Construction and Building Materials 160 (2018) 316–325

Contents lists available at ScienceDirect

Construction and Building Materials

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

Method for controlling the absorbed water content of recycled fine aggregates by centrifugation

Zhen Li [a,*], Jiaping Liu [a,b,c], Qian Tian [b,c]

[a] School of Materials Science and Engineering, Southeast University, Nanjing 211189, China
[b] Jiangsu Sobute New Materials Co., Ltd, Nanjing 211103, China
[c] State Key Laboratory of High Performance Civil Engineering Materials, 211103, China

HIGHLIGHTS

- The centrifugation method is proposed to control the absorbed water content of RFAs.
- SSD condition can be consistently obtained by centrifuging at 2000 rpm for 10 min.
- Accuracy and repeatability of centrifugation is compared with traditional approaches.
- Method can be applied to RFAs irrespective of their size and attached mortar content.

ARTICLE INFO

Article history:
Received 27 July 2017
Received in revised form 10 November 2017
Accepted 14 November 2017

Keywords:
Recycled fine aggregate
Absorbed water content
Centrifugation
Fluidity

ABSTRACT

Accurate determination of the absorbed water content of recycled fine aggregates (RFAs) is necessary for proper proportion cement-based mixtures. However, some current standard methods are time consuming and have high operator error. In this paper, we propose an alternative method to control the absorbed water content of RFAs by centrifugation. The rotation speed, centrifugation time, and initial water content are considered as parameters. Ten commercially available RFAs were tested by a single operator with multiple measurements by the centrifugation method, and the results were compared with those obtained by the cone and volumetric flask methods. In addition, the fluidity of the mortar with RFAs and manufactured sand were compared to evaluate the additional water required for saturation. The experimental results indicate that the pre-wetted RFAs can reach the saturated-surface-dry condition after centrifugation at 2000 rpm for 10 min when the centrifugal radius is 6–10 cm, at which the water content can be defined as absorbed water. By comparing the standard deviations with other methods, the absorbed water content can be more accurately and repeatedly controlled by the centrifugation method. The fluidity of the mortar with RFAs including additional water by centrifugation shows a good relationship with that of manufactured sand. Therefore, the centrifugation method can be used to control the absorbed water content of RFAs and applied to mixture design.

1. Introduction

With rapid urbanization, a large number of buildings and infrastructures have been built in the last few decades and there may be twice the demand for materials by the year of 2050 [1], leading to increased production and utilization of concrete. Billions of tonnes of construction waste are created every year owing to deterioration of old buildings and civil engineering projects [2]. Natural aggregates are being gradually replaced by recycled aggregates produced from recycling construction and demolition waste, which makes a major contribution to sustainable development of the construction industry [3].

Recycled fine aggregates (RFAs) are composed of natural aggregates attached with hydrated cement mortar, resulting in a lower density and higher water absorption capacity than natural fine aggregates (NFAs) [4–6]. This makes it difficult to control the quality of fresh cement-based materials and has an adverse effect on the mechanical strength and durability of hardened cement-based materials [7,8]. To eliminate these adverse effects, the

Abbreviations: RFA, recycled fine aggregate; NFA, natural fine aggregate; SSD, saturated surface dry; W/C, water-cement ratio; LWA, lightweight aggregate; OD, oven dry; MIP, Mercury intrusion porosimetry.

* Corresponding author.
E-mail address: listener122000@126.com (Z. Li).

https://doi.org/10.1016/j.conbuildmat.2017.11.068
0950-0618/© 2017 Published by Elsevier Ltd.

absorbed water content must be accurately determined so that the actual mix proportion can be adjusted [9].

The absorbed water value is the water content at the saturated-surface-dry (SSD) condition. It is difficult to obtain an accurate absorbed water value because it is difficult to define the SSD condition for fine porous aggregates [10]. In theory, the SSD condition is defined as the condition where the aggregates no longer contain surface water but retain absorbed water in the inner pores [10]. If the absorbed water content is overestimated, the paste will contain additional free water and the actual water–cement ratio (W/C) will be higher than the designed value. Conversely, if the absorbed water content is underestimated, the aggregates will contain less water and not be saturated, and free water in the paste will flow into those pores. A mixture with a low water content may lead to decreased workability. Standard methods for estimating the absorbed water content of NFAs [11–13] are also widely used for RFAs. In general, there are three steps: (1) immersion of the fine aggregates in water until saturation (usually for 24 h or more at atmospheric pressure), (2) removal of the water on the surface to reach the SSD state, and (3) drying the aggregates until they reach a constant mass.

It is crucial that the SSD condition is maintained in the whole process. A series of criteria have been proposed for standard methods. The cone method (ASTM C 127 [11] and GB/T 14684 [12]) is widely used for fine aggregates, which defines the SSD according to the slump shape of the sample after warm air drying. In ASTM C1761-13b [13], a dry paper towel is placed around the surface of the pre-wetted fine aggregates and the paper will become wet if the aggregates contain surface water. The aggregates are dried by warm air drying until the SSD condition is reached and a clean paper towel shows no water. In EN 1097-6A [14], a cloth is used to remove the surface moisture. However, wiping in these drying processes may cause detachment of the friable fraction from the aggregate particles [15].

Other effective methods for drying aggregates to SSD state have also been reported. Quattrone [16] and Rueda [17] suggested that drying theory [18] can be applied to determine the SSD mass. According to drying theory, there should be a constant rate of water loss owing to exterior water loss occurring first, which is denoted as the saturated surface wet condition. The transition might then be at the beginning of a decreasing evaporation rate, when the water in the pores of aggregates begins to be removed, so the aggregates should be in the SSD condition. To shorten the drying time, Virtanen [19] used microwave oven drying and Damineli [20] combined 0.5 h vacuum saturation with about 2 h microwave oven drying kinetics to obtained a more rapid and accurate measurement. Kandhal et al. [21] and Gentilini et al. [22] reported methods based on hot air flow drying of the aggregates, which were placed in a rotating drum. Most of these new methods are more suitable for coarse aggregates, because fine particles readily agglomerate and it is difficult to uniformly transfer the drying energy to the surface of every fine aggregate.

Some researchers have investigated the change in the absorbed water content of fine aggregates in the absorption process. You et al. [23] proposed a method for SSD state determination using a laser sensor device in an orbital mixer based on the laws of reflection and scattering of light rays. In the tests, water was injected by a pump until the sample reached the SSD state. Once a water film appeared on the aggregate surface, which absorbs infrared light, the sensors stopped the test. In the testing process of Leite [24], the sample was submerged in water and evolution of the hydrostatic mass was determined by a scale. Because materials including clay might undergo incipient particle agglomeration, Rodrigues [25] used hexametaphosphate solution as a particle dispersant to minimize cohesion between particles and release entrapped air. In addition, Castro [10] used the volumetric flask method to investigate the change in the absorbed water content of fine lightweight aggregates (LWAs) with immersion time. In the process, the mass of the setup with aggregates was recorded until no further change in the mass or reduction in water level occurred, which indicated that the aggregate had reached the saturated condition. The same principle was used by Tam [15], who added additional water at intervals to the pyknometer. However, it may be difficult to accurately determine the initial value.

Generally, the drying process to be SSD state depends on evaporation of surface water or the absorption capacity of the absorbent material. It is difficult to maintain a consistent driving force for expelling the surface water, resulting in inaccuracies in the measurements, especially because of personality error [26]. In addition, it may take a long time to change the pre-wetted condition to the SSD condition. In the paper of Damineli [20], by comparing the time for SSD determination, centrifugal drying takes the shortest time (less than 0.16 h). The centrifugation method has been used to determine water absorption of LWAs, and the method is discussed in ACI 211.2-17 [27]. Miller [28,29] investigated the rotation speed and time for internal curing of pre-wetted fine LWAs. In these tests, a sample of fine LWAs was immersing in water for 24 h was then placed in a centrifuge vessel. The surface water was removed from the LWAs when the centrifuge rate was up to 2000 rpm for 3 min (bowl radius of 11.4 cm). The LWAs were considered to be in the surface saturated condition. Based on the relationship between the centrifugal force and speed, the water removed from the surface and pores with the same radius was consistent.

In this study, the centrifugation method was used to control the absorbed water content of RFAs. The purpose of this paper was to investigate the parameters including rotation speed and centrifugation time, to determine the standard deviation of the water contents of RFAs from the same stockpile, and to compare the fluidity of mortar with RFAs including additional water with that of manufactured sand.

Table 1
List of aggregates.

Note	Batch	Strength grade	Size range	Apparent density/kg/m^3	Attached mortar content/%
RFA-1	A	C30	0.60–1.18 mm	2440	53.41
RFA-2	A	C30	1.18–2.36 mm	2510	45.25
RFA-3	A	C30	2.36–4.75 mm	2600	39.74
RFA-4	A	C30	0.16–4.75 mm	2540	48.43
RFA-5	B	C30	0.60–1.18 mm	2380	76.34
RFA-6	B	C30	1.18–2.36 mm	2460	58.25
RFA-7	B	C30	2.36–4.75 mm	2520	45.25
RFA-8	B	C30	0.16–4.75 mm	2480	60.13
RFA-9	C	C40	0.16–4.75 mm	2560	38.12
RFA-10	D	C50	0.16–4.75 mm	2580	32.51