Low-Carbon Cements from Aluminum Chain By-Products

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Abstract

In emerging countries, Portland cement plays an extremely significant role in the expansion of infrastructure. Global cement production is expected to grow considerably in the next decades, heavily contributing to the global anthropogenic CO_2 emissions, if the way of producing cement will not change. The use of supplementary cementitious materials (SCM) as a partial replacement of clinker in Portland cement is one of the main strategies adopted to reduce CO_2 emissions by global cement industries. However, the availability of conventional SCM like blast furnace slag and fly ash is regional and globally limited compared to the demand for Portland cement. In Brazil, a country of continental dimensions with great regional differences, the same mitigation actions will not necessarily be applied in all regions and 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. An alternative for these regions would be the manufacture of cement with active or inert SCM from mining by-products. Some materials like the gibbsite-kaolinite waste (GKW) and the bauxite residue (BR) have demonstrated their potential use in previous studies. In this experimental investigation, blended cements were produced with clinker replacement levels of 50 % by a combination of metakaolin produced from the calcination of GWK and bauxite residue. The results demonstrated the high mechanical efficiency of these binders compared to ordinary Portland cement. The incorporation of metakaolin provided very high compressive strengths, while the bauxite residue accelerated the clinker hydration and pozzolanic reactions. The combination of the two by-products from the aluminum chain resulted in an increase in both initial and long-term strength, allowing clinker replacements of up to 50 % and reductions of 35 % in greenhouse gas emissions and 50 % in the consumption of non-renewable natural resources (NR^2). The results are promising and noteworthy with respect to early-age compressive strengths, as they increase construction productivity, but also in minimizing the use of NR^2. However, more in-depth studies on durability and dimensional stability are essential.

Keywords: CO_2 emissions, Aluminum Chain by-products, Gibbsite-kaolinite waste, Bauxite residue, Low-carbon cements.

1. Introduction

Due to the accelerated process of urbanization in large cities and their surroundings, especially in emerging countries, there is a growing need for raw materials to meet the demands of the construction industry. In 2020, for example, the global consumption of natural aggregates and cement, fundamental for the construction market, exceeded 48 billion and 4 billion tonnes, respectively [1].

Concrete production is responsible for 5 to 8 % of global anthropogenic CO_2 emissions, with cement being the main contributor, accounting for up to 95 % of the environmental impacts associated with this sector [2]. Global cement production is expected to increase by 12 to 23 % by 2050 compared to its current level, which will make cement production directly responsible for approximately 11 to 15 % of global anthropogenic CO_2 emissions if the method of cement production does not change. Thus, the main challenge is the immediate need to reduce CO_2 emissions related to the production of clinker, the main component of cement, responsible for a large portion of the pollutant gas emissions. In this context, reliance on traditional raw materials also contributes to environmental impacts, highlighting the need to explore more sustainable options.

The use of supplementary cementitious materials (SCM) as a partial replacement of clinker in Portland cement is one of the main strategies adopted by the global cement industry to reduce CO_2 emissions [3]. However, the availability of ground blast furnace slag and fly ash to produce blended cements is not enough to offset the demand for Portland cement [4]. In addition, Brazil is a country of continental dimensions, with enormous regional differences, in which the same mitigation actions will not be necessarily applied everywhere [5].

The development of more sustainable alternatives for cement production must then consider the use of locally and regionally available raw materials. The state of Pará, in Amazon region, is one of the most privileged regions on the planet in terms of mineral resource exploitation. Mining projects in Pará stand out for the quality of their products, the commercial values, and the magnitude of production, also making them responsible for generating significant amounts of waste or by-products. Among the various types of waste from its intense mineral activity, flint kaolin (FK) prevails. FK has excellent technical characteristics, as demonstrated by various studies, indicating its potential application not only in the construction sector but also in the refractory and advanced ceramics industries [6-11]. It is essentially composed of extremely fine kaolinite, has high uniformity, and is easy to handle. All these requirements are excellent to produce a highly reactive pozzolan, called metakaolin, by calcination and grinding of pure kaolinite clays with very few inert minerals.

Two other by-products with great potential for application as active and inert mineral admixtures in Portland cements are the gibbsite-kaolinite waste (GKW) and bauxite residue (BR), respectively. The former is generated in the beneficiation process of bauxite ore to remove kaolinite from gibbsite; the resulting by-product is then enriched with kaolinite [12], with amounts close to 5.4 Mtpa. Bauxite residue (BR) is a by-product of the Bayer process, mainly containing bauxite ore phases such as hematite, goethite, gibbsite, and anatase, as well as sodalite formed during the process and soluble sodium. Approximately 4.7 Mt of this residue are generated annually. The pozzolanic activity of BR is not satisfactory [11].

The mining sector and the aluminum industry have been making many attempts to utilize their by-products instead of simply depositing them, due to the high disposal costs in residue disposal areas or sedimentation ponds.

The aim of this research was to assess the feasibility of producing low-carbon cements (LC^2) through the combined use of GKW and BR as SCM to partially replace clinker in Portland cement, aiming at meeting engineering goals and simultaneously achieving favorable environmental indicators in terms of reduction of both CO_2 emissions and demand for NR^2.

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