Methodology for a Safe and Low-Cost Large-Scale Application for Bauxite Residue in association with Portland Cement in Compositions Applied in Civil Construction

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Abstract

Using bauxite residue (BR) in association with Portland cement (PC) presents an opportunity to address challenges facing the aluminium and cement industries: the roadmap of the International Aluminium Institute identifies this application as one of the most impactful uses for BR in large-scale. The route developed in this study, with support from the Alcoa Foundation, focuses on developing a large-scale and low-cost application for the BR without the requirement for additional treatment of the residue, such as energy intensive calcination or additives addition. This study has investigated the properties and compositional variability of BR collected from two different alumina refineries, and the synergistic interactions of the BR with different Portland cements. The chemical reactions and formation of hydrated products were monitored during the development of eco-friendly compositions, with the performance and durability of the components produced being a key output of this study. This methodology has facilitated the production of components at a pilot-scale, without a negative impact on the development of microstructure. The material was easily molded, demonstrated high performance, and was environmentally safe. This paper presents the methodology, and illustrates the overall strategic approach and challenges faced relating to the production of large-scale cement components exposed to environmental conditions.

Keywords: Bauxite residue, Portland cement, Chemical reaction, Rheology, Performance, and methodology of development.

1. Global Bauxite Residue Overview

Over 95% of the alumina produced globally is through the Bayer process. On average, for every ton of alumina produced, approximately 1 to 1.5 tonnes of BR are produced. Annual production of alumina in 2021 was over 138 million tonnes, resulting in the generation of over 180 million tonnes of BR [4]. The BR is deposited and stored in specially engineered facilities commonly called impoundments [1]. These impoundments securely contain the tailings to avoid BR contact with surface or underground water [2,3] and otherwise serve to store BR safely and efficiently.

The aluminium industry is actively investigating options to reduce the quantity of BR produced and the land area required for storage. An important enabler to this is identifying and developing opportunities for value adding uses of BR [5]. Presently, the main applications evaluated for BR include element recovery (heavy metals, rare earth elements, and other critical minerals), synthesis of zeolites, landfill capping, soil amelioration, production of Portland cement clinker, manufacture of building materials, concretes and cementitious components, tiles and bricks, road construction (sub-base and sub-grade), geopolymers, water treatment, production of red ceramics, selective filters for SO2 or H2S, and others [3,6–26]. The main challenges relating to BR reuse are
high alkalinity and the presence of heavy and alkaline metals. This explains, in part, the reason for why less than 4Mt of BR produced annually is being utilized [17].

The physical properties of BR vary significantly between alumina refineries due to the bauxite mineralogy and processing conditions [27]. For example, the specific surface area (SSA) reported by [28] ranged from 64 - 187 m²/g, according to the BET method [29], highlighting the difference between BR generated from a Bayer process versus a sintering process. In a separate study, the average SSA of BR was ~ 35 m²/g for BR generated in the Bayer process, with a range of 15 and 55 m²/g. Generally BR contains a large proportion of fine particles, varying from 100 nm - 200 μm [5,17,27,28,30], with a d₉₀ <75 μm.

Similarly, BR chemical composition potentially changes with time when stockpiled. Typical BR chemical compositions reported in the literature are presented in Table 1, separated by country and the results for Brazil highlighted.

<table>
<thead>
<tr>
<th>Country</th>
<th>Fe₂O₃</th>
<th>Al₂O₃</th>
<th>TiO₂</th>
<th>SiO₂</th>
<th>Na₂O</th>
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<td>3-10</td>
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<td>5.2-12.2</td>
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<td>8-24</td>
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<td>0.5-4</td>
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<td>6.8-7.5</td>
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<td>5-20</td>
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The main mineralogical phases of BR are presented in Table 2. These predominantly consists of oxides and hydroxides of iron, aluminium, silica, calcium and titanium [2,5,39,40].

² Considering both process of bauxite residue generation, Bayer and sintering.
Leaching of sodium and aluminates, and consequent efflorescence, was higher with increasing BR additions, but it was possible to fix a considerable proportion of these soluble ions by associating the BR with slag and selecting the most suitable Portland cement.

The monitoring of alkali-silica reaction by the Brazilian standard accelerated method, indicates that at up to 20% of BR addition the trend is similar to that observed by the reference material. However, using a larger amount of BR replacement resulted in a lower reaction compared to the reference, possibly caused by clinker dilution or by the higher availability of soluble aluminate ions that may impart a mitigating effect.

Finally, we produced some cementitious components using the best conditions evaluated for the fresh and hardened state properties, chemical reaction, and leaching. The components were evaluated and exposed to the environment. The results indicated that it is possible to produce safe, large-scale applications for BR by using appropriate criteria for particle properties, choice of raw materials, and the development of compositions with correct proportioning to guarantee the performance in the fresh and hardened state, with good durability and environmental performance with respect to leaching.

4. References

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