Construction and Building Materials 100 (2015) 234–245

Contents lists available at ScienceDirect

Construction and Building Materials

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

Efficiency of ternary blends containing fine glass powder in mitigating alkali–silica reaction

Kaveh Afshinnia [a], Prasada Rao Rangaraju [b,*]

[a] Glenn Department of Civil Engineering, Clemson University, Rm. 123 Lowry Hall, Clemson, SC 29634, USA
[b] Glenn Department of Civil Engineering, Clemson University, Rm. 220 Lowry Hall, Clemson, SC 29634, USA

HIGHLIGHTS

- Synergistic role of a finely ground glass powder with other SCMs was evaluated.
- Flow, pozzolanic reactivity and ASR mitigation in mortar mixtures were evaluated.
- Flow of ternary blends with glass is superior over binary blends for all SCMs.
- Blends of glass with slag/fly ash were superior over binary blends in all regards.

ARTICLE INFO

Article history:
Received 19 May 2015
Received in revised form 28 August 2015
Accepted 23 September 2015

Keywords:
Glass powder
Pozzolan
Ternary blends
Compressive strength
TGA
Alkali–silica reaction

ABSTRACT

In this study potential synergistic role of a finely ground glass powder in binary and ternary cementitious blends with conventional SCMs such as meta-kaolin, fly ash and slag was evaluated. Strength activity index, thermo-gravimetric analysis (TGA) and mortar bar tests were conducted to study the pozzolanic behavior and ASR mitigation ability. The results from this study showed that ternary mixtures consisting of finely ground soda glass with either slag or Class C fly ash out-performed binary mixtures consisting of each of these SCMs at an equivalent dosage level. Binary mixtures consisting of meta-kaolin out-performed ternary mixtures consisting of ground glass powder with meta-kaolin at equivalent dosage level. Among all the binary and ternary mixtures that contained 30% level of SCMs, the maximum strength activity index and the most efficient ASR mitigation was obtained in ternary mixtures consisting of at least 10% glass powder. The results from TGA studies supported these findings.

1. Introduction

Alkali–silica reaction (ASR) is one of the common deleterious chemical reactions that can occur in concrete, wherein reactive sources of silica present in certain aggregates are attacked by alkaline pore solution present within the matrix of concrete. The product of ASR in concrete is a hygroscopic alkali–silica reaction gel (ASR gel), which can absorb moisture and undergo significant expansion to exert pressure on the surrounding concrete, causing cracking and deterioration.

Among the different ways to mitigate ASR distress in concrete, the use of supplementary cementitious materials (SCMs) has been found to be an effective measure, provided appropriate quality and dosage of SCMs are used. In this regard, extensive studies have been conducted in evaluating effectiveness of fly ashes [1–5], slag [6–8], meta-kaolin [9–12] and silica fume [13,14] in mitigating ASR. The mechanisms by which SCMs mitigate ASR distress in concrete include: decreasing the permeability of the concrete, diluting or removing alkalis from pore solution through binding by hydration products and improving the strength of the concrete. Although much of the past research in ASR mitigation has focused on the use of conventional SCMs such as fly ashes, slags, silica fume and other natural and manufactured pozzolans, alternative SCM sources derived from industrial waste streams such as ground glass powder, crushed brick powder. are also being explored to address ASR mitigation while reducing the burden of waste disposal and the carbon footprint of the concrete [15–25].

The effectiveness of SCMs in mitigating ASR depends on the chemical composition and the dosage of SCMs used in concrete along with the nature of the reactive component in aggregate, alkali content of concrete and other mixture proportion aspects of concrete and environmental conditions. For instance, significant dosage levels are required with SCMs such as Class C fly ash and slag to effectively mitigate ASR, particularly when highly reactive

* Corresponding author.
E-mail addresses: kafshin@clemson.edu (K. Afshinnia), prangar@clemson.edu (P.R. Rangaraju).

http://dx.doi.org/10.1016/j.conbuildmat.2015.09.043
0950-0618/

aggregates are used [5,26]. However, the dosage level of SCM used in concrete has to be balanced with other demands such as early-age strength and workability of concrete that are often specified due to limitations of construction schedule and ambient environmental conditions. On the other hand, the dosage level of some SCMs may have to be regulated due to other reasons. For instance, SCMs such as certain fly ashes (Class C) and ground glass powder from soda lime glass tend to contain significant levels of alkalis in their structure that may eventually supplement the alkali loading in the concrete to exacerbate the potential for ASR distress in concrete [5,18,20.23]. Similarly, the dosage level of an SCM such as silica fume or meta-kaolin may have to be limited due to their negative impact on the workability of concrete [27,29]. The shortcomings of individual SCMs in meeting multiple and often conflicting demands of concrete properties can be overcome by using combinations of two or more SCMs.

Several studies have been carried out to investigate the synergic effect of using ternary blends containing different SCMs in concrete [28–32]. In majority of these studies, the ternary blends of SCMs have exhibited superior performance compared to binary blends, in terms of the rheological, mechanical and the durability properties of concrete. Numerous laboratory studies have been done to evaluate the efficiencies of ternary blends in mitigating ASR in concrete [26,27,33–35]. Shehata and Thomas (2002) carried out investigations to study the ASR mitigating performance of ternary blends containing the combination of silica fume with low, moderate and high lime fly ashes using concrete prism test [33]. It was found that 5% silica fume with 10% low lime fly ash or with 30% moderate or high lime fly ash were effective in maintaining the ASR expansion below 0.04% after 2 years. Other study by Thomas et al. (1999) confirmed the beneficial effect of using silica fume in combination with high lime fly ash in mitigating ASR distress in concrete [34]. Lane and Ozyildirim (1999) studied the influence of silica fume in improving the ASR mitigation performance of ternary blends containing slag or fly ash and found that the ternary blends not only improved the ASR mitigating ability but also improved the early-age strength development [26]. In another study by Moser et al. (2010), the effectiveness of ternary blends containing meta-kaolin and Class C fly ash in mitigating ASR distress using AMBT and CPT test methods was evaluated [27]. It was found from this study that the ternary blends of meta-kaolin and Class C fly ash resulted in a marginally higher expansion than binary blends incorporating the same amount of meta-kaolin. The possibility of any synergic effect between slag and high lime fly ash to mitigate ASR distress was investigated by Kandasamy and Shehata (2014). It was found that the use of ternary blends of slag and high lime fly ash did not offer any synergic effect over using the individual SCM at the same total dosage level of combined SCMs as in the ternary blend [35].

Based on the previous studies on the efficiencies of ternary blends in mitigating ASR, it is clear that in the majority of the studies, ternary blends were employed to improve the ASR mitigating ability of an SCM which has a lower potential of ASR mitigation (i.e. slag or high lime fly ash) at nominal dosage levels that do not adversely affect the early-age strength behavior of concrete. As a result of these demands, in most studies silica fume was employed as a third valuable component in the ternary mixtures [33,34]. While silica fume and meta-kaolin are very effective in improving the efficacy of other SCMs in ternary blends, these SCMs are cost prohibitive particularly in situations that involve large placements and may negatively affect certain fresh concrete properties such as workability. In this regard, no studies have been found in literature that explore the use of finely ground glass powder pozzolan to address the efficiency of ternary blends with other conventional SCMs. In this study, a comparative study was conducted to evaluate the effectiveness of mixtures wherein glass powder was used in binary and ternary blends to evaluate the ASR mitigation potential of the mixtures. In addition, flow behavior of fresh mortars and pozzolanic reactivity in the hardened mortars was evaluated by assessing the strength activity index and by measuring the residual calcium hydroxide content using the thermo-gravimetric analysis (TGA) technique. The ASR mitigation performance of the binary and ternary blends containing glass powder was evaluated using accelerated mortar bar test method and microstructural and chemical investigation on test specimens was conducted using Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectral Analysis (EDX).

2. Experimental work

2.1. Materials

2.1.1. Portland cement

In this study, an ASTM C150 Type I Portland cement with high-alkali content (Na_2O_{eq} = 0.88%) with a Blaine's fineness of 383 m^2/kg was used [36]. The autoclave expansion of the cement was 0.018%, which is significantly lower than 0.20% limit imposed in ASTM C1260 specification [37]. The chemical composition of the Portland cement is given in Table 1.

2.1.2. Slag

In this study, a grade 100 ground granulated blast furnace slag (GGBFS) with specific gravity of 2.92 was used as a supplementary cementitious material (SCM). The chemical composition of slag is given in Table 1.

2.1.3. Fly ash (Class C)

A high-lime Class C fly ash with a CaO content of 29.8% and a specific gravity of 2.77 was used as a supplementary cementitious material (SCM). The chemical composition of fly ash is given in Table 1.

2.1.4. Meta-kaolin

A high reactivity meta-kaolin with a specific gravity of 2.20 was used as a SCM. The chemical composition of meta-kaolin is given in Table 1.

2.1.5. Fine glass powder

Finely ground bottle glass (glass powder) with an average particle size of 17 μm and a specific gravity of 2.45 was employed in this study. The chemical composition of the glass powder is given in Table 1.

2.1.6. Fine glass aggregate

Crushed glass aggregate with an oven-dry specific gravity of 2.42 and an absorption value of 0.03%, produced from waste soda bottles of different mixed colors was used in this study. A Bico disc-pulverizer with 8-inch ceramic grinding plates was used to crush the glass cullets to obtain the required size fractions of the glass aggregates to meet the gradation requirements of the AMBT test.

2.2. Test procedures

2.2.1. Flow test (ASTM C1437)

Although the flow behavior of mortars in itself is not directly related to the effectiveness of pozzolanic materials in mitigating ASR distress, to ensure proper consolidation of test specimens it is essential to have a good workability in mortars. It is in this regard to evaluate the effect of using glass powder on the workability of the mortars in ternary blends, the flow test was conducted as per ASTM C1437 [38]. Mortar mixtures containing fly ash, slag and meta-kaolin with or without glass powder were prepared with total replacement level of 20%. Additionally, control mix without any SCM was prepared as a reference mixture.

Table 1
Chemical compositions of Portland cement, glass powder and SCMs (based on XRF).

Chemical composition (%)	Cement	Glass powder	Slag	Class C fly ash	Meta-kaolin
SiO_2	19.45	69.6	38.17	31.3	52.4
Al_2O_3	4.85	2.2	7.31	18.6	44.3
Fe_2O_3	3.79	0.9	0.78	5.49	0.50
CaO	61.37	11.6	39.12	29.8	0.02
MgO	2.92	0.4	12.48	5.5	0.12
Na_2O_{eq}	0.88	13.39	–	2.1	–