Construction and Building Materials 182 (2018) 309–323

Contents lists available at ScienceDirect

Construction and Building Materials

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

# The influence of recycled aggregates from precast elements on the mechanical properties of structural self-compacting concrete

F. Fiol [a,*], C. Thomas [b], C. Muñoz [a], V. Ortega-López [c], J.M. Manso [c]

[a] Department of Construction, University of Burgos. EPS, Calle Villadiego s/n, Burgos, Spain
[b] LADICIM (Laboratory of Materials Science and Engineering) University of Cantabria, E.T.S. de Ingenieros de Caminos, Canales y Puertos, Av/Los Castros, Santander, Spain
[c] Department of Civil Engineering. University of Burgos. EPS, Calle Villadiego s/n, Burgos, Spain

## HIGHLIGHTS

- High-quality recycled aggregates (RA) produced from structural precast elements.
- Self-Compacting Concrete (SCC) manufactured with RA fulfilled current regulations.
- Slump loss due to water absorption of RA compensated with superplasticizers.
- SSC with different w/c ratios compared by extrapolation of fitted curves.
- Loss of stiffness is more limiting than loss of compressive strength.

## GRAPHICAL ABSTRACT

## ARTICLE INFO

*Article history:*
Received 19 December 2017
Received in revised form 13 June 2018
Accepted 15 June 2018

*Keywords:*
Recycling
Mechanical testing
In-fresh properties
Recycled aggregate concrete
Precast
Self-compacting concrete

## ABSTRACT

Recycled Aggregates (RA) from structural precast elements and the performance of Self-Compacting Concrete (SCC) containing RA in percentage substitutions of 20%, 50% and 100% are described in this paper. Three Control Concretes (CC-30, CC-37.5, CC-45) manufactured with Natural Aggregates (NA), and their corresponding Recycled Aggregate Concretes (RAC-20, RAC-50, RAC-100) are evaluated in terms of physical and mechanical properties. The in-fresh properties results (flowability, viscosity and passing ability) of the RAC were suitable for their use as SSC. Furthermore, the tests of compressive, splitting tensile and flexural strength, as well as density, porosity, water absorption, ultrasonic pulse velocity, stiffness, and both dynamic and static modulus provided results close to those of the SCC with NA, and in compliance with the requirements of current regulations. The recycling process that takes place in the precast factory supposes an economical improvement and an important contribution to global sustainability, in accordance with the concept of the circular economy.



## 1. Introduction

The construction industry is one of the sectors bearing the greatest responsibility for the consumption of natural resources and the generation of waste. Construction and demolition is one of the principal focuses of attention in the search for sustainable construction. Mean average production in Europe of Construction and Demolition Waste (CDW) stands at 0.38 t/per person/per year, and only countries such as Denmark and the Netherlands have recycling rates of over 85%. >35 million tons of CDW (1.1 t/per person/per year) are produced in Spain alone [1].

* Corresponding author.
*E-mail address:* ffiol@ubu.es (F. Fiol).

https://doi.org/10.1016/j.conbuildmat.2018.06.132
0950-0618/

With regard to prefabricated concretes at an international level, the "*Precast Sustainability Strategy and Charter*" of the British Precast Concrete Federation is first and foremost [2]. This plan encourages precast firms to go beyond the requirements of current legislation, by instituting measures on a voluntary basis to add greater sustainability to their products and operations. In 2013, the British Precast Council approved a new battery of measures for implementation throughout the year. The Netherlands and Germany may be highlighted in Europe among the countries that opt for the precast industry, where precast solutions in construction amount to 45% and 38%, respectively [3].

An effort is made to comply with the basic requirement for "sustainable use of natural resources", included in EU Regulation 305/2011 [4] on harmonized conditions for the marketing of construction products. The European Regulation under article 11.2b [4] also includes the objective for Member states to adopt certain measures, among which: to guarantee recycling to a minimum of 70% by weight of Construction and Demolition Wastes (CDW) before 2020. The promotion of research studies related to the sustainability of companies dedicated to concrete products through the incorporation of recycled aggregates is an incentive and an advance for society. A large number of investigations have arisen from the exploitation of these waste products, in which the different forms of using Recycled Aggregates (RA) in the manufacture of concrete have been analysed [5–8], but there are few studies that use RA from the rejected components in a real precast factory for performing high-performance self-compacting precast concrete, manufactured in the same industrial plant where those rejected RA components are produced.

In general, the use of these types of aggregates implies a loss of the physical and mechanical properties in the final product, the water demand of the recycled concrete depends on the substitution rate of RA. At a low replacement ratio, the rheological parameters do not change significantly without any addition of water [9,10]. However, the following aspects can be highlighted: if the Recycled Aggregate Concrete (RAC) is of acceptable workability, it will have consumed more water than conventional concrete [11]; the density, compressive strength, and modulus of elasticity are lower than those of conventional concrete, and the durability of the RAC is affected at a certain w/c ratio in terms of higher permeability and carbonation rates [10,12]. Equally, the manufacturing method, the use of dry aggregate, saturated RA, or coarse saturated aggregate, influences the concrete properties in both the fresh and the hardened state. The incorporation of pre-saturated RA is the theme of some studies [10,13,14], while the method of water compensation is suggested in others [9,10,15–22].

The use of RA from prefabrication processes is not very common among construction sector firms; the efforts of firms in Spain have been reported in papers by Pérez et al. [23] and Thomas et al. [24]. There is also a study on the use of these types of aggregates from precast components in Portugal that covers their mechanical behaviour and durability [25]. Likewise, Xiao et al. [26,27] tested the seismic behavior of precast recycled concrete.

The objective of the present work is to analyse the behaviour of Self-Compacting Concretes (SCC) that incorporate recycled aggregates from precast elements in terms of their physical, mechanical, and elastic properties when used in structural precast components. The recycled aggregates are in turn taken from rejected structural precast concrete pieces. The high-quality of these RA is expected to contribute to the manufacture of high-performance concretes, with good self-compactability and high strengths. This study was carried out on a real precast factory, where the final self-compacting precast concrete was manufactured and where the recycled aggregates were obtained, contributing in this way to a circular and sustainable economy, with the lowest possible disposal and transport of wastes. The precast concrete company has a total quality control system based on the ISO-9001 [28] and an environmental management system based on ISO 14,001 [29].

Various steps were followed in the experimental study. First of all, the reject precast elements were crushed and the RA was characterized. Secondly, the design of the (dosages for the new recycled SCC was performed. Three Control Concrete mixes (CC) were performed based on the required minimal compressive strengths in each case: 30 MPa (CC-30), 37.5 MPa (CC-37.5) and 45 MPa (CC-45). Then, percentage substitutions of 20%, 50% and 100% by weight of RA were added to each CC mix.

Finally, the in-fresh properties (flowability, viscosity, and passing ability) and hardened properties of the designed RAC were evaluated through physical tests (density, absorption, porosity, ultrasonic pulse velocity) and mechanical tests (compressive, splitting tensile, flexural and elasticity), in order to assess the influence of high-quality RA on the behaviour of the RAC manufactured.

## 2. Materials

The materials, the dosages and the experimental methodology used in the present study are all described in this section.

### 2.1. Cement, filler, admixtures, and natural aggregates

The raw materials used in this study are the same as those used at the precast factory (from where the RA were taken) to manufacture the self-compacting concrete of their products.

- The cement in use is a CEM I 52.5R, with a density of 3.12 g/cm$^3$ and a specific Blaine surface of 365 m2/kg. As an Ordinary Portland Cement (OPC), it provides high initial strengths to hardened concrete. Table 1 shows the chemical composition of the cement that is used.
- Limestone filler: The percentage in weight of $CaCO_3$ in the filler was 96.5%. The limestone filler should partially counteract the effect of the surface roughness of the RA, slightly improving its workability and flowability throughout the concrete mass.
- Admixtures: two super plasticizing admixtures usually employed in precast self-compacting concrete, were jointly used. Admixture A: a water entrainment agent, in proportions of 0.5–1%. Admixture B: showing a high performance for SCC with low water content, in proportions of 0.5 to 1.5% by weight of cement.
- Natural Aggregates (NA): Natural rounded siliceous aggregate (NA) was taken from a quarry owned by the precast concrete company. Table 2 shows the characteristics of the two sizes of aggregate in use: NA0/2 (sand) and NA2 /12.5 (gravel). Their grading curves are also shown in Fig. 1.

where:

| | |
|---|---|
| Dr | Relative density of particle |
| Dsss | Density of particle saturated with dry surface |
| A | Water absorption |
| Dc | Aggregate density |
| LA | Los Angeles Loss |

### 2.2. Crushing process and properties of RA

The RA was taken from precast components (beams, columns and purlins) with a compressive strength between 30 MPa and 50 MPa at 28 days. The components selected for the production of the RA were at all times taken from rejects due to measurement