Construction and Building Materials 98 (2015) 128–136

Contents lists available at ScienceDirect

Construction and Building Materials

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

Influence of ground waste clay brick on properties of fresh and hardened concrete

Zhi Ge, Yuanyuan Wang, Renjuan Sun *, Xinsheng Wu, Yanhua Guan

Department of Transportation Engineering, School of Civil Engineering, Shandong University, Jinan 250061, China

HIGHLIGHTS

- Concrete with CBP had acceptable workability, strength, and durability.
- CBP had more effect on early-age strength instead of long-term strength.
- The elastic modulus was significantly reduced.
- CBP concrete had high resistance to chloride ion penetration and freezing–thawing.
- Only 10% CBP could significantly reduce the autogenous shrinkage.

ARTICLE INFO

Article history:
Received 11 May 2015
Received in revised form 6 August 2015
Accepted 10 August 2015
Available online 24 August 2015

Keywords:
Clay-brick-powder
Workability
Mechanical properties
Static elastic modulus
Chloride ion penetrability
Autogenous shrinkage
Non-evaporable water

ABSTRACT

The influences of partially replacing cement with ground clay-brick on properties of fresh and hardened concrete were investigated. In this study, three different replacement levels (10%, 20%, and 30%) and three types of clay-brick-powder (CBP) with different particle sizes (Type A, B, and C) were adopted. The test results show that CBP reduced the slump of fresh concrete significantly as the replacement level was over 10%. All concrete specimens had similar density around 2400–2500 kg/m^3. As the replacement level increased, the early age strength decreased. However, as the curing age increased, strength of concrete with CBP was similar to that of reference concrete. Most concrete containing CBP had 90-day compressive strength over 50 MPa, 28-day flexural strength in the range of 10–12 MPa, and 28-day splitting tensile strength of 2–4 MPa. Static elastic modulus was between 15 and 30 GPa. The specimens had low chloride ion penetrability with total passed charge value was less than 1742 C. After 300 freezing–thawing cycles, the strength deduction and mass loss were less than 16% and 1.6%, respectively. The water absorption increased with the replacement level, while the autogenous shrinkage can be reduced significantly as over 10% of cement replaced by CBP. The non-evaporable water decreased but not proportionally to the substitution level.

1. Introduction

Cement, the key constitute in making concrete, is an essential building material. In China, 2.5 billion tons of cement, which was around 60% of the world cement production, was manufactured in 2014 with an annual growth rate of 2.3%. Only 10.2 million tons were exported [1–2]. However, the massive production of cement not only leads to substantial consumption of natural resources, but also causes environmental concerns due to significant release of CO_2 and dust, noise, and other hazardous gases. Partially replacing cement with other materials without compromising the properties of concrete is one of the effective ways to make concrete more sustainable. Current researches demonstrate that concrete could be produced with cement partially substituted by clay-brick-powder (CBP) [3–6]. In China, the demolition of brick masonry structures due to large-scale urbanization produces huge amount of construction waste, including large quantities of clay brick which is normally landfilled. However, the landfilling of waste clay brick occupies the rare land resources, especially for cities with limited disposal sites. Therefore, using recycled CBP as part of cementitious material could simultaneously settle the environmental impacts caused by cement production and waste clay brick disposal.

Normally, crushed clay brick is used to partially replace normal aggregate for concrete production. The effects of clay brick aggregate on workability, mechanical properties, volume stability, and durability, have been studied extensively [7–16]. Concrete with

---

* Corresponding author.
E-mail address: sunrenjuan@sdu.edu.cn (R. Sun).

http://dx.doi.org/10.1016/j.conbuildmat.2015.08.100
0950-0618/

crushed coarse brick-aggregate could achieve similar compressive strength as concrete with normal aggregate but higher tensile strength, and exhibit lower drying shrinkage [3]. However, other researches showed increased shrinkage and water absorption rate, and reduced workability, strength, and elastic modulus when recycled brick aggregate was used [13]. Also, as the amount of brick aggregate increased, the chloride ion penetrability increased, wearing and freezing–thawing resistivity decreased. The water to cement ratio and replacement level had significant influence on concrete containing recycle clay brick aggregate.

Currently limited research was performed to study the properties of mortar or concrete containing ground CBP [17–19]. The major factors that affect strength and elastic modulus of concrete with CBP include w/cm, sand ratio, and dosage and fineness of CBP [20]. Research indicates that compressive strength of recycled mortar decreased slightly when using CBP for partial replacement of cement. However, pore size distribution was improved due to the later hydration of cement, resulting in higher later-age strength especially after 90 days. The CBP could also effectively mitigate the mortar expansion caused by alkali–silica reaction (ASR). The reduction increased as the content of CBP increased [6].

This paper aims to study the influence of substitution level and particle size of CBP on the properties of fresh and hardened concrete, such as workability, density, strength, elastic modulus, water absorption, shrinkage, durability, and non-evaporable water (NEW). This study can potentially promote the usage of CBP in concrete, thus to reduce the cement content and conserve natural resources, furthermore alleviate environmental pollution.

2. Experimental materials and testing methods

2.1. Experimental materials

This study used the ordinary Portland cement with major chemical compositions presented in Table 1. The waste clay brick was obtained from demolition site. As shown in Fig. 1, the clay brick mainly contains quartz, hematite, and rutile. In order to get different particle sizes, the waste brick was first crushed with a jaw breaker and then ground by the ball mill for different time. In this research, clay brick particles with three different size distribution, labeled as Type A, B, and C, were produced by different milling time. Fig. 2 shows the grading of these three CBPs and cement. All CBPs had larger particle size than cement. Water absorption and strength activity index of different CBPs are listed in Table 2. Type A CBP had smaller particle size, but higher absorption and strength activity index. Type C CBP had larger particle size, lower absorption and strength activity index. Type B CBP is in the middle. The SEM image (Fig. 3) indicates that CBP particles were angular and had rough surface texture.

Table 1
Chemical composition of cement.

Components	CaO	SiO_2	Al_2O_3	MgO	P_2O_5	K_2O	SO_3	Na_2O
Content (%)	75.4	21.9	1.3	1.3	0.03	2.7	2.0	0.07

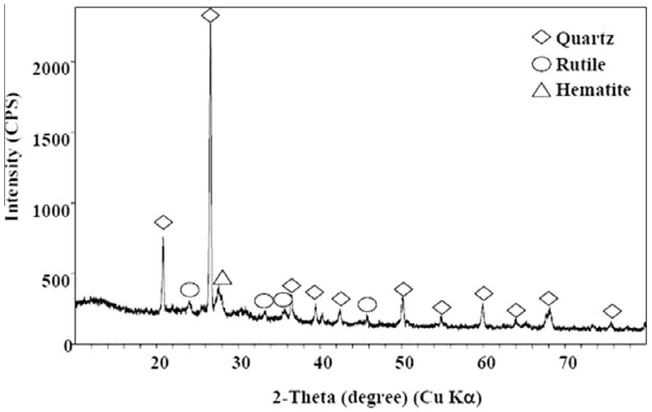

Fig. 1. XRD patterns of CBP.

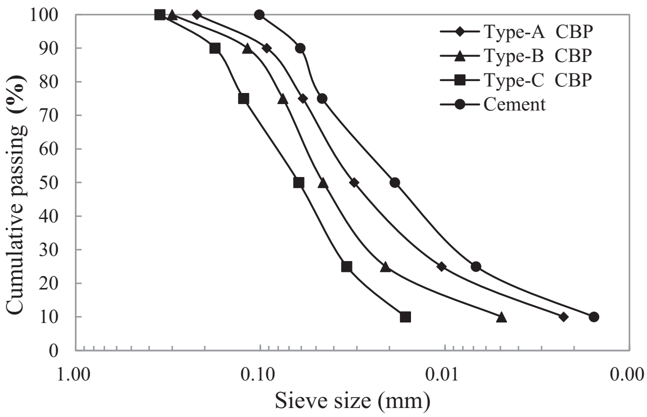

Fig. 2. Grain size distribution of cement and CBP.

Table 2
Water absorption and strength activity index of CBP.

Type	A	B	C
Water absorption (%)	22.07	16.45	12.03
Strength activity index (%)	67.87	59.85	40.20

The coarse aggregates with two different sizes of 5–10 mm and 10–20 mm were local limestone. For the 5–10 mm aggregate, the specific gravity and absorption were 2.28% and 0.79%, respectively. These values were 2.68% and 1.13% for the 10–20 mm aggregate. The ordinary Yellow River sand was employed as fine aggregate with specific gravity of 2.49, fineness modulus of 2.97, and absorption of 2.76%. Superplasticizer from BASF was employed. The water for mixing was normal tap water.

2.2. Testing methods

The water absorption of CBP was measured according to ASTM C128-15 [21]. Strength activity index of CBP was calculated as the ratio between the 28-day compressive strength of standard mortar and that of the mortar with 30% CBP.

Concrete were mixed and cured based on ASTM C192 [22]. The 7, 28, 56, and 90-day compressive strength, 28-day splitting tensile strength, and 7 and 28-day flexural strength were tested. The static elastic modulus was measured according to ASTM C469 [23] at 28 days. The resistances to chloride ion penetration and freezing–thawing were determined based on ASTM C1202-97 [24] and ASTM C666-97 [25], respectively. To measure the water absorption, the lateral and top surfaces were sealed with epoxy. After getting the dry weight of the sample, the bottom surface was immersed in tap water. The samples were then weighted at 24, 72, and 96 h. The absorbed water is then calculated as the mass difference.

For the autogenous shrinkage measurement, the 100 × 100 × 400 mm prism specimen was first cured in the standard environment, demolded after 1 day, then sealed by the plastic film and placed in the steel frame. The length change was measured by the dial gage at both ends. During the testing, concrete temperature was also monitored. The autogenous shrinkage was calculated based on the length change and temperature calibration. For the NEW, the dry weight of the ground powder specimen was first obtained by drying at 105 °C for 18 h. After that, the specimen was heated in the furnace, which was set at 950 °C, for at least 4 h. The NEW content, which is the mass loss between 105 and 950 °C, was then calculated.

3. Experimental design

Based on the previous research [20], water to cementitious material of 0.28 and sand ratio of 33% were adopted in this study. Three types of CBP with different particle size (Type A, B and C) and three replacement levels (10%, 20% and 30%) were employed. A total of 10 mixes were tested, including a reference mix. The mix proportions are listed in Table 3.