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Reduction of the capillary water absorption of foamed concrete by using the porous aggregate

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Abstract. The article reports on the research of reduction of the capillary water absorption of foamed concrete (FC) by using the porous aggregate such as the granules of expanded glass (EG) and the cenospheres (CS). The EG granular aggregate is produced by using recycled glass and blowing agents, melted down in high temperature. The unique structure of the EG granules is obtained where the air is kept closed inside the pellet. The use of the porous aggregate in the preparation process of the FC samples provides an opportunity to improve some physical and mechanical properties of the FC, classifying it as a product of high-performance. In this research the FC samples were produced by adding the EG granules and the CS. The capillary water absorption of hardened samples has been verified. The pore size distribution has been determined by microscope. It is a very important characteristic, specifically in the cold climate territories– where temperature often falls below zero degrees. It is necessary to prevent forming of the micro sized pores in the final structure of the material as it reduces its water absorption capacity. In addition, at a below zero temperature water inside these micro sized pores can increase them by expanding the stress on their walls during the freezing process. Research of the capillary water absorption kinetics can be practical for prevision of the FC durability.

1. Introduction

Building sector consumes up to 40 per cent of all energy [1]. As a result of the growing energy costs the demand for the energy – efficient construction has become increasingly important. [2]. Developing production of more environmentally friendly construction materials has been the focus of the green-minded scientists [3], for example, such as the FC.

The recent trends have led towards a more widespread use of the FC in the structures of modern buildings. It has been one of the most promising types of the lightweight concrete. Production of the FC ensures the construction of a precast building element as well as the construction of a monolithic application [4].

The shrinkage or the decrease in volume over the time in the curing process is one of the main disadvantages of the FC. This insufficiency can be addressed by adding the porous fillers [5]. Behaviour of variety of porous aggregates has been widely researched [6], [7], [8].

Moisture has a considerable impact on the durability properties of the building materials. The material characteristics, as well as the drying conditions affect the drying speed of the building materials, specifically that of the porous materials, such as the FC [9].

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The aim of this research is to analyse reduction of the capillary water absorption of the FC by using the porous aggregate (the EG granules and the CS) and to compare these results to autoclaved aerated concrete results.

2. Materials and methods

All of the experimental mixtures of the FC were obtained in a laboratory by using an intensive mixer with a turbulence effect. This mixer performs three functions simultaneously: it performs as a concrete mixer, a foam generator and eventually – as a pump for delivery of the mixes of foamed concrete.

2.1. Materials used to obtain the FC mixes

The normal type Portland cement CEM I 42.5 N was used as the main binding agent. . According to the information provided by the producer ("CEMEX", Ltd.), the compressive strength is no less than 10 MPa after 2 days, no less than 42.5 MPa after 28 days; the specific surface of the Portland cement – 3500-3900 cm^2/g.

The natural, washed sand (fraction size 0/0.3 mm) was used as a filling component. The sand ensures two main tasks – it works as a filler and it promotes the foaming process during the mixing process.

A synthetic foaming agent (PB-Lux), which had been mixed with water beforehand, was added during the mixing (as the method of mixed foaming was used).

The pozzolanic additives microsilica or silica fume (MS) and metakaolin (MK) were added. The MS works as the supplementary cementing material and has fine particles: 1 μm – 15 nm (approximately 100 smaller than the particle of the Portland cement) [10]. The technogenic waste MK (obtained in form of powder from the manufacturing of the EG granules) improves the workability and durability properties of concrete. The risk of the potential alkali – silica reactions (may occur between the Portland cement and glass aggregate) is decreased by adding the pozzolanic admixtures [11].

The EG granules and the CS were used as the porous aggregate and the shrinkage reducing additive. The EG granules of fraction size 4 to 8 mm in white – cream colour were added to the FC mixes (see figure 1). According to the information provided by the producer (JSC "Stiklaporas") the EG granules is both a chemically and biologically persistent material and has a structure of closed – pores (with a low ability of water absorption). The CS are lightweight spheres filled with inert gas or air that have been produced as a by-product of coal combustion at the thermal power plants. The diameter size of spheres varies from 30 to 350 μm [12] and they usually are in white colour or transparent (see figure 1). The CS are inert to acids and alkalis, have high strength (20 – 100 MPa) [12].

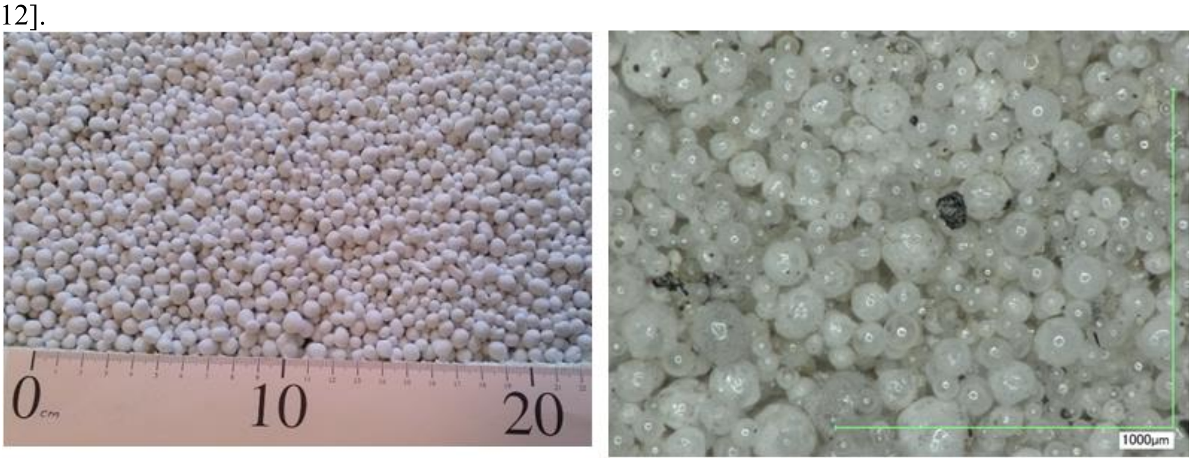

Figure 1. Porous aggregate used in the mixes of the FC (on the left – the EG granules, on the right – a microscope image of the CS).

The polyvinyl alcohol fibres (PVA) with the average length of 12 mm were also used to obtain the FC mixes. The PVA fibres are characterized by large modulus of elasticity (30000 – 40000 MPa) and they have good linking with the cement stone [13].

The polycarboxylate based superplastifying chemical admixture (produced by the "Stachema") was used for some of the FC mixes.

Six experimental FC mixes (density class D800) were produced. The porous aggregate (the EG granules) was added in the mixes IP, IIP, IIIP. The sand was added in the mixes I and IP, however it was replaced by the CS in the mixes II, IIP, III, IIIP. A superplastifying admixture was added in the mixes III and IIIP to reduce water cement ratio. The compiled designations of the experimental FC mixes are presented in table 1.

Table 1. Designations of the FC mixes (weight proportions of the cement).

	I	IP	II	IIP	III	IIIP
Portland cement CEM I 42.5 N	1.00	1.00	1.00	1.00	1.00	1.00
Sand 0/0.3 mm	0.63	0.63	–	–	–	–
Water	0.61	0.61	0.75	0.75	0.63	0.63
Foaming agent	0.006	0.006	0.004	0.004	0.006	0.006
CS	–	–	0.50	0.50	0.50	0.50
Metakaolin	0.05	0.05	0.05	0.05	0.15	0.15
Microsilica	0.04	0.04	0.04	0.04	0.04	0.04
EG granules, 4 to 8 mm	–	0.70	–	0.80	–	0.60
PVA fibres	0.019	0.019	0.019	0.019	0.019	0.019
Superplasticizer	–	–	–	–	0.01	0.01
Water/cement ratio	0.61	0.61	0.75	0.75	0.63	0.63

2.2. Methods of testing

The capillary water absorption test was performed according to the methodology of LVS EN 722-11. During the test the specimens (cubes in size of 100 x 100 x 100 mm) were immersed in water (in depth of 5 ± 1 mm). Masses of samples have been controlled periodically after 10, 15, 20, 30 minutes and 1, 1.5, 2, 3, 6, 24 hours from the beginning of the test. The values of the coefficient of the capillary water absorption were calculated by the formula:

$$C = (m_s - m_d)/A_s, \text{ where:} \quad (1)$$

m_s − specimen mass after the process of soaking (g);
m_d − specimen mass after the process of drying (g);
A_s − cross area of the specimen surface immersed in water (dm^2).

The microstructures of the mixed FC compositions (I, IP, II, IIP, III, IIIP) were researched by the optical microscope VHX-2000 "Keyence Corporation". The pore size of the FC matrix and the porous aggregate was determined by the computer programme "VHX-2000 Analyzer" from the obtained images. Diameters of pores were measured by using a special tool in the computer programme "VHX-2000 Analyzer" by matching two points on the image's surface of pore. In each image were measured at least 50 diameters of pores.

Total porosity was calculated by the formula:

$$P = 1 - \frac{\rho_0}{\rho_1} \cdot 100\%, \text{ where:} \tag{2}$$

ρ_0 − bulk density (kg/m^3), determinated by using Le Chatelier flask;
ρ_1 − material density (kg/m^3), calculated by dry mass and volume of sample;

3. Results and discussion

3.1. Capillary water absorption

The data on the capillary properties obtained from all of the produced FC mixes (mixes with the EG granules: IP, IIP, IIIP; mixes with the CS: II, IIP, III, IIIP; mixes with the superplasticizer: III, IIIP) are summarized in the graph (see figure 2 and figure 3).

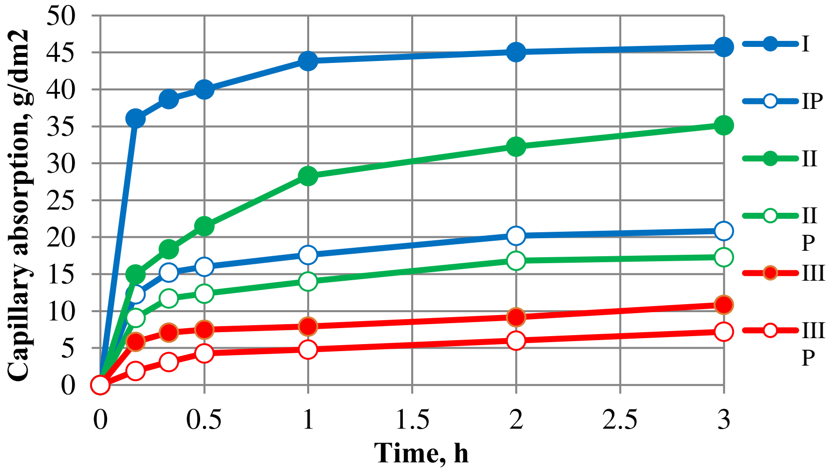

Figure 2. Results obtained from the capillary absorption test (first 3 hours).

Compilation of data obtained from this experiment permits to conclude that the FC samples with the light and porous aggregate present lower values of the capillary water absorption compared to other specimens (although the samples of compositions with added porous aggregate have smaller values of density and more porous structures compared to the reference mixes). It can be explained by the low ability of water absorption of the used aggregates and the closed pore structure.

In comparing the samples with the porous aggregate, it can be concluded that the specimens prepared with the IIP FC mixture (with density 445 kg/m^3) have lower capillary absorption capacity than the IP composition samples (with density 565 kg/m^3). The specimens prepared with the IIP composition presented less dense and more porous (84.4%) structures (see figure 6, table 2) compared to the IP mix (porosity 80.2%) as there were two types of light, porous aggregate mixed – the CS and the EG granules. In comparing the FC compositions with the porous aggregate, the least capillary transport was observed in the IIIP samples where the superplastifying chemical additive had also been added to the porous EG granules and the CS. It resulted in a more dense (density 589 kg/m^3) and less porous (porosity 79.4%) material structure (see figure 6, table 2) than the previous compositions (the IP and IIP); the capillary properties of the FC mixtures have been improved.

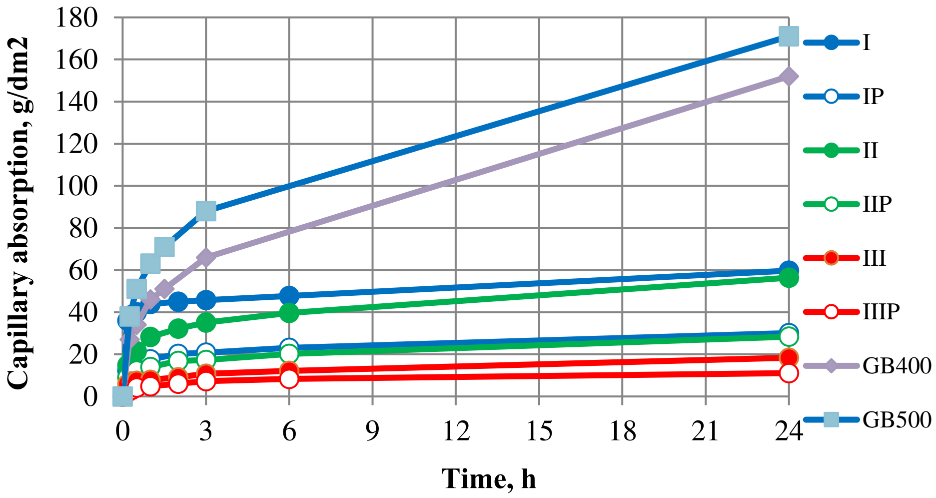

Figure 3. Results obtained from the capillary absorption test (24 hours) comparing to the AAC specimens.

The parameters for all of the experimentally obtained FC samples (from all of the obtained mixtures) have been compared to the samples of commercially available autoclaved aerated concrete (AAC) of similar densities of 400 kg/m^3 and 500 kg/m^3 (samples designated as GB 400 and GB 500), as presented in the graph of figure 3. It can be concluded from the gathered results that the AAC specimens have the highest values of capillary transport compared to the FC samples. For example, comparison of the samples of compositions GB 500 and I shows that the AAC has approximately 63 % higher values of capillary water absorption than the FC. This observation is explained by the pore systems of the AAC and the FC. The non-autoclaved FC mostly has closed pores, in return the autoclaved concrete has the open pore system [14]. Formation of the pore system depends mainly on the manufacture and production technology (thermal treatment of the AAC involves high temperature and pressure).

3.2. Structure investigation

The FC samples were sawn in half for a better analysis of the structure. An equable location of porous aggregate in the matrix of FC is presented in figure 4. It can be seen that the EG granules are not located in a particular area of surface; they are arranged quite evenly throughout the area of composite FC specimen.

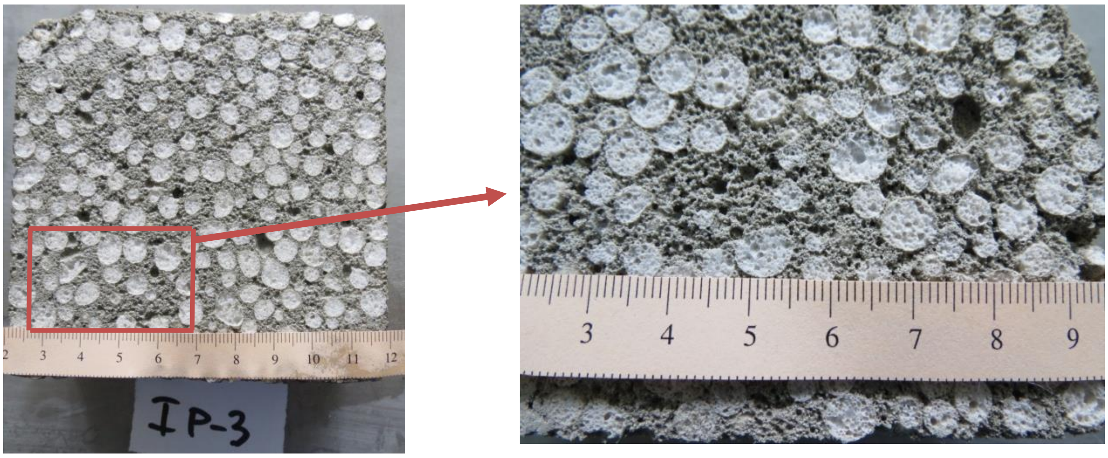

Figure 4. Location of porous aggregate in the FC matrix.

Higher values of density resulted in better parameters of compressive strength as presented by the compiled data in table 2. Approximately 5% growth in density ensures approximately 29 % increase in compressive strength (comparing the data of the mix I and mix II). By adding the superplasticizer to the FC mix III, it was possible to obtain approximately 1.3 times higher value of density and approximately 6 times higher compressive strength, than it was compared to the mix I.

Table 2. Summary of the obtained results.

	I	IP	II	IIP	III	IIIP
Average diameter of pore, µm	525,98	521,02	522,16	500,42	382,18	560,88
Density, kg/m^3	736	565	769	445	952	589
Coefficient of capillary water absorption, g/dm^2	59,8	30,1	66,6	30,5	18,3	11
Total porosity, %	74,3	80,2	73,1	84,4	66,7	79,4
Compressive strength, MPa 28d.	2,52	1,41	6,25	2,46	14,43	5,73

Density (and also values of compressive strength) is reduced by adding the light and porous aggregate to the FC mixes, due to increase the porosity level. In the mixes I and IP the reduction of density and compressive strength is respectively – 30% and 78%, while in the mixes III and IIIP (where superplastifying additive was used) the values of density and compressive strength were approximately 62% lower. The porosity in the mixes IP and IIIP was approximately 1.1 and 1.2 times higher than in the mixes I and III.

A tendency can be observed between the compressive strength and the average diameter of pores (see figure 5).

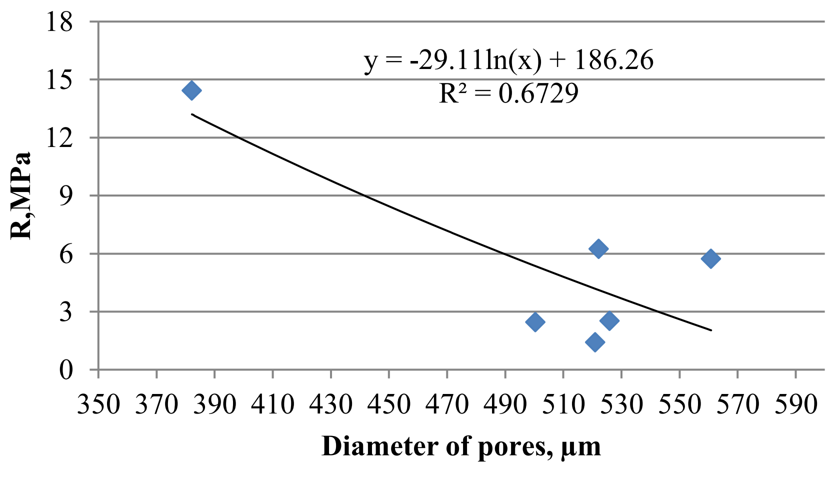

Figure 5. Correlation between compressive strength and average diameter of pores.

The larger is the average diameter of pores, the smaller are the values of compressive strength. However, there are some exceptions. For example, the data obtained from the FC mix III and IIIP. In the mix IIIP the average diameter of pores is 560.88 µm and compressive strength is 5.73 MPa (at the age of 28 days), however in the mix III the average diameter of pores is smaller (382.18 µm), but the value of compressive strength – higher (14.43 MPa). The use of the superplastifying additive could be the reason for this exception.

The view of structures (of the FC mixes IIIP and IIP) is presented in figure 6. In summarizing the obtained data, it can be concluded that the specimens with denser structure are less porous. The average density value of specimens from the mixture IIIP (the superplastifying additive was added) was 589 kg/m^3, while in the specimens prepared from the IIP composition (445 kg/m^3) it was approximately 32 % less. The total porosity of the composition IIIP is 79.4%, however the total porosity of the composition IIP is 84.4%. It has resulted in better capillary absorption properties (the sample from the IIIP mixture showed the smallest values of the capillary absorption coefficient).

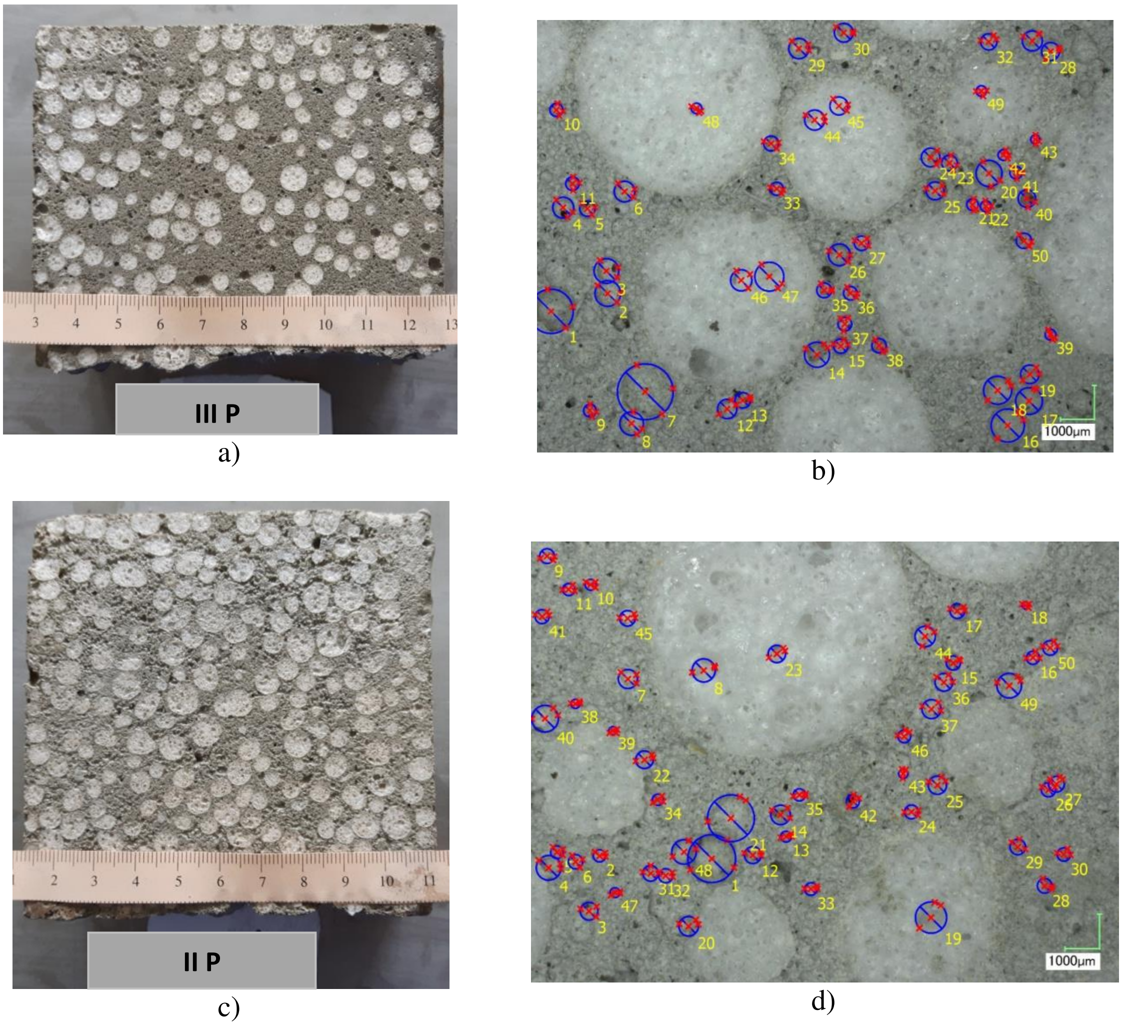

Figure 6. View of the structures (compositions IIIP and IIP).

Contact zones between the porous aggregate (the EG granules) and the main binding material are presented in figure 7. The EG granules are connected by the Portland cement paste. The contact zone between the porous granules and the cement paste, with some particularly small air gaps observed in separate places, is properly presented in figure 7. There is a good adhesion between the binding material and the aggregate. The pore structure is also similar – the EG granules and the matrix of FC have small, mostly closed pores with equable location, as has been mentioned before (homogeneous microstructures were obtained).

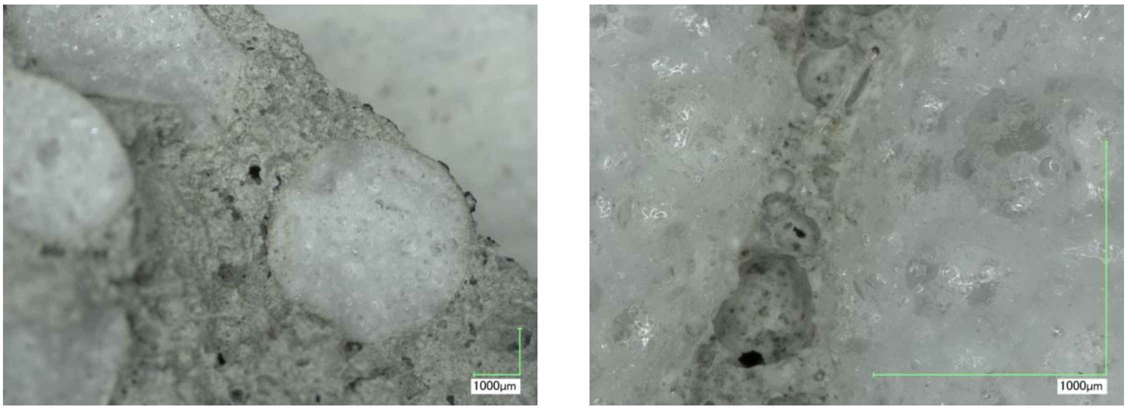

Figure 7. Contact zone between the EG granules and the matrix of FC.

4. Conclusions

- It is possible to obtain mixtures with reduced values of density and increased porosity level by adding the lightweight and porous aggregate to the foamed concrete.
- After 24 hour tests the compositions with porous aggregate (IP, IIP, IIIP) have reached 56, 49 and 40 % lower values of capillary water absorption, compared to the reference mixtures (I, II, III), because of the low ability of water absorption and closed pore structures of the used aggregates.
- As a cause of the closed pore structure of the foamed concrete, it has 10 times lower coefficient value of capillary water absorption, compared to the autoclaved gas silicate with similar densities.
- The use of both the superplastifying additive and the porous aggregate (composition IIIP) has produced a more dense and less porous structure among the obtained compositions resulting in observation of the lowest value of capillary water absorption.
- The porous aggregate and the foamed concrete both have similar structures of pores. As a result there has been a stable mix against segregation, having good homogeneity and contact zone to the cement stone.

Acknowledgement
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References

[1] United Nations Environment Programme Sustainable Buildings and Climate Initiative 2009 *Building and Climate Change. Summary for Decision-Markers* 62
[2] Mydin M 2011 Effective thermal conductivity of foamcrete of different densities *Concr. Res. Lett.* **2** 181–189
[3] Bajare D, Bumanis G and Korjakins A 2014 New Porous Material Made from Industrial and Municipal Waste for Building Application **20** 3–8
[4] Sahmenko G, Korjakins A and Namsone E 2016 High Performance Foam Concrete Produced in Turbulence Mixers in *Europe and the Mediterranean Towards a Sustainable Built Environment: SBE16 Conf.* 71–78
[5] Namsone E, Šahmenko G, Korjakins A and Namsone E 2016 Influence of Porous Aggregate on the Properties of Foamed Concrete *Constr. Sci.***19** 13–20
[6] Bentz D and Snyder K 1999 Protected paste volume in concrete: Extension to internal curing using saturated lightweight fine aggregate *Cem. Concr. Res.* **29** 1863–1867
[7] Zhutovsky S, Kovler K and Bentur A 2004 Influence of cement paste matrix properties on the

autogenous curing of high-performance concrete *Cem. Concr. Compos.* **26** 499–507
[8] Schlitter J, Henkensiefken R, Castro J, Raoufi K and Weiss J 2010 Development of Internally Cured Concrete for Increased Service Life
[9] Karagiannis N, Karoglou M, Bakolas A, Krokida M and Moropoulou A 2017 Drying kinetics of building materials capillary moisture *Constr. Build. Mater.* **137** 441–449
[10] Hwang C and Tran V 2015 A study of the properties of foamed lightweight aggregate for self-consolidating concrete *Constr. Build. Mater.* **87** 78–85
[11] Lian-Tong L, Ding and Zongjin 2002 Effects of Metakaolin and Silica Fume on Properties of Concrete *ACI Mater. J.* **99** 393–398
[12] Krämer C, Kowald T and Trettin R 2015 Pozzolanic hardened three-phase-foams *Cem. Concr. Compos.* **62** 44–51
[13] Li V 2008 *Engineered Cementitious Composites (ECC) – Material, Structural, and Durability Performance in Concrete Construction Engineering Handbook* (CRC Press) 78
[14] Noraini I, Zahari M, Mujahid A and Zaidi A 2009 Foamed Concrete: Potential Application in Thermal Insulation in *Proc. of MUCEET2009 Malaysian Technical Universities Conf. on Engineering and Technology* 47–52