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The effect of elevated temperatures on the mechanical properties of concrete with fine recycled refractory brick aggregate and aluminate cement

Ardalan Baradaran-Nasiri, Mahdi Nematzadeh *

Department of Civil Engineering, University of Mazandaran, Babolsar, Iran

HIGHLIGHTS

- Physico-mechanical properties of refractory brick fine aggregate under elevated temperatures were evaluated.
- The prepared specimens were containing ordinary Portland cement and calcium aluminate cement.
- Aluminate cement and refractory brick aggregate improved the fire behavior of concrete above 800 °C.

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ABSTRACT

The concrete materials in structures are most likely to experience elevated temperatures during their service period due to fire. Therefore, the relative properties of concrete after exposure to fire are of particular interest in the serviceability of buildings and the safety of inhabitants. In this study, a comprehensive experimental program was performed regarding the use of recycled aggregate produced by crushing refractory bricks. To do so, ten mix designs were employed to prepare 210 specimens with the replacement ratios of 0, 25, 50, 75, and 100% of refractory brick fine aggregate instead of natural sand. The specimens were prepared in the two classes, namely the specimens containing ordinary Portland cement and the ones containing calcium aluminate cement. The physico-mechanical properties of the concrete specimens including compressive strength, modulus of elasticity, and loss of weight of the concrete after being exposed to the temperatures of 110, 200, 400, 600, 800, and 1000 °C, together with the porosity, water absorption, and density of the concrete prior to experiencing fire were investigated. The results showed that the refractory brick aggregate and aluminate cement improve the concrete residual strength to twice as much beyond the temperature of 800 °C. Furthermore, the effect of using refractory brick fine aggregate together with aluminate cement on the improvement of concrete modulus of elasticity under fire was not significant.

1. Introduction

During the last two decades, many of the buildings around the world have either reached their design lifetime or become defective due to the use of inappropriate materials or faulty construction. Moreover, the presence of demolished old buildings because of rehabilitation and/or urban development programs may contribute significantly to the waste production [2,4]. Industrial waste management constitutes one of the greatest global problems of our time, especially for large cities lacking landfill. Recycling non-biodegradable wastes is a challenging task, and ceramic wastes (bricks are a subgroup of ceramics) are classified as this kind of waste with a long decomposition period (over 4000 years). The first documented case of crushed brick usage together with Portland cement for producing concrete products occurred in Germany in 1860, but the first notable case of employing crushed brick as aggregate in fresh concrete was recorded for the rehabilitation after World War II [1].

The resources for supplying brick are very widespread; for instance, Xiao et al. [3] reported that during the 2008 Sichuan earthquake, in which 90% of the houses in the region were ruined, a large amount of waste including bricks was resulted, and its effects on the environment created a severe challenge. In addition,

* Corresponding author at: University of Mazandaran, Babolsar 47416-13534, Iran.

E-mail addresses: ardalanb.nasiri@gmail.com (A. Baradaran-Nasiri), m.nematzadeh@umz.ac.ir (M. Nematzadeh).

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in the brick production procedure, due to some probable defects as well as geometrical irregularities caused by non-uniformities existing in the temperature control inside the kiln, a large amount of waste in the form of returned bricks is produced, which can be a potential source of coarse aggregate. However, it should be reminded that the waste of refractory bricks is much more limited due to their specific applications.

With respect to the studies performed so far, the main benefits of using crushed brick as a replacement aggregate include concrete density reduction, decreased usage of natural aggregates, and being an environment-friendly method, among others. Application and performance of crushed brick as aggregate for normal concrete have been completely widespread and satisfying. However, using crushed brick aggregate in concrete production gives rise to some problems that can be summarized as follows: 1) high porosity, high water absorption rate, and quality variations; 2) incomplete in situ specifications; 3) uncertainty regarding material provision as well as the lack of experience regarding using these materials. A series of original research was carried out with the aim of investigating the effect of mixing crushed clay brick as a replacement for the coarse aggregate of recycled concrete materials and natural sand on the characteristics of dry-mixed masonry partition wall blocks [4]. In this work, it was found that the hardened density and shrinkage due to drying of blocks decrease as the amount of brick aggregate increases. A large number of studies in the literature focus on the reuse of recycled concrete materials to produce new concrete, and properly investigate the potential benefits as well as weaknesses of using recycled concrete [5–9]. Replacing a fraction of natural materials by recycled concrete (30% or less) in concrete does not compromise its mechanical properties [7]; however, it is generally believed that concrete compressive strength decreases as the amount of recycled concrete replacement increases [8]. Generally, replacing natural aggregates by red ceramic waste has a negative effect on the strength parameters of concrete, and the higher the amount of the conventional aggregate replaced by red ceramic waste, the lower the concrete strength will be.

Rashid et al. [10] explored the characteristics of the high-strength concrete containing brick aggregate, and found that the compressive strength of the concrete containing brick aggregate decreased as the water-to-cement ratio increased, similar to what is observed in ordinary concrete. The reduction rate of compressive strength is higher for lower water-to-cement ratios. Mansur et al. [11] compared the properties of concrete containing natural aggregates with those of the concrete containing an equivalent amount of brick aggregates, in which the natural aggregate was replaced by an equivalent content of crushed brick, under similar conditions. Cachim [12] studied the mechanical properties of the concrete containing brick aggregate, with partial replacement of natural aggregate by brick aggregate, and reported that there was no strength reduction up to 15% replacement. Debieb and Kenai [13] demonstrated that it is possible to produce a concrete containing crushed brick (coarse and fine aggregates) with properties similar to those of the concrete having natural aggregate provided that the brick aggregate content is limited to 25 and 50% for the coarse and fine aggregate, respectively. Kavas el al. [14] investigated the use of refractory brick waste as a part of fine aggregate in concrete production. They performed a comparison among the mortar made with refractory brick aggregate, the one made with natural aggregate, and the one containing alumina particles in terms of temperature and permeability of acids. Utilization of ceramic sanitary ware waste as concrete aggregate was investigated in the work of Halicka et al. [15] where they compared the resistance of the specimens individually containing natural aggregate, granite aggregate, and ceramic sanitary ware waste, against abrasion and elevated temperatures to each other. The results of this study underline the special property of ceramic to maintain cohesion at high temperatures. Aliabdo et al. [16] explored the use of crushed brick in concrete products. They studied the compressive strength, porosity, modulus of elasticity, and ultrasonic pulse velocity of the concrete specimens containing brick content of 0–100% as the natural coarse and fine aggregate replacement as well as the ones containing a combination of both the crushed brick and natural aggregates.

The concrete with aluminate cement is a type of high-performance concrete (HPC) in which the aluminate cement replaces ordinary Portland cement as the main binder, and is employed in infrastructural works such as sewerage networks and even hydraulic dams. Calcium aluminate cement (CAC) is a special multipurpose cement used in works requiring high performance, e.g. resistance to chemical attack, high initial strength, refractoriness, resistance to abrasion, and low ambient temperature placement [17–19]. Experimental data obtained by exposing CAC (calcium aluminate cement) paste and various mortars to chemically aggressive environment and natural corrosion confirm the efficiency and ability of these materials in creating long-term serviceability under the mentioned conditions [20]. Furthermore, this type of concrete is characterized by its fast hardening and strength improvement, and because of this property, calcium aluminate cement is also preferred as a repair material. In relation to ordinary cement, this type of cement is capable of attaining the equivalent 28-day strength of ordinary Portland cement in just 5–6 h [17]. Moreover, it is preferred as a refractory material for the lining of the kilns in steel industry [21,22]. Khaliq et al. [17] investigated the elevated temperature properties of the concrete containing calcium aluminate, and reported that the reduction in the compressive strength of the concrete containing calcium aluminate with increasing temperature was less than that of the normal concrete. However, both the types of concrete showed similar and significant compressive strength reduction above 600 °C. In addition, the visual observation of the former type demonstrated that the physical and microstructural damage was less than that of normal concrete under elevated temperatures.

Human safety during a fire is one of the issues that should be taken into account while designing residential, public, and industrial buildings, and concrete has demonstrated a good performance and serviceability history in this regard. Mechanical properties such as strength, modulus of elasticity, and volume stability of concrete are considerably reduced during its exposure to fire [23–26]. Among the materials demonstrating a good resistance to heat are aluminate brick and cement that were utilized in this study. Khalaf and DeVenny [27] investigated the thermal characteristics of the concrete with brick aggregate besides its strength parameters under the ambient temperature, and found that the concrete containing brick aggregate performed similar to and/or better than the concrete containing granite aggregate under elevated temperatures. Husem [28] explored the effect of elevated temperatures on the compressive and bending strength of normal and high-strength concrete, and demonstrated that the both types of concrete experienced greater strength reduction when cooled with cold water in comparison with when cooled in the ambient air. Furthermore, his results showed that the compressive strength of high-strength concrete increased in the temperature range of 200–400 °C, while for the normal concrete, a continuous reduction occurred. The normal and high-strength concrete collapsed at the temperature of 600 and 800 °C, respectively, thus no compressive strength testing was performed on them. The effect of high temperatures on the concrete properties was studied in the work of Arioz [29]; the results of which showed significant weight reduction of the concrete specimens with increasing temperature, especially after 800 °C. Additionally, the results indicate the negligible effect of water-to-cement ratio and aggregate type on the loss of weight.