Physico-Chemical Characterisation of Bauxite Residue from The Compagnie Des Bauxites De Guinée (CBG) With A View To Its Potential Use In Habitat Construction

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Abstract: Increased mineral production generates huge quantities of industrial waste, such as gold and bauxite residues, copper ashes, etc. Bauxite residues are collected in cyclone hoppers during bauxite drying, then evacuated to decantation lakes. The sludge is removed to the drying beds by dredging, the residue is dried during the dry season and then stored as industrial waste in the hangar. The need to build, the current cost of traditional construction and the shortage of materials are leading to the development of a building materials industry based on the use of industrial waste such as bauxite residues. This study aims to consolidate knowledge on the application of bauxite residue in building construction. The samples were taken from hoppers in the drying department of the Compagnie des Bauxites de Guinée. Analysis by X-ray fluorescence spectrometry (XRF) yielded results indicating that the Al_2O_3 content is 45.11%, and the loss on ignition is 23.76%. These results are similar to those for lateritic bauxite. The crystalline phase of the residue was determined by X-ray diffraction (XRD). Gibbsite is the predominant mineral in the material (69%), followed by haematite (23%), anatase (3%) and quartz (4%). The geotechnical characterisation reveals that the plasticity index is 10. The results obtained from the various characterisation analyses are comparable with the literature and show the potential for the application of bauxite residues in habitat construction.

Keywords: Bauxite, construction, characterisation, fluorescence, diffraction.

1. Introduction

The growth of industrialisation has resulted in the production of huge quantities of industrial waste, such as bottom ash, bauxite residues, copper ash, etc. Compagnie des Bauxites de Guinée's bauxite dust was collected in the cyclone hoppers when the bauxite was dried [1].

The main challenge facing the alumina industry is the production of huge quantities of bauxite residues (BR). In some countries, these residues are considered hazardous materials. It is estimated that more than 100 million tonnes of bauxite residues are produced each year, a figure that continues to rise every year [2, 3].

The need to build, the current cost of construction and the shortage of materials are leading to the development of a construction materials industry based on the use of bauxite residues [4].

Economic pressure, demographic growth and the need to preserve the environment mean that more attention than ever is being paid to the development of a construction material based on industrial waste. In Guinea, Portland cement is the only binder used in construction. Given its significant impact on the balance of trade, it is obvious that a product derived from industrial waste, which could replace it while offering additional economic and comfort benefits, would be most welcome [5].

It is well known that when clays, bauxite residue or other earth materials are subjected to drying or firing, they acquire pozzolanic properties. During the drying phase, this bauxite residue or some of its minerals develop a disorganised Ferro-Silico-Aluminous structure capable of combining with laterite, cement and sand to form an artificial block capable of withstanding all types of weather [5, 6].

The aim of our study is to characterise and use Guinean bauxite residue in the construction industry.

The main applications for red mud or dust residue are in civil engineering, chemicals (plastics, pigments and catalysts), metallurgy (metal recovery) and the environment, particularly in wastewater treatment, absorption of polluted soil and treatment of acid wastewater [7, 8, 9].

2. Materials And Methods

Sample collection site

The bauxite dust which is the subject of this study was collected at the Compagnie des Bauxites de Guinée (CBG) plant, in the hoppers, in department 42 of the bauxite drying department. It is located between the bauxite crushing and shipping departments. The geographical coordinates of the bauxite residue collection site are 10.64438° N and 14.61173° E, and it is 42m above sea level (figure 1).
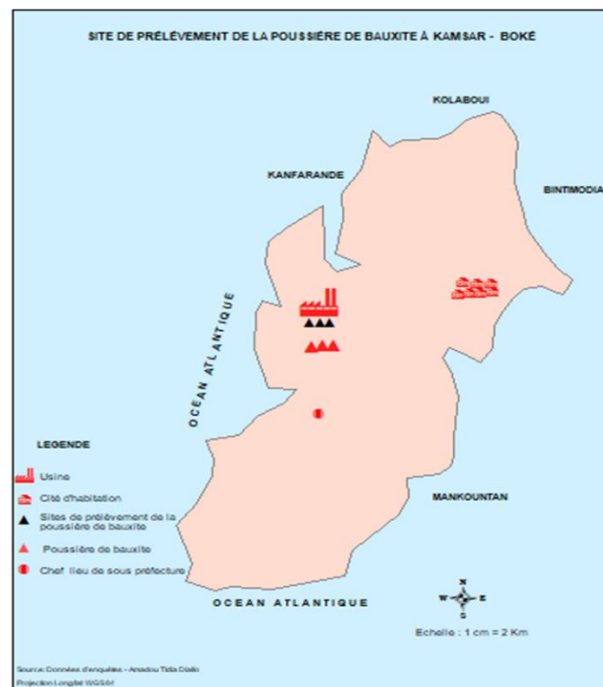

Figure 1: Kamsar bauxite dust sampling site

Sampling

This is an essential step, which involves taking a representative portion of the bauxite dust with all the physico-chemical characteristics required for analysis. Once the bauxite has been extracted at Sangaredi, it is transported to Compagnie des Bauxites de Guinée for crushing, drying and storage. Three samples of bauxite dust were taken from the hoppers in the drying department and placed in plastic bags. They were then transported to the Compagnie des Bauxites de Guinée (CBG) laboratory for analysis to determine their chemical composition. For geotechnical, mechanical and thermal characterisation, the samples were sent to the École Polytechnique de Thiès (EPT) in Senegal. For mineralogical characterisation, a sample was sent to the solid and materials chemistry laboratory, Institut des sciences chimiques de Rennes, in France.

Preparation of samples

In the laboratory, the samples were dried in ovens at 105°C, then ground at 100 mesh, to obtain a powder. For TOC determination, the sample was ground to 200 mesh and then fed to XRF for compositional analysis.

Analysis of bauxite by X-ray fluorescence spectrometry (XRF)

a – Prince

A previously calcined sample of bauxite residue is fused with a melting mixture of lithium metaborate and tetraborate to obtain a homogeneous glass bead. This is irradiated by an X-ray source, which excites the atoms of the elements, which in turn produce characteristic radiation. The intensities of these rays are then converted into concentrations using calibration curves for the individual elements. The analytical results thus obtained are the respective oxide contents of the calcined sample. They are then converted to the content of the uncalcined base during data transfer into the database, using the previously determined mass loss. When the results are transferred to the database, they are converted to natural oxides according to this formula:

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%Natural = % calcined (1- LOM/100) (1)

b – Echantillon

The previously calcined sample is pulverised at -100 mesh, then the mass loss is determined by thermogravimetry.

Determination of mass loss by thermogravimetry and fire loss

- Principle

An analytical portion of 2 to 5 g of each sample is introduced into a crucible and then placed in a thermogravimetric analyser. The sample is heated to 105 ± 2°C until a constant weight is obtained and the decrease in mass, which represents the moisture content, is recorded.

The sample is then heated to 1000°C±10°C and held until a constant weight is reached. The total loss of mass represents the loss of weight due to humidity and the loss of weight due to calcination (%). The low of mixtures (LOM) is defined as the difference in weight between a sample heated to 105°C and the weight of the same sample heated to 1000°C, and results from water of crystallisation, water of constitution, organic carbon and other volatile matter. The results are transferred by diskette or computer network from the analyser to the database where the LOM content is calculated.

Data processing is described in the following procedure.

- How it works

To determine the calcined oxide content, thermogravimetric analysis (TGA) is carried out as follows:

Program the TGA from the computer by entering the code, the number of samples to be analysed and the name of the operator, adding "S" in front of the standard code and "D" in front of a duplicate. Click OK to close the machine and tare the empty crucibles.

Allow the TGA to tare the empty crucible weights, and it will open automatically when finished. When the cover opens, load approximately 2 to 5 g of sample into the crucible opposite and press the green or OK button. Repeat this operation for all the other crucibles, not forgetting the standard. The furnace will continue calcining automatically until the end, and will provide the results, including the loss on ignition (LOM DRY) and the corresponding IDs.

The form to accompany the samples to the landfill is prepared, with the sample codes (sounding, BH or ship), and printed.

After cooling, the contents of the 19 crucibles are unloaded in order into polypropylene capsules with lids, sorted according to the order of loading onto wooden racks and the letter of the rack noted on the corresponding LOM analysis results sheet.

Send the samples to the weighing room.

Weigh 5g of flux (lithium meta-borate and tetra-borate ($Li_2B_4O_7$ 35%/ Li_2BO_2 65%) and 1g of bauxite residue (calcined sample) in a glass capsule and repeat the same operation for all 19 samples and take them to the melting room.

The merger

Melting involves dissolving the oxidised sample in a solvent, generally a lithium borate flux. The temperature required to prepare the samples should therefore be higher than the melting point of the flux, whose role is to

reduce the temperature to around 1000°C. Lithium metaborate (Li_2BO_2), with a melting point of 850°C, reacts with acid oxides, such as sulphur oxide (SO_2). On the other hand, lithium tetraborate ($Li_2B_4O_7$), with a melting point of 920°C, reacts with basic oxides, such as quicklime (CaO). In practice, the flux is composed of these two salts in varying proportions, and fluxes are used.

- How it works

Weigh 1g of bauxite residue (calcined sample) and mix it with 5g of lithium tetra- and meta-borate (which lowers the melting temperature of the oxides in the sample) in a glass bottle.

After homogenisation, the beads are decanted into the platinum crucibles (5% gold). Three to five drops of lithium bromide ($LiBr$) solution are then added, which acts as an anti-sticking agent and strengthens the intramolecular bonds to prevent the pearl from breaking after cooling. The melting process takes around 15 to 20 minutes, depending on the programme. Once the molten product has been poured into the moulds, solidification and cooling take place automatically.

A homogeneous glass bead is obtained, and when the beads are discharged, they are identified by transferring the codes onto the beads with self-adhesive paper so as not to mix the respective samples. The beads thus obtained are ready for XRF analysis.

The Casagrande apparatus was used to determine the plasticity index. It is equipped with a cup, a grooving tool and is mechanically operated.

Plasticity index, IP = LL - LP (2)

The mineralogical composition of the sample was determined using the X-ray diffraction technique, which makes it possible to identify the different crystallised phases of the bauxite residue sample. The equipment used was a Panalytical X'Pert Pro diffractometer fitted with an X'Celerator detector.

Thermal analysis of the sample was carried out with a Perkin Elmer Pyris Diamond TGA/TDA analyser between room temperature and 950°C at a rate of 5°C. In platinum crucibles under a nitrogen (N2) atmosphere. The compounds were kept for 1 h at 950°C in an air atmosphere to ensure complete combustion.

IR measurements of the sample were carried out with a Perkin Elmer Frontier spectrometer using the UATR (Universal Attenuated Total Reflectance) accessory. The spectra were recorded between 650cm^{-1} and 4000cm^{-1}, on pure samples.

Scanning electron microscopy (SEM) of the sample was carried out using a Hitachi TM 1000 benchtop microscope, version 02.11 (Hitachi High Technologies, Corporation Tokyo Japan) with an EDS analysis system (SwiftED TM, Oxford Instruments Link INCA).

3. Results And interpretation

Based on our results of the chemical composition of the dust, the order of abundance of the elements is as follows: Al>Fe>Si>Ti>P (Table 1)

Table1: Chemical composition of bauxite dust from Compagnie des Bauxites de Guinée in its natural state.

Matérials (bauxite residue)	SiO$_2$	TiO$_2$	Fe$_2$O$_3$	Al$_2$O$_3$	V$_2$O$_5$	CaO	K$_2$O	ZrO$_2$	LOI	Total	TOC
Contents (%)	4.16	3.20	23.08	45.11	0.17	0.03	0.03	0.11	23.76	99.65	0.36

The presence of fluxes such as Na$_2$O, K$_2$O and CaO enhances liquid phase sintering by forming low melting eutectic compounds and marks the start of the heating process.

They help to reduce the sintering temperature of the brick by melting at a low temprature and dissolving other grains such as quartz, which melt at a high temperature. This can lead to glassy phases that improve the strength and fracture toughness of the brick. [10].

The variation in the composition of this bauxite residue is mainly linked to the origin of the bauxite and the process used to obtain it [2].

The physico-chemical properties of ceramic materials are highly dependent on their composition [6]. The results of XRF analysis of bauxite dust in Table 1 are consistent with the literature [11]. These analytical results show

the different percentages of the main components of bauxite dust, with a higher alumina content, followed by ferric oxide and silica. The dominant reddish colour is attributed to the presence of ferric oxide [12].

The loss on ignition found was 23.76%. It expresses a low proportion of clay minerals in the bauxite residue. This loss on ignition value can be explained by the high-water content of this sample, as well as the high capillary retention due to its larger specific surface area [13]. The loss on ignition value (23.76%) of the bauxite residue corresponds to various research studies carried out by several researchers with a view to its use in cement manufacture [14].

Furthermore, the result for total organic carbon 0.36 highlights the fact that the alkaline species formed during carbonation are in their soluble forms and that it is the application of the hybrid method (addition of (Ca^{2+},Mg^{2+}) ions) that favours the precipitation of alkaline phases. On the other hand, it is worth talking about a low dissolution of solid phases from the residue during the carbonation process [14].

Geotechnical characterisation of bauxite dust.

The results of the geotechnical characterisation are presented in Table 2.

Table 2: Geotechnical characterisation of bauxite dust

Colour	Reddish
Density	$9.434 10^3 Kg/m^3$
Particle size	
• Argile (0-2µm)	25%
• Silt (2-20 µm)	72%
• Sables fins (20-200 µm)	3%
Atterberg limits	
• Liquidity limit	27
• Plasticity limit	17
• Plasticity index	10

The plasticity index of the bauxite residue is 10; given its silty nature, it can be expected to break when moulded and fired at temperatures above 400°C. This can be explained by a lack of sufficient cohesive bonding during dewatering and a non-uniform heating cycle [14]. The 10% plasticity index is less than 12%, indicating that the sample is not very plastic. This low plasticity is linked to the low clay content and the abundance of quartz [15].

In the construction industry, determining the plasticity index is important to ensure that the sample (bricks) retains the right shear strength and does not change volume too much when it expands and shrinks at different water contents. Consequently, the higher the plasticity index, the more plastic and compressible the ceramic and the greater its volume change characteristics [16].

Mineralogical composition

XRD analysis of the bauxite residue revealed the following mineralogical phases (Figure 2): Gibbsite, haematite, quartz and anatase.
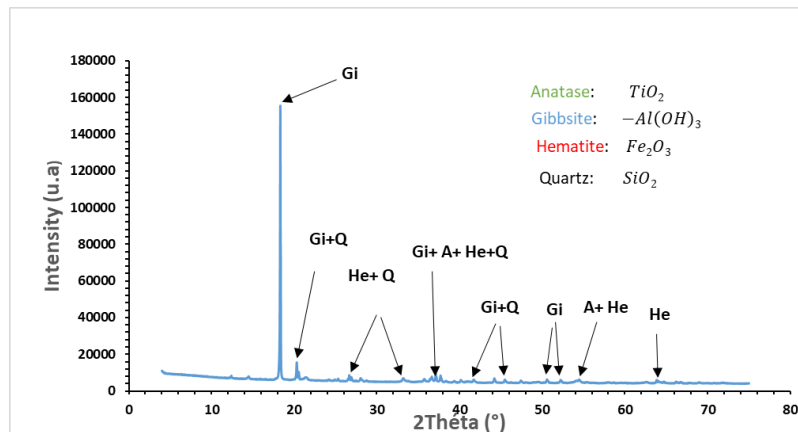

Figure 2: X-ray diffraction pattern of bauxite residue.

NB: u.a is an arbitrary unit, expressing here the proportion of intensities, without any importance on the quantity corresponding to the unit.

Structural phases of ray diffraction

The XRD diffractogram of the bauxite residue sample in Figure 2: shows the

mineral phases:The XRD diffractogram of the bauxite residue sample in Figure 2: shows the

mineral phases:

- The gibbsite 〖(Al(OH)〗_3) of peaks: 52.2 ; 50,6 ; 45.4 ; 44.2 ; 37.7 ; 36.6 ; 20.3 ; 18.3 Å

  The hematite (Fe_2O_3) of peaks: 64.0 ; 54,1 ; 35.6 ; 33.2Å

- The quartz (SiO_2) of peaks: 45.8 ; 36.5 ; 26.6 ; 20.9Å

- The anatase (TiO_2) of peaks: 53.9 ; 37,8 ; 36.9 Å

XRD analysis of the Guinean bauxite residue revealed the following mineralogical phases (Figure 2): gibbsite, haematite, quartz and anatase. The high intensity of the gibbsite peaks indicates a high alumina content (Al_2O_3) and is in good agreement with the particle size distribution, chemical analyses, and in particular the ratio Al_2O_3 /SiO_2 (Table 1, p.7) **[4 ,16]**.

The predominance of gibbsite is linked to the abundance of the mineral in the original bauxite. The same is true of quartz, one of the minerals most commonly found in the original material.

The presence of haematite and anatase is consistent with the results of the chemical analysis. The results show that the bauxite residue contains gibbsite associated with haematite, quartz and anatase **[17]**.

The presence of quartz results in low plasticity (this has been demonstrated in the calculation of Atterberg limits), and the appearance of the phenomenon of textural lamination [18]**.

The mineralogical composition of the bauxite residue revealed the following crystalline structure: gibbsite, boehmite, quartz and anatase (Table 3).

Table 3: Quantitative mineralogical composition of bauxite dust

Phase	Gibbsite	Hématite	Quartz	Anatase	Total	Ind
%	69	23	4	3	99	1

The table shows that the sample has a high gibbsite content (69%), with slightly elevated associated minerals (quartz+haematite+anatase). This result is consistent with the plasticity index and chemical analyses. This can be explained by the geological formation and the processing conditions of the sample [19].

In addition, the haematite and quartz content is in line with the results of the chemical analysis. The absence of montmorillonite in the sample is consistent with its low plasticity, which could be an impediment to its compactness during sintering of the product [19].

ATD/ATG analysis

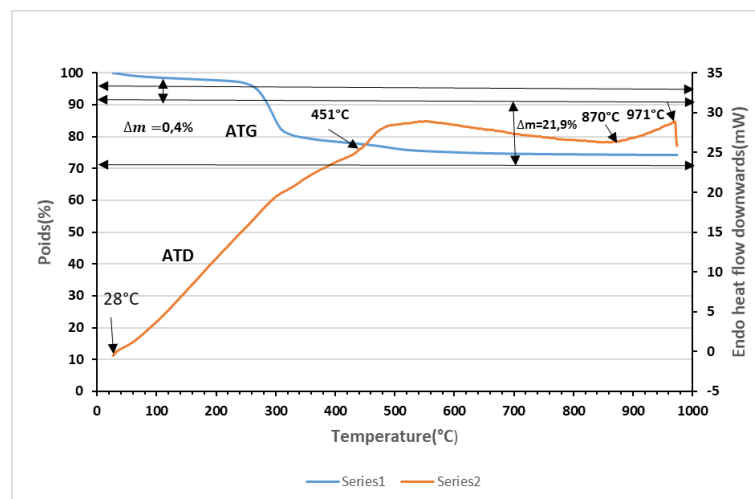The results of the DTA/GTA analysis are shown in Figure 3.

Figure 3: ATD/ATG curves for bauxite residue

The constant growth of the curve can be explained by the nature of the sample material, which may have thermal properties that favour regular heat dissipation, resulting in a temperature curve that grows linearly. In this particular case, we see a slight decrease in the variation of the mass of the material as a function of the increase in temperature. On the other hand, a chemical reaction can release heat continuously, causing the temperature to rise steadily. The ATD/ATG thermograms (ATD red curve, ATG blue curve) of the bauxite residue sample show (04) thermal phenomena materialised by:

- A less marked endothermic peak at around 28°C, associated with a small loss of mass (0.4%), corresponding to the departure of the water of hydration contained in the material;
- A less marked endothermic peak at around 451°C, attributable to the main dehydroxylation of gibbsite to form boehmite, a phenomenon associé par une inflexion of the slope on the ATG thermogram. This results in the equation x and a mass loss of 21.4%.
  - $Al(OH)_3 \quad \rightarrow \quad AlO(OH) + H_2O$ (1)
- A less marked endothermic peak at around 870°C, it corresponds to the conversion of gibbsite, boehmite into alumina-γ (Al_2O_3-γ) The data in the literature approve the complexity of the mechanism of the transformation of boehmite alumina-γ but also the difficulty related to the representativeness of the process by a simple chemical reaction [20];
  - $2AlO(OH) \quad \rightarrow \quad Al_2O_3 - \gamma + H_2O$ (2)
- A final pronounced exothermic peak at around 971°C, corresponding to the break-up of the metakaolin and the appearance of the spinel phase.
  - $Si_2Al_2O_5(OH)_4$ **(Kaolinit)** $\rightarrow$ $Si_2Al_2O_7$ **(Métakaolin)** $+ 2H_2O$

Infrared (IR) of bauxite residue

The results of the infrared spectra of the bauxite residue are shown in Figure 4.
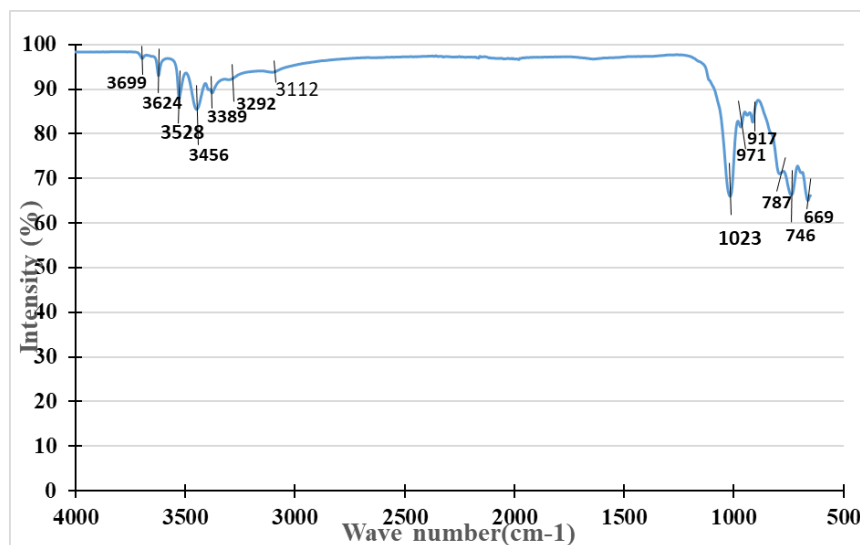

Figure 4: Infrared spectra of bauxite dust

The infrared spectra of the materials studied contain four main groups of absorption bands:
These are the consecutive bands at 3699 and 3624; the one at 3528, 3456, 3389; the one at 3292 and 3112; then at 1023, 971 and 917 and finally the bands 787, 746 and 667.

- Between 3699 and 3624 cm-1 are bands characteristic of the vibrations of OH groups in kaolinite ;
- The 3528, 3456, 3389, 3292 and 3112 cm-1 bands are specific to the elongation vibrations of the Al-OH group of gibbsite ;
- Between 1023, 971 and 917 cm-1 are bands characteristic of the deformation vibrations of the Al-OH group of gibbsite which are observed;
- Bands at 787, 746 and 667 cm-1are absorption bands corresponding to Al^{3+}in VI co-ordination and Si-O vibrations of kaolinite and/or quartz are observed [21].

4. Conclusion

Chemical analyses show that this bauxite residue is characterised by a high content of Al_2O_3 (45.11%). The percentage of Fe_2O_3 is quite high (23.08%) which explains the red colouration of the residue. The percentage of quartz SiO_2 is low (4.16%) and the anatase content is also low (3.20%). The loss on ignition content is fairly high (23.76%). This composition is similar to that of lateritic bauxite. Gibbsite is the predominant mineral (69%) in the material studied, associated with other minerals such as haematite (23%), quartz (4%) and anatase (3%). Gibbsite is an effective component for improving refractory ceramics, as it forms reactive alumina in situ. The plasticity index of the residue is low (10), which can be explained by a lack of sufficient cohesive bonding during dehydration and a non-uniform heating cycle. Based on the results obtained from the physico-chemical characterisation of bauxite residue, this material can be used in the manufacture of bricks, the production of aluminium and its alloys, the production of refractories and the production of cement.

References

[1]. Mohamed salou Diané (1997). Comparative study of red mud from the friguia plant (Guinea) and bauxite waste from the british aluminium company in Awaso (Ghana). 39p.

[2]. D.dodoo-arhin et al (2012). Fabrication and characterization of Ghanaian bauxite clay-red mud composite bricks for building applications. Published in American journal of materials science. 3(5): 110-119 ; DOI :10.5923/j. materials.20130305.02 ;

[3]. Ebenezer annan et al (2013). Physical-mechanical properties of bauxite-clay residue bricks. Published in the journal of the university of missouri of science and technology. email: eannan@ug.edu.gh.

[4]. Brenda O.S (2013). 'Physico-chemical characterisation of Venezuelan bauxite residue: evaluation of recovery options in the environmental field'. Université Lille 1 UFR Sciences de la terre. PhD thesis. 92p.

[5]. Pascal Vachon (2012) " Chemical and biological leaching of aluminium from red mud". Université du Québec; Pages: 3-9.

[6]. Mml Lima et al (2017). Application of red mud in the construction industry: a review of benefits and opportunities. Federal University of santa Catarina. 1-9. DOI: 10.1088/1757(=-899x/251/1/ 012033. email: mayarasiverio@gmai.com.

[7]. Sanoh Ousmane et al (2022). Evaluation and forecast of Guinea bauxite resources using elasticity method. Review article published in the journal School of Resource Engineering and Security in China.10(20): 2-52. DOI : 10.4236/jss.2022.104029.

[8]. Thiago Fernandes de Aquino et al (2012). Mineralogical and physico-chemical characterization of a bauxite ore from Lages, Santa Catarina, Brazil for the manufacture of refractories. 137-148. DOI : 10.1080/08827508.2010.531069.

[9]. McBurney WJ (1970). The effect of brick strength on the compressive strength of masonry. Treat ASTM Part (II) P.28.

[10]. Mackenzie J.KD et al (1996). The formation of mullite from kaolinite under various reaction atmospheres. J.Eur. Ceramics Society: 115-119.

[11]. Karaman S et al (2006). Influence of firing temperature and time on the mechanical and physical properties of clay bricks. Scientific Research Review 65: 153-159.

[12]. S.srikanth et al (2005). Phase constitution during sintering of red mud mixtures and red mud fly ash. Jam. Céam. Soc. 88(9): 2396-2401.

[13]. Younoussa millogo (2008). Geotechnical and mineralogical study of clayey and lateritic raw materials from Burkina Faso improved with hydraulic binders: application to civil engineering (building and road). Thesis defended at the University of Ougadougou. Pages: 20-61.D.dodoo-arhin et al (2012). Fabrication and characterization of Ghanaian bauxite red clay-sludge composite bricks for building applications. Published in the American journal of materials science. 3(5): 110-119.

[14]. Khaoula Daqaoui (2023). Chemical composition of clinker. Pages :22 https://www.academia.edu.

[15]. Poutouenchi amadou (2020). Elaboration and characterization of refractory bricks based on clay materials from koutaba and mayouom (Western region): effect of adding coffee production residues and rice husks. University of Yaoundé 1. Pages: 152.

[16]. Mamadou yaya Baldé (2022). Physicochemical characterisation of aluminosilicates (clays and bauxite) from Kindia, Guinea: application in hydraulic mortar formulations and ceramic compositions. PhD thesis defended at the University of yaoudé1. Department of Inorganic Chemistry. 78p.

[17]. Faycal el eigaier (2013).design, production and qualification of clay and mud bricks. Thesis defended at the University of Lille, northern France. 64p.

[18]. Gordana Ostojič et al (2014). Chemo-mineralogical characterization of bauxites from different deposits. Review article, 5(1) doi: 10.7251/COMEN 14010840. Pages: 84-94.

[19]. Ssyahronini et al (2018). Distribution model of particulate dust from sudoarjo sugar factory chimney. Mohammadiyah University.

[20]. M.S.S lima et al (2017). Application of red mud in the construction industry: a review of benefits and opportunities. Doi: 10.1088/1757-899X/251/1/012033.