Variability of sorptivity in the concrete element according to the method of compacting

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Abstract

Sorptivity is one of the parameters which describe the durability performance of concrete. Its value depends not only on the composition of concrete mixture (including among others w/c ratio) but also on the curing procedure. The presented study attempts to determine the impact of the compacting procedure on the value of concrete sorptivity and its distribution along the height of the element.

Sorptivity tests of two concretes were made. Each concrete was manufactured in two coarse aggregate variants: with natural aggregate and with mixture of natural and recycled concrete aggregate (RCA). Tests were performed on the specimens obtained by slicing cores drilled from 260 mm high concrete blocks. Concrete in the blocks was compacted by three methods and the sorptivity was measured at different distances from the block upper surface. The results of the tests were compared with the results obtained on the 150 mm cube specimens cured in different conditions.

The results showed a clear (approximately linear) decrease of sorptivity values with distance from the upper surface of the element. The influence of the compaction method on the values of sorptivity and it distribution along the height of concrete element is also clearly visible.

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1. Introduction

Sorptivity of concrete is one of its main properties associated with durability of reinforced concrete structures [1, 2, 3]. Sorptivity is a measure of the capacity of concrete to absorb water under capillary forces. It is being tested by many methods and often considered as a constant value for a given concrete, thus its material feature. Measurements of sorptivity S are carried out by mass method or volumetric method in which concrete specimens are dried to the constant mass [4, 5]. In order to determine concrete sorptivity S by the mass method, the mass \( M(t) \) of water which penetrated into specimen under the capillary forces through the surface area \( F \) at time \( t \), should be measured. Water penetrates through one of specimen’s whole surface plane (e.g. bottom surface of cubic specimen) and the movement of penetration is unidirectional. The relation is approximately linear:

\[
M(t) = F \cdot S \cdot t^{0.5}.
\] (1)

Volumetric method is based on measuring the volume of water which penetrates the concrete at given time under the capillary forces through the surface equal to cross-section of glass cylinders with scaled pipettes through which water flows. In the initial stage of measurement, the water movement in concrete is similar to unidirectional flow and later turns into multidirectional flow. Relation between the volume of water which penetrates concrete and sorptivity is non-linear. Some researchers points out that concrete sorptivity in the structure is different than the one tested with specimens being cured in a laboratory in the water or in other conditions [6, 7, 8]. Concrete evaluation method developed by M. Alexander on the basis of its sorptivity among others distinguishes the following values:

- potentially possible to reach by material (in conditions of perfect performance and curing),
- possible to reach in actual conditions for performance and curing,
- sorptivity of concrete in the structure.

Measurement of concrete sorptivity in the structure can be conducted with the volumetric method by its natural relative humidity. However, bringing the result of measurement to concrete sorptivity in dry state, which is recognized as a material feature, encounters difficulties due to problems with determining concrete’s humidity and water absorption in the structure [9, 8]. The easiest way to solve the problem is to drill core specimens of concrete in the structure and to examine their sorptivity after drying with mass method [8]. However, it requires core specimens drilled out of the element thus it is a destructive test which is not always possible to execute. Sorptivity is also used to determine the effectiveness of the concrete curing [10, 11, 12] and the impact of the concrete curing method is being described in the articles [13, 14]. It is known that the concrete consolidation method, especially when improperly performed which cause overvibration, results in differences in material’s structure in the top and bottom part of the element. As a result of over-vibration, the aggregate moves downward, and the water and air move upward, causing porosity increment of the element’s upper part. In the tests which were described in the article, an attempt has been made to assess the impact of concrete consolidation method on the sorptivity, measured by mass method, at different distances from the upper surface of the element.

2. Materials and Research

2.1. Materials

The materials used in the research consist of Portland siliceous fly ash cement CEM II/B-V 32.5 produced by Cementownia Ożarów, natural aggregate composed of fractions 0-2 mm and 0-16 mm, RCA 0-16 mm derived from crushed laboratory specimens in age of at least 180 days remaining after test for compressive strength and tensile strength by splitting. The strength of crushed concrete ranged from 35 to 50 MPa. Four concrete series had been tested. Their composition is given in Table 1. In the R1 and R2 series, 50% by volume of coarse aggregate have been replaced by RCA aggregate. Sand point for N1 and R1 series was equal to 40%, whereas N2 and R2 series had sand point equal to 50%. The water/cement ratio was equal 0.5 for N1 and R1 series and 0.75 for N2 and R2 series. The plasticizer FK 88 produced by MC-Bauchemie was used in N1 and R1 series. Tap water was applied. Concrete was made in a laboratory mixer with working capacity of 150 dm³. Concrete elements in the form of blocks with
dimensions of 300x260x1200 mm, were made in the moulds of furniture board. Concrete was consolidated in one of the following ways:

Table 1: Proportions of concrete mixtures [kg/m³].

| Concrete mixture: | N1 | R1 | N2 | R2 |
|-------------------|----|----|----|----|
| cement CEM II/B-V  | 300| 300| 275| 275|
| water             | 150| 150| 206| 206|
| sand 0-2          | 637| 637| 785| 785|
| gravel 0-16       | 1353| 676| 1084| 542|
| RCA 0-16          | 0| 612| 0| 491|
| plasticizer FK 88 | 3| 3.5| 0| 0|

S - on the vibration table with the frequency of 40 Hz and vibrating period of 2 times for 2 minutes,
P - on the vibration table 2 times for 6 minutes (over-vibration),
W - with internal vibrator with the frequency of 300 Hz for 5 minutes.

After 2 days the elements were unmolded. They were stored under cover i.e. foil and systematically watered for a period of 30 days. Afterwards, 12 cores were drilled from the elements with diamond core drill. Each of them with diameter of 94 mm and height equal to the height of the element (260 mm) in parallel with direction of concreting. The cores were cut in 6 specimens from the top, bottom and the middle. It enabled to examine the sorptivity through the upper and bottom surface of the element and through the surface of cut at the height of 75, 105, 155 and 185 mm from the upper surface of the element. In addition to the elements in the form of blocks, cubic specimens of 150 mm edge were made to conduct the compressive strength test, according to standards PN-EN 206, PN-EN 12390-3 and sorptivity S_15, which was determined on the halves of cubic specimens by means of mass method, described in [15]. Half of the specimens were stored in water in the conditions defined in PN-EN 12390-2 for 28 days. The rest of specimens was stored for 90 days in the same conditions as blocks, from which the cores were taken and the compressive strength test was conducted on specimens in humid state. The average values of compressive strength obtained after 28 and 90 days are given in Table 2.

Table 2: The basic properties of the tested concretes.

| Concrete mixture: | N1 | R1 | N2 | R2 |
|-------------------|----|----|----|----|
| consistency (cone slump) [mm] | 20 | 20 | 180 | 150 |
| compressive strength 28 days [MPa] | 44.91 | 45.37 | 25.81 | 21.57 |
| compressive strength 90 days [MPa] | 50.97 | 54.96 | 26.86 | 31.87 |

3. Research Results

The results of sorptivity test for concretes, are shown in Figures 1 and 2 depending on the distance from the upper surface of the element. The mean values of sorptivity S_15 for concretes N and R, which was tested after 28 and 90 days since the specimens were made, are shown in the figures with horizontal dashed lines.

Dependencies of sorptivity S for concretes, measured on cores, on the distance x to element's upper surface, which were shown in Figures 1 and 2 had been approximated with linear functions in the following form:

\[ S = S_0 - m \cdot x \]  (2)
where $S_0$ is a parameter approximately equivalent to concrete’s sorptivity on element’s upper surface and coefficient $m$ is a measure of the intensity of sorptivity decrease along distance $x$. Function parameters were determined using the method of least squares. Also the coefficients $R_i$ of correlation between the results of measurements and values of approximating functions, had been determined. Calculation results are shown in Table 3. Figures 1 and 2 present graphs of the functions. Functions which were assigned to the series N1 and N2 are marked with a thicker line and functions assigned to the series R1 and R2 with a thinner line.

Fig. 1: Dependence of sorptivity on the distance from the upper surface for concretes N1 and R1.

Fig. 2: Dependence of sorptivity on the distance from the upper surface for concretes N2 and R2.
Consolidation method is marked with the following types of line: dotted-S; dashed-P; solid-W. Correlation coefficient \( R_f \) has reached high values, which are equivalent to an accurate adjustment of the adopted model, for most of the functions. \( R_f \) turned out to be quite lower for the series R1W and R2P but also the correlation of experimentally obtained values with the ones calculated from the adjusted function dependency, can be noticed for those particular series.

Table 3: Adjusted functions and their correlation coefficients \( R_f \).

| Concrete | Approximating function | \( R_f \) coefficient |
|----------|------------------------|----------------------|
| N1W      | \( S = 0.1669 - 0.2188 \times x \) | 0.8078               |
| N1S      | \( S = 0.1637 - 0.1941 \times x \) | 0.9112               |
| N1P      | \( S = 0.1579 - 0.2533 \times x \) | 0.8748               |
| R1W      | \( S = 0.1751 - 0.2379 \times x \) | 0.4685               |
| R1S      | \( S = 0.1687 - 0.0637 \times x \) | 0.7929               |
| R1P      | \( S = 0.1957 - 0.3289 \times x \) | 0.8808               |
| N2W      | \( S = 0.2631 - 0.3230 \times x \) | 0.9818               |
| N2S      | \( S = 0.4169 - 1.0487 \times x \) | 0.9709               |
| N2P      | \( S = 0.4250 - 0.8757 \times x \) | 0.8080               |
| R2W      | \( S = 0.2686 - 0.1056 \times x \) | 0.8997               |
| R2S      | \( S = 0.4313 - 1.0255 \times x \) | 0.9577               |
| R2P      | \( S = 0.3694 - 0.7195 \times x \) | 0.5377               |

The difference in sorptivity, depending on the distance from the upper surface of the element, was alleged for each concrete. It clearly depended on the concrete consolidation method. The lowest difference between the sorptivity tested on the upper and lower surface of the element for series N1 and R1, occurred during consolidation on the vibration table and it amounted to 54.8% and 17.2% respectively. The highest difference occurred during the over-vibration of concrete and it amounted to 97.3% and 125.5% respectively. The lowest difference for series N2 and R2, occurred during vibration with the internal vibrator and it amounted to 43.0% and 13.1% respectively. The highest difference occurred as in the previous series thus during the over-vibration of concrete mixture. It amounted to 193.6% and 177.1% respectively. The above mentioned values are much higher than presented in [16] differences in compressive strength of the concretes. The differences in the compressive strength of the core specimens of diameter and height equal to 94 mm, between the upper and lower layer of concrete amounted from 21.0% for series N1W to 26.6% for series N1P. During the compressive strength test with ultrasonic method, the differences amounted from 18.9% for series N1W to 30.3% for series N1P. Sorptivity of concrete specimens with natural aggregate N1 and R1 cured in the water was lower than sorptivity of specimens cured along with the beam. Differences amounted to 32.7% and 69.4% respectively. Concretes with recycled aggregate turned out to be less susceptible to the conditions of curing and the sorptivity of specimens stored along with beam was higher of 24.5% for R2 series and the same value \( S_{15} \) has been reached for R1 series after 28 and 90 days. These results are consistent with the assumptions presented in Durability Index (concrete quality control system). Sorptivity determined on specimens cured in water in a laboratory can be considered as a material’s potential capability, however in the actual conditions, even with proper curing, the higher sorptivity results are obtained.

4. Summary and Conclusions

Sorptivity tested on specimens stored in a laboratory and cured in water can be considered as a material’s feature of concrete and can be used to its classification. However, it must be taken into consideration that the measured values obtained with concrete in the structure can be much higher. Regardless of the vibration method, the better
consolidated concrete in the bottom part of the element had lower sorptivity for all the series than sorptivity measured after 90 days on specimens stored along with the beam. Sorptivity tested on the upper surface of the element in comparison to the result of the test on specimens after 90 days was higher from 4.7% for series R2W to 96.1% for series R1P.

On the basis of the results presented in the article, the following conclusions have been summarized:
- concrete sorptivity depends on the distance from the upper surface of the element,
- this dependency varies depending on concrete consolidation method in the element,
- the impact of improper consolidation (over-vibration) on the sorptivity is much higher than the impact on the mechanical properties of concrete,
- the impact of curing method on the sorptivity is lower for concretes with RCA aggregate than for concretes containing natural aggregate.

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