

Behaviors of Concrete with Recycled Clay Brick as Fine Aggregate

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Abstract. *Massive waste materials were produced by the construction and demolition industry every year. In residential constructions, clay bricks are a dominant material and they account for a large proportion of construction and demolition waste. Using crushed bricks in cement concrete is an effective way to preserve natural aggregate and to reduce construction and demolition waste. The mechanical properties, the permeability and the carbonation resistance of concrete with recycled clay brick as fine aggregate were studied in this paper. The results showed that the compressive strength, the flexural strength and the impermeability of concrete decreased with the increasing of the replacement percent of recycled clay brick. However, the permeability of concrete with the water to cement ratio of 0.35 was still at the “Low” level when the replacement percent was less than or equal to 75%. The carbonation resistance of concrete using recycled clay bricks as fine aggregate was degraded.*

Keywords: *Construction and Demolition Waste, Fine Recycled Aggregate, Clay Brick, Durability.*

1 Introduction

Vast amounts of waste materials are produced by the construction and demolition industry every year. The volume of these materials has reached an unacceptable level from an environmental, economic and social point of view (Vieira *et al.*, 2016). In residential construction, clay bricks are a dominant material, so they account for a large proportion of construction and demolition waste (Crowther, 2000; Formoso *et al.*, 2002). Since concrete is the most widely used construction materials in the world, using crushed bricks in concrete is an effective way to preserve natural aggregate and to reduce construction and demolition waste.

Several studies have been conducted to investigate the potential of using clay brick as aggregates. Poon and Chan (2006) investigated the possibility of using crushed clay brick as aggregates in sub-base materials. A study by Lan Zong showed the permeability of water, air and chloride ions increased when recycled coarse aggregates were used. Additionally, the recycled concrete containing clay brick waste had increased porosity and exhibited a loose paste matrix (Zong *et al.*, 2014). Schackow used a powdered (<45 μ m) fired clay brick clean waste to replace Portland cement, and 28 and 90 days-compressive strength, water absorption, apparent porosity, absorption by capillarity, chloride retention, carbonation depth and sulphate resistance were evaluated. According to the results, they suggested that a moderate clay brick clean waste addition (up to 10 wt.%) is desirable if a comparable workability is desired (Schackow *et al.*, 2015). Adamson's research (2015) showed that the natural coarse aggregates can be replaced by crushed bricks, without significant change in the durability of concrete when the steel is not present. However, when concrete is reinforced with steel, replacing natural aggregates with crushed brick is not recommended. Bektas's study (2009)

indicated that as the brick replacement level increased, the mortar flow ability reduced. The 10% and 20% brick replacements had no negative effect on the mortar compressive strength and very limited effect on the mortar shrinkage.

This paper reports a study with the aim to investigate the mechanical properties and durability of concrete with recycled clay brick as fine aggregate. By conducting a sort of laboratory experiments, the compressive strength, flexural strength, permeability and carbonation resistance of concrete with recycled clay brick were studied.

2 Experimental Program

2.1 Materials

Ordinary Portland Cement (P·O 42.5) was used in accordance with China National Standard GB/175-2009, and Table 1 summarized its properties.

Table 1. Chemical and physical properties of cement.

Initial setting time (min)	Final setting time (min)	Tensile strength (MPa)		Compressive strength (MPa)	
		3d	28d	3d	28d
190	250	4.2	7.1	22.9	43.8

Natural river sand was used as fine aggregate, the fineness modulus of river sand was 2.9. Crushed limestone was used as coarse aggregate, and the grading of coarse aggregate is given in Table 2. Recycled clay bricks were broken into pieces. And the grading of recycled clay brick was controlled as the requirements of Chinese National Standard GB/T 25176-2010. Table 3 and Table 4 show the properties and the gradation of the recycled clay bricks as fine aggregate. A super plasticizer was used to adjust the workability of concrete.

Table 2. The grading of coarse aggregate.

Sieve pore size (mm)	19.0-26.5	16.0-19.0	9.5-16.0	4.75-9.5
Percentage (%)	25	25	35	15

Table 3. The properties of recycled clay brick.

Apparent density (g/cm^3)	Packing density (kg/m^3)	Close packing density (kg/m^3)
2.34	899	994

Table 4. The grading of recycled clay brick as fine aggregate.

Sieve pore size (mm)	4.75	2.35	1.18	0.6	0.3	0.15	<0.15
Percentage (%)	2	7	10	30	36	13	2

2.2 Mix Proportions and Sample Preparation

The proportions of reference concrete with the water to cement ratio of 0.35 and 0.47 are given in Table 5. The recycled clay brick was introduced as volume percentage of the

concrete fine aggregate, and four levels of replacement, 25%, 50%, 75% and 100%, were investigated.

Due to the high water absorption of recycled clay brick, it is suggested to soak the brick aggregate in water prior to adding to concrete [Khalaf, 2005; Khalaf, 2006; Cachim, 2009]. Therefore, this procedure was adopted in this work for recycled clay brick. The recycled clay brick aggregate was soaked in water for 24h and added to concrete mixture in a saturated condition.

Table 5. Mixture proportions of reference concrete (kg/m³).

<i>W/C</i>	Water	Cement	Sand	Gravel	Super plasticizer
0.35	175	500	629	1106	4.5
0.47	175	372	702	1151	4.5

2.3 Methods

2.3.1 Mechanical properties

The compressive strength and flexural strength of concrete were tested at 28d age. The compressive strength specimens with the size of 100mm×100mm×100mm and the flexural strength specimens with the size of 100mm×100mm×400mm were tested in accordance with the Chinese standard GB/T 50081-2002.

2.3.2 Carbonation resistance

The concrete cubes with the size of 100mm×100mm×100mm were casted, and the samples were demoulded after 24h and cured in the standard curing condition until 28 days, then the samples were placed in a carbonation chamber with the CO₂ concentration of 20%, the temperature of 20°C and the RH of 70%. The carbonation depth was determined at the start of exposure and after 3, 7, 14 and 21 days according to Chinese standard GB/T 50082-2009.

2.3.3 Permeability

The permeability of concrete was measured at 28d age according to the Chinese standard GB/T 50082-2009, and the size of specimen was φ100mm×50mm.

3 Test Results and Discussion

3.1 Mechanical Properties

Table 6 demonstrates the compressive strength and the flexural strength obtained from the concrete samples with different replacement of recycled clay bricks. Each data represents the average of three samples. It was observed that with the increasing of recycled clay brick content, both the compressive strength and the flexural strength decreased. When the water to cement ratio was 0.35, the compressive strength loss of approximately 20% at 28 days was observed in concrete produced with 25% recycled clay brick replacement ratio. The reduction in compressive strength was observed more significantly in concrete with 75% or more replacement ratio as it decreased over 30%. The compressive strength of concrete with the

water to cement ratio of 0.47 showed the similar change, and the decrease of compressive strength was more than 30% when 25% recycled clay brick was added. It was shown the replacement of recycled clay bricks had more influence on the concrete with higher water to cement ratio.

Table 6. Mechanical properties of concrete (28d).

<i>W/C</i>	Replacement percentage (%)	Compressive strength (MPa)	Flexural strength (MPa)
0.35	0	51.8	6.0
	25	42.3	4.8
	50	41.5	4.1
	75	35.2	3.8
	100	32.3	3.6
0.47	0	48.3	4.5
	25	33.2	4.1
	50	31.2	3.7
	75	26.8	3.4
	100	24.3	3.1

3.2 Permeability

The electric flux method was used to evaluate the permeability of concrete to chlorides, and the results was described in Figure 1. It can be found that with the increasing of the recycled clay brick content, the impermeability decreased. According to ASTM C1202, the permeability of concrete to chlorides could be divided into 5 classes by charge passed, which is shown in Table 7. When the water to cement ratio was 0.35 and the replacement percent of recycled clay brick was less than or equal to 75%, the permeability of concrete could be evaluated as “Low”. When the water to cement ratio was 0.47 and the replacement percent of recycled clay brick was less than or equal to 25%, the permeability of concrete could be evaluated as “Low”.

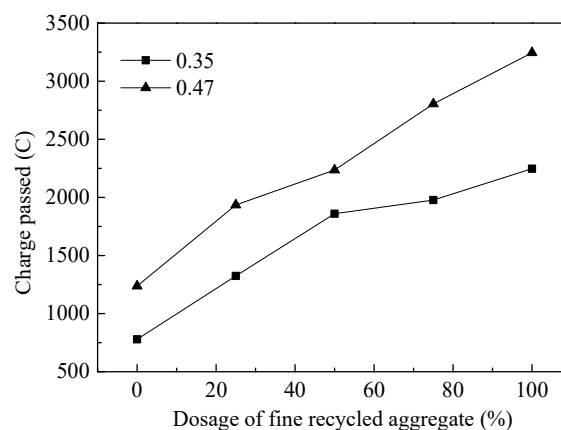


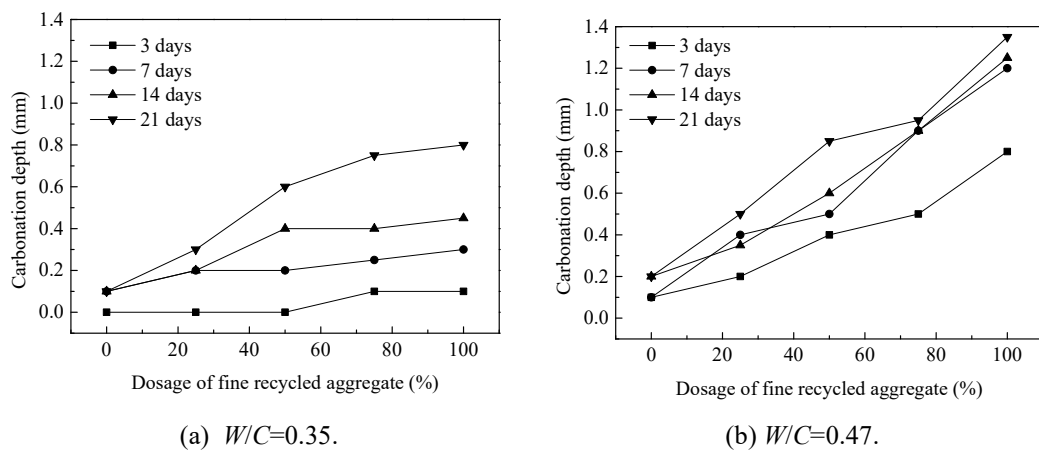
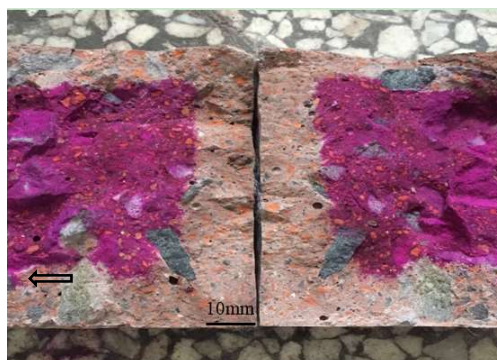
Figure 1. Effect of the dosage of fine recycled aggregate on the permeability of concrete.

Table 7. Chloride ion penetrability based on charge passed.

Electric flux (6h, C)	Permeability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

3.3 Carbonation Resistance

The effect of the dosage of fine recycled aggregate on the carbonation depth of concrete is described in Figure 2. Generally, concrete with higher water to cement ratio has more pores, and CO_2 could get into concrete much easier through these pores. Consequently, the carbonation depth increased with the increasing of water to cement ratio for all test age. The carbonation depth also increased with the increasing of the test age and the replacement level of recycled clay brick. The porous recycled clay brick may carbonate considerably faster than the concrete with natural aggregate, causing a increase of the carbonation depth which was shown in Figure 3.

**Figure 2.** Effect of the dosage of fine recycled aggregate on the carbonation depth of concrete.**Figure 3.** Surface of split concrete cube with the replacement level of 100% used in the carbonation test after being sprayed with phenolphthalein at 21days ($W/C=0.47$).

4 Conclusions

Based on the above experimental results, some conclusions could be drawn below:

- Both the compressive strength and the flexural strength decreased with the increasing of the replacement percent of recycled clay brick.
- The impermeability of concrete decreased with the increasing of the replacement percent of recycled clay brick. But the permeability of concrete with the water to cement ratio of 0.35 was still kept at “Low” level when the replacement percent was less than or equal to 75%.
- The carbonation resistance of concrete using recycled clay bricks as fine aggregate was degraded.

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