# Development of Concrete with Bauxite Residue for the Production of Paving Blocks by Casting

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**Abstract**



The use of bauxite residue (BR) in concrete compositions can be a safe solution to use a large amount of this waste in construction products. However, there are literature indications that due to the higher specific area of BR compared to cement, this association can result in compositions with higher water demand, reducing the performance at the hardened state and affecting durability. One of the challenges of this solution is to produce concretes with suitable rheological properties for each production stage without compromising the hardened state properties. The main purpose of this work was to evaluate concretes with up to 30 % of BR in relation to Portland cement as a filler or a substitute to cement. Compositions were formulated using raw materials collected in Barcarena, in northern Brazil. Concretes were mixed in a rheometer to evaluate the impact of BR in the mixing process and the rheological properties were measured after mixing by applying a shear cycle. Standard rheological control was performed with slump-test according to the standard method used in concrete plants. Up to 10 % of BR as a filler and 20 % as a substitution to cement did not result in considerable changes in the fresh properties. However, with a higher amount of BR, adjustments had to be made to control consistency, which was done by adding water or superplasticizer. After 28 days of curing, compressive strength, water absorption, abrasion resistance, and permeability of the paver blocks were measured. Results show that the products made from BR comply with the Brazilian standards of road paving blocks and can be classified as suitable for conditions subject to severe abrasion effects when BR was used in addition to cement, and for lighter traffic when used in substitution.

**Keywords:** Bauxite residue, Concrete, Paving blocks, Rheology, Hardened state properties.

## 1. Introduction

Brazil is among the four largest global players in the area of bauxite reserve, bauxite extraction, and alumina production [1]. In the production process of this mining sector, 0.8 to 1.3 tonnes of bauxite residue (BR) is generated for every tonne of alumina produced depending on the quality of the ore and the digestion process [2].

Almost unused, these Bauxite residues are stored in deposits that grow exponentially as the bauxite-based industry expands [3]. Although there are more than 50 years of research and hundreds of publications and patents for the use of BR in different areas, there are still very few applications. So, the waste continues to be stored with construction and maintenance costs [4], as well as considerable investment and operational costs for dewatering the residue (e.g. filter press technology) [5] to decrease the risk of environmental contamination in the bauxite residue storage facilities.

To have a significant impact, any application or product candidate should consume an important amount of BR, demonstrate adequate performance, and consider quality, cost, and risk of contamination of the environment [3]. One sector that has the potential to meet these requirements is the construction sector with cementitious materials and components for civil construction. Compared to the world production of Portland cement (> 4 billion tonnes per year), the global generation of BR is equivalent to less than 4 % of this amount. Compared to products derived from cement, such as concretes and mortars, it represents less than 1 %.

Incorporating BR into these products seems to be a promising option to be considered [6–9]. Due to its fine size, BR tends to be used as a filler (in addition to cement) or as a partial substitute for cement or traditional cementitious materials. Several studies point to technical feasibility in the production of Portland cement clinker [10,11] or as a supplementary material to cement [4,8,12]. If possible, solutions without the need for prior treatment (such as drying, grinding, calcination, etc.) are preferable. This would simplify and make the product development proposal cheaper with a smaller environmental footprint (lower energy consumption and $CO_2$ emissions).

However, there are also indications in the literature that the higher specific surface area of BR compared to cement can result in compositions with higher water demand reducing the performance at the final stage and affecting durability [13]. One of the challenges is to produce concretes with suitable rheological properties for each production stage (mixing, transportation, and application) without compromising the properties of the final stage (hardening process). The issue of high alkalinity and in some cases the presence of heavy metals has raised concerns about the impact on health and the environment [14].

An application that is marketable on a scale that allows for the consumption of a significant fraction of the BR is the production of urban infrastructure products, such as paving blocks. There are opportunities both for paving for the light traffic (people and light vehicles) and for areas with more intense traffic subject to more abrasion. As this solution can be adapted to the local market, it reduces the need to transport raw materials over long distances. The production can take place near the BR storage area and consumer markets using concrete batching plants and casting facility on site; or a production plant can be built inside or close to the BR storage area, greatly reducing the need for transportation.

In this context, the main purpose of this work was to produce concretes, intended to produce paving blocks with up to 30 % of BR in relation to Portland cement as a filler or substitute to cement. The impacts of the introduction of BR on several properties of the fresh and hardened state were evaluated.

## 2. Experimental

### 2.1 Materials and Concrete Compositions

In a previous step, a reference concrete without Bauxite residue (BR) was developed (labeled as REF in Table 3). The main targets were characteristic compressive strength of 50 MPa, a slump of 100 ± 20 mm, production by casting, and applicability on paver floors for heavy traffic.

Table 1 describes the granular materials used with their properties, and Figure 1 shows the particle size distributions. BR is finer than cement, indicating a potential to improve the packing of the paste. It also has a higher specific surface area.

A cement type CPV-ARI RS was used. This cement meets the requirements of the Brazilian standard ABNT NBR 16697:2018. The Bauxite residue of the Bayer process was obtained from Alunorte/Hydro in Barcarena (north of Brazil), from the active production process of alumina. It

## 4. Conclusion

Several concretes were developed to produce paving blocks. Strategies for adding and replacing cement with BR were evaluated, as well as rheological adjustments with water and superplasticizer additive were tested.

In the study carried out, up to 20 % replacement and 10 % addition resulted in little effect on rheological properties, indicating that the improvement in paste packing may have compensated for the increase in the surface area resulting from BR addition. For higher BR percentages, the results showed an important increase in yield stress, particularly in the case of 30 % addition. The plastic viscosity remained similar and, in some cases, even slightly lower than the reference concrete. This reduction, however, is not enough to counterbalance the increase in yield stress, and thus, at high shear rates, an increase in apparent viscosity is still observed in concretes with higher BR contents.

In some cases, the rheological properties changed so much that it would compromise casting of concrete. In these concretes, it was possible to add water or superplasticizer, thus getting similar slump, flow torque, and mixing torque at intermediate rotations. As a side effect, plastic viscosity reduced when adjusted with water and increased if adjusted with superplasticizer. This increase would require careful consideration if higher levels of RB are to be used.

Most properties in the hardened state showed similar trends, mainly depending on the water/cement ratio and air content. The air content followed the introduced BR content, which needs to be better evaluated and controlled in future research.

It was possible to obtain concretes with strengths between 38 and 61 MPa, with up to 30 % BR in relation to the cement mass of the reference concrete. This is a significant quantity considering the global production of cement and concrete. Also, supplementary additions in composite cements, if these additions are not reactive, usually do not exceed 25 %.

Evaluating the eco-efficiency of the concretes, based on the binder intensity (ratio between binder consumption and strength performance), shows that the concretes have values between 6.0 and 6.8 $kg/m^3/MPa$, similar to the reference concrete (6.2 $kg/m^3/MPa$). The best result refers to the concrete with 30 % BR in addition to the cement: the increase in performance was attributed to a better dispersion when adjusted with a superplasticizer additive to improve workability.

All the paving blocks produced with BR comply with the Brazilian standards of road paving blocks. The products could be classified as suitable for areas subject to severe abrasion when BR was used in addition to cement, and for lighter traffic when used in substitution. More general use of these concretes, even in other applications, may be feasible, provided that additional performance criteria are assessed successfully such as leaching, efflorescence, steel bar corrosion, alkali-silica reaction, and others.

## 5. References


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