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Influence of crushing index on properties of recycled aggregates pervious concrete

Zhiquan Zhang [a], Yufen Zhang [b,*], Changgen Yan [c], Yunxiao Liu [a]

[a] School of Civil Engineering, Chang'an University, Xi'an 700061, PR China
[b] School of Civil Engineering, North China University of Technology, Beijing 100144, PR China
[c] Highway College of Chang'an University, Xi'an, Shaanxi Province, PR China

HIGHLIGHTS

- Natural aggregate was replaced with discarded concrete and clay brick aggregates.
- Addition of recycled clay brick aggregates increases the crushing index.
- Increase of crushing index exerts a negative impact on mechanical properties.
- The effects of crushing index on the porosity and permeability can be ignored.

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ABSTRACT

In this study, recycled aggregates (RA) produced by mechanical shredding from discarded concrete and clay bricks were used to make pervious concrete. Six groups of recycled aggregates pervious concrete (RAPC) were designed with different crushing index of aggregates under the condition of same concrete mixture ratio. The crushing index of aggregates increases with the replacement of RA increases. Experiments about compressive strength, elasticity modulus, flexural strength, permeability coefficient, total void ratio were conducted, including freezing and thawing cycle test. Test data of RAPC indicated that compressive strength, flexural strength and elasticity modulus of 28 days decreased by 36%, 28% and 21% respectively when crushing index changed from 9% to 37%, simultaneously strength loss rate increased from 6.6% to 18.7% and mass loss rate increased from 2.3% to 8.5%. Especially when crushing index is greater than 24%, except permeability coefficient and total void ratio, other properties of RAPC decreased significantly due to the lower quality of RA. Therefore, experimental results show that increase of crushing index has significant effects on compressive strength, elasticity modulus, flexural strength and freeze-thaw durability of RAPC. However, the effects of increasing crushing index on the permeability coefficient and total void ratio of RAPC can be ignored.

1. Introduction

Concrete mainly consists of cement, sand, pebble (or crushed stone), and each cubic meter of concrete consumes about 1700–2000 Kg aggregates. With economic development, concrete aggregate consumption grows very rapidly. Depletion and difficulty of mining sand and gravel resources are increasing. Meanwhile, billions of ton of construction waste were produced per year, including waste concrete, brick and others [1,2]. Such a large number of construction waste, if not well handled and effective utilized, the urban environment will suffer enormous damage. Using the waste concrete and brick can protect resources and reduce environmental pollution, so it has significant economic and social benefits [3].

Pervious concrete (PC) uses a small amount or no fine aggregate during preparation, and the right amount of cements are used to paste and wrap the bonding aggregate particles, then connected pore can quickly drain [4]. Its previous behavior depends on the porosity and the particle size of the aggregate. PC can reach a certain intensity and water permeability through rational design of mixture ratio [5,6]. PC as a unique and effective eco-friendly materials have been widely used at low-grade roads, squares, parking lots and other areas in North America, Europe and Japan [7]. It can regulate urban microclimate and sound absorption, maintain ecological balance, reduce the adverse effects of heavy rain or flood [8,9]. There were also many achievements published about PC

* Corresponding author.
E-mail address: yufenzh@gmail.com (Y. Zhang).

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design [4], strength and water permeability [10], frost resistance [11], microstructure [12], workability [13,14].

Recycled aggregate pervious concrete (RAPC), as one new type of ecologically concrete, can reduce environmental pollution, and help to protect the ecological balance [15]. So in recent years, some researchers have studied the different behaviors of RAPC including strength, total void ratio, and permeability coefficient. Research results showed that pervious concrete containing recycled aggregate (RA) gave lower mechanical properties than those containing natural aggregate (NA) [3]. Although, there is not enough research about the effect of RA on total void ratio and water permeability of RAPC, it is reported that the gradation and shape of RA can affect the void texture and void ratio of porous concrete [5]. Test research on the shrinkage and frost-resistance of RAPC showed that after 25 times and 50 times of freeze-thaw cycles, the strength loss rate of the pervious concrete were 5.6% and 18.9% [16]. The main factors that result in the strength loss are large pore structure of PC and weak bond between aggregates. The characteristic and mechanism of RA were studied in the Refs. [17–19], and it was concluded that durability of concrete changed greatly with the RA behaviors because RA differed from NA in pore volume and size on a micro level, water absorption and apparent density on a macro level. Kwan et al. have conducted the influencing test of aggregate size, grading and content on the behaviors of RAPC, showing the remarkable influence of water cement ratio and the RA content [20–22].

However, few researches of RAPC were relative to crushing index of aggregate. NA are hard and compact with low porosity, while RA produced by crushing waste concrete and brick is rough with many edges and corners, so RA has porosity property and high water absorption [23]. Crushing index is related to the strength, shape, water absorption, density, micropore and microfracture of aggregate, which can represent the quality of aggregate [24]. Consequentially, different crushing index can affect the performance on RAPC greatly. This paper focused on the sorts of recycled aggregates grouped by different crushing value, and some tests on compressive strength, flexural strength, elasticity modulus, porosity, permeability, frost resistance were conducted for 6 groups of RAPC specimens.

2. Experiment program

2.1. Materials

All the parameter indexes of cement are shown in Table 1. The value of strength, setting time, soundness and fineness of cement were measured according to Method of testing cements-determination of strength (GB/17671-1999) [25], Test methods for water requirement of normal consistency setting time and soundness of the Portland cement (GB/1346-2001) [26] and Test method for fineness of cement (GB/1345-2005) [27]. The Fineness was measured on 45 μm sieve.

The value of water demand ratio, loss on ignition (LOI), fineness and main chemical composition of fly ash (FA) are shown in Table 2. Fineness was measured on 45 μm sieve. It can be classified as ClassII according to Technical code for application of fly ash concrete (GB/T50146-2014) [28].

RA particles produced by mechanical shredding from discarded concrete and clay bricks, ranging from 5 mm to10 mm in size. The particle size distribution curve of the RA is shown in Fig. 1. Crushing index, water absorption and distribution curve were tested according to Pebble and crushed stone for construction (GB/T14685-2011) [29]. In this study, NA is crushed stone, while RA is discarded concrete and clay brick particle. Six groups of aggregate, the recycled aggregate took different content of the total aggregate, were prepared for RAPC. Crushing index of each group was measured as 37%, 34%, 30%, 24%, 19% and 9% respectively. Water absorption of each group was measured as 12.8%, 9.54%, 7.12%, 4.67%, 2.85% and 0.9% respectively.

The mixing water was tap water. Water-reducing admixture (WRA) was polycarboxylate superplasticizer, and the recommended participate amount is 1%.

2.2. Mix proportions

The mix proportion of RAPC was set at 1.00:0.20:0.34:4.34:0.012 for Cement:FA:Water:RA:WRA as shown in Table 3. Six mix proportions were set for crushing index 37%, 34%, 30%, 24%, 19% and 9% respectively. Some tests were conducted about compressive strength, flexural strength, elasticity modulus, permeability coefficient, total void ratio and freeze-thaw durability. All mixtures were mixed in a standard mixer. Firstly, all solid ingredients were mixed together for about 1 min before adding water, then water and WRA were added in and mixed for 2 min. The mixture was then placed into molds and demoulded after 24 h. After demoulded, all specimens were cured for 3, 7 and 28 days in a standard condition where the relative humidity is more than 95% and the temperature is 20 ± 2 °C [30].

2.3. Testing methods

The crushing index was determined in accordance with Pebble and crushed stone for construction (GB/T14685-2011) [29]. Firstly, 3000 g of sample (M_1) was put into the determinator under pressure testing. Then test machine was started by the velocity of 1 kN per second until the load of 200 kN. Kept the load for 5 s, and uninstalled it. Finally, the crushed fine particles were screened out using sieves with holes in 2.36 mm. The leaves of the sample was measured as M_2. The crushing index (Q_e) was calculated by

$$Q_e = \frac{M_1 - M_2}{M_1} \times 100\% \quad (1)$$

where, Q_e is the crushing index (%); M_1 is the initial mass of sample (g); M_2 is the mass of leaves of sample (g).

The results of compressive strength, flexural strength and elasticity modulus were reported by the average readings. The compressive strength, flexural strength and elasticity modulus were measured according to Standard for test methods of mechanics performance of common concrete (GB50081-2011) [31]. The compressive strength and elasticity modulus were both measured on three prism specimens $150 \times 150 \times 300\ mm^3$ in size. The flexural strength was measured on prism specimens $150 \times 150 \times 600\ mm^3$ in size. The compressive load was applied by a servo-controlled hydraulic testing machine. In compressive strength test, specimens were tested at a constant loading rate of 9.5 kN/s. For the flexural

Table 1
Cement parameter index.

Fineness (%)	Soundness	Setting time (min)		Strength (MPa)	
		Initial setting	Final setting	7d	28d
3	up to standard	160	285	25.5	48.8