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Alkali-activated Portland blast furnace slag cement mortars: Performance to alkali-aggregate reaction

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HIGHLIGHTS

- OPC mortars had the highest susceptibility to alkali-silica attack.
- Alkali-activated hybrid material (HB) showed expansion value of 0.09% at 14 days.
- A gel with Rosette crystals form of expansive nature was observed in AA system.

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ABSTRACT

This report evaluates the performance to alkali-aggregate reaction of two types of binder systems: a Portland blended cement and an Alkali-activated Portland blended cement. The first system consists of 80% granulated blast furnace slag and 20% Portland cement (OPC) and was hydrated in the presence of water (CE), whereas the second incorporated an alkaline activator, making it a hybrid cement (HB). Expansion measurements of mortar bars were carried out, and their behaviour was compared to a reference system based on 100% OPC. Additionally, a microstructural characterization was performed using scanning electron microscopy. The results show that CE and HB cements had smaller expansions than OPC, although Rosette and pseudo-Rosette structures were observed.

1. Introduction

In addition to the mechanical properties of concrete, its durability is another important factor to consider, as it can be associated with lifetime. Properties of concrete can be affected by physical and chemical phenomena, such as freeze-thaw, carbonation processes, sulphate attack, alkali-aggregate reaction (AAR), and others [1,2]. Among these, the AAR causes the greatest threat to the durability of massive concrete installations since its action combines chemical reactions and generates cracks in the material and thus diminish its mechanical properties [3]. The conditions necessary for alkali-aggregate reactions include the presence of alkalis (Na_2O and K_2O) in sufficient proportions in the concrete to react with the aggregates, a reactive aggregate and the presence of 80–85% humidity (conditions found near structures exposed to frequent rain, dams, etc.). These alkalis can be found in the cement or water or introduced by exposure to the service medium. Additionally, some studies on ordinary Portland cement (OPC)-based cementitious materials claim that the alkali-aggregate reaction also requires the presence of Ca^{+2} [4]. Depending on the type of aggregate used in the mixture, two reaction types have been defined: alkali-silica and alkali-carbonate.

The alkali-silica reaction, on which this study is based, occurs when the amorphous or poorly crystallized silica of the aggregates (sand or gravel) is attacked and dissolved by alkali hydroxides (NaOH or KOH) from the pore solution of the cementing material. This attack leads to the formation of an alkali-silica gel, which swells and cracks the material. Cyr and Pouhet [3] indicated that there is great concern regarding the alkali-aggregate reaction (AAR) in alkaline activated materials due to the high amounts of alkali present, which favour this type of attack. However, the alkali-silica reaction in alkaline activation systems is still under-researched and fiercely debated [5]. The comparison made by García-Lodeiro et al. [6] between alkaline-activated fly ash systems and normal OPC systems using aggregates with different reactivities showed that alkali-activated fly ash mortars were more resistant to alkali-aggregate attack than normal OPC systems. In contrast, Bakharev et al. [7] found that alkali-activated slag

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Table 1
AAR test methods used in alkaline activated systems [12].

System applied	Testing method	Experiment Conditions
Alkaline-activated slag	ASTM C1260	Cured: 80 °C in water for 24 h Exposure: 80 °C, NaOH solution (1 N)
	ASTM C1293	38 °C, wet conditions
	Mortar bar method	Curing and exposure: 38 °C, RH > 95
	ASTM C1260 Modified	Cured: 80 °C steam cured for 24 h Exposure: 80 °C, under water or wet conditions
Alkaline-activated fly ash	ASTM C1260 Modified	Cured: 85 °C, RH > 99% per 24 h Exposure: 85 °C, 1 N NaOH solution
	ASTM C1260 Modified	Cured: 60 °C, 100% RH for 24 h, after demoulding water bath at 80 °C for 24 h Exposure: 80 °C, 1 N NaOH solution

Table 2
Chemical and physical characteristics of the materials used.

(%)	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	LOI	D [4,3] (μm)
OPC [13]	10.45	73.21	3.59	3.71	3.66	3.05	1.36	–	–
GBFS	31.99	46.86	14.54	1.12	1.05	0.82	0.39	1.8	21.38

concretes had a greater susceptibility to deterioration (i.e., large expansions and cracking of the concrete) from the alkali-silica reaction than normal OPC concretes. Nevertheless, Fernández-Jiménez and Puertas [8] found that alkali-activated slag mortars exhibited expansive behaviour but expansion occurs at slower rate than with OPC mortars under similar conditions. They attributed this behaviour to the formation of calcium and sodium silicate hydrate with a Rosette type morphology.

Some authors have indicated that the alkali-aggregate reaction of the alkaline activated materials is affected by factors such as the nature and dosage of the activator, the type of binder used, the type of reactive aggregate and even the test method. In a study on alkaline-activated slag mortars, You-zhi et al. [9] observed a greater expansion for the samples activated with waterglass and the lowest expansions for those activated with NaOH. Nevertheless, Gifford and Gillott [10] reported that they did not find any difference between using Na_2CO_3 and Na_2SiO_3 as activators. Al-Otaibi, [11] and Bakharev et al. [7] found that these alkaline activated systems, because of the rapid development of resistance, present initially low expansions from the alkali-aggregate reaction, thus requiring modification of the test methods (Table 1) to assess this deterioration phenomenon and even suggesting the need for longer duration trials. Therefore, Shi et al. [12] suggested it is necessary to evaluate the combination of the above mentioned factors to better understand the behaviour of these materials.

As can be seen in the studies mentioned above, the AAR in alkaline activated materials is still under study due to the various contradictory results reported and its dependence on factors such as the precursors and activators used. In this sense, the purpose of this work was to investigate the resistance to the alkali-aggregate reaction of an Alkali-activated Portland blended cement or Hybrid cement (80% GBFS/OPC 20%) and compare its performance with a blended cement (80% GBFS/OPC20%) and one without addition (100% OPC). It should be noted that previous studies about the durability, and especially the alkali-aggregate reaction, in Alkali-activated Portland GBFS cement have not been published, although the addition of alkaline activators can significantly improve the mechanical performance of highly blended cement at early ages, which would make even more interesting the use of this type of materials in a near future due to low Portland clinker

Table 3
ASTM C227 standard specifications of the aggregate (reactive sand) to be used in the AAR test.

Sieve	ASTM C227 specification
#8	10%
#16	25%
#30	25%
#50	25%
#100	15%

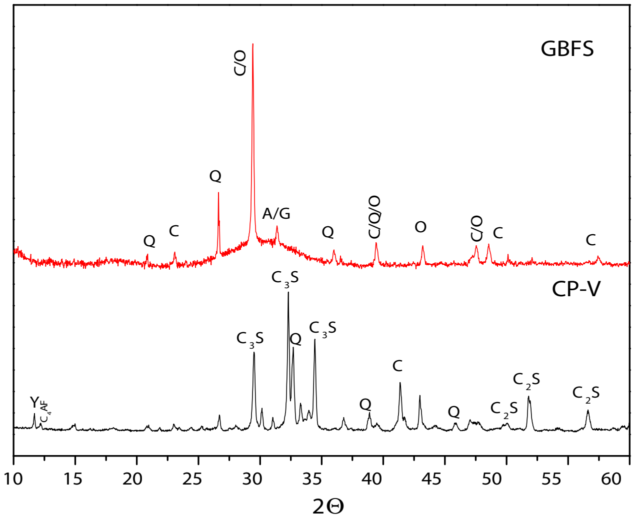

Fig. 1. Diffractogram of the raw materials used. Q: Quartz, C: Calcite, O: Olivine, A: Aragonite, G: Gehlenite, Y: Plaster.

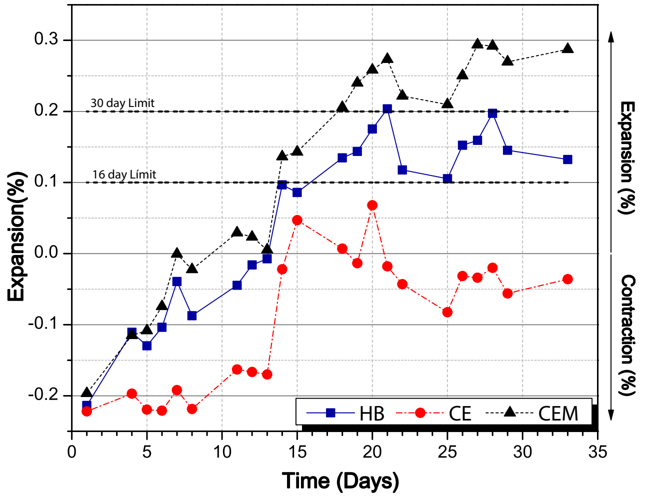

Fig. 2. Longitudinal expansions of the mortar bars: CE, HB and CEM in 1 N NaOH at 80 °C.