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The potential of ground clay brick to mitigate Alkali–Silica Reaction in mortar prepared with highly reactive aggregate

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HIGHLIGHTS

- A brief study has been done to evaluate the pozzolanic reactivity and ASR mitigation performance of ground crushed brick.
- A brief study has been done to evaluate the effect of ground crushed brick fineness on ASR mitigation performance.
- Microscopic analysis has been conducted to evaluate the microstructure of the mortar containing ground crushed brick.
- A comparison has been made to investigate the pozzolanic reactivity of ground crushed brick using XRD analysis.

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ABSTRACT

The objective of this work was to study the effect of ground clay brick on mitigating the Alkali Silica Reaction (ASR) in mortar bars prepared with highly reactive aggregates. To evaluate the potential of ground crushed clay brick to mitigate ASR distress in mortar, mortar bars and mortar cubes were cast with combination of different dosages of ground clay brick (partial replacement of portland cement). The pozzolanic reactivity of ground clay brick was also evaluated using strength activity index test. In addition, the Scanning Electron Microscopy (SEM) and the Energy-Dispersive X-ray Spectroscopy (EDS) were conducted to evaluate the microstructure and location of the ASR gel and its chemical composition. The results from this study indicated satisfactory level of pozzolanic reactivity when cement was partially replacement by the ground clay brick. Also, it was found that replacing 25% of cement with ground clay brick (by weight) could significantly decrease the ASR expansion by 67% at the age of 14 days. However, this study suggested that the compressive strength values of the specimens containing higher dosages of ground crushed brick (i.e. 50% replacement level) were significantly lower than that of the control specimens.

1. Introduction

Alkali Silica Reaction (ASR) is a chemical reaction occurs between the specific source of silica from aggregate and the hydroxyl ions that are usually available in the alkaline environment of the pore solution. The product of this reaction is a hygroscopic ASR gel, which by itself does not cause any problem for the concrete. However, at the presence of moisture, the ASR gel swells and consequently causes significant pressure through the surrounding concrete matrix.

Typically, Supplementary Cementitious Materials (SCMs) such as fly ashes [1–5], slag [6–8], meta-kaolin [9–12], silica fume [13,14] and other SCMs derived from waste materials such as glass [15–19] have been used successfully to mitigate the ASR distress in concrete. Depletion of alkali loading in concrete mixture due to the replacement of portland cement (dilution effect), better alkali binding provided by modified C–S–H (Calcium–Silicate–Hydrate) gel (particularly, where the calcium to silica ratio are low), higher strength provided by pozzolanic reaction of SCMs and decreasing the rate of silica dissolution from aggregate surface [20] are some of the main causes by which the SCMs can mitigate ASR distress in concrete mixtures. Moreover, the SCMs may refine the pores' distribution in concrete paste; therefore, the reactive aggregates have less access to the external moisture compared to the conventional concrete (without SCMs) [21,22]. Even though the beneficial influence of typical SCMs such as fly ash, meta-kaolin, slag and silica fume have been well investigated in different studies, the use of pozzolans derived from waste materials such as ground clay brick needs further investigations. In addition, due to the different environmental agency reports, alternative methods of recycling waste

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materials such as using them in construction materials must be considered to reduce the high volume of waste disposed of in landfills.

Typically, the main components of the clay bricks are kaolin and shale. However, small amount of magnesium and/or barium are added to modify its color. Based on the chemical composition of clay brick, this material typically contains approximately 70% silica and 15–20% alumina. It has been reported that the presence of soluble alumina in SCM may improve the ASR mitigation performance by formation of C–A–S–H (Aluminum containing Calcium–Silicate–Hydrate) gel instead of the C–S–H gel, which has more potential to bind the alkalis and consequently deplete the alkalinity of the pore solution [23]. Several studies were conducted to assess the beneficial influence of ground clay brick when used as a portland cement replacement on the fresh properties as well as mechanical properties of mortar or concrete mixtures [24–28]. Wild et al. evaluated the pozzolanic reactivity of ground clay brick with a maximum particle size of 250 μm collected from four European countries [24]. They found that the ground clay brick could be replaced up to 30% of the portland cement by weight without significant reduction in mechanical properties of concrete. Other study by Naceri et al. was carried out to evaluate the influence of using waste brick powder as a cement replacement at 5%, 10%, 15% and 20% dosage levels on the mechanical properties of mortars [25]. It was found that the 28-day compressive strength of the mortar cubes gradually decreased with increasing waste brick powder content. Lin et al. evaluated the fresh and mechanical properties of paste specimens containing 0–50% waste brick powder [26]. They found that the use of waste brick powder increased the initial and final setting time of the paste. Also, the compressive strength of the paste specimens with brick powder developed slowly in the early ages, and increased at the later ages. O'Farrel et al. showed that at early ages, the pore volume of the mortar mixtures containing brick was higher than that of the control [27]. Therefore, the compressive strength of such mixtures was less than the control mixtures. However, at later ages, the pore volume and the compressive strength of the mortar specimens were comparable with control mixtures. A study by Gonçalves et al. was carried out to compare the compressive strength, modulus of elasticity and pore size distribution of mortar mixtures containing waste clay brick powder with mortar mixture containing meta-kaolin [28]. It was found that the use of clay brick powder as a cement replacement reduced the proportion of macro pores and modulus of elasticity of the mortar specimens. As aforementioned studies, the majority of the studies showed that the pozzolanic reactivity of ground brick was more profound at later ages compared to that in early ages.

A limited number of studies conducted to assess the mitigation ability of the ground brick powders to suppress the Alkali Silica Reaction in mortars or concrete [29,16]. A study by Turanli et al. on mortar bars containing 0%, 10%, 20% and 30% ground crushed brick as cement replacement using accelerated mortar bar test (AMBT) showed that the ASR distress was properly mitigated in mortar bars containing 20% or 30% ground crushed brick [29]. Other study by Bektas et al. on the ASR mitigation performance of ground clay brick combined with other conventional SCMs such as fly ash and natural pozzolan indicated that the ground clay brick was not as effective as fly ash while a similar mitigation performance of ground clay brick compared to that of the natural pozzolans was observed. Nevertheless, the ASR mitigation performance of ternary blend of ground clay brick and fly ash out-performed the mitigation performance of binary blend containing just ground clay brick, but underperformed the mitigation performance of binary blend containing fly ash [16].

Some studies were carried out to assess the ASR reactivity in specimens containing crushed brick as their aggregates replacement [30,31]. A study by Bektas showed that both mortar bars and concrete prisms containing crushed brick aggregate indicated significant amount of ASR distress [30]. In addition, both ASR gel and ettringite from delayed ettringite formation (DEF) were seen within the mortar or concrete specimens. Another study by Bektas et al. was carried out to investigate the ASR distress in mortar bars containing 10% and 20% crushed brick aggregate as a fine aggregate replacement using the accelerated mortar bar test (AMBT) [31]. It was found that the crushed brick aggregate was susceptible to ASR attack.

This study was aimed to evaluate the impact of ground clay brick as both cement and aggregates partial replacements on mitigating the ASR in mortar bars prepared with highly reactive aggregates. Moreover, the pozzolanic reactivity of ground brick as a cement replacement was evaluated. The microscopic analysis was also conducted to study the ASR gel in the specimens.

2. Materials and experimental procedures

2.1. Materials

2.1.1. Cement

Type I high alkali cement (Na_2O_{eq} = 0.88%), with the chemical composition shown in Table 1, was used in this study.

2.1.2. Clay brick as an aggregate material

Clay brick with chemical composition shown in Table 1, was used in this study. The clay bricks were first crushed using laboratory jaw crusher. Then, crushed brick with the specific size gradation in accordance with ASTM C1260 was used as fine aggregates in mortar bars [32].

2.1.3. Ground crushed brick (GCB) as a cementitious material

A laboratory ball mill crusher was used to prepare the ground crushed brick with an average particle size of 40 μm. Fine crushed brick was grounded in a laboratory ball mill for 10 min with the speed of 250 rpm.

2.1.4. Reactive fine aggregate

Rhyolitic gravel from Las Placitas Pit in Bernalillo County, New Mexico with oven-dry specific gravity (SG_{OD}) of 2.6, saturate-surface-dry specific gravity (SG_{SSD}) of 2.63, absorption of 1.09%, and dry rodded unit weight (DRUW) of 1585.3 kg m^{-3} was used as the reactive sand in all mixtures. Previous study showed considerable 14-day expansion value of mortar bars containing Rhyolitic gravel, thus, it is used in this investigation as reactive aggregate [3].

2.2. Mixture proportion

Mortar bars containing 10%, 25% and 50% ground crushed brick as portland cement replacement by weight were cast. To consider the influence of cement dilution effect (reducing the proportion of alkali loading), two more mortar mixtures wherein 10% and 25% of the cement in the mixture proportion were replaced by inert non-reactive material, were cast. In order to evaluate the effect of crushed brick fineness on the ASR mitigation, a mortar mixture containing 100% portland cement and 25% crushed brick as an aggregate replacement was prepared. Table 2 shows the mixture proportions of the mortar mixtures used in this study.

Table 1
Chemical compositions of portland cement and ground crushed brick.

Chemical analysis (%)	Portland cement	Clay brick
SiO_2	19.45	69.43
Al_2O_3	4.85	17.29
Fe_2O_3	3.79	6.4
CaO	61.37	0.51
SO_3	3.3	2.54
MgO	2.92	1.14
Na_2O_{eq}	0.88	1.72
Loss on ignition	2.54	0.17