Construction and Building Materials 123 (2016) 690–703

Contents lists available at ScienceDirect

Construction and Building Materials

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

Measuring the water absorption of recycled aggregates, what is the best practice for concrete production?

M. Quattrone [a,*], B. Cazacliu [b,*], S.C. Angulo [a,*], E. Hamard [b], A. Cothenet [b]

[a] Escola Politecnica, Universidade de São Paulo, Av. Prof. Almeida Prado, trav. II, 05508-070 São Paulo, Brazil
[b] LUNAM Université, IFSTTAR, MAST, GPEM, F-44340 Bouguenais, France

HIGHLIGHTS

- Total porosity and kinetics methods for recycled aggregates are suggested.
- Measurement's accuracy increases by vacuum saturation and alternative SSD methods.
- Standard method over time reduces errors due to air bubbles in WA kinetics' measurement.

ARTICLE INFO

Article history:
Received 4 May 2015
Received in revised form 4 July 2016
Accepted 8 July 2016

Keywords:
Recycled aggregate
Porosity
Water absorption
Kinetics
Concrete production

ABSTRACT

In this paper, we compare different methods for determining the water absorption of recycled aggregates (RAs) and, highlighting advantages and critical points, attempt to suggest alternatives for a better way to measure it. Water absorption (WA) capacity has two purposes: (a) measuring the interconnected porosity, which is useful for mechanical concrete analysis and durability issues, and (b) allowing adjustment of the amount of water used in concrete production. Our analysis shows that vacuum during soaking is recommended for the RAs' interconnected porosity determination. This approach enables shorter testing time (from $\geqslant$24 h to $\leqslant$1 h) and increases the accuracy of the measurement. The saturated surface dry (SSD) state determination can also be fastened using centrifuge, air flow drum, laser scattering, and microwave drying evaporometry, without significant differences. The use of these techniques is still restricted due to such factors as commercial availability, geometric limitations of the sample containers, and difficulty in controlling the temperature and the relative humidity. For concrete production, WA kinetics during the first 30 min is fundamental. Accuracy of the results is arguable regarding the practical issues, for example, vibration or trapped air bubble. Mathematical artefacts can overcome those problems but need to be calibrated with experimental data determined by standard tests over time. Because the WA kinetics probably changes when RAs are in contact with cement paste, a method to understand and quantify this phenomenon is still a research demand.

1. Introduction

Recycled aggregates (RAs) from construction and demolition waste are widely used in civil engineering applications, such as roads, embankments, and trench reinstatements [1–6]. Although a number of studies regarding the use of RAs in concrete have been conducted [7–16], this possibility deserves more attention. On the one side, this practice is hampered by the lack of technical confidence in its practical use due to the different behaviours that RAs exhibit, i.e., higher porosity, higher water absorption (WA) capacity and lower density [14,17–24]. On the other side, these characteristics negatively affect the performance of the Recycled Aggregate Concrete (RAC) if we compare it with normal concrete (made with natural aggregates).

In cement based material, capillary pores and air voids of cement paste at the interfacial transition zone (ITZ) are responsible for porosity [25,26] and WA. Pore structure is different in mortar and concretes depending also on the size of the natural aggregates used in the mix [27]. The RAs' porosity and WA vary [28,29] due to the presence of the adhered old cement paste [30,31], ceramic material and impurities, such as gypsum [32]. The recycling process, i.e., crushing, grinding, etc., can also generate cement based particles with variable amount of adhered cement paste, increasing or reducing the WA [33].

---

* Corresponding authors.
E-mail addresses: marco.quattrone@lme.pcc.usp.br (M. Quattrone), bogdan.cazacliu@ifsttar.fr (B. Cazacliu), sergio.angulo@lme.pcc.usp.br (S.C. Angulo).

http://dx.doi.org/10.1016/j.conbuildmat.2016.07.019
0950-0618/© 2016 Elsevier Ltd. All rights reserved.

Although different water transport mechanisms are involved in porous materials, capillary suction is the main one. Parrot [34] analysed the WA of concrete over time considering different W/C ratio and curing methods. His results showed that WA after 4 h of wetting was close and almost linearly related to WA after l h regardless of exposure condition, water/cement ratio, curing or cement type. Castro et al. [35] showed that the water to cement ratio, and the relative humidity (RH) affect the WA of mortar. The water uptake of oven dry samples is higher than those in relative humidity higher than 50%. The kinetics is also affected, water absorption rate decreasing with the initial RH.

The effects of RAs' quality used in concrete production appear in both fresh and harden states [36–38]. The faster and higher WA of RAs implies a lower degree of concrete's workability for the RAC with the same water to cement ratio as for natural aggregate concrete [21,39]. Among the conventional strategies to control workability without affecting mechanical performances, the use of a greater amount of additives is the more commonly performed [40,41]; the other one is the pre-soaking of RAs [14,42–44]. Each one has advantages and disadvantages; however, the pre-soaking seems to be the more gainful in terms of costs and environmental impacts. As showed from different authors, pre-soaking can reduce the suction of water from cement paste, but the right level of partial saturation must be determined in order to avoid bleeding [39,42] and occurrence of a weak ITZ between the new cement paste and the RAs [40,45]. This occurrence was also confirmed by the ITZ nanoindentation analysis, i.e., indentation modulus and hardness measurements [46]. The knowledge of WA kinetics is the key to predict the effective W/C to maintain the workability after the mixing period without affecting the material at hard state.

In harden concrete, the RAs porosity influences the resistance of the material, the freezing and thawing [47], and the abrasion [31,48,49]. Most of the time these characteristics are lower while using RAs instead of natural aggregate [7,8,50]. In wet conditions, the RACs compressive strengths resulted lower than the normal concrete at different strain rates [51]. Investigations to extend the stress-strain analytical expressions for normal concrete to the recycled ones have been done [52], but difficulties still exist. Other effects like higher creep and shrinkage [53,54], and decreasing of durability of RAC [55–57] are primary problems associated with the use of RAs in concrete whereas the higher porosity of RAs can be exploited as a reservoir of water for internal curing of concrete [58,59]. Therefore, the water absorption of recycled aggregates has a twofold importance. First, WA kinetics allows foreseeing the behaviour of fresh RAC during mixing, transportation and casting, and second, 24 h WA is used for assessing the RA's open porosity and how it affects other properties, such as strength, shrinkage, and durability. The systematic control of the water absorption is fundamental to ensure good RAC's performances in its fresh and harden state.

Despite the different properties that RAs exhibit, the standard methods designed for natural aggregates are still used. This approach does not comply with the needs of a plant's quality control procedures that are needed to produce recycled aggregates for different applications. Indeed, the standard methods are time-consuming, as they need, at least, 30 h to determine the water absorption value of samples. Moreover, the standard procedures have a number of critical points and might be not entirely appropriate for investigating RAs' properties. These procedures do not consider the different response of RAs, e.g., saturation level and time, compared with natural ones.

In this paper, methods proposed in the literature to determine the water absorption capacity have been analysed, and data published have been used in additional analyses, primarily studies focused on the coarse fraction (grain size >4 mm) of RAs. By comparison with standard and experimental methods for water absorption determination, we tried to look at the primary critical points of those methods and to suggest alternatives for measuring that property in a better way, as a function of what we are really seeking. One method aims for concrete production based on WA kinetics phenomena, and another aims for mechanical and durability issues based on total WA capacity, i.e., total open porosity.

2. Methods to determine the water absorption of recycled aggregates

Water absorption measurements allow the calculation of the interconnected porosity of porous granular materials. On the one hand, this parameter is used to estimate the reduction of the concrete's mechanical strength and the increase of the concrete's permeability, which is responsible for the concrete's degradation due to the ingress of aggressive agents. On the other hand, concrete technologists use this parameter to estimate the amount of mixing water necessary to achieve the required workability at the casting time.

Water absorption is also determined in combination with density. As reported by Webb [60], the literature presents a number of different definitions for "density". In this paper, we use the term "skeletal density" to indicate the ratio between the mass and the volume of solid material (the volume includes closed pores) and the term "envelope density" to indicate the ratio between the mass and the volume of particles, including not only the solid matter but also open and closed pores of particles. This case does not consider the inter-particle voids in its determination.

2.1. Standard methods

Standard methods for determining the water absorption of coarse natural aggregates [61–63] are widely used even for RAs. All standards recommend the following steps: (a) saturate the material by soaking (usually for 24 h or more, at atmospheric pressure); (b) use a towel to remove the film of water covering the surface and weigh the saturated surface dry (SSD) mass; (c) measure the hydrostatic mass; (d) dry the sample until it reaches a constant mass and measure the oven-dry (OD) mass (Fig. 1). Usually the constant mass state, depending on the aggregates' porosity, may be achieved after 6 h in a ventilated oven at 110 ± 5°C. Standards also suggest taking into account the initial material's moisture condition before soaking. However, this rarely occurs, so oven-dried materials at the equilibrium point (temperature and humidity equal to that of controlled environment) are usually tested.

2.1.1. Saturation

A number of remarks regarding the saturation method can be addressed. On the one hand, 24 h of saturation is not sufficient to determine the total porosity of RAs. Several researchers [64–66] showed that the degree of saturation still increases after 24 h. WA of porous aggregates can also double after one year [67], being inaccurate the determination of interconnected porosity (permeable to water, gas or other liquid). This point is extremely important to ensure that we have a perception of the porosity's influence on the strength and durability of products containing RAs. On the other hand, 24 h is too much time when RAs are used in fresh stage concrete. Usually, concrete production times are approximately 2 h (mixing, transportation and casting), and other factors may affect the system, e.g., aggregates adsorb/exchange water from and with the cement paste (as a function of the mixing procedure). In this case, a reasonable saturation time to be considered could be lower than 2 h. Moreover, kinetics (Section 2.3) shows that the saturation level after 2 h is approximately 90% of the 24-h saturation. Certain authors and standards adopt the