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Review

Natural volcanic pozzolans as an available raw material for alkali-activated materials in the foreseeable future: A review

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HIGHLIGHTS

- The paper reviews the utilization of natural volcanic pozzolan (NPs) in the production of AAM.
- The available raw materials are a vital aspect for the technological transition of the AAM.
- This review analyzed the role of characteristics of NPs in the alkaline activation.
- This paper can encourage and promote the research on the alkaline activation of NPs.
- This review presents the future challenges and opportunities in this topic.

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ABSTRACT

Alkali-activated materials (AAM) represent a line of research of great interest around the world as a real alternative to replace Portland cement (OPC). Despite this global interest, it is believed that current and future research should focus on overcoming the challenges that this technology faces with regard to its application at an industrial level. One of the main barriers to scale at the industrial level is the scarcity of studies on truly available and sustainable raw materials (precursors and activators). This review emphasizes natural volcanic pozzolans (NPs), also named volcanic ashes, as a globally available and sustainable raw material for industrial production of AAM in the foreseeable future. To this end, the most important findings about mechanical performance and durability reported by researchers at a global level are presented and described, and a constructive analysis is carried out in order to establish the future challenges and opportunities to carry out a technological transition of these advances (industrial application) in countries rich in materials derived from volcanic activity.

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1. Introduction

In the search for new cementitious materials that have a global warming potential (GWP) lower than that of ordinary Portland cement (OPC)—that is to say, whose manufacturing processes are less energy intensive—there have been, among others, (1) so-called "*blended cements*," which involve the partial replacement of clinker by supplementary cementitious materials (SCMs), such as natural pozzolans or industrial by-products; (2) "*alkali-activated cements and concretes*" (AACs), including so-called "*geopolymers*" (GPs), which allow the use of SCMs (100%) as the base material, giving rise to OPC-free cements; and (3) "*hybrid cements*" (HYCs), also known as "*alkali-activated Portland blended cement*", [1] which combine the two technologies, i.e., the positive effects of OPC with AACs. This search implies the production of binders based on a high content of SCMs (≥70%) and a low level of OPC addition (≤30%) [1–3]. The production of AACs eliminates the process of clinkerization, which leads to a significant reduction of CO_2 emissions linked to the process necessary in the manufacture of OPC [4]; it is estimated that this reduction would reach values close to 70%, which is relevant considering that, today, the cement industry is responsible for 5–7% of the CO_2 emitted into the atmosphere, and it is estimated that this figure will exceed 10–15% by 2020 [5–8].

Standards, such as ASTM C1157-11 "*Standard Performance Specification for Hydraulic Cement*" in the USA and, recently, NTC 121 (third update) "*Performance Specification for Hydraulic Cement*" in Colombia, classified cements based their performance rather than composition, which allows the introduction to the market of these new types of binders that are more environmentally friendly and feature mechanical properties and durability equal to or greater than conventional options using OPC. In recent years, RILEM and ASTM committees have been formed for the study and/or standardization of these cement products (AACs), seeking the formulation of standards and recommendations for their implementation in different civil infrastructure applications. In effect, the standard PAS 8820: 2016 "*Construction materials. Alkali-activated cementitious material and concrete. Specification*" emerges as the UK's strategy for encouraging the use of these materials in the construction industry and for achieving some of the proposed objectives for this sector by 2025.

The SCMs commonly used to produce GP, AACs and/or HYCs are metakaolin (MK), fly ashes (FA) and granulated blast furnace slags (GBFS), with extensive and satisfactory studies reported since the last century by various authors worldwide [9–13]. Despite the excellent properties reported for FA- or GBFS-based AACs, the very nature of these precursors which are by-products from CO_2 producing industries means their chemical and mineralogical composition are variable, making it difficult to standardize an alkaline activation process for its introduction to the market [14]. In addition, the global production of these by-products is limited—500–700 Mt/year for FA [15] and 170–250 Mt/year for GBFS [16]—compared to global production of OPC (3–4 trillion tons/year) [17]. Such proportions limit the replacement of OPC with a cement system based exclusively (100%) on the alkaline activation of these materials. The global demand for OPC by 2030 is projected to increase by 216%; in this same period, the generation of FA and GBFS may increase by only 15% [18]. Provis [19] added that, at present, the use of quality FA or GBFS precursors can achieve a price similar to the unit price of OPC, and mentioned that the use of aluminosilicates, also used by the cement industry in the production of "*blended cements*", makes this industry its main competitor. In this sense, it is reasonable to think now about the use of FA and GBFS as correctors or modifiers in the production of *alkali-activated binary cements*, where the by-product content is low (≤30%) and whose precursor base (≥70%) is a material of greater availability and homogeneity.

The local availability of natural volcanic pozzolans (NPs) in significant quantities is promoted as a viable alternative (from the commercial point of view) for the adoption of AACs on an industrial scale because there would be better quality control of raw materials [20–23]. NPs deposits account for approximately 0.84%

Fig. 1. Global distribution of NPs deposits (grey areas). *Source:* [28].