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# Experimental Determination and Estimation of Water Absorption Capacity of Hardened Concrete with Recycled Aggregate

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**Abstract.** The use of recycled construction and demolition waste, especially recycled concrete, as an aggregate for new concrete mixes, leads to saving of natural resources. The high water absorption capacity (WA) of recycled aggregate has a negative impact of concrete mix workability and influences the water-cement ratio. This paper presents results of experimental measuring of WA of recycled aggregate and recycled concrete. Series of concrete with various replacement ratios of natural aggregate by recycled aggregate were prepared for this study. The main aim of this study is to analyze the influence of recycled aggregate WA, and mixture ratios on WA of concrete. Regression model to estimate WA of hardened concrete is presented.

## Introduction

Long service life of concrete depends on a good durability performance. Modified construction and demolition waste as recycled aggregate is able to be used for concrete structures, but some of its properties negatively influence durability of concrete. The durability of concrete depends on various factors such as aggregate properties, constituents of concrete and its proportion and external environmental conditions [1]. A possibility to use recycled concrete according to environmental exposure classes is listed in European standard EN 206-1 [2]. Durability of concrete is closely related with WA. The WA of concrete increases with the WA of aggregate [3, 4] and with replacement ratio of recycled aggregate [5]. Proportional dependency was identified between the replacement ratio of recycled aggregate and WA of concrete [6].

## Materials and Experiments

**Materials.** In this research, two natural aggregates (NA) and five samples of coarse recycled aggregate (RA) from recycling plant were tested and used as aggregates for concrete. Each aggregate was divided to fractions 4/8 mm and 8/16 mm. All types of aggregate were used to concrete mixture.

**Determination of aggregate WA.** WA of aggregates was tested by pycnometric method according to EN 1097-6 [7]. Samples were soaked 24 hours in pycnometres and periodically measured. After 24 hours were dried on surface and then dried in oven for 24 hours. See WA of aggregate in Table 1.

**Mixtures.** Mixtures were designed with different replacement of coarse recycled aggregate 0 %, 31 %, 50 % and 62 %. All mixtures had same amount of natural sand, cement and had same effective water-cement ratio. Percentage of aggregate composition in concrete mixtures is presented in Table 1. This table also shows WA capacity of all used aggregate and measured values of WA capacity of hardened concrete.

**Determination of WA of hardened concrete cubes.** WA capacity of hardened concrete (HC) was tested by immersion. Cubes were after 28-days wet curing removed from water and dried in oven for 7 days. See WA of concrete in Table 1.

Table 1. Composition of the mixture, WA of aggregate and WA of hardened concrete.

| | Concrete | CN1 | CN2 | CR1 | CR1 | CR2 | CR2 | CR2 | CR3 | CR4 | CR5 | CR6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Repl. [%] | 0 | 0 | 50 | 63 | 31 | 50 | 62 | 25 | 62 | 70 | 70 |
| Aggregate | WA [%] | 4.9 | 4.2 | 9.5 | 10.8 | 6.8 | 8.5 | 9.4 | 5.5 | 7.6 | 6.0 | 8.8 |
| Sand | 1.3 | 40 | 35 | 43 | 43 | 43 | 43 | 44 | 33 | 42 | 46 | 47 |
| NA1 4/8 | 1.1 | 23 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| NA1 8/16 | 0.8 | 37 | 0 | 13 | 0 | 18 | 13 | 0 | 0 | 0 | 0 | 4 |
| NA2 4/8 | 1.2 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 0 |
| NA2 8/16 | 0.9 | 0 | 54 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 0 | 0 |
| RA1 4/8 | 10.4 | 0 | 0 | 21 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RA1 8/16 | 7.5 | 0 | 0 | 23 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RA2 4/8 | 9.2 | 0 | 0 | 0 | 0 | 11 | 17 | 16 | 0 | 0 | 0 | 0 |
| RA2 8/16 | 7.0 | 0 | 0 | 0 | 0 | 17 | 27 | 40 | 0 | 0 | 0 | 0 |
| RA3 0/20 | 5,4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 0 | 0 |
| RA4 4/8 | 7.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 0 |
| RA4 8/16 | 6.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 0 |
| NA5 0/4 | 6,2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 |
| NA5 4/8 | 2.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0 |
| NA5 8/16 | 6,2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 0 |
| NA6 0/4 | 7.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| NA6 4/8 | 9,7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| NA6 8/16 | 8.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24 |

## Model and Estimation

The influence of WA of aggregates and mixture ratios on WA of HC was analyzed with statistical approach of multiple linear regression.

**Model.** It is assumed that the influence of WA of mixture constituent on WA of HC is directly proportional to its relative amount given by mixture recipe multiple by its WA. To get practical WA estimator, which can handle many mixture constituents, there are introduced groups $G$ of mixture constituents. Mixture constituents are classified in the groups according material type and WA. Recycled aggregate were defined according to their WA to three groups, RA with WA< 6 %, RA with 6 % <= WA < =8 % and RA with WA> 8 %. Parameter groups of recycled aggregate were also selected to minimize error of estimation. Other two groups are natural aggregate and natural sand. Groups of aggregates are shown in Table 2. Each group has its own coefficient $c_g$ and there is one extra coefficient $c_0$ as an intercept term.

The WA of HC $w_h$ is calculated as

$$w_h = c_0 + \sum_{g \in G} \left( c_G \sum_{i \in g} (r_i w_i) \right),$$
(1)

where $g$ is a group member, $i$ is an index of used constituent, $r_i$ is relative amount of the $i$-th constituent given by mixture recipe, $w_i$ is WA of the $i$-th constituent.

**Estimation.** The material group coefficients are estimated from all experimental data. The model is linear in terms of coefficients. Estimate of WA of all HC samples $\widehat{\boldsymbol{w}_h}$ is calculated as follows

$$\widehat{\boldsymbol{w}_h} = \boldsymbol{A}\boldsymbol{c}, \quad (2)$$

where $\boldsymbol{A}$ is a regressor matrix and c is the vector of coefficients. Regressor matrix is defined

$$\boldsymbol{A} = [\boldsymbol{R}^T diag(\boldsymbol{w})\boldsymbol{G} \quad \boldsymbol{1}], \quad (3)$$

where matrix $\boldsymbol{G}$ maps mixtures constituents to the material groups (1 if belongs to group, 0 if not), $\boldsymbol{R}$ is the mixtures recipe according to Table 1. Vector $\boldsymbol{w}$ is a vector of WA of constituents, $\boldsymbol{w}$ is shown in Table 1. as a column of WA of aggregates. The last regressor column contains ones.

Estimation of the coefficient vector $c$ which is based on the *least squares* of the error between estimated $\widehat{\boldsymbol{w}_h}$ and measured $\boldsymbol{w}_h$ WA of hardened concrete is realized by pseudo-inversion as

$$\boldsymbol{c} = pinv(\boldsymbol{A})\boldsymbol{w}_h. \quad (4)$$

Measured values of WA $\boldsymbol{w}_h$ of concrete are shown in a row WA in Table 1. and also row $WA_{HC}$ in Table 3.

## Results

In this investigation, the WA of aggregates was tested. WA of recycled aggregate reaches up to ten times higher values than natural aggregate. WA of HC increases with WA of aggregate and with replacement ratio of recycled aggregate in mixture. WA of HC with high content of recycled aggregate in mixture reaches up to two times higher values than normal concrete. This results leads to a relation between WA capacity of aggregate and WA capacity of HC.

From measured values of WA of aggregates and HC was estimated values of material group coefficients $c_g$ and intercept term coefficient $c_0$.

Estimated values $c_g$ and $c_0$ are shown in Table 2.

Table 2. Groups of aggregates and group coefficients.

| Group | NA | $RA_{WA<6\%}$ | $RA_{6\%<WA<8\%}$ | $RA_{WA>8\%}$ | Sand | $c_0$ |
|---|---|---|---|---|---|---|
| Coefficients | 13.192 | 2.468 | 2.852 | 2.154 | 16.515 | -0.111 |

Estimated values of WA $\widehat{\boldsymbol{w}_h}$ are evaluated in a row $WA_{HC,Est}$ in Table 3.

Table 3. Measured and estimated WA of HC.

| Concrete | CN1 | CN2 | CR1 | CR1 | CR2 | CR2 | CR2 | CR3 | CR4 | CR5 | CR6 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Repl. [%] | 0 | 0 | 50 | 63 | 31 | 50 | 62 | 25 | 62 | 70 | 70 |
| $WA_{HC}$ [%] | 4.9 | 4.2 | 9.5 | 10.8 | 6.8 | 8.5 | 9.4 | 5.5 | 7.6 | 6.0 | 8.8 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $WA_{HC,Est}$ [%] | 4.7 | 4.6 | 9.1 | 10.6 | 7.2 | 8.3 | 9.5 | 5.0 | 8.0 | 5.9 | 9.1 |

Graph in Fig. 1 shows the goodness of fit of measured and estimated values of WA of HC.

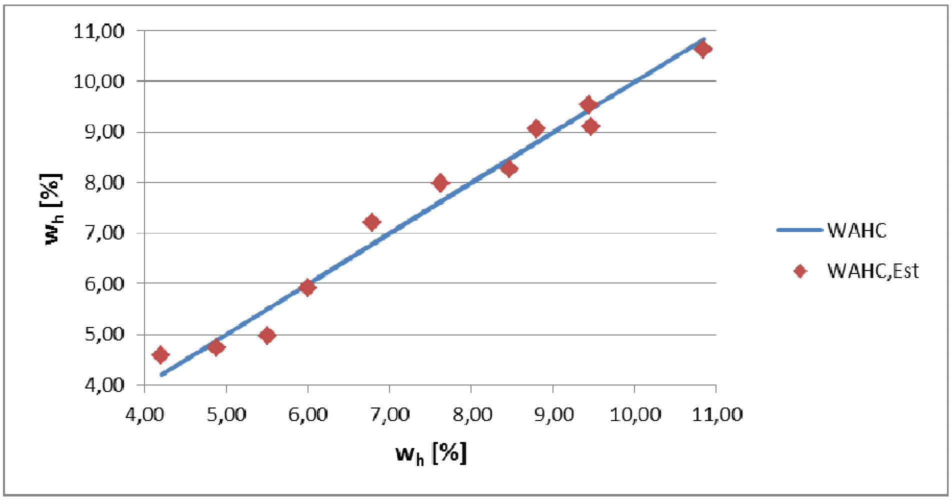


Fig. 1. Correlation between measured and estimated values of WA capacity of hardened concrete.

## Conclusions

Experimental determination of WA of aggregate samples and concrete mixtures with different replacement ratios samples were presented. Regression model of relationship between WA of concrete constituent, mixture recipe and WA of HC was defined. The coefficients of model were identified. Error of estimation of WA is acceptable. The WA estimator must be checked against greater number of measured data.

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## References

[1] J. de Brito, N. Saikia, Recycled aggregate in Concrete, Springer-Verlag, London, 2013.

[2] EN 206-1 Concrete – Part 1: Specification, performance, production and, CEN, Brussels, 2000.

[3] C.S. Poon, C.S. Lam, The effect of aggregate-to-cement ratio and types of aggregates on the properties of pre-cast concrete blocks, Cement & Concrete Composites 30 (283-289) 2008.

[4] M. Chakradhara Rao, S.K. Bhattacharyya, S.V. Barai, Influence of field recycled coarse aggregate on properties of concrete, Materials and Structures 44 (2011) 205-220.

[5] W.H. Kwan, M. Ramli, K.J. Kam, M.Z. Sulieman, Influence of the amount of recycled coarse aggregate in concrete design and durability properties, Construction and Building Materials 26 (2012) 565–573.

[6] L. Evangelista, J. de Brito, Durability performance of concrete made with fine recycled concrete aggregates, Cement & Concrete Composites 32 (2010) 9–14.

[7] EN 1097-6 Tests for mechanical and physical properties of aggregates – Part 6: Determination of particle density and water absorption, CEN, Brussels, 2000.