Construction and Building Materials 52 (2014) 227–235

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental analysis of properties of high performance recycled aggregate concrete

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HIGHLIGHTS

- HPC was designed using coarse recycled concrete aggregates (RCA).
- The effect of quality and replacement percentage of RCA on HPC was analysed.
- Physical, mechanical and durability properties of HPC were investigated.
- The RCA showed similar behaviour to conventional concrete due to the low w/c ratio.
- HPC can be produced using RCA sourced from original medium–high strength concrete.

ARTICLE INFO

Article history:
Received 11 March 2013
Received in revised form 11 November 2013
Accepted 12 November 2013

Keywords:
Recycled concrete
High performance concrete
Recycled concrete aggregates
Mechanical properties
Durability properties

ABSTRACT

Due to the increase in the demolition of high strength concrete structures and the interest of precast concrete companies in being more competitive, it is necessary to analyse the use of recycled concrete aggregates (RCA) in high performance concrete (HPC). In this study, HPC were produced using 20%, 50% and 100% of RCA on substitution of natural coarse aggregates. Three types of RCA were used, they were produced crushing original concrete of 100, 60 and 40 MPa of compressive strength. The physical, mechanical and durability properties of the recycled aggregates concretes and conventional concrete were analyzed. The results showed that considering mechanical properties, the 100% natural coarse aggregates' replacement would be possible when RCA were produced from original concrete with a minimum compressive strength of 60 MPa. When durability properties were considered concrete produced with up to 50% of RCA could be used in HPC production.

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1. Introduction

The high performance concrete (HPC) is designed to have better mechanical properties and higher workability and resistance to aggressive chemicals than traditional concrete [1]. Certain demolition waste materials have been successfully used in the manufacture of conventional concrete, and even in HPC. However, there have only been a few attempts to use recycled concrete aggregates (RCA) in HPC production because of the inherent negative aspects associated to RCA. None the less, the use of this recycled material is important in HPC, since the use of HPC is becoming more extensive worldwide. The use of RCA in the concrete industry could lead to a situation much closer to that of sustainable development.

The suitability of RCA for use in different applications with a low or moderate degree of requirement has been extensively tested and proved by many authors [2–13]. Dosage method and substitution rates of the natural aggregate were established considering the properties of RCA in concrete production to achieve adequate fresh and hardened properties, comparable to those of natural aggregate concrete (NAC). Some authors [4,5] suggested that the use of coarse RCA could be extended to high performance concrete (HPC), offering additional value to RAC.

Following on from previous research work, Limbachiya et al. [14] examined the influence of coarse RCA in high-strength concrete, 50 MPa or more. The concrete performance was assessed, while practical issues and durability properties were also tackled. The results obtained showed that concrete containing up to 30% of coarse RCA could be used in a wide range of applications in high performance engineering and the durability properties were similar to those of NAC concrete.

Moreover, Ajdukiewicz and Kliszczewicz [15] studied high performance concrete using RCA obtained from medium and high strength demolition concrete and analysed their influence on concrete properties. The properties of the original concrete had significant influence on mechanical properties of the recycled aggregate concrete (RAC); the RAC obtained higher compressive strength

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0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.11.054

than conventional concrete when the RCA was produced with HPC aggregates.

In this research work, three different compressive strength (40 MPa, 60 MPa and 100 MPa) crushed concretes were used as coarse RCA for high performance concrete production. High performance concretes were made by replacing 20%, 50% and 100% of natural coarse aggregates for one of the three types of RCA employed. The production of the RCA concrete was carried out in the laboratory and the physical (density, absorption, volume of permeable pore space and ultrasonic pulse velocity), mechanical (compressive, splitting tensile, flexural strengths and modulus of elasticity) and durability (capillary water absorption, electrical resistivity and chloride ion penetrability) properties were determined and the obtained results were compared to those of conventional concrete (CC), whose mix proportions was the same as the original concrete of 100 MPa RCA.

2. Experimental details

2.1. Materials

2.1.1. Cement and additive

ASTM Type I Portland cement, CEM I 52.5R, was used in concrete mixtures with the characteristic rapid hardened strength of 52.5 MPa, low alkali content and specific surface of 4947.8 cm^2/g. The chemical properties of cement are given in Table 1.

A high performance additive of a superplasticizer type was used for the concrete production.

2.1.2. Aggregates

Natural and recycled aggregates were used as coarse aggregate in the concrete mixtures. In this study, a mixture of two types of natural coarse aggregates was used, crushed dolomite and river gravel.

Three types of coarse RCA with different characteristic strength were used. Type 1 (coded as RCA 100 MPa), using the crushed high strength concrete obtained from a precasting factory of rejected specimens of 100 MPa compressive strength.

Type 2 (coded as RCA 60 MPa), using the crushed 60 MPa compressive strength concrete produced in the laboratory and crushed after 28 days of curing; Type 3 (coded as RCA 40 MPa) using the crushed rejected 40 MPa compressive strength concrete produced by precast concrete company. These three recycled aggregates were selected for their high strength quality as a lower strength quality aggregate would not achieve the properties required for a high performance concrete. Etxeberria et al. [2] and Tabsh and Abdelfatah [6] found that the weak point of medium–high strength concretes made with coarse recycled aggregates can be determined by the strength of the recycled concrete and its attached mortar.

The nominal sizes of the natural and recycled coarse aggregates were 10 mm and their particle size distributions are shown in Fig. 1. It can be seen that the size grading of the natural and recycled coarse aggregate was similar. Physical and mechanical properties of the coarse aggregate were determined according to EN specifications. As Table 2 shows, the natural aggregate had a higher density and lower absorption capacity than any other RCA. In contrast, when the original concrete had higher compressive strength, the RCA achieved better physical properties. However the three types of RCA had a lower absorption capacity than 7%, which is the maximum absorption capacity required by the Spanish Structural concrete regulation [16]. The Los Angeles Index of all the aggregates was lower than 30%, which indicates high strength to abrasion; moreover the RCA index were similar, or even lower, to that from dolomitic coarse aggregate.

Two different types of river sand were used as fine natural aggregate in all the concrete mixtures. Their particle size distributions were adequate according to Spanish Structural concrete regulation [16]. The physical properties of the fine aggregate are shown in Table 3.

2.2. Concrete mixtures

All concrete mixtures were prepared and produced in the laboratory (referenced as 100, 60 and 40, according to the original concrete strength of the recycled aggregates). The three types of recycled coarse aggregate that were used on substitution (by volume) were those of 20%, 50% and 100% natural aggregates.

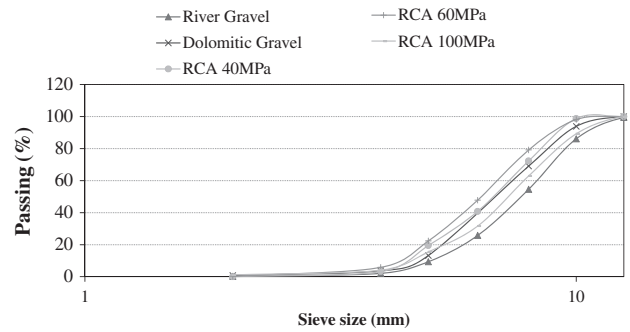

Fig. 1. Particle size distribution of coarse aggregate according to ASTM.

In order to control the concrete production, recycled coarse aggregates were wetted the day before use by means of a sprinkler system and then covered with a plastic sheet until used in the concrete production in order to maintain the level of high humidity. A recommended level of moisture is 80% of their total absorption capacity [2]; however the most important point was that the aggregates employed were wet in order to reduce their absorption capacity [7]. Due to moderate initial moisture content, recycled aggregate absorbed a certain amount of free water and lowered the initial w/c ratio in the ITZ consequently improving the interfacial bond between the aggregates and cement [8]. However, recycled aggregates should not be saturated [17], as that would probably result in the failure of an effective interfacial transition zone between the saturated recycled coarse aggregates and the new cement paste. In line with these recommendations, Poon et al. [18] discovered that the compressive strength of concrete made with saturated aggregate was lower than concrete made with air dried aggregates due to the negative effect of the bleeding of the saturated aggregates.

The same process of wetting used for the RCA was employed on the natural fine aggregate in order to control the results at 1-day compressive strength and avoid dispersions. In order to reduce the amount of added water at the mixing stage the moisture content of the fine aggregates were fixed at 3–4% (oversaturated) as this would achieve higher compressive strength at very early ages.

The concrete mix proportions were defined according to the Fuller's dosage method [19]. The coarse and fine aggregate percentages of the conventional concrete dosages were adjusted to be within the standard curve that allows for the maximum compaction of granular elements, which is the method that corresponds to the Gessner parabola. This parabola is defined by the aggregate maximum size and the sieve sizes and, it permits one to calculate an ideal (theoretical) passing percentage. The percentage of each type of natural fine and coarse aggregate was corrected to achieve passing percentages similar to the passing percentages defined by the Gessner parabola in all sieve sizes. Despite the fact that RCA aggregate did not have the same size distribution as NCA the theoretical parabola was also similar.

As shown in Table 4, 380 kg of cement and the effective water–cement ratio of 0.285 were used in all concrete productions. The effective water–cement ratio of CC concrete was determined and maintained constant for all concretes (the effective water was the water reacted with the cement). In order to control the effective water–cement ratio in all the other concretes, oversaturated fine aggregates were used (the unabsorbed water was considered as part of effective water), the natural coarse aggregates were used in a dry condition and it was considered that they absorbed 20% of their total water capacity (which was the water absorption capacity of aggregates submerged in water up to 30 min), and recycled aggregates were used with approximately 80% of humidity and their effective absorption capacity was that of 70%. The total water amount of the concrete was considered as the amount of effective water weight plus the moisture (or absorbed water) of the aggregates (see Table 4).

Dry consistency was maintained in all concrete mixtures and the 1.5% respect to cement weight of superplasticizer was used in all mixtures.

The recycled concrete mixtures were coded as RC-*x*-*y* (*x* = percentage of recycled aggregate replacement level; *y* = type of recycled aggregate used).

2.3. Specimens casting and curing

For each concrete mixture, 100 mm cubes were used to determine the hardened concrete density, absorption, the permeable pore voids, the ultrasound pulse velocity (UPV) and the electrical resistance. 150 mm cubes and 100 × 100 × 400 prisms

Table 1
Chemical composition of cement.

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Cl^-	SO_3	LOI
(%)	21.75	3.38	4.55	64.65	1.63	0.64	0.01	2.66	0.91

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