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Effect of cement addition on the properties of recycled concretes to reach control concretes strengths

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A B S T R A C T

Recycled aggregates from construction and demolition waste have previously been used to manufacture recycled concrete. Generally, these aggregates weaken the physical properties of concrete, such as the density, durability, compressive strength, flexural strength, water penetration, and chloride penetration. This is predominately attributed to the porosity of particles with adhered mortar or to ceramic particles. In other studies, cements with additions (fly ash, slag, silica fume …) were used to compensate for the effect of incorporation of recycled aggregates. In another, plasticizers were used to improve workability or mechanical properties of recycled concrete. However, the innovation of this research is the use of different amounts of cement according to replacement ratios of natural aggregates for recycled concrete aggregates to achieved structural concretes. Also, two different water/cement ratios were used to analyse if these reached compressive strength similar to control concrete manufactured with natural aggregates. The results revealed that a small increase in the volume of cement (12%) maintained the mechanical properties and reduced the loss of concrete durability. Therefore, increasing the amount of cement in recycled concretes is a feasible technique in works with low exposure to aggressive agents.

1. Introduction

In the last two decades, numerous researchers have studied the properties of recycled aggregates (RA) and their use as substitutes for natural aggregates (NA). According to Agrela et al. (2011), RA contains adhered mortar or ceramic particles that increase the porosity of its particles. It results adversely affects material properties, such as density, water absorption and chemical and mechanical resistance (Kwan et al., 2012). Consequently, NA generally exhibit lower optimum moisture content and a higher maximum Proctor density than RA (Barbudo et al., 2012).

However, RA are a promising construction material with possible application as a sub-base for roads and embankments. Jimenez et al. (2012) evaluated the performance of RA in an experimental unpaved rural road built in Cordoba, Spain. Additionally, Agrela et al. (2012) used RA with cement as a sub-base in the construction of a highway access in Malaga, Spain.

RA have also been widely used in new concrete mixtures. Maier and Durham (2012) investigated the effect of recycled aggregates from concrete (RCA) and glass waste in fresh and hardened concrete, and Mas et al. (2012a) studied the effect of mixed recycled aggregates in non-structural concrete.

There are studies in which fine fractions of RA were used to manufacture new concrete. Evangelista and Brito (2007) substituted natural sand for fine RA in structural concrete and evaluated its mechanical behaviour, and Pereira et al. (2012) applied superplasticisers to limit the disadvantages associated with concrete incorporated with fine RA. However, coarse fractions of RA are more commonly used. Bairagi et al. (1993) conducted a study on the mechanical behaviour of concrete that was produced by varying the replacement ratio of NA with coarse RA and using various water/cement (w/c) ratios. Tabsh and Abdelfatah (2009) studied the mechanical properties of concrete that was produced with coarse RCA.

RA particles have a high porosity due to mortar adhered and, therefore, low densities. Consequently, new concretes that are manufactured with RA also have lower densities. This porosity also results in an increased demand for water and produces concrete with inferior mechanical properties, including a reduced compressive strength (Gomez Soberón, 2002, obtained a loss of 12% for 100% replacement rate of NA by RCA). (*lower* flexural strength (Topçu and Sengel, 2004 obtained an average loss of flexural strength of 32%) and lower elastic modulus (Katz, 2003 obtained a loss of elastic modulus up to 25%). Some authors have

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Table 1
Chemical properties of cement.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl
19.29	1.42	4.44	66.02	1.27	3.29	0.34	0.09	0.01

recommended washing the aggregates to eliminate the finer fraction, which has more soluble sulphate content and greater water absorption (Rodrigues et al., 2013).

However, at replacement rates below 20%, the compressive strength of concrete can be maintained (Thomas et al., 2013). Previous studies found differences in compressive strength between replacement ratios upper than 20%. Exteberría et al. (2006) concluded concretes with 100% of recycled aggregates had a lower compressive strength compared to concrete control (20–25%), and Kou et al. (2011) studied compressive strengths of concretes with recycled aggregates were lower for all ages.

In fact, the Spanish Concrete Instruction (EHE, 2008) specifies the use of RA particles with sizes larger than 4 mm and replacement rates of up to 20%, provided that the RA is obtained from crushed concrete and fulfils certain requirements.

However, compared to control concretes, the use of RCA has been shown to reduce concrete durability. Mas et al. (2012)b observed that the penetration of water under pressure increased with NA replacement ratio. A similar negative effect was observed for other durability properties, including dry shrinkage and chloride ion penetration. Sanchez de Juan (2009) suggested that the adhered mortar contained in RA causes this reduction of durability.

Several investigations have been made to improve the properties of RA-containing concrete. Kou et al. (2007) recommended the addition of fly ash, Pereira et al. (2012) and Barbudo et al. (2013) proposed the use of superplasticisers, Hwang et al. (2013) advised the use of pozzolanic materials, and Kou et al. (2011) suggested the addition of silica fume or metakaolin, Other studies have applied several types of recycled aggregates for the manufacture of recycled concrete, as used tyre aggregates (Bravo and de Brito, 2012), crushed glass aggregates (De Castro and de Brito, 2013), or marble wastes (André et al., 2014).

To maintain the desired concrete properties, the incorporation of recycled materials must adequately balance the replacement percentage.

For this, this study is focused on providing another alternative for obtaining properties similar to control concrete. Thus, the objective of this study is to investigate the behaviour of recycled concrete adding cement in amounts proportional to the replacement ratio of NA by RCA. To do this, two w/c ratios, from two different characteristic strengths, were selected that maintained the workability and compressive strength of control concrete made with natural aggregates. These w/c ratios were used to produce two series of concrete samples. To determine whether the addition of cement reinforced these properties, some mechanical and durability properties were measured and analysed.

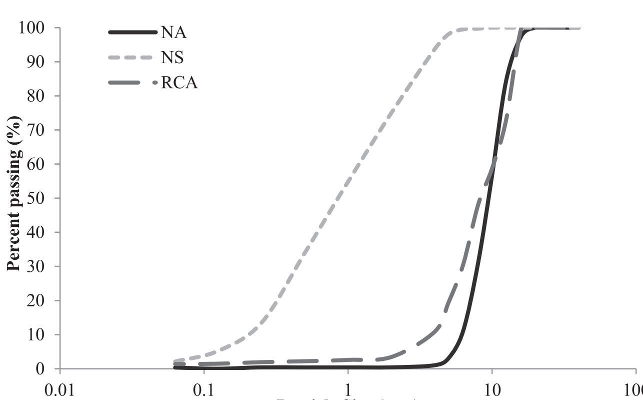

Fig. 1. Particle size distribution.

Table 2
Physical and chemical properties of recycled and natural aggregates.

		NA	RCA	NS
SSD density (mg/m^3)	EN-1097-6	2.68	2.38	2.53
Absorption (%)		1.53	6.94	1.39
Friability ratio (%)	EN-83-115	–	–	12
Los Angeles coefficient (%)	EN-1097-2	20	29	–
Sulphur content (%)	EN-1744-1	<0.01	0.34	<0.01
Soluble sulphate (%SO_3)	EN-1744-1	<0.01	0.86	<0.01
Chlorides (%)	EN-1744-1	0.1	0.03	<0.01
Organic matter content (%)	EN-1744-1	<0.1	<0.01	<0.01

2. Materials and methods

2.1. Materials

2.1.1. Cement

Portland cement type 1 (OPC) with a characteristic strength of 42.5 MPa was used according to ASTM C150. This cement is a pure grey cement clinker that exhibits rapid hardening and is resistant to attack by sulphates. Its chemical properties are presented in Table 1.

2.1.2. Recycled and natural aggregates

The following aggregates were used in this research: a coarse *natural aggregate* (NA) with a nominal particle size of 4–16 mm (Fig. 1), a *recycled concrete aggregate* (RCA) composed of crushed concrete blocks and mortar (>85%) from a treatment plant in Córdoba (Spain) with a nominal particle size of 4–20 mm (Fig. 1), and *natural sand* (NS) particles ranging from 0 to 4 mm (Fig. 1). The physical and chemical properties of these materials are presented in Table 2.

It is apparent from Table 2 that NA have the highest saturated surface dry density (SSD density) of the coarse aggregates. Because of the presence of adhered mortar, the RCA had a lower SSD density and higher absorption than the NA, as expected (Debied et al., 2010).

The Los Angeles coefficient was determined for the coarse aggregates, and the Micro-Deval abrasion or friability ratio was measured for the fine aggregates. Significantly higher abrasion values were obtained for RCA than NA, as expected (A. Domingo-Cabo et al., 2009). Compared to other studies, the coefficient of friability for NS was low (Vegas et al., 2009).

All of the aggregates presented continuous granulometry, as shown in Fig. 1. In manufacturing, RCA were used to replace NA.

2.1.3. Water-reducing admixture

A super-plasticiser admixture (SP) with high water reducing ability (BASF Rheobuild 1222) was used as the admixture. Because

Table 3
Nomenclature of concrete mixtures.

	C1				C2			
	C1-0	C1-20	C1-50	C1-100	C2-0	C2-20	C2-50	C2-100
NA (%)	100	80	50	0	100	80	50	0
RCA (%)	0	20	50	100	0	20	50	100
w/c	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5

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