Co-calcination of Bauxite Residue with Kaolinite to Enhance its Performance as Supplementary Cementitious Material

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Abstract

The cement industry is one of the world's largest users of mineral waste streams and is continuously searching for alternative resources to reduce its environmental impact. With a global cement production of around 4 Gt/year and global bauxite residue (BR) generation of approximately 160 Mt/year, the cement industry is an often-targeted market for BR valorization. The use of industrial residues as supplementary cementitious material (SCM) – a material partially replacing the CO_2 intensive clinker in Portland cement – is one of the key solutions to decrease the CO_2 emissions of the cement industry on the short term. The use of BR as SCM can thus be a solution for both the alumina industry and cement industry. Unfortunately, the performance of BR as SCM is poor without additional treatments. Calcination (i.e. thermal treatment at 600 – 900 °C) has been shown to enhance the reactivity of BR and the contribution of BR to compressive strength of cement mortars to some extent. The results of this work show that co-calcination of a blend of BR and kaolinite drastically boosts the reactivity and performance as SCM of the calcined BR-containing product. The calcination of a mixture of 70 wt% BR and 30 wt% kaolinite produces a reactive SCM. When this SCM is blended with Portland cement (30 wt% SCM) in mortar samples, the strength after 7 and 28 days is 85-90% of that of the reference sample, outperforming conventional SCMs such as coal combustion fly ashes.

Keywords: Bauxite residue, Red mud, Cement, Supplementary cementitious material, Calcination.

1. Introduction

The utilization instead of storage of bauxite residue (BR) allows for a reduction in resource depletion by keeping materials in beneficial use for longer. In addition, it would reduce costs and liability of the alumina producers associated with the BR storage facilities. The incentive can even become economically favorable if good quality products can be engineered from BR and introduced on a high-volume market. The cement industry is identified as one of the key markets for the high-volume use of BR [1]. With a global production of 4 Gt cement/year [2] and 160 Mt BR/year [1] (volumes in 2020), cement could easily absorb BR production volumes. The development of cementitious products from BR is the crucial step forward. Transformation is also required from the perspective of the cement sector. Supplementary cementitious materials (SCMs) are required to further decrease the CO_2 emissions of the cement industry while current SCM resources are in short supply [3].

The performance of BR as an SCM is a matter of dispute in the scientific literature. There is a consensus that high substitution levels of cement for untreated BR (> 20 wt%) are not technically feasible, however, for low replacement levels (< 20 wt%) the reported findings disagree: the contribution of BR to strength development ranges from worse than inert filler to no decrease in strength in comparison with the pure cement [4-7]. The cement hydration is accelerated and workability (flow) decreased by the introduction of BR in the cement blend [4-6, 8]. The reactivity of an SCM measured by the R3 test provides an indication of the amount of hydration products that can be formed by the reaction of the SCM and therefore the strength development the SCM can cause and the impact on the durability it might have [9]. The reactivity of BR is only slightly higher than that of inert fillers, but this can be slightly increased by calcination if the calcination temperature is below 800 °C [10, 11]. A high-quality BR-containing SCM was obtained by Danner et al [4] using co-calcination after blending with kaolinite. This co-calcination process increased the reactivity drastically and reduced the soluble Na content, with positive effects on long-term strength development of the blended cement.

This proceedings paper presents the results of an experimental study on co-calcination of BR and kaolinite for the production of an SCM. The process is applied to BRs from different alumina producers to assess whether the variability in SCM quality in literature might be caused by the characteristics of the different BRs used in the references. The reactivity, soluble Na content and compressive strength development are investigated on calcined and co-calcined BRs.

2. Materials and Methods

BRs from 3 different alumina plants were used to study the effect of variability in BR characteristics on their performance as SCM. All 3 samples are received in the state as they would be sent to their respective storage area. The samples are dried before the start of the experiments. The chemical composition in Table 1 was determined using ED-XRF on glass beads. The composition is presented as oxides with the elements in the expected main oxidation state. The chemical compositions were similar for all 3 received samples. The samples are predominantly iron-rich. A significant amount of alumina and silica are present at similar levels among the different BRs. Minor elements were Na, Ti and Ca. Approximately 10 wt% of loss on ignition (LOI) was measured for the BRs, mostly related to the hydroxide and hydrate phases, but also due to the potential presence of calcite.

Table 1. Chemical composition of the BRs determined using XRF. All values are in wt%.

BR sample	Fe_2O_3	Al_2O_3	SiO_2	Na_2O	TiO_2	CaO	Others	LOI
Alum (Alum)	47	18	9	5	4	4	2	11
Rio Tinto (Rio)	49	18	10	5	5	2	2	9
Aughinish Alumina (AAL)	49	16	8	4	7	4	2	10

Particle size distribution (PSD) analysis was done after dispersing the BRs in isopropanol using ultrasound. Measurements were made using a Horiba LA-350 laser diffractometer. The distributions in Figure 1 show that the 3 BRs have similar PSDs. The d_{50} was 3-4 µm. Batch leaching tests were carried out on the calcined samples to determine the soluble Na content. The samples were mixed with demineralized water at a liquid/solid ratio of 10 and shaken for 24 hours. After 24 hours, the leachate was collected and the Na concentration was analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES).

The BRs were blended with Bole White from VWR, which is a high purity kaolin (> 95 wt% kaolinite). The dried BR was blended with kaolin (K) in a weight ratio of 70:30 (BR:K). Calcination was carried out on the BR-K blends and the BR itself, using a dwell time of 1 hour at 750 °C and heating and cooling rates of 5 °C/min. The resulting 6 samples were named using an abbreviation of the BR origin, the BR content in wt% and "/K", indicating the addition of kaolinite: i.e. Alum100, Alum70/K, Rio100, Rio70/K, AAL100, AAL70/K. When referring to calcined samples with kaolinite in general BR70/K is used, while BR100 refers to the calcined BRs without kaolinite.

6. References

1. International Aluminium Institute, Technology roadmap: Maximising the use of bauxite residue in cement, 2020, available from https://international-aluminium.org/resource/technology-roadmap-maximizing-the-use-of-bauxite-residue-in-cement/ (accessed on 22/09/2021).
2. M. Garside, Cement production worldwide from 1992 to 2020, 2021, available from: https://www.statista.com/statistics/1087115/global-cement-production-volume/ (accessed on 22/09/2021).
3. Karen L. Scrivener, Vanderley M. John, Ellis M. Gartner, Eco-efficient cements: potential, economically viable solutions for a low-CO_2, cement-based materials industry, *UNEP Report 2016*.
4. Tobias Danner, Harald Justnes, Bauxite Residue as Supplementary Cementitious Material – Efforts to Reduce the Amount of Soluble Sodium, *Nordic Concrete Research*, Vol. 62, No. 1, (2020), 1-20.
5. Marijana Serdar, Ivan Biljecki, Dubravka Bjegovic, High-Performance Concrete Incorporating Locally Available Industrial By-Products, *Journal of Materials in Civil Engineering*, Vol. 29, No. 3, (2017), 04016239.
6. Daniel V. Ribeiro, João A. Labrincha, Márcio R. Morelli, Use of red mud as addition for portland cement mortars, *Journal of Materials Science and Engineering*, Vol. 4, No. 8, (2010).
7. Chava Venkatesh, Nerella Ruben, Madduru Sri Rama Chand, Red mud as an additive in concrete: comprehensive characterization, *Journal of the Korean Ceramic Society*, Vol. 57, No. 3, (2020), 281-289.
8. W. C. Tang, Z. Wang, S. W. Donne, M. Forghani, Y. Liu, Influence of red mud on mechanical and durability performance of self-compacting concrete, *Journal of Hazardous Materials*, Vol. 379, (2019) 120802.
9. Ruben Snellings et al., Rapid, Robust, and Relevant (R3) Reactivity Test for Supplementary Cementitious Materials, *ACI Materials Journal*, Vol. 116, No. 4, (2019).
10. Eliz P. Manfroi, Malik Cheriaf, Janaide C. Rocha, Microstructure, mineralogy and environmental evaluation of cementitious composites produced with red mud waste, *Construction and Building Materials*, Vol. 67, (2014), 29-36.
11. Daniel V. Ribeiro et al., Rheological properties and hydration behavior of portland cement mortars containing calcined red mud, *Canadian Journal of Civil Engineering*, Vol. 40, No. 6, (2013), 557-566.
12. Ruben Snellings et al., Classification and milling increase fly ash reactivity as supplementary cementitious material, *Frontiers in Built Environment*, Vol. 7, (2021), 44.