Development of Concretes with Different Strength Classes and Variations of Untreated Bauxite Residue Consumption

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Abstract

Most (estimated > 90 %) of the world's concrete exhibits compressive strength of up to 50 MPa, with the remaining percentage divided between high- and ultra-high-strength concretes. These different compositions find applications in monolithic floors, paving blocks, ordinary concrete for columns and beams, urban furniture, and more, and are of great practical interest. It's important to note that a solution designed for a specific application and using certain raw materials may not be suitable for another purpose, particularly in highly demanding situations. Therefore, development efforts must be driven by the requirements of both fresh (before hardening) and hardened (aged) state properties. The combination of bauxite residue (BR) with Portland cement (PC) is closely linked to the key sustainability challenges facing the aluminium and cement industries. This integration is in line with the roadmap outlined by the International Aluminium Institute, which recognizes it as one of the most impactful applications for this residue. The focus of this project is to develop large-scale and low-cost applications for BR without the need for additional treatments, such as energy-intensive calcination or environmentally harmful additives. The research presented here, explores alternatives for incorporating a significant amount of BR into cementitious compositions (up to 116 kg/m³ of concrete, equivalent to 5.4 % of total solid mass or 27 % of cement mass) with compressive strengths in the range of 30 to 50 MPa. These compositions are intended to produce paving or monolithic concrete, suitable for various cementitious building components. In particular, the study used raw materials from the northern region of Brazil, considering logistical considerations. The material was easy to mould, showed satisfactory fresh and hardened (aged at 28 days) performance, and, as a considerable amount of residue was incorporated without compromising performance, it resulted in more environmentally friendly products.

Keywords: Normal strength concrete, Bauxite residue, Rheological properties, Mechanical properties, Colour.

1. Introduction

The bauxite residue (BR) generated by the Bayer process for alumina production is accumulating worldwide, posing costs and risks for the aluminium industry in terms of handling and storage. Despite research efforts, applications on a relevant scale remain limited. Any proposed solution should not only consume significant volume, but also demonstrate adequate technical performance considering quality, cost, and risk of environmental contamination [1, 2].

The roadmap developed by the International Aluminium Institute [3] recognizes the use of BR in cementitious products as one of the most promising applications. Various applications can be envisaged, such as monolithic floors (roads, logistics warehouses, sidewalks), interlocking pavers, general-purpose concrete for structures (columns, beams, slabs, and walls), urban furniture, etc., which show significant practical interest.

Different routes have been proposed for the use of BR in cementitious materials, some of which involve the beneficiation of BR. As these stages usually involve significant energy consumption (grinding, calcination) or the use of special additives, they result in higher costs and potential environmental impacts. However, studies indicate that it is possible to use the residue in its natural state, without any additional process [4–7].

The objective of this work is to assess the impact of adding BR without additional processing (only filter pressed) for use in common concrete applications with strengths of up to 50 MPa. As these applications include most - estimated > 90 % [8, 9] - of the concrete volume produced currently, the aim is to reach a relevant potential market share. In addition, local aspects of material availability have been considered, integrating the use of BR into the regional consumption logic.

2. Experimental

The study started with the development of reference concretes (without BR) with cement consumption ranging from 318 to 429 kg/m³ and water/cement ratios between 0.48 and 0.65 to obtain concretes for different applications. Table 1 presents these mix designs.

A cement type CPV-ARI RS (Sulfate Resistance High Early-Strength Portland Cement) was used, which meets the requirements of the Brazilian standard ABNT NBR 16697:2018. As aggregates, river sand and gravel were used, both of which are common in the region where the BR is generated. A water-reducing plasticizer admixture (Miraset® 63 from GCP) was also employed, in a proportion of 0.9% by mass of cement.

The water and admixture consumption were adjusted to achieve suitable workability to produce various products, such as moulding pieces in moulds applying vibration through vibrating tables, or for use in ready mix concrete and vibration through immersion vibrators. A target slump of 100 ± 20 mm was adopted.

Table 1. Compositions of reference concretes (mass in kg/m^3).

ID	Cement	Sand	Gravel	Water
REF_L	318	785	980	209
REF_M	374	750	997	201
REF_H	429	710	1010	204

For each reference concrete, three additional concretes containing BR were produced, in proportions of 10, 20, and 30 % relative to the volume of cement (mix design presented in Table 2). This addition of BR was done by replacing part of the sand, therefore not changing the cement, gravel and total (added + water in BR) water consumption. So, the total water/cement ratio was kept unchanged.

The bauxite residue (BR) was obtained from Alunorte/Hydro in Barcarena (north of Brazil), from the production of alumina by the Bayer process, directly from the filter presses. It was delivered with a moisture content of 26 % and used in this condition for the production of concrete. Table 3, Figure 1 and Table 4 present the physical and chemical properties of the materials.

100 kg/m^3 of concrete, an increase in water content was necessary to adjust workability. The decision to make the adjustment with water resulted in impacts on properties in the hardened (aged) state, reducing strength and increasing water absorption. This highlights the need to consider applicability criteria (workability) when developing an application and seeking higher BR incorporations.

- The introduction of BR in concretes enables a reduction in environmental impact. Firstly, due to the possibility of reducing cement consumption, which reduces the CO_2 footprint of concrete, especially in applications designed for flexural stress. Secondly, by offering a destination for an industrial waste. And finally, by reducing the consumption of natural sand, requiring less extraction of this natural resource.

Regarding colour, even with lower BR contents, there's a shift from grey to reddish. If the obtained colour cannot be integrated into the architectural proposal, its use can be limited to non-visible applications, with subsequent finishing using another material for desired colour. But it is worth to remember that colour is a matter involving the type of application as well as regional and cultural considerations.

Lastly, it is necessary to consider that besides technical adequacy, environmental safety evaluations are still necessary, especially regarding leaching and solubilization of elements that may be harmful to the environment.

5. References

1. Craig Klauber, Markus Gräfe and Greg Power, Bauxite residue issues: II. Options for residue utilization. *Hydrometallurgy*, volume 108, No 1, (2011), 11–32. https://doi.org/10.1016/j.hydromet.2011.02.007.
2. Ken Evans, The history, challenges, and new developments in the management and use of bauxite residue. *Journal of Sustainable Metallurgy*, Volume 2, (2016), 316–331. https://doi.org/10.1007/s40831-016-0060-x.
3. IAI – International Aluminium Institute, 2020. Technology roadmap - Maximizing the use of bauxite residue in cement. https://international-aluminium.org/resource/technology-roadmap-maximizing-the-use-of-bauxite-residue-in-cement/ (accessed on 23 February 2024).
4. Roberto Romano et al., Impact of using bauxite residue in microconcrete and comparison with other kind of supplementary cementitious material, *Proceedings of 35th International ICSOBA Conference*, 2017, *TRAVAUX* 46, 505–518.
5. Waiching Tang et al., Influence of red mud on fresh and hardened properties of self-compacting concrete. *Construction and Building Materials*, Volume 178, (2018), 288–300, https://doi.org/10.1016/j.conbuildmat.2018.05.171.
6. Roberto Romano et al., Case study of a potential large-scale application for bauxite residue in the composition of paver blocks: Evaluations of producing, building and monitoring performance and durability, *Proceedings of 39th International ICSOBA Conference*, Online Conference, 2021, *TRAVAUX* 50, 343–355.
7. Markus Rebmann et al, Development of concrete with bauxite residue for the production of paving blocks by casting, *Proceedings of 40th International ICSOBA Conference*, 2022, *TRAVAUX* 51, 739–752.
8. Mordor Intelligence, 2024. High-Strength Concrete Market Size & Share Analysis. https://www.mordorintelligence.com/industry-reports/high-strength-concrete-market (accessed 7 March 2024).
9. Global Cement and Concrete Association, 2021. The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete. https://gccassociation.org/concretefuture/wp-

content/uploads/2021/10/GCCA-Concrete-Future-Roadmap-Document-AW.pdf (accessed 7 March 2024).

10. Bruno Damineli et al, Measuring the eco-efficiency of cement use. *Cement and Concrete Composites*, Volume 32, No 8, (2010), 555–562. https://doi.org/10.1016/j.cemconcomp.2010.07.009.