Construction and Building Materials 77 (2015) 501–508

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of the quality of parent concrete on the properties of high performance recycled aggregate concrete

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HIGHLIGHTS

- The effect of the quality of parent concrete on the properties of RAC.
- Parent concrete with strength grades ranging from 30 to 100 MPa was used.
- The strength of RAC with 80 and 100 MPa PCs was slightly higher than that of NAC.
- The durability of RAC can be improved with RA are derived from higher strength PCs.
- The RA derived from 80 and 100 MPa PCs can be used to produce HPC.

ARTICLE INFO

Article history:
Received 3 October 2013
Received in revised form 23 June 2014
Accepted 22 December 2014

Keywords:
High performance concrete
Recycled aggregate
Parent concrete strength
Property
UPV

ABSTRAC1T

This paper presents the experimental results of a study on the effect of the quality of parent concrete (PC) on the properties of recycled aggregates (RAs) that are derived from them, and on the mechanical and durability properties of normal strength and high performance recycled aggregate concrete (NSRAC and HPRAC). PC with strength grades ranging from 30 to 100 MPa was crushed to the size of coarse aggregates (<20 mm), and then used to produce new NSRAC and HPRAC mixes. The results indicated that the compressive strength of the NSRAC and HPRAC prepared with RA derived from 80 and 100 MPa PCs was similar or slightly higher than that of natural aggregate concrete. Moreover, the concrete mixtures made with RA are derived from parent concrete with higher strength had lower drying shrinkage and higher resistance to chloride ion penetration. The RA derived from 80 and 100 MPa PCs can be used to replace 100% natural aggregates for the production of high performance concrete.

1. Introduction

It is necessary to effectively reuse construction and demolition (C&D) waste in order to conserve nonrenewable natural aggregate resources and alleviate the pressure on finding new disposal sites to manage the wastes. Recycling and reusing of C&D waste as coarse aggregates for new concrete facilitate its large-scale utilisation. The influences of using recycled coarse aggregates as a replacement of natural aggregates in normal strength concrete have been documented in many past studies [1–11]. Generally, the use of recycled aggregate increases the drying shrinkage, creep, carbonation rate and water sorptivity, and decreases the compressive strength, modulus of elasticity and resistance to freezing and thawing of concrete compared to those of natural aggregate concrete. But with the use of appropriate mix design and mineral admixtures, the drawbacks can be mitigated.

According to Akbarnezhad et al. [12], the parent concrete properties such as the strength, size of the natural aggregates used in the parent concrete, and the number of crushing stages strongly affect the properties of coarse recycled concrete aggregates.

High Performance Concrete (HPC) can be designed to have the desired higher workability, higher mechanical properties and improved durability than those of traditional concrete [13]. Many types of waste materials have been proven to be able to be re-utilised in the manufacturing of normal strength concrete (NC) [14]. However, there have only been a few attempts to utilise recycled aggregates in the production of HPC due to the limitations imposed by the inherent defects of recycled aggregates [15,16]. This paper presents the results of laboratory studies on the properties of HPC prepared with recycled aggregates which were originally derived from old (parent) concrete with strength grades ranging from 30 to 100 MPa.

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http://dx.doi.org/10.1016/j.conbuildmat.2014.12.035
0950-0618/

2. Experimental details

2.1. Materials

2.1.1. Cement and 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. Crushed natural granite was used as the natural aggregate. The recycled aggregates were obtained by crushing old concrete cubes previously prepared in the laboratory. The strength grades of the cubes (28-day designed compressive strength) ranged from 30 to 100 MPa. Natural river sand with a fineness modulus of 2.11 was used as the fine aggregate in the concrete mixtures. The physical properties of the aggregate are given in Table 3.

2.1.3. Superplasticizer

In this study, a superplasticizer ADVA 109 (WR Grace) was used in all the concrete mixtures. ADVA 109 contains no added chloride and weighs approximately 1.045 ± 0.02 kg per litre.

Table 1
Chemical compositions of cement and fly ash.

Materials	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.

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

2.2. Concrete mixes

The concrete mix was prepared at a water-to-cement ratio (W/C) of 0.50, and a cement content of 390 kg/m^3 with a design 28-day strength of 45 MPa. The HPC mix was prepared with a water-to-cement ratio (W/C) of 0.35, and a cement content of 420 kg/m^3 with a designed 28-day strength of 65 MPa. The recycled aggregates were used at the level of 100% of the total volume of coarse aggregates. The proportions of the HPC mixes were designed using the absolute volume method. The mix proportions of the concrete mixes with the aggregates under the saturated surface-dried (SSD) condition are shown in Table 4. The actual proportions of the mixes at mixing were adjusted according to the moisture content of the aggregates.

2.3. Specimens casting and curing

For each concrete mix, 100 mm and 150 mm cubes, 75 × 75 × 285 mm prism, and 200 × 100 mm dia. cylinders were cast. The 100 mm cubes were used to determine the compressive strength of the concrete. The cylinders were used to evaluate the splitting tensile strength, the static modulus of elasticity and chloride ion penetration of the concrete. The 150 mm cubes were used to evaluate the ultrasonic pulse velocity (UPV). The prismatic concrete specimens with sizes of 75 × 75 × 285 mm were used to determine the drying shrinkage and weight loss of the concrete. All the specimens were cast in steel moulds and compacted using a vibrating table. The specimens were demoulded after 24 h in a controlled laboratory environment (23 °C). Three cube specimens were used to test the 1-day compressive strength and the rest of the specimens were cured in a water curing tank at 27 ± 1 °C until the ages of 1, 4, 7, 28 and 90 days were reached.

2.4. Tests

2.4.1. Workability

The workability of the fresh concrete prepared was measured using the standard slump and slump flow tests immediately and 60 min. after concrete mixing.

2.4.2. Compressive and splitting tensile strengths

The compressive and splitting tensile strengths of concrete were tested using a Denison compression machine with a capacity of 3000 kN. The loading rates were 200 kN/min and 57 kN/min for the compressive and splitting tensile tests, respectively. The compressive strength of the hardened concrete was determined at the ages of 1, 4, 7, 28 and 90 days, and splitting tensile strength was determined at the ages of 7, 28 and 90 days.

2.4.3. Static modulus of elasticity

The static modulus of elasticity (*E* values) of the natural and recycled aggregate concrete were determined on the 100 × 200 mm cylindrical specimens according to ASTM C 469-65 at the ages of 28 and 90 days.

Table 3
Physical properties of aggregates.

Notation	28-Day strength of parent concrete (MPa)	Water absorption (%)		Moisture content (%)		Density (SSD) (kg/m^3)	
		10 mm	20 mm	10 mm	20 mm	10 mm	20 mm
NA (natural aggregate)	–	1.1	1.1	0.6	0.7	2.62	2.62
RA30 (30 MPa parent concrete)	35.8	8.63	5.48	3.63	2.69	2.31	2.44
RA45 (45 MPa parent concrete)	51.1	6.97	4.86	2.89	2.15	2.40	2.48
RA60 (60 MPa parent concrete)	61.8	6.28	4.29	2.54	1.98	2.38	2.43
RA80 (80 MPa parent concrete)	87.9	5.76	3.97	2.13	1.65	2.39	2.49
RA100 (100 MPa parent concrete)	101.7	5.14	3.24	2.01	1.44	2.36	2.44
Sand	–	0.89				2.62	

Table 4
Mix proportions of normal strength concrete (Series I).

Notation	W/C ratio	Proportion (kg/m^3)				
		Cement	Water	Sand	10 mm aggregate	20 mm aggregate
NA-I	0.50	390	195	642	375	794
RA30-I	0.50	390	195	642	351	740
RA45-I	0.50	390	195	642	363	753
RA60-I	0.50	390	195	642	361	738
RA80-I	0.50	390	195	642	362	754
RA100-I	0.50	390	195	642	357	740