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Case study

# Awaso bauxite red mud-cement based composites: Characterisation for pavement applications

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ABSTRACT

This paper presents the development of Bauxite residue (red mud) based cement composite mortar blocks for applications in pavement construction. The experimental techniques considered include the structural, thermal, morphological and microscopy analysis of the raw bauxite and red mud samples calcined at 800 °C. Composite mortar blocks of different batch formulations were produced and their physicochemical properties were investigated. The results show that the compressive strength of the as-prepared composite mortar blocks increased by ~40% compared to the type M mortar strength of ~2500 N/mm$^2$. The load bearing applications of the composites are discussed to influence the adoption of the calcined red mud as supplement in the production of low-cost Portland cement based composite mortar blocks for the construction industry.

## 1. Introduction

The search for recycling alternatives of several industrial wastes has become a very common practice aimed at reducing cost of industrial waste disposal and protection of the environment. One of such industrial waste is bauxite red mud; an alkaline leaching waste with typical pH of 10–13 [1–4], which is generated during the Bayer process or bauxite calcination method for alumina production [5–7].

Bauxite consists of ~75% of hydrated alumina ($Al_2O_3{\cdot}3H_2O$ and $Al_2O_3{\cdot}H_2O$) with the main impurities including iron oxide (goethite, $Fe_2O_3{\cdot}H_2O$), hematite ($Fe_2O_3$), anatase ($TiO_2$), rutile ($TiO_2$) and silicate impurities. The silicate impurities in bauxite are primarily quartz ($SiO_2$) and kaolinite. During the treatment of the bauxite ore by the Bayer process (Fig. 1), it is initially crushed and digested with a hot solution of sodium hydroxide (NaOH), and lime liquor at ≈175 °C and subjected to attack at high pressure and temperature. This condition makes it possible to convert the hydrated alumina into sodium aluminate solution (Eq. (1)), while the impurities remain in a solid state.

$$Al(OH)_{3(aq)}+NaOH_{(aq)} \xrightarrow[pressure]{Heat} AlO_2Na_{(aq)}+2H_2O \quad (1)$$

The impurities are separated from the aluminate solution by decantation and filtration, followed by washing. The solid residues thus obtained are called red mud and are mainly made up of oxides of iron, aluminium, silicon and titanium. However, despite being

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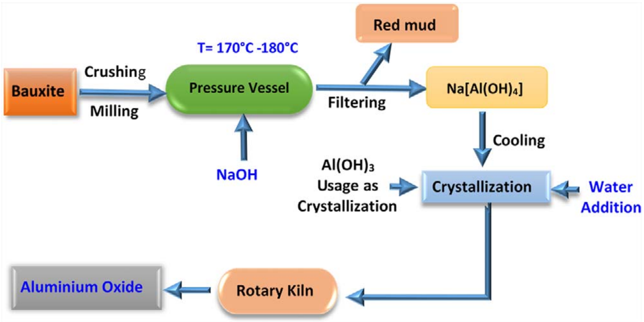


**Fig. 1.** The Bayer process of red mud and alumina production.

washed and considered as an inert solid waste, red mud remains strongly alkaline and highly corrosive. It is usually discharged as highly alkaline slurry (pH 10–13.5) with 15–40% solids, which is pumped away for appropriate disposal. This strong alkaline character ($Na_2O$ + NaOH = 2.0–20.0 wt.%), restricts the disposal conditions of red mud in order to minimize environmental problems such as soil contamination and ground water pollution. Its chemical and mineralogical composition may however slightly vary, depending on the source of bauxite, the technological processing conditions (Bayer process or bauxite-calcination method) and storing ages. It is composed of six major oxides ($Al_2O_3$, $Fe_2O_3$, $Na_2O$, $SiO_2$, CaO, and $TiO_2$), and a large variety of other minor elements.

It has been estimated that 66 million tons of red mud [8] is produced annually across the world and it is considered to be "hazardous" according to the Brazilian NBR 10004 standard [9]. Over the years, the disposal of red mud by methods such as sea water discharge, lagooning and dry- stacking has been a major challenge to alumina companies and environmentalist. It is expensive, requires lot of land and poses numerous environmental and health hazards. As a result of these challenges, lots of research has been carried out to device means of economically utilizing this highly alkaline waste as a raw meal for the production of Portland cement clinker, as a partial substitute for clay in the production of bricks [10], in the preparation of special cements [11] and pozzolanic pigment.

Portland cement happens to be one of the most popular and widely used building materials across the world due to the availability of raw materials over the world, easy processing and its amenability to conceivable shapes [12]. However, there are two major drawbacks with respect to sustainability in the use of Portland cement which are: (1) about 1.5 tons of raw materials is needed in the production of every ton of Portland (PC), at the same time also about one ton of carbon dioxide ($CO_2$) is released into the environment which means that the production of Portland cement is a resource and energy intensive process. (2) Concretes made of Portland cement deteriorate when exposed to severe environments and this affects the service behaviour, design life and safety of structural constructions [13]. Studies have shown that utilization of red mud in the production of construction and building materials has the potential of consuming the red mud waste in higher quantities. For instance, it was reported that 2.5 million tons of red mud was consumed by the cement industry during 1998–1999 in India and researchers found that the hydration reaction of Portland cement is favoured by a highly alkaline environment which red mud is noted for [14]. The high alkalinity of red mud which is of environmental concern serves as a major asset in the attempt of inhibiting corrosion in reinforced concrete rebar and reducing sulphur build-up in the kiln system of cement plants. Tsakiridis et al., [11] in Greece studied the addition of red mud residue by 1% in the raw mix for the production of Portland cement and found that the red mud can be utilized as a raw material in cement production, at no cost to the producer thus, contributing in the reduction of the process cost. It has also been found out that the maximum potential strength developed by cement is never fully utilized as about half of the amount of Portland cement consumed in building construction is used in masonry and plastering whose strength requirement is about 4.0 MPa while Portland cement is suited for applications with strength requirements exceeding 15.0 MPa [15]. Materials with pozzolanic characteristics may thus be used to partially replace the cement in those applications and red mud is tested here for this purpose.

This study investigates the physico-mechanical and economic influence of calcined Bayer red mud addition in Portland cement based pavement blocks.

## 2. Experiment

### 2.1. Materials and methods

#### 2.1.1. Bayer red mud sample preparation and characterisation

The bauxite for the red mud preparation was obtained from Awaso in the western region of Ghana (Fig. 2) which is the main bauxite occurrence in Ghana. The bauxite rests on a layer of kaolin or lithomarge, which separates it from the underlying slates and the lower Birimian phyllites which strikes at N40E to N80E with steep dips to the NW. Hence, this bauxite can be classified as lateritic silicate bauxite because they have been formed as a result of indirect bauxitization processes under tropical weathering conditions. The built up sections range from the top soil, Bauxite and to Lithomargic clay (rock like) occurrences.

In a typical red mud production via the Bayer process, ball milled bauxite with particle sizes < 355 µm were slurred with hot (135 °C–140 °C) 2 M concentration of NaOH and digested in a 1L pyrex beaker at atmospheric pressure under constant stirring for