SLD4 CONFERENCE

Ivan S. Ignjatović [(1)], Vedran N. Carević [(1)]

(1) Faculty of Civil Engineering, University of Belgrade, Serbia

Abstract ID Number (given by the organizers): ……..

Keywords: concrete, carbonation, fly ash, accelerated test

Author contacts

Authors	E-Mail	Fax	Postal address
Ivan S. Ignjatović	ivani@imk.grf.bg.ac.rs		Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia
Vedran N. Carević	vedran@imk.grf.bg.ac.rs		Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia

Corresponding author for the paper: Ivan S. Ignjatović

Presenter of the paper during the Conference: Ivan S. Ignjatović

Total number of pages of the paper (the first excluded): 4

Instructions to authors submitting a final paper

Authors should submit a final paper corresponding to the accepted abstract **no later than 1 March 2018**. The organisers do not commit themselves to include in the Proceedings any paper received later than the above-mentioned deadline. At least one of the authors must register and pay his/her registration fee during the advance period (before May 1st 2018) for their paper to be included in the final programme of the Conference. In case an author has more than one paper, the registration would be valid only for one paper and co-author/s should be registered for publication of multiple papers.

This document provides information and instructions for preparing a paper to be included in the Proceedings of the SLD4 Conference. Papers and all related correspondences should be written in English.

In the manuscript, the paper article should be preceded by one page containing the author(s) information (as in this page). The page should contain the paper title, abstract ID number (given by the organisers), keywords, e-mail and postal address of each author. The first name will indicate the principal/corresponding author and those that follow, the co-authors in the order of precedence.

CARBONATION RESISTANCE OF HIGH VOLUME FLY ASH CONCRETE ESTIMATED WITH ACCELERATED AND NATURAL TESTS

Ivan S. Ignjatović (1), Vedran N. Carević (1)

(1) Faculty of Civil Engineering, University of Belgrade, Serbia

Abstract

The reuse of industrial residue streams such as fly ash (FA) can be beneficial both from economic and ecological points of view but the durability properties remain the key properties to ensure sustainable application of these materials.

The paper presents the results of accelerated carbonation tests carried out under CO2 concentration of 1%, 2%, 4% and 16% on high volume fly ash concrete (HVFAC) with 200 kg/m3 of cement and the same amount of fly ash. Concrete samples were also exposed to natural conditions of 0.0471% CO2 in the laboratory and after 21 months carbonation depths were measured. The effect of CO2 concentration on the kinetics of the carbonation process was analyzed. The suitability of widely used Tuutti's model for the prediction of carbonation depth was tested on designed HVFAC. Based on collected results, modified expression derived from this model was proposed in order to secure a more accurate and reliable prediction of carbonation depth of HVFAC under natural conditions.

1. INTRODUCTION AND OBJECTIVES

One of the most effective options for reducing the environmental impact of concrete is the use of high volume fly ash concrete (HVFAC) - concrete containing more than 50% of FA in the total cementitious material's mass [1]. In order to ensure a safe application of these green alternatives to cement concrete production, durability properties of HVFAC along with existing models for service life prediction must be evaluated.

Carbonation resistance of HVFAC was a topic of many studies, but there is still a lack of consistent results regarding the impact of CO_2 concentration during accelerated tests on these concretes. The main objectives of this study were to determine the influence of CO_2 concentration on the kinetic of carbonation process in HVFAC during accelerated tests. The relationship between carbonation depth at different CO_2 concentrations and the time of exposure as well as the prediction of carbonation depth in natural conditions based on the accelerated tests were determined.

2. INFLUENCE OF FA ON CARBONATION RESISTANCE

The use of FA in the concrete leads to a denser structure due to the formation of additional Calcium–Silicate–Hydrate (C–S–H) bond through the pozzolanic reaction. This leads to the higher compressive strength and lower porosity of concrete. On the other hand, the use of FA in concrete decreases the amount of $Ca(OH)_2$ due to a lower amount of used cement and FA pozzolanic reaction [2]. Therefore, a binding capacity of CO_2 (the reaction of $Ca(OH)_2$ and CO_2) will be lower in HVFAC compared to ordinary Portland cement concrete. The result will be higher HVFAC porosity and consequently higher carbonation depth [3], [4]. As therefore expected, results from the literature show opposite conclusions [2], [5]–[9].

2. MATERIALS

For the purpose of this research, HVFA concrete mixtures with 50% of class F FA in total cementitious materials mass were prepared and tested. Class F FA was obtained from "Nikola Tesla B" power plant in Obrenovac, Serbia. Bulk density of FA was 2075 kg/m^3, and the mean particle size was 8.53 μm. Fresh concrete mix contained 200 kg/m^3 of FA and the same amount of cement, 195 kg/m^3 of water and 1620 kg/m^3 of aggregate. The designed mixture provided 28-day compressive strength of $f_{c,28}$=32.2 MPa and 90-day compressive strength of $f_{c,90}$=42.5 MPa. At the age of 90 days, samples were divided into two groups: one for the accelerated carbonation tests and the other for the natural carbonation test (RH 52.2%, t=24.0^{o}C and CO_2 0.0471%).

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Carbonation resistance at different CO2 concentrations

In order to analyze the kinematic of this process, the measured carbonation depths at all CO_2 concentration levels (1%, 2%, 4% and 16%) are shown as a function of the exposure time (7, 14 and 28 days), Figure 1 (left). For all CO_2 concentrations, carbonation depth and square root of time showed a linear correlation with coefficient of determination (R^2) ranges between 0.779 and 0.891.

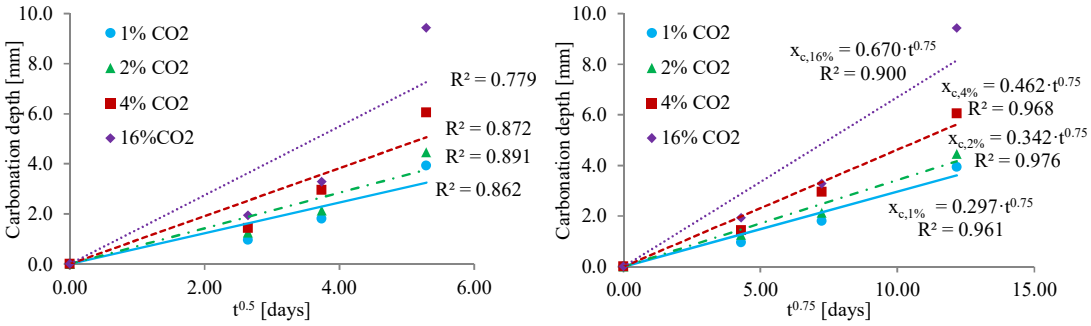

Figure 1. Carbonation depth at CO_2 concentrations of 1%, 2%, 4% and 16% versus time: $t^{0.5}$ (left) and $t^{0.75}$ (right)

Obviously, after 7 and 14 days of exposure HVFAC showed lower carbonation depth while after 28 days HVFAC had higher carbonation depth then can be expected by the trendline prediction. There was a slower increase of carbonation depth in HVFAC in the first two weeks of exposure, which was accelerated after 14 days resulting in higher carbonation depth compared to predictions. That raised the question regarding the reliability of predictions formed on the assumption that the relationship between carbonation depth and square root of time is linear, which is common for ordinary Portland cement concrete.

During the carbonation depth measurements a change in the carbonated front shape was noticed in HVFAC samples. Until 14 days carbonated zone was uneven and jagged (Figure 2a,b). The reason may lie in the fact that in HVFAC pozzolanic reaction consumes a part of available $Ca(OH)_2$ most likely in an uneven extent. This allows the CO_2 to penetrate faster in some parts of the concrete sample where $Ca(OH)_2$ is lacking. As the process took place over time, carbonation of the C-S-H bond occurred leaving a more flat and deep front (Figure 2c).

Having this in mind, a conclusion can be made that a linear relationship between the carbonation depth and square root of time ($t^{0.5}$) was not appropriate for HVFAC. Instead, functions considering $t^{0.75}$ as a parameter showed a much better correlation with measured results, Figure 1 (right). Coefficient of determination in this case for all CO_2 concentrations ranged from 0.900 to 0.976.

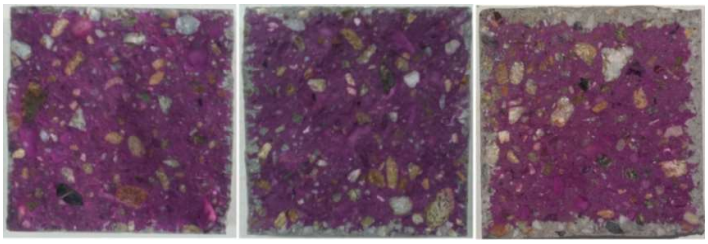

Figure 2. Carbonation depth at 4% CO_2 concentration and at the age of 7, 14 and 28 days

Carbonation depth in natural conditions at a certain time can be calculated based on the carbonation depths measured in accelerated tests by applying the equation:

$$x_{c,NAT}(t) = x_{c,ACC}\sqrt{\frac{CO_{2,NAT}}{CO_{2,ACC}}}\cdot\left(\frac{t}{t_{ACC}}\right)^{n} \quad (1)$$

where exponent n takes the value 0.5 for Portland cement concrete [10] or 0.75 for HVFAC as it is proposed here. In order to approve that, values of the measured carbonation depth for HVFAC after 21 months of exposure in natural conditions (8.13 mm) were compared to the values based on the accelerated test measurements at different CO_2 concentration levels, Figure 3. These calculated values were obtained using Eq. 1.

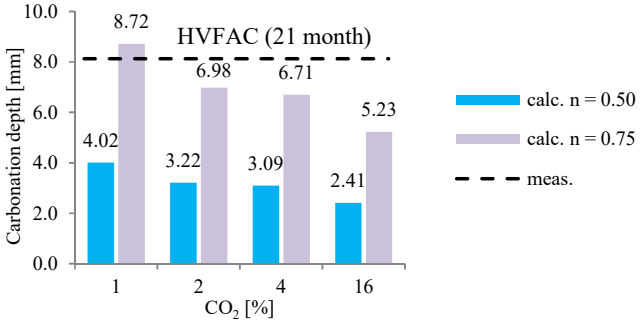

Figure 3. Calculated and measured carbonation depth of HVFAC after 21 months of exposure in the natural conditions

Calculated carbonation depths using n=0.75 showed better correlation to the measured value under natural exposure conditions. The best results were obtained with the lowest CO2 concentration of 1%. In that case, the calculated value was 7% higher than the measured value. Calculated values based on accelerated tests at 2% and 4% CO2 were 14% and 17% lower than the measured ones, respectively. The only value of the estimated depth that significantly deviates from the measured value is the one calculated with concentration of 16% CO2 and it was 36% lower than the measured value.

5. CONCLUSIONS

Based on the conducted measurements of carbonation depth of HVFAC and performed calculations, the following conclusions can be made:

- Linear relationship between the carbonation depth and square root of time ($t^{0.5}$) was not appropriate for tested HVFAC. New proposed function ($t^{0.75}$) had a better correlation with the measured results, for all applied CO_2 concentrations.
- With the increase in CO_2 concentration, carbonation depth increased, but carbonation process slowed down.
- Prediction of carbonation depth at a certain time and under certain exposure conditions cannot be performed based on the laboratory measurements at high CO_2 concentration (16%). CO_2 concentration up to 2% can be used to predict the carbonation depth using Eq. 1 for all tested concretes in sheltered exposure conditions. The discrepancy of the results was up to 17% compared to measured values.

ACKNOWLEDGEMENTS

The work reported in this paper is a part of the investigation within research project: TR36017, 'Utilization of byproducts and recycled waste materials in concrete composites in the scope of sustainable construction development in Serbia: investigation and environmental assessment of possible applications', supported by the Ministry of Education, Science and Technological Development, Republic of Serbia.

REFERENCES

[1] ACI Committee 232.3R-14, "Report on High-Volume Fly Ash Concrete for Structural Applications.," Farmington Hills, MI, USA, 2014.
[2] P. Sulapha, S. F. Wong, T. H. Wee, and S. Swaddiwudhipong, "Carbonation of Concrete Containing Mineral Admixtures," *J. Mater. Civ. Eng.*, vol. 15, pp. 134–143, 2003.
[3] M. D. A. Thomas and J. D. Matthews, "Carbonation of fly ash concrete," *Mag. Concr. Res.*, vol. 44, no. 160, pp. 217–228, 1992.
[4] A. Younsi, P. Turcry, A. Ait-Mokhtar, and S. Staquet, "Accelerated carbonation of concrete with high content of mineral additions: Efect of interaction between hydratation and drying," *Cem. Concr. Res.*, vol. 43, pp. 25–33, 2013.
[5] V. G. Papadakis, "Effect of supplementary cementing materials on concrete resistance against carbonation and chloride ingress," *Cem. Concr. Res.*, vol. 30, pp. 291–299, 2000.
[6] K. Sisomphon and L. Franke, "Carbonation rates of concretes containing high volume of pozzolanic material," *Cem. Concr. Res.*, vol. 37, pp. 1647–1653, 2007.
[7] L. Jiang, B. Lin, and Y. Cai, "A model for predicting carbonation of high-volume fly ash concrete," *Cem. Concr. Res.*, vol. 30, no. 5, pp. 699–702, 2000.
[8] J. Khunthongkeaw, S. Tangtermsirikul, and T. Leelawat, "A study on carbonation depth prediction for fly ash concrete.pdf," *Constr. Build. Mater.*, vol. 20, pp. 744–753, 2006.
[9] W. Ashraf, "Carbonation of cement-based materials: Challenges and opportunities," *Constr. Build. Mater.*, vol. 120, pp. 558–570, 2016.
[10] K. Tuutti, *Corrosion of steel in concrete*. Stockholm, Sweden: Swedish Cement and Concrete Reasearch Institute, 1982.