Construction and Building Materials 164 (2018) 625–643

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Alkali-activated natural pozzolan/slag mortars: A parametric study

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HIGHLIGHTS

- Various properties of alkali-activated natural pozzolan/slag mortars are provided.
- Effects of different variables on properties of alkali-activated mortars are studied.
- Alkali-activated mortars with proper properties are produced.

ARTICLE INFO

Article history:
Received 21 August 2017
Received in revised form 7 December 2017
Accepted 27 December 2017

Keywords:
Alkali activation
Natural pozzolan
Slag
Fresh properties
Strength
Transport properties
Sodium hydroxide concentration
Activator combination
Binder combination
Alkaline solution-to-binder ratio

ABSTRACT

This study was devoted to assess the influence of binder' aluminosilicate precursor combination (natural pozzolan/slag combinations), activator combination (sodium silicate/sodium hydroxide combinations), sodium hydroxide concentration, and alkaline activator solution-to-binder ratio (S/B) on properties of alkali-activated natural pozzolan/slag mortars. The evaluated properties included flow, setting time, hydration heat, compressive strength, absorption, rapid chloride permeability, and drying shrinkage. The performance of alkali-activated natural pozzolan/slag mortars were also compared with the performance of Portland cement mortars. The results of this study revealed that in comparison with the Portland cement mortars, alkali-activated natural pozzolan/slag mortars generated significantly lower heat, thus offering a great benefit to mass concreting. Their hydration activity accelerated and setting time shortened with increases in sodium hydroxide concentration and dosage within the studied ranges, increases in slag portion of binder, and decreases in S/B. The compressive strengths of alkali-activated mortars were lower than those of the Portland cement mortars. It was shown, however, doable to produce alkali-activated natural pozzolan/slag mortars reaching the strength of portland cement mortars. The compressive strength improved with increases in sodium silicate dosage and reduction in S/B. Regarding compressive strength, the optimum binder combination and sodium hydroxide concentration were found to be interdependent of one another. While absorption of alkali-activated mortars was slightly higher than that of the portland cement mortars, their chloride penetration depths were significantly lower than those of the portland cement mortars. The chloride penetration depth reduced with decreases in natural pozzolan portion of binder, sodium silicate dosage, NaOH concentration, and solution-to-binder ratio. A similar trend was seen for the drying shrinkage as reduction of these variables also decreased the drying shrinkage. The drying shrinkage of the studied alkali-activated natural pozzolan/slag mortars was considerably higher than those of the portland cement mortars.

1. Introduction

Concrete, as a foundational component to infrastructure in any modern society, faces two major concerns. The first concern stems from its main component, portland cement (PC) which its production is responsible for approximately 7% of world's total CO_2 emission. Long-term material durability is another concern as PC concrete is not as long lasting as many believe. Past reports have

Abbreviations: AANPSL, Alkali-activated natural pozzolan/slag; S/B, Alkaline activator solution-to-binder ratio; PC, Portland cement; NaOH, Sodium hydroxide; RCPT, Rapid chloride penetration test; RMT, Rapid chloride migration test.

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https://doi.org/10.1016/j.conbuildmat.2017.12.222

frequently documented failures of PC concrete infrastructures due to aging and deterioration [1–3].

The desire to reduce CO_2 emissions and to produce more durable concrete has given impetus to search for new binders. In recent years, several studies have been conducted to find alternative binders for PC [1–3]. These research investigations have resulted in introducing different types of binders such as alkali-activated binders, calcium aluminate cements, calcium carbonate cements, magnesium oxy-carbonate cements, Bellite-calcium sulphoaluminate-ferrite cements, and partially pre-hydrated C-S-H based binders; from which several researchers suggested alkali-activated binders have the potential to lead the transition to the cement of the future [1–3]. Low CO_2 emission and adequate durability of alkali-activated binders have been proven in various studies [4–7]. These binders are not only a more sustainable and economical choice due to reducing PC consumption and providing adequate durability, but also they (1) incorporate industrial by-products such as slag and/or fly ash, thus resulting in reduction of disposal sites, and (2) are suitable for stabilization/solidification of hazardous and radioactive wastes [8–10].

There are two major types of alkali-activated binders; low calcium and high calcium binders. For several decades, a great deal of research has been dedicated to alkali activation of blast furnace slag (high-calcium binders). In recent decades, the research has been shifted towards activation of low-calcium binders including fly ash, to a larger extent, and metakaolin and natural pozzolans, to a lesser extent. Each of these alkali-activated binders provide certain benefits, in particular in terms of durability. The N-A-S-H gel (Na_2O-Al_2O_3-SiO_2-H_2O) as the main reaction product of low-calcium binders offers excellent chemical and thermal resistances, while C-(N)-A-S-H (Na_2O-Cao-Al_2O_3-SiO_2-H_2O) or C-A-S-H (Cao-Al_2O_3-SiO_2-H_2O) as the primary reaction products of high-calcium binders provide chemical binding of water which reduces permeability. "The N-A-S-H gel may also offer anion-binding mechanisms that retard chloride ingress, thus increasing service life of reinforced concrete by prolonging the time taken to initiate corrosion of embedded steel" [11]. Aside from their benefits, these binders face two major concerns which can potentially limit their viability for construction materials including (1) the need of low calcium-based alkali-activated binders (such as alkali-activated fly ash and natural pozzolan) for curing at elevated temperatures, which limits their applications to precast concrete products, and (2) the fast setting time of high calcium-based alkali-activated binders (e.g. alkali-activated slag).

In order to address these concerns and take advantage of benefits offered by each of low- and high-calcium binders, authors combined low calcium and high calcium binders [12]. It was found that a suitable combination of low calcium with high calcium binders along with a proper selection of alkaline concentration mitigated the need for elevated temperatures as well as the concern for fast setting times [12]. While the suggested combination showed the capability to alleviate the abovementioned concerns, further investigation was needed to assess properties of the resulting binder as influenced by mixture ingredients and proportions. The literature on combination of low- and high- calcium binders; in particular on combination of natural pozzolan and slag, is limited. Fig. 1 shows that while there is a growing attention to the combined binders (Fig. 1(a)), combination of natural pozzolan (low-calcium binder) and slag (high-calcium binder) has been rarely investigated. As shown in Fig. 1(b), there are only 3 studies which dealt with fresh and strength properties of natural pozzolan/slag pastes.

The study presented herein is devoted to a parametric study on the properties of alkali-activated natural pozzolan/slag (AANPSL) mortars. The studied parameters were binder' aluminosilicate precursor combination hereafter called binder combination (natural pozzolan and slag combinations of 30/70, 50/50 and 70/30), activator combination (sodium hydroxide and sodium silicate combinations of 80/20, 75/25 and 70/30), NaOH concentration (0.5, 1 and 2 M), and alkaline activator solution-to-binder ratio (S/B of 0.52, 0.56 and 0.6). Additionally, two portland cement mortars were made for the purpose of comparison. The properties studied included fresh properties (flow, setting time and heat of hydration), compressive strength, transport properties (rapid chloride penetration test, rapid chloride migration test, and absorption), and volume stability (drying shrinkage).

2. Literature on alkali-activated natural pozzolan/ slag binders

Fig. 1 presents the number of publications on fly ash/slag and natural pozzolan/slag combinations. It can be seen that there has been a growing research activity on the activation of combined binders mainly using fly ash/slag combinations. There have been a total of 33 publications on fly ash/slag binders as listed in Table 1. On the other hand, there have been only three research studies reported on alkaline activation of combined natural pozzolan and slag. A brief review of the studies on natural pozzolan/slag binders is presented below:

Allahverdi et al. [13] replaced 5, 15 and 25% of natural pozzolan with blast-furnace slag. In addition to SEM and XRD tests, they assessed effects of these replacements on compressive strength and setting time of the produced pastes. They reported that the setting times of mixtures were long and use of slag didn't considerably affect the setting times. By analyzing the individual values in their study, setting times even slightly increased by replacing a portion of natural pozzolan with slag. They also observed that the strength of pastes having natural pozzolan and slag was similar to or slightly lower than that of pastes containing only natural pozzolan. The observation of this study was in contrast with the expectation driven from the literature on use of blast-furnace slag. The authors attributed this finding to the increases in Si/Al of the binder by use of slag which served to inhibit strength development. The observed behavior, however, could also be related to unsuitability of the used slag for the purpose of alkaline activation.

Robayo et al. [14] did a similar study by replacing 10, 20, 30% of natural pozzolan with slag. They measured setting time, hydration heat, and compressive strength of the produced pastes. In contrast to the results reported by Allahverdi et al. [13], they noticed significant increase in compressive strength and considerable reduction in setting times through partial replacement of natural pozzolan with slag. These replacements also led to a considerable increase in heat of hydration.

In the most recent study, Jafari Nadoushan and Ramezanianpour [15] replaced 5, 10, 15, 20, 50, 75 and 100% of slag with natural pozzolans (pumice) and assessed flow and strength of the produced pastes. For the purpose of activation, they used sodium or potassium hydroxides (6 and 8 M) combined with sodium silicate and provided a constant sodium silicate-to-hydroxide ratio of 0.4. In general, flow of alkali-activated pastes reduced by inclusion of natural pozzolans. This observation was related to the higher specific surface area of pumice in comparison with that of slag. They also noticed improvement in 91-day strength of the studied pastes by replacing 5–25% of slag with natural pozzolan. The higher replacement level resulted in a significant strength reduction. The optimum replacement level was found to be 5–10%.

3. Research significance

Lack of prior research activity on alkali-activated natural pozzolan/slag binders was the impetus for this study to assess the effects of a number of influential parameters; i.e. binder combination, activator combination, S/B and alkaline concentration, on var-