

Physico-Mechanical Properties of Bricks Made from Bauxite Residue Produced by the Compagnie des Bauxites de Guinée (CBG)

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Abstract

This study aims to further our understanding of the use of bauxite residues from the Compagnie des Bauxites de Guinée in the construction industry. X-ray fluorescence (XRF) reports on the bauxite residue are available. The mechanical properties were determined using an electric press (Contrelab). Bricks composed of bauxite residue mixed with laterite and cement were formulated in the following proportions: 80%-10%-10%, 50%-25%-25% and 70%-15%-15%. They were left to dry naturally for 28 days. The results obtained from various characterisation tests, such as compressive and tensile strength, were 1.550 MPa and 1.155 MPa respectively. Compressive and tensile strength generally increase with drying time. The plasticity index of the bauxite residue is 10. This plasticity index result indicates that this residue is a material composed mainly of silt, mixed with a small amount of sand and clay. These results are consistent with those reported in the literature and suggest potential for the low-cost recycling of bauxite residue.

Keywords

Bauxite Residue, Compaction, Recycling, Bricks

1. Introduction

Bauxite was discovered in 1821 by Pierre Berthier in the commune of Les Baux-

de-Provence (Bouches-du-Rhône), from which it takes its name. Its mining has increased exponentially worldwide, particularly following the development of the Bayer process in 1887. Bauxite is, in fact, the mineral resource on which the production of alumina and aluminium is based, and it remains an essential resource for many industrial sectors. The Bayer process enables a more efficient and cost-effective extraction of the alumina contained in bauxite, compared with other contemporary processes [1].

Bauxite dust is produced during the drying of bauxite at Department 42 of the Compagnie des Bauxites de Guinée. The slurry resulting from the removal of bauxite dust in the scrubber using water jets has a pH of 5.55. This residue is non-toxic. In contrast, the bauxite residue commonly known as “red sludge” is produced during the conversion of bauxite into alumina using the Bayer process; its pH varies between 10 and 13, making it highly alkaline and potentially hazardous to health.

Mining residues can be defined as “any product or deposit resulting from prospecting, mining or the processing of ore”. They are regarded as economically barren, that is to say, devoid of any commercially exploitable substance. Mining tailings can have extremely diverse physico-chemical characteristics, which significantly influence their potential impacts on the environment and human populations. The risks they may pose are determined by the nature and concentration of the pollutants they may contain, whilst their biological reactivity and mobility within the environment may be influenced by the location and morphology of the tailings heap [2].

Bauxite dust from the Compagnie des Bauxites de Guinée was sampled from the cyclone hoppers in the drying department. During the drying of the bauxite, the dust and gases that escape from the cyclone hoppers are carried through the duct into the scrubber, where they are washed out by jets of water. The sludge settles at the bottom of the cyclone separator, where it is cooled, whilst the gas escapes via the chimney. The sludge is pumped back into the settling ponds via two (2) pumps, one to the west and one to the east. After settling in the east and west basins, the overflow (water) is transferred to the central basin. This water is drawn off and recirculated into the system to supply the sprinklers. The slurry is removed by dredging to drying beds, where it is left to dry during the dry season before being transported to the shed. This bauxite residue contains, like gibbsite bauxite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$), silica (SiO_2), anatase (TiO_2) and iron oxide (Fe_2O_3). The quantity of red mud currently available is estimated at over 2,040,240 tonnes.

Bauxite residues, due in particular to the use of soda ash and lime during the Bayer process, are an alkaline, salty and sodium-rich material that prevents the establishment of virtually any form of life. Another major concern regarding these residues is the presence, in varying and sometimes very high concentrations, of potentially toxic metals and metalloids such as aluminium, vanadium, chromium and lead. Research projects are being carried out around the world to assess not only the environmental and health risks associated with the residues, but also the

feasibility of remediating them and their potential use in construction [3]. It is estimated that around 117 million tonnes of red mud are generated worldwide each year, with no prospect of being reused, representing a potential risk of pollution and contamination. Consequently, the environmental liabilities arising from red mud affect not only the environment but also the companies responsible for the waste, which will be required to pay the highest charges [4].

Several studies have been carried out into the use of red mud as a raw material for the production of a range of construction products. Red mud can be used as a construction material in bricks, blocks, lightweight aggregates, tiles, ceramics, the cement industry (in the form of special cements), and the concrete industry. The residue is transformed into useful ceramic articles by mixing 51 - 90 per cent by weight of the residue with 10 - 49 per cent by weight of at least one mineral and/or silicate-containing material, shaping the mixture and firing it at 950°C - 1250°C [5] [6].

A patent [7] describes a method for manufacturing fired bricks in which 50 to 90 per cent by weight of red mud can be used in combination with clay and a water-retaining agent. The green bricks are dried using gas heated to a temperature below 70°C and at a humidity level below 50 per cent.

The Republic of Guinea (Conakry) has estimated reserves of over 40 billion tonnes of bauxite, according to surveys carried out in certain regions. The nature of bauxite is determined by its origin and the conditions under which it is processed. Guinean bauxite is characterised by a high alumina content and a low silica content [8]. In this article, research was carried out on the manufacture of bricks using bauxite residue, with cement and laterite as additives to improve their strength in the production of test specimens. The results concerning the physical properties, compressive and tensile strengths, and formulations of the batches RB80%-C10%-L10%, RB70%-C15%-L15%, and RB50%-C25%-L25% (Table 1), dried naturally, are discussed.

Table 1. Formulation of the test batches.

Code	Bauxite residue (Kamsar)%	Thiès laterite (Diasse)%	Cement (Dengoté)%
RBA80-10-10	80	10	10
RBB 50-25-25	50	25	25
RBC70-15-15	70	15	15

2. Materials and Methods

2.1. Sampling Site

The bauxite dust samples covered by this study were collected at the Compagnie des Bauxites de Guinée (CBG) plant, from the hoppers in Department 42 of the bauxite drying section. It is situated between the bauxite crushing and dispatch departments. The sampling site for the bauxite residue has geographical coordinates of 10.64438°N and 14.61173°E, and is situated at an altitude of 42 metres (Figure 1).

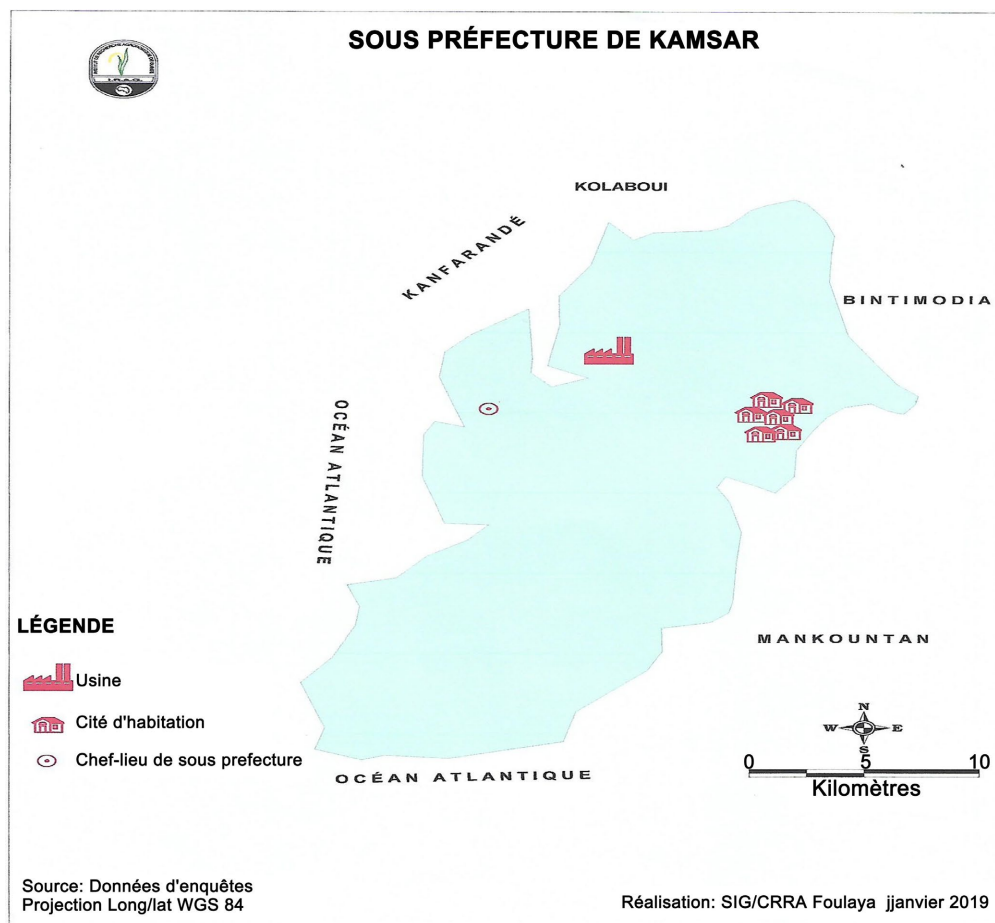


Figure 1. Bauxite dust sampling site at Kamsar.

2.2. Sampling

This is an essential step involving the collection of a representative sample of bauxite dust, possessing all the physico-chemical characteristics required for analysis. After the bauxite is mined at Sangaredi, it is transported to the Compagnie des Bauxites de Guinée for crushing, drying and storage. Three samples of bauxite dust were taken from the cyclone hoppers in the drying department and placed in plastic bags. They were then transported to the Compagnie des Bauxites de Guinée (CBG) laboratory to be analysed to determine their chemical composition. For physical and mechanical characterisation, the samples were sent to the École Polytechnique de Thiès (EPT) in Senegal.

2.3. Sample Preparation

Bauxite dust was collected from the cyclone hoppers at the Compagnie des bauxites de Guinée (CBG); it has a particle size of less than 100 μm . The laterite sample used was taken from the municipality of Diass, in the Thiès region of Senegal. The sand sample was also taken from the sand quarry located in Thiès centre, Senegal. The cement used was grade 42.5, manufactured by Dengoté.

For the manufacture of bricks, the proportions of the various constituents are

expressed by mass; the three samples were mixed, homogenised, moulded and then air-dried for at least 28 days. The amount of water used ranged from 8 to 15 per cent of the total mass, or between 0.3 litres of water per brick. A mould measuring $29.5 \times 10 \times 10$ cm, a 3.5 mm sieve, a plastic basin and a pot 6.5 cm long and 2 cm wide were used to produce the batches of bricks (**Figure 2**).

Compression and splitting bending tests were carried out in accordance with standards NF EN 772-1+A1:2015 and NF EN 772-6, respectively. For the tensile test, the upper part of the brick is placed on the lower platen of the press and then covered by the upper platen. The test specimen is then subjected to a load until failure using an electric press. For the flexural strength test, the lower part of the brick is placed on the lower platen of the press, then covered by the upper platen before being subjected to a load until failure. The test specimens are loaded using a programmable Controlab electric press, with a crushing rate of 0.005 N/(mm·s).



Figure 2. Image of the briquettes.

The chemical composition in terms of major oxides was determined using an X-ray fluorescence spectrometer. This analysis was carried out using the “AXIOS FAST, PANalytical 206204” instrument.

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

The plasticity index, $PI = LL - LP$.

The compression and tensile tests were carried out by crushing the test specimens using a Controlab programmable electric press, with a loading rate of 0.005 N/mm·s. The results recorded at the end of the test are expressed in kN and in N/mm or MPa.

3. Results and Discussion

3.1. Chemical Analysis

The results of the chemical composition analysis are set out in **Table 2**.

A loss on ignition value of 23.76 per cent; this figure is similar to that of lateritic

bauxite. A high Al_2O_3 content (45.11 per cent), which would indicate a high proportion of gibbsite in this material. A fairly high Fe_2O_3 content (23.08 per cent), explaining the red colour of the bauxite residue. A percentage of SiO_2 (4.16%), which indicates the possible presence of quartz and/or kaolinite, whilst also being a marker of the bauxite's good quality. A low content of TiO_2 (3.20%), which would suggest the presence of rutile and/or anatase. The alumina content is over 40 per cent and the $\text{Al}_2\text{O}_3/\text{SiO}_2$ ratio falls within the range of 2.2 - 13.1. This residue is economically viable [9] [10].

The sum of the "impurities" (TiO_2 , Fe_2O_3), alkali and alkaline earth metals which may contribute to a reduction in the melting temperature and to the formation of a glassy phase following cooling [11]. The presence of fluxes such as Na_2O , K_2O and CaO improves liquid-phase sintering by forming low-melting-point eutectic compounds and marks the start of the heating process. They help to lower the sintering temperature of the brick by melting at a low temperature and dissolving other grains, such as quartz, which melt at a high temperature. This can lead to glassy phases that improve the brick's strength and fracture toughness [12].

The industrial applications of ceramic materials are strongly influenced by their mineralogical composition and their physical and chemical properties. X-ray fluorescence spectroscopy is one of the analytical tools widely used to determine elemental/chemical composition [13].

Table 2. Results of the chemical analysis of bauxite dust.

Material (bauxite residue)	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	V_2O_5	CaO	K_2O	ZrO_2	LOI	Total	TOC
Content (%)	4.16	3.20	23.08	45.11	0.17	0.03	0.03	0.11	23.76	99.65	0.36

3.2. Plasticity Index

The results of the plasticity index are set out in **Table 3**.

The results presented in this table were obtained following repeated tests to minimise margins of error, as they are highly dependent on the method of execution. The repeatability and reproducibility of the tests were verified.

The liquidity limit on the Casagrande plasticity chart is 27 per cent, corresponding to 25 blows. The plasticity index (10), which is less than 12 per cent, indicates that the sample is slightly plastic. This low plasticity is due to the low clay content and the presence of quartz [13].

The silty nature of the bauxite residue suggests that it will break apart when moulded and fired at temperatures above 400°C . This can be explained by the lack of sufficient cohesive bonding during dehydration and by a non-uniform heating cycle [14].

Table 3. The plasticity index of bauxite dust.

Sample	Liquidity limit	Yield strength	Plasticity index
Bauxite dust	27	17	10

In **Figure 3**, the liquidity limit is 27 per cent, following a projection of 25 points on the x-axis.

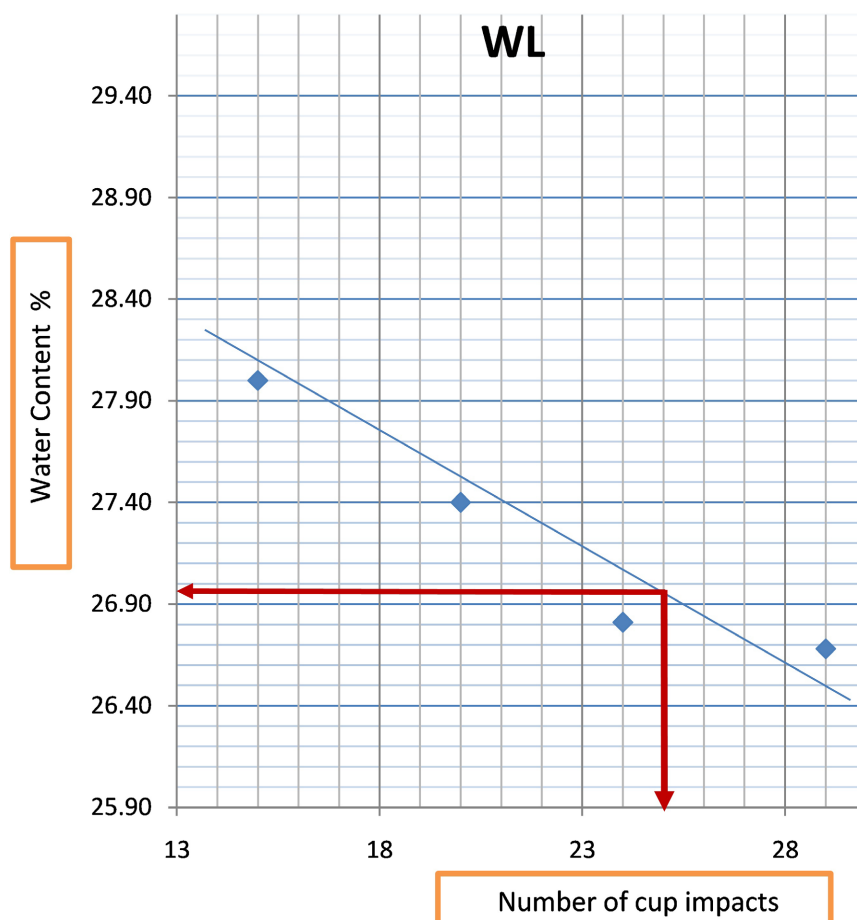


Figure 3. Plot of the plasticity index of bauxite dust (blue dots).

The low plasticity index of the bauxite residue ($I_p = 10$) indicates that the residue has low plasticity; this means that only a small amount of water is required to cause it to change from a solid to a liquid state. The low clay content and the presence of quartz are the main factors responsible for the soil's behaviour.

The yield strength obtained provides an approximate figure for the amount of water required ($Ll = 27$ per cent) during the brick-making process, without taking additives into account. These tests make it possible to plan ahead in order to reduce the amount of water required in brick production [15].

3.3. Resistance to Compression and Splitting

The results of the tensile strength tests carried out on bauxite residues mixed with additives (laterite and cement) are shown in **Figure 4**. The uniaxial compressive strength and splitting tensile strength are 1.550 and 1.155 MPa respectively. The maximum stresses in the compression and split-tensile tests are 45.044 and 24.544 kN respectively.

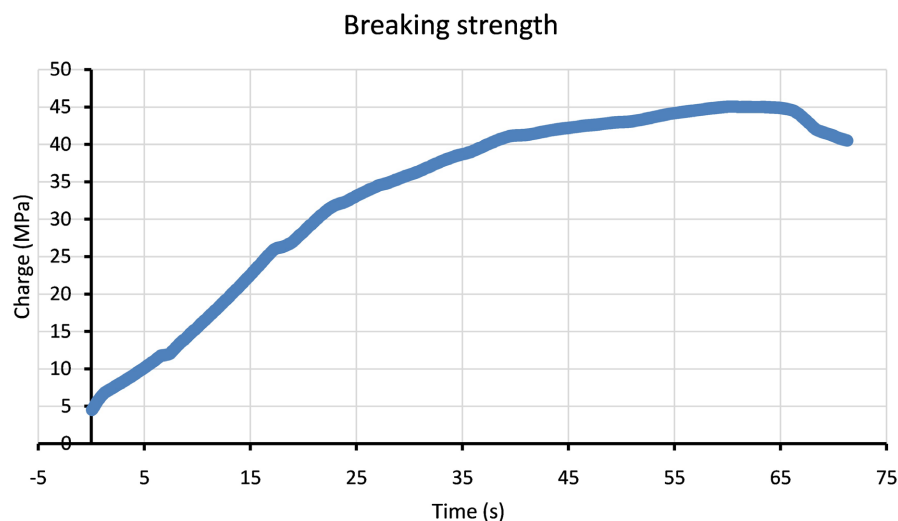


Figure 4. Stress-strain curve of the specimen after 28 days of curing.

These results for compressive and tensile strength show that the second formulation can be used in brick manufacturing. The curve's progression and these results can be attributed to the nature and homogeneity of the mixture. Compressive strength is in the range of 0.5 - 1.5 MPa [16]. For all the formulations tested, compressive and tensile strengths were found to increase with the duration of natural drying [17]. The improvement in physical properties over time is essentially linked to the fact that the pozzolanic reaction progresses over time; this is a reaction with slow kinetics. When the curing time reaches 28 days, there is no longer any significant difference in the evolution of the physical properties. Normally, 28 days is sufficient to complete the pozzolanic reaction (Figure 2). The results of the mechanical tests show that the RB80%-C20%-L20% formulation exhibits uniaxial compressive strength and splitting tensile strength of 0.633 MPa and 1.053 MPa, respectively. For the RB70%-C15%-L15% formulation, the strengths obtained were 0.674 MPa in simple compression and 1.195 MPa in splitting bending. For each formulation, two test specimens were prepared and tested after 28 days of natural drying. The values given correspond to the best results obtained for each formulation.

The results obtained with the RB50%-C25%-L25% formulation—namely 1.155 MPa and 1.550 MPa for uniaxial compressive strength and splitting tensile strength, respectively—represent the best mechanical performance among the three formulations studied. These results thus reflect the influence of increased proportions of cement and laterite, as well as drying time, on the mechanical properties of the test specimens [18]. Analysis of the chemical composition of the oxides makes it possible to determine the chemical composition of the bauxite residue and to provide indications of the mineralogical composition likely to be present.

4. Conclusions

The use of bauxite residue as a raw material in the production of bricks for construction applications has been investigated. The bricks were manufactured from bauxite

dust, laterite and cement. The physico-mechanical properties considered were the plasticity index, and compressive and tensile strength after 28 days of curing. Based on the results obtained, the following conclusions can be drawn from this study:

- The compressive and flexural strengths, which are 1.550 MPa and 1.155 MPa respectively, increase with the duration of the bricks' natural drying period. This result shows that the mixture is homogeneous.
- The plasticity index, which is 10, is low. This can be explained by the low clay content in the bauxite residue, as well as by the absence of cohesive bonds during dewatering.

Author Contributions

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Conflicts of Interest

The authors declare that they have no conflicts of interest in relation to this publication.

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