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Permeability of recycled aggregate concrete containing fly ash and clay brick waste

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ABSTRACT

The quantity of construction and demolition waste is continually increasing throughout the world, and recycling this waste is beneficial and necessary for environmental preservation. Because the permeability of concrete materials is closely related to their durability, this paper predominately discusses the permeability of recycled concretes composed of fly ash and clay brick waste. Various proportions of recycled coarse aggregates obtained from clay brick waste were used to replace natural coarse aggregates. The properties of natural aggregates and recycled aggregates were studied, and recycled aggregates exhibited a higher porosity. Additionally, the strength of the recycled concrete decreased because of the incorporation of recycled coarse aggregates. The permeability of water, air and chloride ions was evaluated through water absorption, water permeability, air permeability and chloride ion diffusion tests. The results indicated that 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, which may be the reason for the increased permeability.

1. Introduction

Waste reuse and recycling are among modern society's environmental priorities, and considerable effort is being devoted to achieve these objectives (Martínez-Lage et al., 2012). Green construction materials play an important role in the sustainable development of the construction industry. Concrete, the most widely used construction material, absorbs natural mineral resources and should be considered to reduce energy consumption during construction. A sustainable concrete design includes minimizing both the quantity of global CO_2 released and the energy consumed to produce concrete and the various components required (Limbachiya et al., 2012). The preparation of concrete consumes many natural aggregates, and the use of recycled aggregate concrete (RAC) is one technique that resolves problems associated with the utilization of natural aggregates. Large quantities of clay brick waste generated from construction and demolition sites are predominately delivered to landfills or reclamation sites for disposal. With limited landfill space and reclamation areas, it is important to evaluate the possible reuse of clay bricks (Poon and Chan, 2006a,b).

Sustainability benefits the environment by reducing the consumption of non-renewable natural resources and increasing waste recycling (Arezoumandi and Volz, 2013). Concrete, which is the most consumed man-made material in the world, uses a significant amount of non-renewable resources. The feasibility of producing concrete with mixed recycled aggregates has been addressed in the literature (Khalaf and DeVenny, 2004; Senthamarai and Devadas, 2005; Chen et al., 2003; De Brito et al., 2005). Chen et al. (2003) reported that the decline in compressive strength of concrete containing 100% mixed recycled material as the coarse aggregate ranged from 25% to 40% depending on the water to cement ratio. De Brito et al. (2005) reported a decline in compressive strength and bending strength of such concrete on the order of 45% and 26%, respectively, which confirms that concrete could be manufactured with mixed recycled aggregates. Furthermore, Cachim (2009) observed no significant changes in the mechanical properties of concrete, however, a reduction of approximately 30% was observed for concrete containing 30% mixed recycled aggregates by volume. Poon and Chan (2006a,b) concluded that using 100% recycled concrete aggregates increased the optimum moisture content and decreased the maximum dry density of subbase materials when compared with natural subbase materials. Xiao and Falkner (2007)

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Table 1
Chemical compositions of cement.

Sample	Chemical composition (wt%)						
	CaO	MgO	Fe_2O_3	Al_2O_3	SiO_2	SO_3	Loss
Cement	64.43	1.57	3.26	4.76	20.85	1.47	2.65
Fly ash	4.10	1.30	9.60	26.10	51.21	0.40	6.19

studied the bond between recycled aggregate concrete and steel rebars and observed a reduced bond strength between the recycle aggregate concrete and the plain rebar with increasing replacement percentages of recycled aggregate (RA). Additionally, Marie and Quiasrawi (2012) discovered that recycled concrete had a lower workability (slump) compared with normal concrete. Various waste materials have been utilized as recycled aggregates. Medina et al. (2013) explored the durability of concrete made with aggregates containing 20–25% ceramic sanitary ware industrial waste, and their findings showed enhanced concrete freeze-thaw resistance with increasing recycled aggregate content. Zhao et al. (2013) prepared concrete using cathode ray tube funnel glass sand as recycled fine aggregates and concluded that cathode ray tube funnel glass can be treated, processed and reutilized for the production of high-density concrete.

Most existing research compares the mechanical properties of recycled concrete with conventional concrete (Akhtaruzzaman and Hasnat, 1988). According to research achievements, the mechanical performance of RAC nearly satisfies the requirements that are imposed for conventional concrete. However, there are fewer studies on the permeability of RAC. The service life of concrete structures depends on the durability of the concrete materials. Furthermore, permeability is the most important factor that affects concrete durability. The economic impact of concrete durability has motivated over two decades of extensive research. The mechanism that controls permeability depends on the fluid or chemical species of interest. For example, in concrete, the permeation of air affects carbonation action, whereas the permeation of chloride ions affects steel corrosion. Many durability test methods consider the penetration of deleterious substances into concrete as a rate-controlling step in the degradation process. Highly permeable concrete facilitates the penetration of water and harmful substances, which results in the deterioration of either the concrete or the steel reinforcements embedded in the concrete (Chia and Zhang, 2002). The transport of gases, liquids and ions through concrete is important because their interactions with concrete constituents or pore water can directly or indirectly alter the integrity of the concrete and deteriorate the structure, as mentioned above (Basheer et al., 2001). Experimental evidence exists that illustrates a correlation between relevant transport properties and either the penetration of different aggressive substances or mechanisms of deterioration (Dhir et al., 1994).

Fly ash, a type of industrial waste, has been widely applied in concrete materials. The use of fly ash as a partial replacement for cement in concrete has numerous benefits; it reduces greenhouse gas emissions, demonstrates good long term strength and durability, reduces the demand for water, consumes less energy and decreases the pressure on natural resources (Mehta and Monteiro, 2006; Bagheri et al., 2013). Moreover, fly ash is economical, and there are numerous fly ash resources. In this paper, recycled concretes made with fly ash were studied. Clay brick waste was treated and used as a recycled aggregate. The permeability of RAC under different permeation medium was also investigated and compared with the permeability of natural concrete.

2. Materials and methods

2.1. Materials

Samples were prepared using ordinary Portland Cement (OPC) and grade I fly ash. The chemical composition of the cement and fly ash are provided in table 1. Crushed stones with a maximum size of 25 mm were used as the natural coarse aggregate, and quartz sand with a fineness modulus of 2.48 was used as the fine aggregate. It has been proven that concrete admixtures are beneficial for material performance, therefore a high performance polycarboxylate water-reducing admixture (PCA) was used in this study (Barbudo et al., 2013). A recycled coarse aggregate was prepared from clay bricks, which were collected from a construction site. The strength of the waste bricks was measured according to the National Standard of Fired Common Brick GB5101-2003, and the strength was determined to be MU10 (the compressive strength exceeded 10 MPa). The clay bricks were crushed and washed before use. The basic performance of the RA was evaluated, and the grade, density and crush index were determined. The physical properties of natural aggregates (NAs) and recycled aggregates (RAs) made from clay bricks are given in Table 2. Fig. 1 illustrates the RA preparation process, which includes crushing, sieving and grading. Fig. 2 shows the grading curve of the RAs and NAs. The standard error calculated from the experimental data was less than 1. According to GB/T 14685-2001, the national standard on the use of pebble and crushed stone for buildings, and based on grading, the crushed RAs collected from the demolition plant were qualified for use in concrete.

2.2. Methods

2.2.1. Preparation of concrete samples

All concrete mixtures were prepared in the laboratory. Concrete samples with sizes of 100 mm × 100 mm × 100 mm, 100 mm × 100 mm × 400 mm, 200 mm × 200 mm × 200 mm and Φ100 mm × 200 mm were prepared. The proportions of the concrete mixtures are presented in detail in Table 3. The following RA levels were used to replace coarse aggregates: 0%, 30%, 40% and 50% by volume fraction. Additionally, 15% by weight fly ash was used as a replacement for cement. Because the RAs have a high saturated surface dry absorption, similar to recycled aggregates made with old concrete (Mefteh et al., 2013), additional water was used to prepare the recycled concrete. Therefore, the water content in the

Table 2
Physical properties of NAs and RAs.

Sample	Apparent density (kg/m^3)	Bulk density (Kg/m^3)	Grading (mm)	Elongated particle content (%)	Saturated surface dry absorption (%)	Moisture content (%)	Crush index (%)
NA	2860	1580	5–20	4	1.45	1.0	8.8
RA	1650	830	5–20	9	16.58	0.6	29.5