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Tools for the study of self-compacting recycled concrete fresh behaviour: Workability and rheology

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A B S T R A C T

This work studies the fresh behaviour of self-compacting recycled concrete (SCRC) with different replacement percentages of recycled concrete coarse aggregate (20, 50 and 100%). To control the high absorption of recycled aggregate, three different mixing methods are also used in each studied concrete: M1 (dry aggregate and extra water), M2 (pre-soaked aggregate) and M3 (aggregate with a 3% of natural moisture and extra water). The fresh-state properties are measured with empirical and rheological tests, both carried out at 15, 45 and 90 min from the water-cement contact.

Results obtained lead to conclude that rheology is the best tool to control fresh state behaviour of SCRC mixes and that Bingham 5-lowest is the suitable model to describe their rheological behaviour.

Additionally, it has been concluded that the best method to produce SCRC is to compensate the recycled aggregate absorption during mixing using an extra quantity of water. With this method, self-compacting behaviour can be maintained with all replacement percentages until 45 min, and even until 90 min when the replacement ratio does not exceed 50%. Moreover, the use of the recycled coarse aggregate with a previous moisture content involves a greater difficulty to control workability and rheology than its use in dry-state condition.

1. Introduction and objectives

1.1. Introduction

Concrete made up of recycled aggregates in terms of fine or coarse or both fractions processed from construction and demolition waste, either as a partial or 100% replacement of conventional natural aggregates, is known as recycled concrete (Behera et al., 2014 and Collery et al., 2015). Its use generates interest in civil engineering construction regarding sustainable development as it is the means of achieving a more environmentally friendly concrete. The greatest distinctive features of recycled aggregates compared to natural aggregates is their lower density and higher absorption capacity, due mainly to the adhered mortar (Pedro et al., 2014, González-Taboada et al., 2016a,b and Silva et al., 2014).

A high absorption capacity influences fresh concrete properties. It is necessary to control accurately the casting process, with the aim of controlling the effective water to cement ratio (Pepe et al., 2016). Thus, the volume of mixing water is determined before concrete production, in order to maintain constant the water amount reacting with the binders (effective water). The volume of mixing water is composed of the effective water and the water absorbed by the aggregates at concrete production (González-Corominas and Etxeberria, 2016 and González-Taboada et al., 2016a,b). Then, to obtain the desired workability of recycled concrete, it is necessary to add a certain amount of water to saturate recycled aggregate, before or during mixing (Ferreira et al., 2011; Etxeberria et al., 2007 and González et al., 2011).

"More fluid is one of the big trends of the last twenty years in the field of modern concretes" (Roussel, 2006a,b). In this context, self-compacting concrete (SCC) can flow through and fill the gaps of reinforcements, corners of moulds and voids of rock blocks without any need for vibration and compaction during the placing process, which improves the overall efficiency of concrete construction projects (Okamura and Ouchi, 2003 and Zhang et al., 2016).

The greatest particularity of self-compacting concrete is its specific fresh behaviour. During the course of time, empirical test

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methods of different types and quality have been developed and used to give some kind of rheological description of the fresh concrete (Wallevik and Wallevik, 2011; Banfill, 2006 and Koehler, 2009). It is stated that the empirical tests are very often operator-sensitive. The same literature discusses the need for describing the rheological properties of fresh concrete in terms of fundamental physical quantities, not depending on the details of the apparatus with which they are measured (Ferraris and Brower, 2003). Viscometers and advanced rheometers are usually designed to be operatively insensitive, meaning that variations in the technique of carrying out the test, does not affect the results. However, one of the major obstacles to a more wide spread use of self-compacting concrete is to obtain further understanding of the importance of rheology on the final concrete quality (Thrane et al., 2010).

Rheology has been properly defined as the study of the flow and deformation of materials, with special emphasis being usually placed on the former (Barnes, 2000 and Banfill, 2003). Workability is defined as the property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition (Koehler, 2009).

Fresh concrete workability is most often associated with the slump value measured using the European Standard EN 12350-2 "Testing fresh concrete. Part 2: Slump-test" (EN 12350-2). This is the most famous, oldest and currently most used empirical test and it gives only a single value, namely the slump value (Wallevik and Wallevik, 2011). However, the slump value does not completely describe the workability of some concrete mixes. For example, two self-compacting concrete mixes with the same "slump" or slump flow values can have different flow capabilities when filling reinforced formwork (Ferraris and Brower, 2003). Therefore, concretes having the same slump can behave differently during placement because flow is not defined by a single parameter (Roussel, 2006a,b).

Then, as workability of a fresh concrete mix is closely related to its flow properties (its rheology), a sufficient description of such flow properties requires a minimum of two parameters: the yield stress and the plastic viscosity (Ferraris and Brower, 2003 and Roussel, 2006a,b). Yield stress represents the stress necessary to initiate (static yield stress) or maintain flow (dynamic yield stress) whereas plastic viscosity expresses the increase in shear stress with increasing shear rate once the yield stress has been exceeded (Koehler, 2009).

Self-compacting recycled concrete is a new technology which links characteristics and performance of both recycled and self-compacting concretes (Carro-López et al., 2015; Pereira-de-Oliveira et al., 2014 and Gesŏglu et al., 2015). It is a further step towards the usage of environmentally friendlier technologies and the promotion of sustainable economic growth. This new concrete has been recently developed for the last decade and limited studies have been conducted on the use of recycled aggregates and their influence on self-compacting concrete behaviour (Kou and Poon, 2009; Faleschini et al., 2014 and Kebaïli et al., 2015).

As a general conclusion, the SCRC literature indicates that the use of recycled coarse aggregate could improve the environmental aspects of SCC without significant impact on workability and strength characteristics when low replacement percentages are used (up to 50%) (Grdic et al., 2010). However, the study of SCRC is still at an early stage. Most of studies from the SCRC literature are specifically focused on the basic properties of hardened concrete and only verify that workability criteria for the fresh SCC are fulfilled. In this way, most of works have studied the workability characteristics (filling ability, passing ability and resistance to segregation) through empirical tests as slump flow, L-box, V-funnel, J-Ring and sieve segregation (Corinaldesi and Moriconi, 2011; Tuyan et al., 2014 and Güneyisi et al., 2016). However, not so much works have studied the rheological properties of SCRC. Hence, this concrete requires more in-depth analysis by researchers looking into the fresh-state behaviour (especially the analysis of its rheology).

1.2. Objectives

Self-compacting recycled concrete (SCRC) is expected to show a greater influence of the particular properties of recycled aggregate and of the particular fresh behaviour of self-compacting concrete.

This study deals with the influence of the replacement percentage of natural coarse aggregate with recycled aggregate obtained from concrete waste on the fresh-state behaviour of SCRC and with the influence of the mixing method used to compensate the high absorption of this particular aggregate. To do so, this work focuses on the properties of fresh self-compacting recycled concrete obtained with a rheometer (such as yield stress and plastic viscosity) and those measured using empirical tests (slump flow, L-box, V-funnel, J-Ring and sieve segregation).

Therefore, both rheology and workability are used as tools to study the fresh behaviour of SCRC. All mixes were tested over time at 15, 45 and 90 min from water-cement contact. Then, the research also studies the time-dependent fresh-state behaviour of SCRC.

In this context, the innovative aspect of this study is the use of rheology as a tool to define the fresh-state behaviour of self-compacting concrete incorporating recycled concrete coarse aggregate. In this sense, the objective is to demonstrate that the recycled coarse aggregate can be incorporated in SCC production and to confirm that rheology is the best tool to control the fresh behaviour of self-compacting recycled concrete and to determine the delay time available between the mixing and the placement of SCRC.

2. Experimental program

2.1. Materials and concretes

The following materials were used in this research:

Portland cement without admixtures labelled CEM-I 52.5 R according to European Standard EN 197-1 (EN 197-1) and a limestone filler were used as powder fraction. Properties of both materials can be seen in Tables 1 and 2. A modified polycarboxylate superplasticiser was used, the Sika ViscoCrete-70.

As fine aggregate (NFA – natural fine aggregate), a limestone sand with nominal size 0–4 mm and a fineness modulus of 4.19 was used. A crushed granitic coarse aggregate (NCA – natural coarse aggregate) with nominal size 4–11 mm and a fineness modulus of 7.14 was also used.

As recycled aggregate, the size fraction used was a 4–11 mm with a fineness modulus of 6.47. The grading curves of recycled and natural coarse aggregate presented similar particle size distribution (Fig. 1). This recycled coarse aggregate (RCA) was obtained from real demolition debris of structural concrete. Actually, according to EN 933-11 (EN 933-11), it is made up mainly of concrete and stone (more than 90% of natural aggregate and aggregate with mortar) (Fig. 2). Since this experimental program is part of a long research project, some of these results have been more thoroughly presented in a previous paper (González-Taboada et al., 2017).

Table 3 summarises the basic properties of the aggregates used.

In addition to the standard absorption test (EN 1097-6), in this work, continuous measurement of water absorption of all aggregates (natural and recycled) over time was conducted. The procedure consisted of measuring, by hydrostatic weighing, the mass variations of a sample immersed into a thermo regulated bath.