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Enhancing the durability properties of concrete prepared with coarse recycled aggregate

S.C. Kou, C.S. Poon *

Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

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ABSTRACT

It is generally known that the use of recycled aggregates in concrete would reduce its compressive strength and render the concrete less durable. Various methods have been attempted to compensate for the lower quality of the recycled aggregates for concrete production. In this paper, the effects of incorporating Class F fly ash in the concrete mix design to mitigate the lower quality of recycled aggregates in concrete is presented. The results show that one of the practical ways to utilize a high percentage of recycled aggregate in concrete is by incorporating 25–35% of fly ash since some of the drawbacks induced by the use of recycled aggregates in concrete could be minimized.

1. Introduction

Recycled aggregate has been used as a replacement of the natural aggregate for a number of years. The potential benefits and drawbacks of using recycled aggregate in concrete have been extensively studied [1–8]. The use of recycled aggregate generally increases the drying shrinkage, creep and water sorptivity and decreases the compressive strength and modulus of elasticity of recycled aggregate concrete compared to those of natural aggregate concrete [9–12]. The poor performance of the recycled aggregate concrete is associated with the cracks and fissures, which were formed in recycled aggregate during processing, thereby rendering the aggregate having weaker and more susceptible to permeation, diffusion and absorption of fluids [10]. This may also be due to the presence of old ITZ and adhesive mortar in the recycled aggregate, which makes recycled aggregate concrete more permeable than normal aggregate concrete [13]. These drawbacks limit the utilization of the recycled aggregate with higher percentages (>30%) in structural concrete.

Many studies have shown that using recycled aggregates in concrete suffers from durability problems [10,14–21]. Hansen and Boegh [14] reported that, compared with the reference concrete, the shrinkage of recycled aggregate concrete was increased by up to 60%. Domingo-Cabo [16] observed that the shrinkage of recycled concretes using 100% recycled aggregates was about 70% higher than that of the control concrete after a period of 180 days. Olorunsogo and Padayachee [10] reported that, at the curing ages of 3, 7, 28 and 56 days, compared with natural aggregate concrete, the water absorptivitiy of recycled aggregate concrete was increased by 47.3%, 43.6%, 38.5% and 28.8%, respectively, although the processes of water absorption in both types of concrete were similar and obeyed the same law. Cui et al. [17] reported that the carbonation level of recycled aggregate concrete was 3 times that of the natural aggregate concrete. Crentsil et al.'s [18] and Levy Salomon and Helene's [19] experimental results showed that, after 6 months of curing, the carbonation depth of the recycled aggregate concrete was 1.3–2.5 times than that of the reference concrete. Otsuki et al. [20] reported that the resistance of recycled aggregate concrete to chloride ion penetration and carbonation were slightly inferior to those of natural aggregate concrete given the same water-binder ratio was used. In a study carried out by Olorunsogo and Padayachee [16], it was found that the concrete mix containing 100% recycled aggregates showed a 73.2% increase in chloride conductivity at a curing age of 28 days. Evangelista and de Brito [21] reported that the water permeability, capillary absorption and chloride diffusion of concrete was increased with an increase in the replacement ratio of fine natural aggregate by fine recycled aggregate.

The negative effects of recycled aggregate on concrete quality limit the use of this material in structural concrete. However, it has been suggested that the shortcomings of using recycled aggregate can be mitigated by using the double mixing approach in concrete mixing, particularly for concrete prepared with high water-binder ratio as it has been demonstrated that improvements in strength, chloride penetration, and carbonation resistances of recycled aggregate concrete can be achieved [22,23]. Abbas et al. also have demonstrated that by using an equivalent mortar volume

* Corresponding author. Tel.: +852 2766 6024.
E-mail address: cecspoon@polyu.edu.hk (C.S. Poon).

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(EMV) method, RCA-concrete mixes have higher resistance to freeze–thaw action, chloride penetration and carbonation than those designed with the conventional method can be prepared [24].

It has also been shown that by negative effect of RCA can be mitigated by incorporating a certain amount mineral admixtures [25,26]. Recently Kou et al. [27,28] found that when Class F fly ash was used as an additional or cement replacement in the RCA mixes, it can improve the mechanical and durability properties of recycled aggregate concrete.

This paper presents the results of a study on the use of fly ash as a substitution and addition of cement in recycled aggregate concrete to improve the durability properties of the concrete.

2. Experimental details

2.1. Materials

2.1.1. Cement & fly ash

ASTM Type I Portland cement and ASTM Class F low-calcium fly ash were used in the concrete mixtures. The chemical and physical properties of cement and fly ash are given in Tables 1 and 2, respectively.

2.1.2. Aggregates

Natural and recycled aggregates were used as the coarse aggregate in the concrete mixtures. In this study, crushed granite was used as the natural aggregate and recycled aggregate sourced from a recycling facility in Hong Kong was used. According to the quality control requirements of the recycling facility, the recycled aggregate contained less than 0.5% by weight of wood and particles less dense than water and less than 1% by weight of other foreign materials. The compositions of the recycled aggregate are shown in Table 3. Therefore, the recycled aggregate used in this study could be considered as recycled concrete aggregate (RCA). The nominal sizes of the natural and recycled coarse aggregates were 20 and 10 mm and their particle size distributions are shown in Fig. 1. It is seen that the size grading of the coarse natural and recycled aggregate was similar and conformed to the requirements of BS 882 (1985). The physical and mechanical properties of the coarse aggregate are shown in Table 4. The porosity of the aggregates was determined using mercury intrusion porosimetry (MIP). River sand was used as the fine aggregate in the concrete mixtures.

2.2. Concrete mixtures

Two series of concrete mixtures were prepared in the laboratory. The recycled aggregate was used as 0%, 20%, 50%, and 100% by volume replacements of the natural aggregate. In Series I, fly ash was used as 0, 25 and 35% by weight replacements of cement (i.e. the water to binder ratio (W/B) was kept at constant at 0.55); and in Series II, fly ash was used as 0%, 25% and 35% by weight addition of cement (i.e. the W/B decreased with increasing percentage of fly ash added from 0.55 to 0.42). The concrete mixtures were coded r-RxFy (*x = percentage of recycled aggregate replacement level*; *y = percentage of Fly ash replacement of cement level*) and a-RxFz (*z = percentage of addition of Fly ash by cement weight*). The absolute volume method was used to proportion the concrete mixtures (Tables 5 and 6). In each concrete mixture, the 10 and 20 mm coarse aggregates were used in a ratio of 1:2. The slump of the concrete mixtures was kept constant at about 100 mm by the use of superplasticizers.

2.3. Specimens casting and curing

For each concrete mixture, 100 mm cubes, 70 × 70 × 285 mm prisms, and 100ϕ × 200 mm cylinders were cast. The cubes and prisms were used to determine the compressive strength and drying shrinkage, respectively. The 100ϕ × 200 mm cylinders were used to evaluate the resistance to chloride-ion penetration of concrete. Additionally, creep test was performed for the concrete mixtures using the 150ϕ × 300 mm cylinders.

Table 1
Chemical composition of cement and fly ash.

	Composition (%)						
	LOI	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3
Cement	2.97	19.61	3.32	7.33	63.15	2.54	2.13
Fly ash	3.90	56.79	5.31	28.21	<3	5.21	0.68

Table 2
Physical properties of cement and fly ash.

	Materials	
	Cement	Fly ash
Density (g/cm^3)	3.16	2.31
Specific surface area (cm^2/g)	3520	3960

Table 3
Composition of the recycled aggregates.

Materials	Composition (%)	
	10 mm	20 mm
Stone	32.8	38.9
Old concrete	66.2	60.1
Brick, tile etc.	1.0	1.0

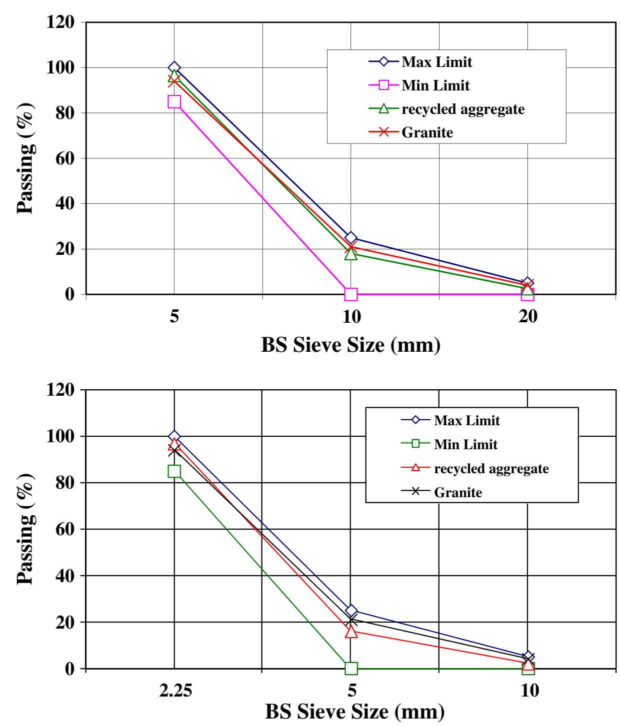

Fig. 1. Particle size distribution of coarse aggregate according to BS 882 (a) 20 mm and (b) 10 mm.

All the specimens were cast in steel moulds and compacted using a vibrating table. Three cubes and three cylinders were immediately used after demolding to measure the 1-day compressive and tensile splitting strengths. The rest of the specimens were cured in a water-curing tank at 27 ± 1 °C until the age of testing.

2.4. Tests

2.4.1. Compressive strength

The compressive strength of concrete was determined using a Denison compression machine with a loading capacity of 3000 kN. The loading rates applied in the compressive tests were 200 kN/min. The compressive strength was measured at the ages of 1, 4, 7, 28 and 90 days.

2.4.2. Drying shrinkage

A modified British Method (BS1881, part 5: 1970) was used for the test. After removing the concrete prisms from the curing tank, the initial length of each specimen was measured. The specimens were then stored in an environmental chamber with a temperature of 55 °C and a relative humidity of 95% until the next measurements at 1, 4, 7, 28, 56, 90 and 112 days. Before each measurement was taken on the scheduled day, the specimens were first removed from the environmental chamber and conveyed to a second cooling chamber for about 4 h at a controlled