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METODA ZA KONTINUALNO ODREĐIVANJE UPIJANJA VODE KRUPNOG AGREGATA OD RECIKLIRANOG BETONA

Rezime:

Agregati od recikliranog betona poseduju značajno veće upijanje vode u odnosu na prirodne agregate zbog prisustva cementne paste zaostale nakon drobljenja betonskog otpada. Visoka vrednost upijanja vode ovih agregata utiče na procedure spravljanja receptura betona sa agregatom od recikliranog betona. U ovom radu je predstavljena metoda za kontinualno određivanje upijanja vode agregata od recikliranog betona koja je bazirana na kontinualnom merenju mase uzorka. U istraživanju je ispitan i uticaj temperature sušenja na upijanje vode i analizirani su različiti efekti na agregat od recikliranog betona i prirodni agregat.

Ključne reči: agregat od recikliranog betona, prirodni agregat, upijanje vode

A METHOD FOR THE CONTINUOUS MEASUREMENT OF WATER ABSORPTION OF COARSE RECYCLED AGGREGATES

Summary:

Recycled concrete aggregates have a significantly higher water absorption compared to natural aggregates due to the presence of the residual cement paste after concrete waste crushing. This high water absorption determines the mixture proportioning for recycled aggregate concrete. In this study a method for the continuous measurement of the kinetics of water absorption is proposed based on the continuous measurement of the sample's mass. Also investigated, is the influence of the drying temperature on water absorption and different effects on recycled and natural aggregates are analysed and discussed.

Key words: recycled concrete aggregate, natural aggregate, water absorption

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1 INTRODUCTION

1.1 RECYCLED CONCRETE AGGREGATE

Concrete is the most widely used construction material with global production reaching 21 billion tons annually [1]. This poses an enormous strain on natural resources used in its production. Global annual consumption of natural aggregates is around 15 billion tons [2].

At the same time, aging structures are being demolished and large amounts of construction and demolition (C&D) waste are being generated. In the EU alone, almost 850 million tons of C&D waste are produced annually, and waste concrete is a large portion of it [3].

These problems have prompted researchers to study alternative materials for use as aggregates. One of the most promising alternatives is recycling of waste concrete which aims at solving both problems at once—reducing the consumption of natural resources and the amount of waste being landfilled. This approach has been studied for several decades [4].

Usually, waste concrete is crushed into aggregates called recycled concrete aggregates (RCA) which can be used in new applications. This crushing is performed in mobile or stationary recycling facilities using single or multiple-stage crushing in different crusher types, together with the removal of any impurities such as steel, wood, gypsum, masonry and glass. When this new aggregate, RCA, is used for the production of concrete, that new concrete is called recycled aggregate concrete (RAC).

The main difference between RCA and natural aggregate (NA), river gravel or crushed stone, is the so-called ‘residual cement paste’ that is left attached to RCA particles after crushing. This is actually a part of the hardened cement paste around the NA aggregate particles in the original concrete being recycled. Because of this, RCA can be viewed as a two-phase material containing natural aggregates and cement paste.

The main implication of the residual cement paste is higher water absorption of RCA compared with NA. Water absorption of RCA can range from 2% to 10% in the case of coarse aggregate (particle size >4 mm) and up to 15% in the case of fine RCA (particle size <4 mm) [5]. The extremely high absorption of fine RCA has led many standards to impose restrictions on its use in concrete [6]; hence, it was not considered in this study.

The large water absorption of RCA poses problems when designing RAC mixtures. During mixing RCA can absorb a certain amount of water, thus reducing the w/c ratio, causing workability problems. This has led some researchers to adopt an effective water-to-cement ratio (w/c_{eff}) which is maintained constant in the mix by adding additional water to saturate oven-dry (OD) aggregates or by using saturated surface dry (SSD) aggregates. Researchers have studied the effect of the moisture state of RCA on RAC properties, investigating the differences between using dry, semi-saturated and fully saturated RCA, and found a non-negligible influence of the moisture state [7,8]. Also investigated were different mixing procedures that would more adequately take into account the large water absorption of RCA [9].

Another important aspect of the residual cement paste attached to RCA particles is its potential for carbonation and consequently, CO₂ sequestration. Previous research has studied the possibilities of using RCA as a low-cost carbon sink, through open-air exposure during stockpiling. Such carbonation modification of RCA was shown to potentially decrease water

absorption and reduce porosity, thereby improving RCA properties making it better-suited for use in RAC [10,11].

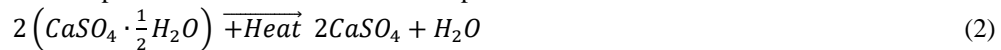
1.2 EXISTING PROCEDURES FOR MEASURING WATER ABSORPTION

All of the aforementioned only highlights the importance of adequately determining water absorption of RCA. So far, the most common method, at least in Europe, has been the EN 1097-6 standard's procedure used for NA [12]. In this method an aggregate sample is submerged in water for 24 h after which its SSD mass (M_a) is recorded. The SSD state is subjectively assessed by drying the wet aggregates with a cloth. The aggregates are then placed in a dryer and left at a temperature of $110 \pm 5^\circ\text{C}$ until mass stabilization after which the OD mass (M_s) is measured. Water absorption (WA) is then calculated from Equation 1:

$$WA = 100 \cdot \frac{M_a - M_s}{M_s} \quad (1)$$

However, several problems exist with this procedure, especially when it is used on RCA and this has already been highlighted in previous studies [13]:

When RCA is dried at 110°C , not only free water, but also a part of the chemically bound water is evaporated from the residual cement paste:



There is no measurement of the kinetics of water absorption i.e. the development of absorption through time, which can be considered different in RCA compared with NA and significant for mixture proportioning [14].

There is no perturbation of the aggregates during soaking which means that air bubbles can remain trapped between aggregate particles and prevent complete absorption.

The SSD condition is subjectively assessed by wiping the aggregates with a cloth, although it was shown that this subjectiveness can introduce differences usually smaller than 5% [14].

This situation has led several researchers to search for alternative methods of measuring water absorption of RCA [13–18]. All of the proposed methods concentrate on using hydrostatic weighing as a way of measuring RCA absorption kinetics, sometimes in combination with pycnometer measurements.

2 EXPERIMENTAL PROGRAMME

2.1 SCOPE AND OBJECTIVE

In this study, water absorption of natural and recycled non-carbonated and fully carbonated aggregates was measured. For this purpose, a new test procedure was developed which relies on previously proposed methods by other authors [13–18].

The aim was, first, to determine whether the standard drying temperature proposed in EN 1097-6 [12] is adequate for RCA, and second, to determine whether carbonation modification of RCA has an effect on water absorption.

2.2 MATERIALS

Two particle sizes of both NA and RCA were used in this study – fraction II (4-8 mm) and fraction III (8-16 mm).

Natural aggregate was standard, commercially available river gravel from the Danube river, purchased from Gradient d.o.o., Belgrade.

Recycled concrete aggregate was obtained from a demolished 40 year old highway bridge in the vicinity of Belgrade. The aggregate was obtained by crushing columns and the deck of the bridge in a construction site mobile crusher. The demolished structure was relatively clean from impurities as the asphalt had been scraped of the deck prior to demolition. After crushing, RCA was sieved into fractions II and III. Cores taken from the existing structure prior to crushing, showed a compressive strength of 23 MPa in the column and 35 MPa in the deck of the bridge. Carbonation depth of the parent concrete was tested and shown to be 25 mm in the column and 0 mm in the deck.

Immediately after crushing and sieving, a part of both RCA fractions were sealed in plastic bags to prevent further carbonation while another part of both fractions was put in a Memmert ICH260C carbonation chamber and exposed to $5 \pm 1\%$ of CO_2 concentration, $55 \pm 5\%$ relative humidity and a temperature of $20 \pm 2^\circ\text{C}$ until full carbonation i.e., mass stabilization.

2.3 METHODS

For the purpose of this study, a new method was used, based on hydrostatic weighing and on methods proposed in previous studies [13–18]. Since hydrostatic weighing was used, the sequence of the measurement procedure had to be reversed, compared with EN 1097-6 [12].

First, the aggregates were washed to clean them from fine particles. Afterwards, they were placed in an oven and dried at $110 \pm 5^\circ\text{C}$ or $45 \pm 5^\circ\text{C}$ for 24 h or until mass stabilization.

After this, the OD mass of the sample (m_0) was measured. Then, the sample was placed in a perforated steel basket. The sample size was chosen in such a way that no more than two or three layers of aggregate were in the basket. This amounted to ca. 400 g for fraction II and ca. 800 g for fraction III. For fraction II a basket with a finer perforation was used, compared with the basket for fraction III, as is shown on Figure 1.



Figure 1 – Apparatus for absorption measurement of aggregate fraction II (left) and III (right)

The basket with the sample inside was hung from the scale and the water container was raised so that the basket was completely immersed in water. The measurement procedure was

as follows—the mass of the immersed sample with the basket ($M(t)$) was recorded after 1, 3, 5, 10, 15, 30 minutes, every hour until 6 hours and the final reading (M_{24}) was taken after 24 hours. Before each reading the basket was unhung from the scale, shaken to remove entrapped air bubbles and hung again on the scale.

After 24 h, the water container was lowered and the aggregates were spread on a dry cloth and left to dry in open-air until the SSD condition was achieved, judged by naked eye observation. Then, the SSD mass of the sample (m_{24}) was measured.

The increase in sample mass at time t , equal to the mass of the absorbed water ($\Delta m_w(t)$) was calculated according to Equation 3:

$$\Delta m_w(t) = m_{24} - m_0 - (M_{24} - M(t)) \quad (3)$$

Finally, water absorption at time t , was calculated according to Equation 4:

$$WA(t) = \Delta m_w(t)/m_0 \quad (4)$$

3 RESULTS AND DISCUSSION

The sample designation was as follows: for NA “NA-II(III) 45(110)”, with II and III signifying the fraction and 45 and 110 the drying temperature; for RCA “RCA-II(III)-NC(FC) 45(110)”, the same as for NA, with and addition of NC signifying non-carbonated and FC fully carbonated RCA.

The results for NA, fractions II and III, are shown in Figure 2. Vertical lines were drawn at 1 h and these absorption values highlighted because this time was deemed typical for ready-mixed concrete transport in Serbia and hence, important for mix design.

Several things can be seen from the figures. First, the absolute values of absorption are low, just above 1% for fraction II, although this is relatively high for NA. Second, the absorption kinetics are such that it can be said that most of the absorption occurs within the first hour. Finally, and most importantly, there is, for practical purposes, no significant difference between drying the samples at 45 or 110°C. This justifies the use of EN 1097-6 in the case of NA.

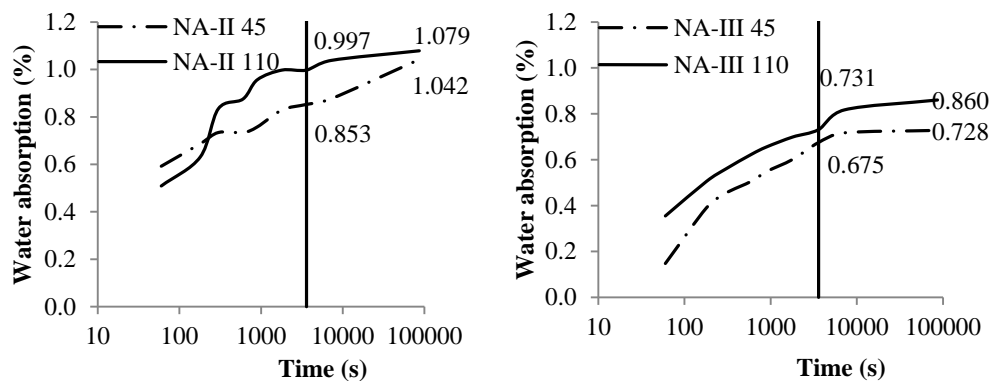


Figure 2 – Water absorption kinetics of NA fraction II (left) and fraction III (right)

The results for RCA, fractions II and III, non-carbonated and fully carbonated, are shown in Figures 3 and 4. From these figures, several important conclusions can be drawn. First, there is

a significant difference between drying the samples at 45 and 110°C, for both non-carbonated and fully carbonated RCA, although the difference is smaller in the case of fully carbonated aggregates.

For non-carbonated fraction II, the decrease in absorption is 29.5% after 1 h and 27.1% after 24 h. For fully carbonated fraction II, the decrease is 11.6% after 1 h and 10.4% after 24 h. For non-carbonated fraction III, this decrease is 47.1% after 1 h and 46.5% after 24h. For fully carbonated fraction III, the decrease is 26.4% after 1 h and 24.6% after 24 h.

Compared to NA, the kinetics of RCA absorption seem to be much faster in the first hour and they don't change with carbonation modification. Finally, there is a substantial decrease in water absorption after carbonation modification. For fraction II dried at 110°C the decrease in absorption after 24 h is 17.6% and an increase of 1.2% for drying at 45°C. For fraction III dried at 110°C the decrease in absorption after 24 h is 33.9% and 6.7% for drying at 45°C.

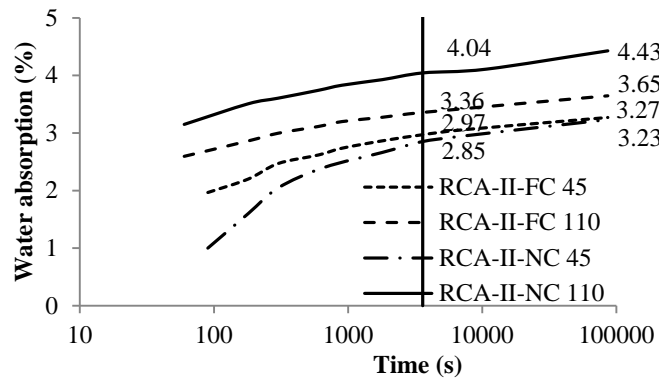


Figure 3 – Water absorption kinetics of RCA fraction II

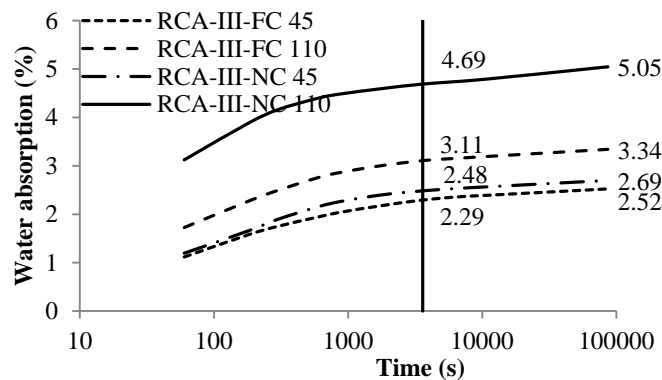


Figure 4 – Water absorption kinetics of RCA fraction III

These results have important implications for mixture proportioning of RAC. Since in practice RCA will never be exposed to temperatures above 100°C, measuring absorption by drying RCA at 110°C will lead to overestimated water absorption values. The overestimation

decreases with increasing carbonation of RCA, but it does not fall below 10% even in the extreme case of fully carbonated RCA.

Using this overestimated absorption in mixture proportioning can lead to the usage of unnecessarily high amounts of additional water for absorption compensation. This can then lead to higher w/c ratios and weaker bonds between the cement paste and aggregates. It must be concluded then, that the observed problems of workability of RAC arise not from high water absorption, but from the irregular and jagged shape of the particles. This problem should be solved by using plasticizers and not by increasing the water content.

It is necessary therefore, to adopt new standards for RCA water absorption measurement which would take into account its specificities in an appropriate manner.

4 CONCLUSIONS

In this study, the water absorption of NA and RCA was measured using a hydrostatic weighing technique enabling continuous measurement and different drying temperatures were analysed. Carbonation modification of RCA and possible improvements in water absorption were also analysed. Based on the results presented in the previous section, the following conclusions can be drawn:

- It is possible to measure water absorption continuously using the hydrostatic weighing technique and the procedure described in this paper.
- For the measurement of water absorption of NA, the standard technique described in EN 1097-6 can be used.
- For RCA, significant differences in absorption are obtained when drying the aggregates at 45°C compared with 110°C. These differences range from 47.1% in the case of non-carbonated fraction III after 1 h, to 10.4% for fully carbonated fraction II after 24h.
- Carbonation modification of RCA can significantly change water absorption, ranging from 33.9% decrease in the case of fraction III dried at 110°C to an increase of 1.2% in the case of fraction II dried at 45°C.
- It's necessary to develop new standards for RCA water absorption that will take into account its specificities, thus eliminating potentially erroneous mixture proportioning of RAC.

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