activity and microstructure of blended ultra-fine coal bottom ash-cement mortar. *Construction and Building Materials, 153*, 317-326. https://doi.org/10.1016/j.conbuildmat.2017.07.088

Rafieizonooz, M., Mirza, J., Salim, M. R., Hussin, M. W., & Khankhaje, E. (2016). Investigation of coal bottom ash and fly ash in concrete as a replacement for sand

and cement. *Construction and Building Materials, 116*, 1-6. https://doi.org/10.1016/j.conbuildmat.2016.04.080

Rijalalaina, R., Ramaroson, D. J. D., Maholy, M., & Oliva, A. J. (2014). Valorisation à l'échelle pilote des déchets plastiques pour la fabrication de matériaux de construction. *Mada-Hary, 2*(1), 54-69.

Saïfoullah, D., Pahimi, A. L., & Gové, A. (2020). Valorisation des déchets plastiques dans la production des matériaux de construction : Cas des pavés dans la ville de Garoua (Nord-Cameroun). *American Journal of Innovative Research and Applied Sciences*, 215-221.

Sanjith, J., Kiran, B. M., Chethan, G., & Kumar, K. N. (2015). A study on mechanical properties of latex modified high strength concrete using bottom ash as a replacement for fine aggregate. *International Journal of Emerging Engineering Research and Technology, 3*(6), 114-121.

Savadogo, N., Messan, A., Hannawi, K., Tsobnang, F., & Agbodjan, W. P. (2015). Durabilité d'un ciment composé à base de mâchefer de Tefereyre (Niger): Absorption capillaire, porosité accessible à l'eau et attaque acide. *Journal of Materials and Engineering Structures, 2*, 213-223.

Shahbaz, M., Yusup, S., Inayat, A., Onoja, D. P., & Ammar, M. (2017). Cleaner production of hydrogen and syngas from catalytic steam palm kernel shell gasification using CaO sorbent and coal bottom ash as a catalyst. *Energy & Fuels*. https://doi.org/10.1021/acs.energyfuels.7b03237

Siddique, R., Aggarwal, P., & Aggarwal, Y. (2012). Mechanical and durability properties of self-compacting concrete containing fly ash and bottom ash. *Journal of Sustainable Cement-Based Materials*. https://doi.org/10.1080/21650373.2012.726820

Sigvardsen, N. M., & Ottosen, L. M. (2018). Characterization of coal bio ash from wood pellets and low-alkali coal fly ash and use as partial cement replacement in mortar. *Cement and Concrete Composites, 95*, 25-32. https://doi.org/10.1016/j.cemconcomp.2018.10.005

Singh, M., & Siddique, R. (2013). Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete. *Journal of Cleaner Production, 72*, 20-32. https://doi.org/10.1016/j.jclepro.2015.08.001

Singh, N., & Bhardwaj, A. (2020). Reviewing the role of coal bottom ash as an alternative of cement. *Construction and Building Materials, 233*.

Singh, N., Mithulraj, M., & Arya, S. (2018). Influence of coal bottom ash as a fine aggregate replacement on various properties of concretes: A review. *Resources, Conservation and Recycling, 138*(March), 257-271. https://doi.org/10.1016/j.resconrec.2018.07.025

Syahrul, M., Sani, M., Muftah, F., & Muda, Z. (2010). The properties of special concrete using washed bottom ash (WBA) as partial sand replacement. *International Journal of Sustainable Construction Engineering & Technology, 1*(2), 65-76.

Vinai, R., Lawane, A., Minane, J. R., & Amadou, A. (2013). Coal combustion residues valorisation: Research and development on compressed brick production. *Construction and Building Materials, 40*, 1088-1096. https://doi.org/10.1016/j.conbuildmat.2012.11.096

Wie, Y. M., & Lee, K. G. (2020). Composition design of the optimum bloating activation condition for artificial lightweight aggregate using coal ash. *Journal of the Korean Ceramic Society, 57*(2), 220-230. https://doi.org/10.1007/s43207-020-00025-0

Yüksel, I., Bilir, T., & Ozka, O. (2007). Durability of concrete incorporating non-ground blast furnace slag and bottom ash as fine aggregate. *Building and Environment, 42*, 2651–2659. https://doi.org/10.1016/j.buildenv.2006.07.003

Zainal Abidin, N. E., Wan Ibrahim, M. H., Jamaluddin, N., Kamaruddin, K., & Hamzah, A. F. (2014). The effect of bottom ash on fresh characteristics, compressive strength, and water absorption of self-compacting concrete. *Applied Mechanics and Materials, 660*, 145-151. https://doi.org/10.4028/www.scientific.net/AMM.660.145

Zhang, B., & Poon, C. S. (2015). Use of furnace bottom ash for producing lightweight aggregate concrete with thermal insulation properties. *Journal of Cleaner Production, 99*. https://doi.org/10.1016/j.jclepro.2015.03.007

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/127299