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Alkali reactivity of crushed clay brick aggregate

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HIGHLIGHTS

- Mortar bars produced with crushed clay brick aggregate show expansions in ASR testing.
- High alkali concrete mixes with brick aggregate demonstrate higher expansions compared to the control mix.
- SEM investigations prove the presence of ASR gel and show ettringite formation.
- Alkali reactive brick aggregate does not affect engineering properties.
- NaOH added to the mixing water reduces concrete strength but not modulus of elasticity.

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ABSTRACT

Use of recycled aggregate in concrete is a viable alternative when it is economically feasible. Recycled red clay brick either from construction rubble or from brick manufacturing rejects has been widely investigated as concrete aggregate. While engineering properties of clay brick aggregate has been the focus of numerous studies, research on the durability characteristics is limited. This paper presents the findings of a laboratory study that investigates the alkali reactivity of crushed red clay brick aggregate. Mortar mixes, in which crushed brick constitutes 10%, 25%, 50% and 100% of aggregate, and concrete mixes, which contained 0%, 50% and 100% crushed coarse brick aggregate, were produced. Expansion was determined by employing mortar bars and concrete prisms that were subjected to ASR-promoting conditions (e.g., elevated temperature, high humidity, enhanced alkaline environment). Effects of clay brick aggregate on engineering properties (i.e., compressive strength, flexural strength, and static elastic modulus) of concrete were also investigated using cylindrical and prismatic specimens conditioned as the other specimens for ASR testing. Additionally, microstructural investigation was carried out on samples using scanning electron microscope. The test results showed that the clay brick aggregate caused linear expansion proportional to its quantity. Based on a 0.05% expansion at 6 months criterion for the mortar bars stored at 38 °C over water none of the brick aggregate levels were deleteriously expansive. On the other hand, 10%, 25% and 50% brick aggregate mixtures, when tested in sodium hydroxide solution at 80 °C, produced significant expansions according to 0.10% expansion limit at 14 days. Microscope investigation confirmed the presence of alkali silica gel. Ettringite formation was also observed in the specimens examined. Compressive and flexural strengths of concrete were found to be negatively affected by the sodium hydroxide that was added to the mixing water. The clay brick aggregate concretes experienced expansion, however, no visual cracking was observed and there was no measured loss in engineering properties (i.e., compressive strength, flexural strength, and static elastic modulus) when compared to the control mix.

1. Introduction

Recycling crushed brick in construction is an old concept. It is well known that the Romans used powdered and crushed clay brick in their structures in order to produce durable hydraulic mortars. The first recorded use of crushed brick in Portland cement based concrete products is dated back to 1860s in Germany [1]. Furthermore, crushed brick aggregate is extensively used in concrete during the reconstruction of Germany after the Second World War. It is reported that 175,000 dwelling units were built using 11.5 million m^3 of crushed brick aggregate [1]. Use of recycled aggregate both reduced the site clearing and disposal costs, and met the demand for aggregate in new concrete.

There is an increasing revisit to the crushed brick aggregate research in the 21st century. The motive is the sustainability: construction industry is trying to reduce its impact on the environment, hence, implementing more sustainable approaches when

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feasible. For instance, in highly populated metro areas, natural sources are being depleted, and disposal landfills are limited and costly [2]. Moreover, some regions lack good quality rock or gravel, and aggregate import is not economical, therefore, reject units from brick manufacturing process is used as a source of coarse aggregate for concrete. In some locations where sources of natural aggregate are nonexistent or prohibitively costly to utilize brick is intently produced for use as concrete aggregate [3,4].

Mechanical properties of concrete made with crushed clay brick aggregate, both as fine and coarse, have long been studied and research has proven that concrete with adequate engineering properties can be produced with crushed clay brick aggregate. Using crushed fired bricks Akhtaruzzaman and Hasnat [5] prepared four different grades of concrete with strengths ranging from 13.8 to 34.5 MPa. They reported favorable strengths as compared to normal weight concrete. However, the modulus of elasticity was about 30% lower than normal weight concrete. Khaloo [6] replaced equal volumes of crushed stone coarse aggregate with crushed brick: 100% substitution of crushed brick produced 7% lower compressive, 2% higher tensile and 15% higher flexural strengths. Zakaria and Cabrera [7] also studied laboratory crushed brick aggregate in concrete and compared its performance to gravel: crushed brick aggregate achieved a compressive strength of 53.7 MPa at 28 days as compared to gravel aggregate concrete's 55.9 MPa. Mansur et al. [8] evaluated granite and crushed brick coarse aggregate in concrete mixes with varying water-to-cement ratios ranging from 0.30 to 0.60. For identical mix proportions crushed brick aggregate led to higher compressive and tensile strengths but lower modulus of elasticity as compared to granite aggregate. 28-day cube strength of crushed brick aggregate was as high as 70 MPa. Khalaf [9] investigated crushed clay brick as coarse aggregate in concrete and concluded that normal and high strength concrete can be produced using crushed brick. Even though the density of crushed brick aggregate concrete was lower than granite aggregate concrete, their strengths were comparable. Debieb and Kenai [10] found that the reductions were 35%, 15% and 30% for compressive strength, flexural strength and modulus of elasticity, respectively, when crushed brick replaced natural coarse aggregate. Cachim [11] also reported reductions in mechanical properties when natural coarse aggregate was partially (i.e., 30%) replaced by crushed brick. Research on crushed clay brick as fine aggregate is relatively limited. Reluctance in using brick fine aggregate in concrete is perhaps due to its high water demand. Khatib [12] reported only 9% reduction in compressive strength at 90 days when conventional concrete sand was replaced by fine crushed clay brick aggregate and attributed this performance to the pozzolanic activity of very fine brick particles. On the other hand, Debieb and Kenai [10] have reported significant losses in compressive and flexural strengths with the use of fine brick aggregate.

Research on durability performance of crushed clay brick aggregate is relatively limited. Correia et al. [13] reported higher abrasion resistance of clay brick aggregate in comparison to limestone. The increased resistance is attributed to better bonding between the paste and the brick aggregate. Gomes and De Brito [14] tested 50% coarse crushed brick for carbonation and chloride ion penetration. They found no significant difference between the performances of clay brick aggregate and normal aggregate concretes. However, crushed brick aggregate increased the chloride ion penetration. Bektas et al. [15], in their study with mortars incorporating crushed clay brick aggregate, claimed the porous nature of crushed brick aggregate increased the freeze–thaw resistance of mortars. The same study demonstrated that the crushed clay brick aggregate was highly alkali reactive based on the accelerated mortar bar method which tests fine aggregate in alkaline solution at 80 °C.

Table 1
Chemical composition of the Portland cement.

Oxide (%)								LoI[a] (%)
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	
19.64	5.53	2.47	61.74	2.38	4.56	0.24	1.15	2.01

[a] Loss on ignition.

The aim of this paper is to report the findings of an experimental study which investigated the alkali silica reaction (ASR) durability of crushed clay brick aggregate concrete. Crushed clay brick was employed at various replacement levels in mortar and in concrete mixes which were cured at ASR-promoting conditions (e.g., high humidity, elevated temperature). Expansions of mortar bars and concrete prisms stored at 38 °C and 60 °C, respectively, were measured. Mechanical properties of concrete mixes cured in normal and in ASR conditions were determined in order to assess the effect of ASR on engineering properties. Finally, microscopic investigation was done using scanning electron microscope (SEM).

2. Materials

A high alkali (Na_2O_{eq}: 1.00%) ASTM Type I Portland cement was used in the study (Table 1). Crushed red clay brick was used in the experiments—as fine aggregate in mortar and as coarse aggregate in concrete. Clay brick aggregates were obtained from a source that sells aggregate manufactured from reject fired bricks. Similarly, crushed limestone was used as non-reactive fine and coarse aggregates. Aggregate properties are given in Table 2.

3. Experimental methods

Mortar and concrete specimens were exposed to accelerated ASR conditioning. Mortar bars (25 × 25 × 285 mm^3) were cast and stored over water at 38 °C (i.e., ASTM C227 storing conditions). Brick aggregate replacement levels were 10%, 25%, 50% and 100% by weight. These four mixes are designated as M10, M25, M50 and M100, respectively. Expansion of the bars was recorded periodically. After almost two and a half years of exposure these bars were transferred to 1 N NaOH solution at 80 °C for additional 100 days.

Alkali reactivity of coarse brick aggregate were investigated utilizing three concrete mixes—control, 50% coarse clay brick aggregate (i.e., C50) and 100% coarse clay brick aggregate (i.e., C100). The control mixture design was based on limestone coarse and fine aggregates that were combined 1:1 ratio by weight. The brick aggregate was introduced on volumetric basis. Concrete prisms (75 × 75 × 285 mm in dimensions) and cylinders (75 mm in diameter and 150 mm in height) were manufactured using a high cement content mix (i.e., 400 kg/m^3). Water-to-cement ratio was 0.45. Alkali content of the mixtures was boosted to 10 kg/m^3 by dissolving NaOH in the mixing water. The specimens were stored at 60 °C over water in an insulated tank up to 90 days. Prism expansions were measured periodically. Additionally, the prisms were tested for flexural strength (ASTM C78), and the cylinders were tested for modulus of elasticity (ASTM C469) and compressive strength (ASTM C39) at 90 days. After evaluating the results two more sets of concrete mixtures were prepared—an identical mix and another one without the addition of NaOH. These specimens were stored in moist room at 23 °C, and tested for mechanical properties at 28 days.

Microstructural investigation was carried out on polished sections using low/variable pressure scanning electron microscope (SEM) with energy dispersive X-ray spectrometer (EDS). Samples from the mortar bars and concrete prisms that were stored over water at 38 °C and 60 °C, respectively, were investigated. No water was used in cutting and polishing of these microscope samples.

4. Results and discussion

4.1. ASR expansion of mortar bars

Fig. 1a demonstrates the measurement of mortar bars stored over water at 38 °C: the expansion increases with increasing brick aggregate content. The test regime for the mortar bars is identical to ASTM C227 which utilizes different aggregate gradation. While there is no given limit in ASTM C227 it is considered that a length change of either 0.05% at 3 months or 0.10% at 6 months is sign of