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Investigation of using recycled powder from waste of clay bricks and cement solids in reactive powder concrete

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HIGHLIGHTS

- Use of the recycled powder from construction and demolition wastes in RPC is studied.
- Environmentally-friendly and cost-saving RPC mixtures with high performance are developed.
- Natural sand can be used instead of crushed quartz in the green RPC mixtures.
- Mix proportions of the green RPC are studied through theory and designed experiments.

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ABSTRACT

Recycled powder, produced from the construction and demolition wastes, contains unhydrated cement particles. It can reduce environment pollution to use recycled powder as a cementing material. It is investigated to use recycled powder to partially replace silica fume or cement in Reactive Powder Concrete (RPC) to develop environmentally-friendly and cost-saving RPC mixture with high performance. Properties of the recycled powder are tested firstly. And according to maximum packing theory, the RPC mix with the recycled powder is designed. Influences of the fine aggregate, quartz and natural sand, on the RPC are investigated. The water-cementitious materials ratio (w/cm) for RPC mixes with the recycled powder are studied and selected. The recycled powder is used to replace the silica fume and cement in RPC respectively, and influences of the replacement ratio on the flowability, strength and durability are investigated. The standard curing is used for all the tests instead of steam curing normally required for RPC. Considering the flowability, strength, durability, cost and environmental savings, it is suggested that the recycled powder can be used to replace the silica fume and cement in RPC partially, and natural sand can be used instead of quartz. Additionally, influences of GGBFS powder on RPC mix with the recycled powder are investigated.

1. Introduction

RPC was developed with dense microstructure and reduced defects (pores and micro-fractures), and thus ultra-high strength and high durability can be ensured. Compressive strengths of 200–800 MPa and flexural strength of 140 MPa have been achieved with RPC. And with the steel fiber, RPC also exhibits remarkable ductility, about 250 times higher than that of conventional concrete. Typical compositions of RPC include cement, silica fume (SF), crushed quartz, superplasticizer and steel fiber [1,2]. The cement dosage is normally 800–1000 kg/m^3, SF content is often over 25% (by the weight of cement), and crushed quartz is 40% (by the weight of cement). This increases the production cost. Also high amounts of cement and silica fume can raise the hydration heat and may cause shrinkage problems. To overcome these problems, some mineral admixtures were used to replace cement or reduce the SF amount [3]. Yazici et al. (2009) [3] found that RPC containing high volume mineral admixtures (fly ash (FA) and ground granulated blast furnace slag (GGBFS)) have satisfactory mechanical performance (compressive strength, flexural strength, and toughness). Compressive strength exceeded 200 MPa after standard water curing, although the cement and silica fume

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Table 1
Chemical composition of cementitious materials.

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
Cement (%)	23.25	7.79	2.41	46.78	0.459	0.116	0.574	4.10
Silica fume (%)	94.51	0.87	0.10	0.43	1.56	0.082	0.33	–
Slag powder (%)	28.48	13.88	–	36.79	9.06	0.43	0.33	1.32
Recycled powder (%)	53.8	13.2	5.15	13.6	2.58	0.65	2.77	–

Table 2
Physical and mechanical properties of cement.

Fineness (%)	Density (g/cm^3)	Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)	
		Initial	Final	3d	28d	3d	28d
5.7	3.13	150	490	5.5	7.6	24.6	44.3

contents of the mixtures lower than conventional RPC. SF can also be reduced by increasing GGBFS and/or FA content.

Kasami et al. (2001) [4] investigated recycled concrete powder, by-product in the process of producing recycled aggregate. It was found that the recycled concrete powder can be used for self-compacting concrete without further processing, although the dosage of high-range water reducer for a given slump-flow and in drying shrinkage may increase. The superplasticizing effect of high-range water reducer and properties of concrete can be improved by the addition of recycled concrete powder together with ground blast-furnace slag to self-compacting concrete.

Malhotra and etc. (1996) [5] reported that clay brick powder can be used as a pozzolanic supplement like fly ash because of the rich pozzolanic ingredients. It can replace part of cement in concrete, and the expansion induced by the alkali–silica reaction could be suppressed [6]. Kartini et al. (2012) [7] investigated 10%, 20% and 30% replacement of cement in concrete by recycled clay brick powder. 30% replacement still attained strength of grade 30 concrete, and water absorption and water permeability can be reduced efficiently. Wild et al. (1997) [8] investigated the ground brick from different European countries. It was confirmed that all the ground brick types studied exhibit pozzolanic activity by both results of the chemical tests for pozzolanicity and also the results for the strength development of the mortars. Baronio et al. (1997) [9] concluded that a good degree of hydraulicity of the mortar could be developed with finely powdered clay bricks.

Large amount of construction and demolition wastes of clay bricks and cement solids are produced. It is possible to use the recycled powder of clay bricks and cement solids as a cement supplement, considering its pozzolanicity. Use of the recycled powder from construction and demolition wastes in RPC is studied, and environmentally-friendly and cost-saving RPC mixtures with high performance are developed. Mix proportions of the green RPC are studied through theory and designed experiments.

Concrete mix design is always desirable to compose the aggregates as densely as possible, i.e. with maximum packing [10]. The performance of a concrete mix can be optimised by maximising the packing densities of the aggregate particles and the cementitious materials. It is believed that maximisation of the packing density of the cementitious materials and the packing density of the aggregate particles could improve the overall performance of the resulting concrete mix and thus should be the general guideline for mix optimisation [11]. Lange and etc. [12] and de Larrard and Sedran [13] demonstrated that the increase of packing density of the cementitious materials can reduce the water/cementitious materials (W/CM) ratio, decrease the porosity, speed up the hydration process, and improve the microstructure which result in good mechanical properties and great durability. Investigation of Richard and Cheyrezy [1,2] showed that the incorporation of ultra-fine powders with different grain sizes and the improvement of packing properties of pozzolanic minerals were successful ways to obtain super-high performance cementitious materials (Reactive Powder Concrete).

The mix proportion is designed based on Dinger-Funk equation [14] of the maximum packing theory. Influences of recycled powder on the strength, workability and durability of RPC are investigated through designed experiments.

2. Experiment preparation

2.1. Materials

P·O 42.5 ordinary Portland cement conforming to GB175-2007 [15] was used, and the chemical composition and physical and mechanical properties are listed in Tables 1 and 2 respectively. The chemical composition of silica fume used is listed in Table 1. The average grain size is 0.26 μm and the specific surface area is over 20 m^2/g. S95 GGBFS powder conforming to GB/T18046-2008 [16] was used, and the chemical composition and physical and chemical properties are listed in Tables 1 and 3 respectively.

Recycled powder in this study was made through smashing, grinding, drying and grading abandoned clay bricks and cement solids. The chemical compositions of the recycled powder were summarized in Table 1. The density measured was 2.63 g/cm^3.

Crushed quartz used has the grain diameter range of 200–650 μm and the average grain size of 280 μm. The natural sand used has the grain size range of 150–8000 μm and the average grain size of 300 μm. Superplasticizer used was a type of polycarboxylate agent. The solid content is 41% and the water reduction rate is 31.8%.

The particle size distribution of recycled powder was measured by laser particle size analyzer. The result is shown in Fig. 1. The average grain size was 31.4 μm. The amount of particles with a grain size under 10 μm was high.

The water demand of recycled powder was tested following GB/T 18736-2002 [17] and GB/T17671-1999 [18]. The dosage suggested for the fly ash was used for the recycled powder, considering the fineness (15.8% for fly ash and 6.8% for recycled powder) and the particle size distribution (Fig. 1) of the two materials are similar. The ratio of water demand is 99.3%, and it can be concluded that the water demand of recycled powder is similar to that of cement.

Activity index of the recycled powder was tested following GB/T 18736-2002 [17] and GB/T17671-1999 [18]. The standard sand by GB/T17671-1999 [18] was used. The compressive strength and flexural strength at 28 days were tested. The compressive strength for the mix with the recycled powder was 71% of the control mix and the flexural strength was 68% of the control mix. The results indicated that the recycled powder had pozzolanic activity.

2.2. Specimen preparation

Specimens for strength and shrinkage tests were prepared following GB/T17671-1999 [18] and JC/T 603-2004 [19] respectively. The cementitious materials were mixed for 1 min in the mixer. Then 70% water and 70% superplasticizer were

Table 3
Physical and chemical properties of GGBFS powder.

Specific surface area (m^2/kg)	Density (g/cm^3)	Activity index at 28 days (%)	Cl^- (%)	Loss on ignition (%)
437	2.85	97	0.03	2.8