Bauxite By-Products as Mineral Admixtures for Portland Cements

Marcio Barata[1], Euler Arruda Junior[2], Caio Melo[3], Marcelo Montini[4] and Raphael Costa[5]
1. Associate Professor
2. Doctoral Student
Universidade Federal do Pará, Belém, Brazil
3. R&D Specialist
4. Senior Chemical Consultant
5. Head of Technology B&A
Hydro, Belém, Brazil
Corresponding author: marciobarata@ufpa.br

Abstract

In emerging countries, Portland cement plays an extremely significant role in the expansion of infrastructure. Global cement production is expected to grow between 12 and 23 % by 2050 compared to its current level, which will produce approximately 11 % to 15 % of global anthropogenic CO_2 emissions, per turn if the way of cement production doesn't change. The use of mineral admixtures as a partial replacement of clinker in Portland cement has been one of the main strategies for reducing CO_2 emissions by global cement industries. However, the availability of blast furnace slag and fly ash is limited compared to the demand for Portland cement. In addition, Brazil is a country of continental dimensions, with great regional differences, where the same mitigation actions will not necessarily be applied in all regions. Nowadays, in regions where slag and fly ash are not available, such as the Amazon, pozzolanic and Portland-composite cements are manufactured with up to 30 % calcined clays or 25 % limestone filler. Another alternative for these regions would be the manufacture of cement with active or inert mineral admixtures from mining by-products. The aluminum production chain, responsible for generating significant amounts of waste, could meet the demand of the local building industry, since some wastes such as the gibbsite-kaolinite waste (GKW) and the bauxite residue (BR) have demonstrated their potential use in previous studies. The incorporation of GKW increased the compressive strength by 44 % in relation to Portland cement. Mortars with 25 % replacement of clinker by BR showed compressive strengths at early ages higher to those obtained with limestone fillers. These results are promising, but require more in-depth studies, especially on durability aspects, dimensional stability, alkali-aggregate reaction and others.

Keywords: CO_2 emissions, Bauxite by-products, Gibbsite-kaolinite waste, Bauxite residue, Mineral admixtures.

1. Introduction

In emerging countries, Portland cement plays a significant role in dwelling construction and infrastructure expansion, where concrete is the most widely used material. The production of concrete is responsible for about 5 to 8% of the world's CO_2 emissions, and cement production is responsible for 95% of this total [1]. In 2016, emerging countries, including China, India, Russia, South Africa, and Brazil, accounted for 81% of the total global cement production, whereas industrialized countries accounted for only 9% [2]. Global cement production is expected to grow between 12 and 23% by 2050 from its current level, which will make cement manufacturing directly responsible for approximately 11 to 15% of global anthropogenic CO_2 emissions [3] if the cement production way doesn't change.

The use of mineral admixtures as a partial replacement of clinker in Portland cement has been one of the main strategies for reducing CO_2 emissions by the global cement industry [4-7]. In

Brazil, the reduction of clinker-cement ratio from the use of mineral admixtures could represented 69% of CO_2 total mitigation emissions in the country's cement sector by 2050 [8]. However, the availability of ground blast furnace slag and fly ash is not enough afford the demand for Portland cement [9].

In addition, Brazil is a country of continental dimensions, with enormous regional differences, in which the same mitigation actions will not be necessarily applied in all Brazilian regions [8]. Currently, in regions where ground blast furnace slag and fly ash are not available, such as the Amazon region, composite and pozzolanic cements are manufactured with up to 25% limestone filler and 30% calcined kaolin, respectively.

Another alternative for the region would be the cement manufacturing with active or inert mineral admixtures from mining by-products. The aluminum production chain produces by-products that can fit this description and can potentially meet the demand of the local building industry.

At HYDRO group, two by-products are generated with great application potential as active and inert mineral admixtures in Portland cements, namely, the gibbsite-kaolinite waste (GKW) and bauxite residue (BR), respectively. The first is generated from the bauxite ore beneficiation process in order to remove kaolinite from gibbsite; the resulting by-product is enriched with kaolinite [10], whose quantities generated are close to 5.4 Mtpy. Bauxite residue (BR) is a by-product of the Bayer process, containing mostly phases from bauxite ore such as hematite, goethite, gibbsite and anatase, in addition to sodalite formed during the process and soluble sodium. Approximately 4.7 Mt of this residue is generated annually. The pozzolanic activity of BR is not satisfactory [11].

The aim of this research was to investigate the effect of incorporating GKW and BR as mineral admixtures to Portland clinker. The first as a supplementary cementitious material in pozzolanic cements and the second as a filler, replacing limestone in Portland-composite cements, CP IV and CP II F, according to Brazilian cement standard ABNT NBR 16697. Both are equivalent to CEM IV and CEM II/BL on European cement standard EN197-I, respectively.

2. Experimental

2.1 Raw Materials

There were four raw materials analyzed in the experimental program. The first one was BR from ALUNORTE, generated in Barcarena. The second, the residue from the bauxite washing process in Paragominas (Mineração Paragominas), rich with kaolinite and gibbsite, called here GKW [10]. The others were included in the experimental for comparison purposes. The flint kaolin (FK), extracted from the deposits in the middle Capim River valley in Ipixuna do Pará, is recognized as a high-grade kaolin for the production of high-performance pozzolans [12-13]. And finally, the limestone (LS), as it is the inert mineral admixture used at the production of Portland-composite cement, mining from the Northeast region of Pará, from calciferous occurrences denominated Pirabas Formation.

2.2 Production of Mineral Admixtures

The active mineral admixtures produced in the experimental program were derived from calcination and grinding of kaolins (GKW and FK). The inert mineral admixtures (BR and LS) were only dried and ground. Two and a half kilograms of each kaolin were thermally treated at 800 ºC with a 2-hour plateau. The calcined kaolins were ground for 3 hours in a ball mill using 10 liter porcelain jars with alumina spheres in a 1:9 ratio (ore:spheres). The BR and the limestone were dried in an oven at 105 ºC until reaching the constant mass and ground under the same than at 28 days. The results are promising, but they should be viewed with caution, as there are other aspects that must be taken into account when using BR in Portland cement, such as alkali-aggregate reactivity, the appearance of efflorescence, shrinkage and color.

GKW consists mostly (60%) of a kaolinite with a high degree of defects and extremely fine. The SSA_{BET} of untreated and thermally treated GKW were 19 and 42 $m^2.g^{-1}$, respectively. These characteristics, whereas providing high reactivity, can also cause problems associated with dimensional stability such as excessive shrinkage and creep.

Metakaolin derived from GKW obtained a PI at 28 days of 144 %, similar to that calcined FK which is considered one of the most reactive mineral admixtures. In addition, M-GKW also showed a high-value of PI for the early ages, mainly at 7 days. This is an extremely important aspect for the cement industry, considering that the major problem of pozzolanic cements, with large incorporation of mineral admixtures, is the low compressive strength at early ages. The use of GKW may eliminate this problem as long as the issue of fineness is controlled.

5. References

1. Robbie M Andrew, Global CO_2 emissions from cement production, *Earth System Science Data*, Vol. 11, No. 4, (2019), 1675-1710.
2. CEMBUREAU, Activity Report, 2017, *CEMBUREAU Blog*. https://cembureau.eu/media/vxyilmsd/activity-report-2017.pdf (accessed on 15 April 2018).
3. International Energy Agency, Tecnnology Roadmap: Low-carbon transistion in cement industry, *IEA Blog*. https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry (accessed on 31 Jan 2020).
4. Raili Kajaste and Makka Hurme, Cement industry greenhouse gas emissions – management options and abatement cost, *Journal Cleaner Production*, Vol. 112, Part 5, (2016), 4041-4052.
5. M. Schneider et al., Sustainable cement production—present and future, *Cement and Concrete Research*, Vol. 41, No. 7, (2011), 642–650.
6. J.S. Damtoft et al., Sustainable development and climate change initiatives, *Concrete Research*, Vol. 38, No. 2, (2008) 115–127.
7. United Nations Environment, Karen Louise Scrivener, Vanderley Moacir John, Ellis M. Gartner, Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry, *Cement and Concrete Research*, Vol. 114, (2018) 2-26.
8. Sindicato Nacional da Indústria do Cimento and Associação Brasileira de Cimento Portland, Roadmap tecnológico do cimento: potencial de redução das emissões de carbono da indústria do cimento brasileira até 2050, *SNIC Blog*. snic.org.br/assets/pdf/roadmap/roadmap-tecnologico-do-cimento-brasil.pdf (accessed on 2 feb 2020).
9. Ruben Snellings, Assessing, understanding and unlocking supplementary cementitious materials, *RILEM Technical Letters*, Vol. 1, No. 1, (2016), 50-55.
10. Caio Cesar Amorim Melo et al., Gibbsite-kaolinite Waste from bauxite beneficiation to obtain FAU zeolite: Synthesis optimization using a factorial design of experiments and response surface methodology, *Applied Clay Science*, Vol. 170, (2019), 125-134.
11. Pedro Secco, Elias Soares and Márcio Barata, The use of red mud and kaolin waste in the production of a new building material: Pozzolanic pigment for colored concrete and mortar, *Proceedings of 36th International Symposium ICSOBA*, Belém, Brazil, 29 October - 1 November 2018, Paper BR 9, *TRAVAUX* 47, 459-464.
12. Márcio Barata and Rômulo Angélica, Characterization of kaolin wastes from kaolin mining industry from the amazon region as raw material for pozzolan production, *Cerâmica*, Vol. 58, (2012), 36-42.

13. Márcio Barata and Rômulo Angélica, Atividade pozolânica dos resíduos cauliníticos das indústrias de mineração de caulim da Amazônia, *Matéria*, Vol. 16, No. 3, (2011), 795-810.
14. Karen Scrivener et al., Limestone calcined clay cements (LC^3), *Cement and Concrete Research*, Vol. 114, (2018), 49-56.