Construction and Building Materials 175 (2018) 496–507

Contents lists available at ScienceDirect

Construction and Building Materials

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

# Quantitative assessment of the saturation degree of model fine recycled concrete aggregates immersed in a filler or cement paste

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## HIGHLIGHTS

- The saturation degree of fine porous aggregates immersed in a paste is assessed.
- For this purpose, an experimental method has been introduced.
- The procedure is validated using different pure cement paste aggregates.
- A maximum saturation of aggregates is reached no later than 6 min after mixing.
- The saturation degree of aggregates is less than 1 and remains constant over time.

## ARTICLE INFO

*Article history:*
Received 29 November 2017
Received in revised form 24 April 2018
Accepted 25 April 2018

*Keywords:*
Recycled aggregates
Cement paste
Filler paste
Water transfer
Spread

## ABSTRACT

We study water transfer between different model fine recycled concrete aggregates and fresh filler or cement paste in which they are immersed. Our aim is to introduce a spread based experimental protocol for studying the time evolution of water content in initially dry aggregates when mixed with such pastes. The procedure developed hereby is tested on three model Cement Paste Sands (CPS) prepared with different water-to-cement ratios leading to very different porosities and pore structures. The results show that water content in the CPS reaches a maximum no later than 6 min after first contact with limestone filler or cement paste then remains fairly constant afterwards. The saturation degree, i.e. ratio of the water content in the CPS to their water absorption, increases with the porosity of the CPS and remains less than one whatever the paste. The corresponding reduction of water absorption capacity in a cement paste should be taken into account during mix design of a recycled concrete.



## 1. Introduction

In 2014, the building and public works sector has produced 223 million tons of construction and demolition wastes in France concrete wastes represent 15% [1]. Only 43% of these wastes are recycled mainly in non-structural applications, the rest being landfilled. Furthermore, this sector is responsible for an overconsumption of natural aggregates, contributing to the shortage of these natural resources in many regions of the world. Concrete recycling is a viable solution to preserve natural aggregates and reduce the needs for landfill disposal. For this reason, the European Directive 2008/98/CE has set the objective of recycling 70% of the CDW by 2020.

A number of researchers have studied the performances of concrete incorporating Recycled Concrete Aggregates (RCA) [2–4]. A systematic study is challenging because of the heterogeneity of RCA, the properties of which depend on the original concrete. Yet, physical and mechanical characteristics of RCA can be identified [5] and some general observations may be reported. When natural aggregates are replaced by dry RCA, insufficient workability of the mix is observed [2]. Hardened properties appear to be affected as well. Le et al. [6] reported a 37% decrease of compressive strength when fine natural aggregates are replaced by fine RCA in mortar. In a study by Evangelista et al. [3], the replacement of fine natural aggregates by fine RCA in a concrete did not result in a significant decrease of compressive strength but decreased the split tensile strength and the modulus of elasticity by 30.5% and

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https://doi.org/10.1016/j.conbuildmat.2018.04.211
0950-0618/© 2018 Published by Elsevier Ltd.

18.5% respectively. Evangelista et al. [7] also studied the impact of fine RCA addition on the durability performances of a recycled concrete. They found that water absorption by immersion or suction as well as the chloride penetration increase linearly with the replacement ratio.

The decreased performances of a recycled concrete are mainly due to poorer properties of RCA. RCA consist of a mixture of natural aggregates and attached cement paste. This cement paste is responsible for lower density, a higher porosity and a higher water demand of RCA compared to natural aggregates (NA) [8]. The porosity and water absorption of a recycled concrete increase proportionally with RCA content, while the density decreases slightly [9]. Effective water content ($W_{eff}$) is one of the governing parameters affecting fresh and hardened properties of a concrete. It is equal to the total water amount in the concrete ($W_{tot}$) less the amount of water absorbed by the aggregates. Its determination in the case of recycled concrete is not easy because of possible water transfers between fresh cement paste and RCA. When dry RCA are introduced in a fresh cement paste, they absorb part of the mixing water during the dormant period. Conventional mix design methods should be avoided because they overlook the effective water content modification due to the presence of RCA.

Different methods have been tested to limit the impact of water transfer between the cement paste and RCA on the fresh and hardened properties of recycled concrete. A common method consists in adding an excess of mixing water corresponding to the theoretical water absorption of RCA minus their initial moisture content. Substantial shortcomings of this method have been reported in the two extreme cases of oven dried aggregates or saturated surface dried aggregates. In a study of Poon et al. [2], the use of RCA in oven dried state leads to a high initial workability due to a temporary increase of the effective water content, thus causing the segregation of coarse particles. Afterwards, a faster workability loss than for the reference concrete is observed during the 165 min test period due to water transfer from the cement paste to the porosity of RCA. The use of saturated surface dried aggregates yields normal levels of workability but causes a decrease of the compressive strength whatever the total water content of the mix. Zhao et al. [10] found that the compressive strength of a mortar made with saturated fine RCA is lower than that of mortar made with dry aggregates. This has been explained by a thinner interfacial transition zone for mortars containing dry RCA as compared to saturated RCA, slightly caused by water bleeding from the saturated RCA. The use of aggregates, “as received”, seems to have the least negative effect on the workability [11] and the compressive strength [2].

Water transfer between RCA and the cement paste at early age has to be quantified in order to be accurately accounted for in mix design. NMR spectrometry has been successfully used to measure water transfer between a cement paste and model porous media. Fourmentin et al. [12] studied water absorption by initially dry densely packed beads (diameter ranged between 128 and 240 μm) immersed in a cement paste. They reported that, whatever the water-to-cement ratio of the cement paste taken between 0.3 and 0.63, such a packing is saturated within 30 min. After 8 h, an amount of water is transferred back to the cement paste under the action of suction forces arising from micro pores induced by cement hydration. In the case of cement paste aggregates in contact with a fresh paste, complete saturation is not reached. Water transfer between initially dry cement paste aggregates with a high porosity (35.5%) and a surrounding fresh cement paste or pure water have been studied using NMR spectrometry in reference [13]. The results show that the asymptotic moisture content of aggregates is 64% lower in the case of a cement paste than in the case of pure water. This decrease would be due to anhydrous phase rehydration inside the cement paste sand which is responsible for calcium precipitation in the pore entries, thus limiting water transfer to the porosity of aggregates. Similar results were found in the case of industrial RCA mixed with a cement paste. Likewise, for a fixed total water content, the comparison of slump measurements through time of mortars containing RCA either in saturated or dry state has shown that initially dry RCA remain unsaturated during mixing period when mixed to a fresh cement paste [2,4,10].

The present study is focused on how water transfer between fine RCA and a cement paste affect the mortar workability during mixing. For this purpose, water transfer occurring between an inert limestone filler or cement paste and a fine cement paste sand in contact with it are studied using spread measurements. A new testing protocol based on spread measurements is implemented to follow this water transfer. Materials are presented in Section 2. The experimental protocol and the mix design of tested mortars are presented in Section 3. Experimental results are shown in Section 4 and discussed in Section 5.

## 2. Materials

### 2.1. Filler and cement

Water absorption of porous aggregates is first studied in a limestone filler paste. The use of this model inert paste eliminates the effects of chemical hydration on the evolution of workability. The filler is a Betocarb HP-OG calcareous filler by OMYA Company coming from the quarry Orgon. By using helium pycnometry, its density is found equal to 2.72 g/cm$^3$. Water absorption by model RCA is also studied in a cement paste. For this purpose, a white cement CEM I 52.5N from Lafarge Company is used. White cement is used to enhance the contrast between the new cement paste and model RCA during microscopic investigations performed in a further study. Its absolute density is 3.11 g/cm$^3$. The particle size distributions of the filler and the cement are roughly the same (see Fig. 1).

### 2.2. Model fine recycled concrete aggregates

First, model porous RCA are prepared. Model aggregates consist of pure cement paste with known W/C ratio, W and C being respectively water and cement mass contents. Grey cement CEMI 52.5N by Lafarge is used to prepare three cement pastes with different water-to-cement ratios by weight: 0.3, 0.5 and 0.7. Water is mixed with cement in a mixer to reach the desired W/C ratio. Superplasticizer MC-Powerflow 3140 of the MC-Bauchemie Müller GmbH & Co Company is added to the most concentrated mix (W/C = 0.3) at a ratio of 0.2% by mass of dry cement to enhance its fluidity. Each time, around 4 L of fresh cement are prepared. The fresh paste is then poured in hermetic plastic bottles. The bottles with W/C equal

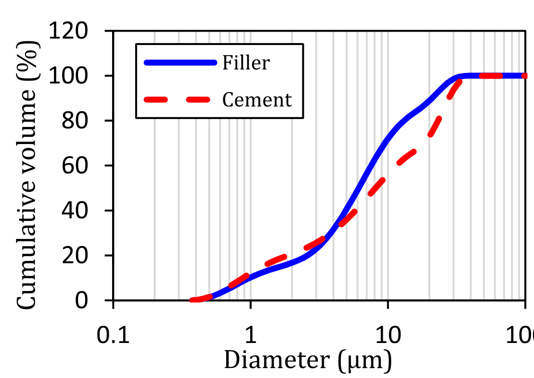


**Fig. 1.** Particle size distributions of the filler and cement powders measured using laser granulometry.