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Influence of curing conditions on recycled aggregate concrete

C. Thomas [a,*], J. Setién [a], J.A. Polanco [a], A.I. Cimentada [a], C. Medina [b]

[a] LADICIM (Laboratory of Materials Science and Engineering), University of Cantabria. E.T.S. de Ingenieros de Caminos, Canales y Puertos, Av/Los Castros 44, 39005 Santander, Spain
[b] University of Extremadura, UEX-CSIC Partnering Unit, School of Civil Engineering, Avda. de la Universidad, s/n, Cáceres, Spain

HIGHLIGHTS

- Humidity chamber and marine environment have been analysed.
- Negative effect on durability due to the worst curing conditions.
- Higher durability reduction for low w/c ratio than for the mechanical properties.
- Temperatures and humidity affect more the durability than the mechanical properties.

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ABSTRACT

This paper presents the results of a study of permeability and its influence on the durability of recycled concrete exposed to an aggressive environment. Recycled concretes with 20%, 50% and 100% in weight of recycled aggregate and 24 effective w/c ratios have been exposed directly to a marine environment. Control specimens cured in a humidity chamber have been also tested in order to compare the influence of the curing environment. The durability of recycled aggregate concretes exposed to aggressive conditions decreases in terms of permeability, as the results show. However, the influence of the environment on the recycled concrete also depends on the quality of the cement paste. The differences between the control and the exposed concrete are lower for low water/cement (w/c) ratios. The lower capillarity obtained in the new cement paste of the recycled concretes with low w/c ratios isolates the porosity of the recycled aggregate, increasing the durability but with a rise in the cement content.

1. Introduction

The search for ways of using recycled aggregate (RA) from construction and demolition wastes (C&DW) in the production of recycled aggregate concrete (RC) has been going on for many years. Most researchers agree about the reduction in the physical and mechanical properties and the durability [1]. However, there are no comparable results on the durability of RC exposed to marine environments due to the heterogeneity of the RA, the w/c ratios and the types of cement used in different countries. Different studies [1–4] show that permeability, carbonation and risk of reinforcement corrosion increase when RC is used. However, no information is found in the literature about how the w/c ratio and capillary network affect the durability of RC exposed to a marine environment. A recent study shows that the durability of recycled concrete depends on the quality of the RA and that the most suitable RA comes from precast-structural concretes [2]. Also, several studies have analysed the behaviour of RC under cyclic stress (fatigue) [5–8], showing that the negative effect of the incorporation of recycled aggregate is significantly higher in the case of dynamic rather than static conditions. Other authors have found solutions, using other recycled materials, to improve the properties of the cement paste. Using this method, the effect of the RA [9] can be minimised, not only in no-cement but also in polymeric matrixes [10]. The use of RA containing contaminants such as sulphur and properties of recycled aggregate mortar (RAM) and RC has also been studied [11], finding a reduction in the quality of the concrete proportional to the quality of the recycled aggregate.

This paper presents the results of a study of permeability and its influence on the durability of recycled concrete exposed to an aggressive environment. On the one hand, the effect of RA on concrete properties has been analysed by studying the same w/c ratios and, on the other hand, the influence of the w/c ratio and its capillary network has been measured for equivalent degrees of RA.

* Corresponding author.
E-mail address: carlos.thomas@unican.es (C. Thomas).

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With this aim, RC with 20%, 50% and 100% wt of RA and 24 effective w/c ratios have been exposed directly to a marine environment.

2. Experimental program

This research is a continuation of a previous study and uses 6 control concretes (CC) made up of natural limestone aggregate (NA) and 18 substitutions of 20%, 50%, 100% of coarse NA with recycled aggregates (RA). The RA comes from demolished structural concrete (over 10 years old) with more than 25 MPa. The properties of the concrete at the age of 28 days cured in a standard environment and in XS1 environment [12] have been studied.

2.1. Materials

Portland cement CEM I 52,5N/SR of 3.11 g/cm^3 and Blaine fineness of 361 m^2/kg was used. Table 1 shows the chemical composition by XRF of the cement. Table 2 shows the NA and RA properties. Fig. 1 shows the aggregate grading including the natural sand (NS).

2.2. Mix proportions

The mixing specifications of four different environments were considered: a 0.65 w/c ratio concrete for a non-aggressive environment, Class X0 for an environment with no risk of corrosion or attack; a 0.55 w/c ratio concrete for an exposure class of corrosion induced by carbonation, XC; a 0.50 w/c for a marine air exposure, XS1-Corrosion induced by chlorides from sea water; and a 0.45 w/c for a marine environment (tidal and splash zone exposure), XS3-Corrosion induced by chlorides from sea water. Table 3 shows the mix proportions, the effective w/c ratios and the new properties. Three different mixing methods have been followed in three phases. In the first phase, dry coarse aggregate has been used. In this phase, RC-X0-DA and RC-XS1-DA, both the coarse NA and the coarse RA used were dry at the time of mixing. In a second phase, coarse saturated aggregates have been used. In order to avoid the effect of the higher absorption of the RA, both the NA and the RA have been presaturated with water before being incorporated into the mixture: RC-X0-SA and RC-XS1-SA. In a third stage, only the coarse RA is saturated. In this last phase, the coarse NA is incorporated dry and the coarse RA is incorporated saturated to the mixture: RC-XC-SR and RC-XS3-SR. The effective w/c ratio is obtained by the method proposed by Sanchez and Alaejos [13,14] taken at 70% of the absorption capacity during mixing using dry aggregates.

2.3. Specimens and curing conditions

More than 600 standard cylindrical specimens [15,16] were prepared and distributed in the two environments: first, in a humidity chamber at 20 °C and 95% humidity and, second, under direct exposure to a marine environment: Type IIIa with a one-year average temperature of 13.9 ± 5 °C temperature and 74.3 ± 2% humidity.

2.4. Mechanical properties

A Compressive strength test [17,18] and a Tensile splitting test [19] were performed on 3 specimens of each mix with 28 days curing. The modulus of elasticity was performed following the standard [20].

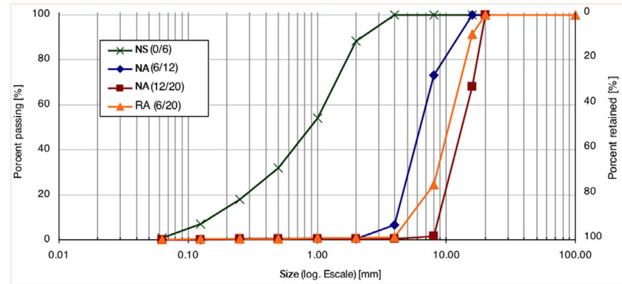

Fig. 1. Grading of the natural and recycled aggregates.

2.5. Physical properties

Standard [21] was followed in order to obtain the physical properties. Also, the water absorption coefficient and the open porosity of the concrete were determined.

2.6. Permeability

The maximum water penetration was determined following standard [22]. The oxygen permeability coefficient was determined according to [23].

2.7. Accelerated chloride penetration

In order to evaluate the chloride penetration, an accelerated test in a salt fog spray cabinet was carried out. After 250 h of exposure, eight subspecimens were obtained from four specimens to evaluate the degree of the chloride ion penetration. Compositional analyses by Energy-dispersive X-ray spectroscopy (EDAX) were performed to determine the profile of chloride ion penetration. A detailed explanation of how the measurements were performed is provided in [11].

3. Results and discussions

The results and discussion are presented in this section. The results of the concretes cured in a marine environment are compared with the results of the concretes cured in a humidity chamber [1].

3.1. Mechanical properties

Fig. 2 shows the compressive strength of the recycled concrete after 28 days of curing. The results indicate that curing under the marine environment leads to significant changes with respect to the standard environment [1] both for the control and the recycled concretes. According to [1], a similar recycled concrete cured a humidity chamber reached 60 MPa for a 0.4 w/c ratio and 35 MPa for a 0.75 w/c ratio. Hence, the loss of compressive strength due to curing environment is 12 MPa (15%) and 5 MPa (12%), respectively. According to these results, concretes cured in a

Table 1
Chemical composition of the cement.

Component:	CaO	SiO_2	SO_3	Al_2O_3	Fe_2O_3	MgO	K_2O	TiO_2	C
% in wt:	69.60	18.60	3.22	3.10	2.66	1.17	0.54	0.17	0.47

Table 2
Properties of the aggregate.

Aggregate	Dr [g/cm^3]	Dssds [g/cm^3]	A [% wt]	P [% v.]	Dc [g/cm^3]	LA [%]
NA (6/12)	2.510	2.550	1.80	4.70	1.530	31.0
NA (12/20)	2.540	2.590	1.60	4.00	1.530	–
RA (6/20)	2.320	2.310	5.30	12.30	1.420	42.0

Where: Dr is the relative density of particle (g/cm^3); Dssds is the saturated with dry surface density (g/cm^3); A is the water absorption in weight (%wt); P is the open porosity in volume (% vol.); Dc is the bulk density (g/cm^3); LA is the Los Angeles index (%).