Construction and Building Materials 131 (2017) 641–654

Contents lists available at ScienceDirect

Construction and Building Materials

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

Prediction of self-compacting recycled concrete mechanical properties using vibrated recycled concrete experience

González-Taboada Iris [a], González-Fonteboa Belén [a,*], Pérez-Ordóñez Juan Luis [b], Eiras-López Javier [a]

[a] School of Civil Engineering, Department of Construction Technology, University of A Coruña, E.T.S.I. Caminos, Canales, Puertos, Campus Elviña s/n, 15071 La Coruña, Spain
[b] School of Building Engineering, Department of Construction Technology, University of A Coruña, E.U. Arquitectura Técnica, Campus Zapateira s/n, 15071 La Coruña, Spain

HIGHLIGHTS

- Hardened-state behaviour of self-compacting recycled concrete (SCRC) was analysed.
- Recycled aggregate affects SCC basic hardened properties to a similar extent as vibrated concrete.
- Prediction of some of the most important hardened properties of SCRC was analysed.
- Correction coefficients can be used with the same accuracy in vibrated RC and SCRC.
- Specific expressions for vibrated RC can be accepted to predict SCRC properties.

ARTICLE INFO

Article history:
Received 1 August 2016
Received in revised form 20 September 2016
Accepted 23 November 2016

Keywords:
Self-compacting recycled concrete
Database
Mechanical properties
Recycled aggregate

ABSTRACT

According to literature review, self-compacting concrete (SCC) is expected to present properties in hardened-state similar to those of its equivalent vibrated concrete. Therefore, this work aims to prove that, then, it will be possible to predict the self-compacting recycled concrete (SCRC) properties (compressive strength, f_c, modulus of elasticity, E_c, and splitting tensile strength, f_{sp}) using proposed expressions adjusted with vibrated recycled concrete.

Therefore, a wide experimental program has been developed and more than 50 SCRCs have been tested at different ages (f_c, E_c, f_{sp}). The experimental results have been used to analyse the accuracy of different prediction expressions that had been adjusted using a database created with published results regarding vibrated recycled concrete.

Results aim to conclude that the expressions can be used with the same accuracy in vibrated recycled concrete as in SCRC. Therefore, the incorporation of recycled concrete coarse aggregate affects SCC to a similar extent as it affects vibrated concrete.

1. Background and objectives

Recycled concrete use has grown up in the last years supported by a great scientific experience. A significant number of research papers has been published regarding recycled concrete mechanical properties and this has reduced the uncertainty related to its performance. Therefore, it is easy to create a database [1–81] that includes these published results in order to draw general conclusions regarding recycled concrete (RC).

On the other hand, many studies deal with hardened properties of self-compacting concrete (SCC), comparing them with the ones of its equivalent vibrated concrete. Regarding this subject, some authors indicate that changes in mixture design and in fluidity of SCC can influence its hardened properties, which can diverge from what is commonly expected from vibrated concrete of normal consistency [82]. However, most of studies state that, if a SCC is well designed, it can provide similar mechanical properties to its equivalent vibrated concrete [83].

Therefore, considering this hypothesis, self-compacting recycled concrete (SCRC) is expected to present properties in hardened-state similar to those of its equivalent vibrated recycled concrete, being then possible to study the SCRC hardened-state behaviour analysing the vibrated recycled concrete one, where the experience is wide.

1.1. Background

The analysis made in vibrated recycled concrete [14,84,86,87] states that compressive strength, modulus of elasticity and split-

* Corresponding author.
E-mail addresses: iris.gonzalezt@udc.es (I. González-Taboada), bfonteboa@udc.es (B. González-Fonteboa), jlperez@udc.es (J.L. Pérez-Ordóñez), jeiras@udc.es (J. Eiras-López).

http://dx.doi.org/10.1016/j.conbuildmat.2016.11.112
0950-0618/

ting tensile strength of recycled concretes decrease as recycled concrete coarse aggregate percentage increases. These reductions are mainly due to the weak interface (ITZ) between recycled aggregate and new cement paste. The properties of this ITZ depend on different features, concluding that quality of recycled aggregate and also mixing procedure are two of the main ones. Therefore, in a previous work a database was created [1–81] and with it different adjustments have been proposed to predict the basic mechanical properties of structural recycled concrete (compressive strength, modulus of elasticity and splitting tensile strength) taking into account, not only the recycled percentage and quality of the recycled aggregates used, but also the production method [84]. Furthermore, that analysis concludes with the proposal of simple expressions which allow engineers to estimate properties of recycled concrete similarly to how those of conventional concrete are estimated [84].

Regarding self-compacting concrete (SCC), in general, its compressive strength should be higher than that of conventional vibrated concrete since SCC is designed with relatively low water to cementitious materials ratio (w/cm) necessary to enhance resistance to segregation [82].

Even at the same w/cm, properly designed SCC can exhibit higher compressive strength than conventional vibrated concrete due to the incorporation of supplementary cementitious materials and fillers that can serve as nucleation sites and refine the porosity of the cement paste. In fact, limestone powder, a commonly used addition in SCC, contributes significantly to strength at ages up to at least 28 days [83].

Regarding the modulus of elasticity of SCC, it can be in reasonable agreement with the elastic stiffness assumed during the design of conventional slump concrete structures [85].

However, it is also reported that for some SCC mixtures, the modulus of elasticity may be 80% of that typically found in high-performance concrete of normal consistency [82]. The modulus of elasticity of the parent rock and the relative volume of the aggregate in the concrete mixture has significant influence on the modulus of elasticity of the concrete. In addition to the total aggregate volume, also adjustments of the sand-to-aggregate ratio can influence the elastic modulus of SCC. Spread of up to 20% could be obtained compared to the modulus of elasticity of vibrated high-performance concrete due to the lower coarse aggregate volume of SCC. However, under air-drying curing conditions, the elastic modulus of SCC can be higher than that of conventional vibrated concrete in long term. These results can be attributed to the lower loss of water that may occur in the case of SCC.

Domone [83] concluded that the elastic modulus of SCC can be up 40% lower than that of normal vibrated concrete at low compressive strength, but the difference can be reduced to less than 5% at high strengths. This behaviour will be consistent with the lower coarse aggregate quantities in SCC.

Finally, some authors stated that code expressions predict higher modulus of elasticity than that experimentally obtained [82]. However, in spite of this fact, it is accepted that code expressions used with vibrated concrete can be used with SCC.

Regarding splitting tensile strength, the common use of supplementary cementitious materials (and in some cases fillers) and the high content of ultra-fine materials can contribute to the densification of the cement matrix and to the reduction of the extent of interfacial transition zone with the aggregate. These parameters are of decisive importance when the tensile load bearing behaviour is analysed. Therefore, it was reported that higher tensile strength values can be obtained with SCC compared to those with conventional vibrated concrete [82].

On the other hand, some author state that, in general, no significant difference can be observed in the splitting tensile strength of SCC and vibrated concrete [85]. Moreover, the ratio of splitting tensile strength to compressive strength for SCC is similar to that of conventional vibrated concrete [83].

Therefore, it can be expected that hardened-state behaviour of self-compacting recycled concrete (compressive strength, modulus of elasticity and splitting tensile strength) can be predicted using equations developed with vibrated recycled concrete.

1.2. Objectives

According to the background, the main objective of this study is, then, to prove that the adjustments obtained with vibrated recycled concrete in a previous work [84] can be accurately applied when self-compacting recycled concrete behaviour is analysed. This will demonstrate that the mechanical properties (compressive strength, modulus of elasticity and splitting tensile strength) of SCRC are affected by the incorporation of recycled aggregates to a similar extent as the ones of vibrated recycled concrete.

The methodology used to develop this objective was the same as the one described in [84]:

- Firstly, the experimental results obtained were used to compare the mechanical properties of the control self-compacting concrete (SCC) with those of different self-compacting recycled concretes (SCRC) made with the same dosage and materials except for the coarse aggregate, which was replaced with recycled concrete coarse aggregate (by volume) at different percentages. With the experimental results obtained, and using linear regression, a coefficient was adjusted which allows the estimation of the SCRC property as a function of that of SCC. This coefficient takes into account the recycled content and the mixing procedure used. Once obtained, the coefficients were compared with those obtained with vibrated concretes.
- Secondly, code predictions (some of them adjusted specifically for SCC) were analysed to observe that they are not able to predict SCRC properties with the same approximation degree as in SCC, as it occurs with vibrated concretes. So, the correction coefficients adjusted with vibrated concretes were used. The new predictions were analysed and the suitability of the correction coefficients when SCRC is used was evaluated.
- Lastly, the specific expressions adjusted with vibrated recycled concrete have been used to predict SCRC properties (modulus of elasticity and splitting tensile strength). Actually, as aforementioned, although some authors state that mechanical properties of SCC are quite different from those obtained with vibrated concrete, they finally conclude that code expressions regarding vibrated concrete can be used with SCC. So, in this case, the suitability of the specific expressions adjusted with vibrated recycled concrete was analysed comparing their predictions with those obtained using the expressions proposed by codes (that is the expressions used with vibrated conventional concrete).

2. Materials and methods

2.1. Experimental program

This work belongs to a wide research work, so the experimental program was divided into three working phases.

In the first one, called “Phase 1”, four types of self-compacting concrete were studied: a reference concrete and three recycled concretes. The replacement percentages of natural with recycled coarse aggregate were 20%, 50% and 100% (by volume).

According to literature review, in order to control the high absorption of recycled aggregates, two different mixing procedures have been developed. The first one consists of working with the aggregates in their natural moisture state while increasing the amount of water incorporated in the mix to compensate up to a