INFLUENȚA TIPULUI DE AGREGAT ASUPRA PERMEABILITĂȚII FAȚĂ DE APĂ A BETONULUI
AGGREGATE TYPE IMPACT ON WATER PERMEABILITY OF CONCRETE

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Permeability of concrete to water depends on a number of factors. The actual micro-structure of cement paste, and consequently also the number and size of pores in the paste have a major impact on it. Aggregate type used in concrete making also affects the depth of pressurized water penetration into the concrete. The influence of various types of crushed mineral aggregates (basalt, limestone, diabase and andesite) on the concrete pressurized water absorption in comparison to the benchmark concrete produced with river aggregate was studied. The porosity of hardened concrete cement matrix has been examined by the Krüss optical stereo-zoom microscope and adequate software. The share of the pores smaller than ≤1μm in the hardened cement paste decreases with the increase of water-cement factor. On the other hand, the share of the pores larger than ≥10μm increases with the increase of water/cement factor.

Permeabilitatea față de apă a betonului depinde de o multitudine de factori. Microstructura matricei de ciment, porozitatea şi distribuția porilor după mărime influențează major permeabilitatea față de apă. De asemenea, agregatele influențează adâncimea de pătrundere a apei sub presiune în beton, ca măsură a permeabilității față de apă. În cadrul lucrării s-a studiat influența agregatelor de concasare (bazaltice, calcaroase, diabazice şi andezitice) prin comparație cu agregatele de râu, din compoziția betonului, asupra pătrunderii apei sub presiune.

Porozitatea matricei betonuui a fost examinată prin microscopie optică cu un software dedicat. Proporția porilor cu dimensiunea ≤1μm în matricea betonului scade cu creşterea raportului apă/ciment. Pe de altă parte proporția porilor cu dimensiunea ≥10μm creşte cu raportul apă/ciment.

Keywords: *hardened cement structure, concrete, porosity, optical microscopy, aggregates*

1. Introduction

Cement paste can contain a wide spectrum of pores, in terms of their size. Jawed, Skalny and Young provided one of the possible classifications of pores in cement paste: the large pores and capillary pores [1]. According to these authors, large pores have the size larger than 5 μm. The origin of these pores can vary. They can be intentionally produced by using air entrainers, further they can be formed as a consequence of the air trapped in process of concrete mixing, or as a consequence of high water/cement ratio [1,2]. The importance of large pores is reflected in their considerable impact on the concrete strength [3,4].

The research of Luhoviak, Callot, Wittman and Zaytsev [5] have shown what the influence of large pores on propagation of micro-fissures in hardened cement paste is. It was determined that micro-fissures, when they occur under the action of a certain value of stress, start from large pores. Micro-fissures propagation is faster if the large pores are numerous.

Capillary pores are divided into macropores, mesopores and micropores. Macropores have the size larger than $5 \cdot 10^{-2}$ μm. They represent the remains of the space which was filled with water in fresh cement paste, and have a considerable impact on permeability and durability of cement paste. Mesopores have the size of $26 \cdot 10^{-4}$ do $5 \cdot 10^{-2}$ μm and they occur as a remaining space which was filled with water in fresh cement paste, and as the pores which build the C-S-H structure. Micropores are sizes smaller than $26 \cdot 10^{-4}$ and they represent a part of C-S-H structure – gel pores. Open porosity represent the volume of the pores which can communicate between themselves, and which can be filled with fluid using some procedure [6,7].

Apart from porosity, within the microstructure of hardened concrete, attention should be paid to the contact zone between the aggregate grains and hardened cement paste – the so called transit zone.

Winslow [8,9] et al. demonstrated that cement pastes in concretes and mortars have a different arrangement of pores in comparison to the ordinary paste which was hydrated without any aggregate. They have demonstrated that in mortars and concretes, there is an additional formation of pores which have the larger diameter than the critical pore diameter of ordinary cement paste. We have concluded that these larger pores were present only in the contact zone between the

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aggregate and cement paste. These pores have the negative impact on permeability and durability of concrete. [8,10].

From the theoretical point of view, introduction of low-permeability aggregate grains into a considerably more porous and permeable cement paste should contribute to reduction of overall concrete permeability to water.

In practice, however, something quite the opposite occurs; the coarser the aggregate, the higher the permeability [11]. The explanation to this phenomenon lies in the properties transit zone at the contact of the aggregate and hardened cement paste [12].

Lower water/cement ratio and higher hydration degree result in the reduction of water diffusion (expressed through the diffusion coefficient) through the hardened cement paste in the function of time, where: A – is the Portland cement paste, B – aluminate cement paste, C – Portland cement mortar with limestone aggregate, D – concrete, figure 2 [13].

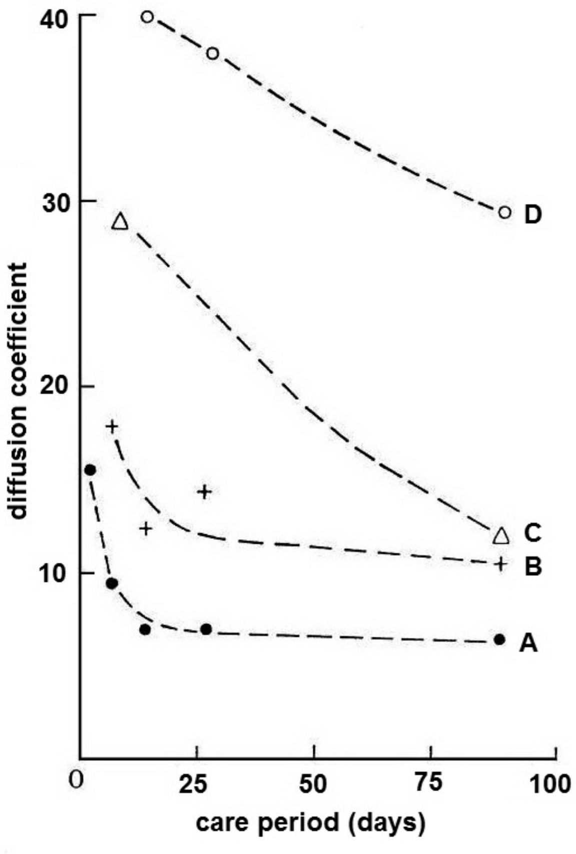

Fig. 1 - Water diffusion through the cement materials at various ages / / *Variația coeficientului de difuzie a apei prin materiale cu matrice de ciment, în funcție de timpul de păstrare.*

In figure 1 it can be seen that the presence of the aggregate increases water diffusion due to the forming of a transit zone. According to the previous statement, as expected, the diffusion degree decreases in time.

2. Theoretical considerations of the hardened concrete microstructure

When discussing microstructure of hardened concrete, one has in mind the microstructure of its components, and in such considerations the pores are invariably taken into account. A good aggregate for concrete production features very low porosity and it can be neglected in such considerations. Much more important is the porosity of hardened cement paste. Three structural characteristics which are basic for the description of porous materials are: total porosity, specific surface area and pore distribution.

The shape of the pores can be listed as the fourth fundamental characteristic, though it is more difficult to quantify than the previous three characteristics.

The pores in concrete have the different origin [14]. A part of water, primarily in concretes which is made with high water/cement ratio can form structural defects by creating "pockets" filled with water under the coarse aggregate grains, particularly of those having irregular shapes. Later on, in these places remain large pores when the free water from the hardened concrete evaporates in the process of drying. A large share in the concrete porosity is constituted by the gel pores which are the integral part of the hardened cement paste structure, as well as capillary pores. In the hardened concrete may also be present the air floccules which were not evacuated from the concrete due to inefficient placing, or which have been intentionally caused by applying air entrainers.

With the increase of water/cement ratio, the total porosity increases, and with the increase of hydration degree, it decreases, as presented in figure 2 [15].

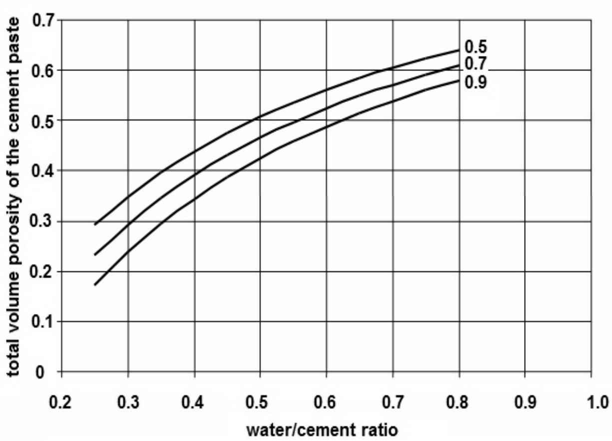

Fig. 2 - Impact of water/cement ratio and hydration degree (0.5, 0.7 and 0.9) on the total porosity of hardened cement paste (percent of volume) / *Influența raportului apă/ciment şi a gradului de hidratare (0,5; 0,7 şi 0,9) asupra porozității totale a pietrei de ciment (% vol.)*

Cement paste occupies 20 to 30% of concrete volume, so its total porosity, considering almost negligible porosity of aggregates, is significantly lower. For partially hydrated cement paste, the capillary pores are interconnected and constitute a system of capillary pores. The consequence of that is lower strength, higher permeability, higher susceptibility to damage caused by freezing and thawing and due to the action of aggressive chemical solutions. These problems can be avoided to a certain extent when a sufficiently high level of hydration of cement paste is achieved [16,17].

According to the tests, it has been found that the maximum points on the differential curve (that is, the points corresponding to the critical width of the pores), were dependent on the initial water/cement ratio, but that they depend yet on the hydration time [18]. As the hydration progresses, the newly formed gel destroys the system of capillary pores which becomes segmented. In the process the capillary pores remain interconnected, but via gel pores, which, due to their size, are impermeable to water. Approximate period of concrete curing to achieve a certain degree of hydration when the pores become segmented, for various water/cement ratios, according to Powers, is given in the Table 1 [18].

3. Experimental section

3.1. Materials used in the experiment

Cement Holcim PC 35M (S–Q) 42,5N was used for making concrete because it often used in civil engineering practice in Serbia.

In the experimental work, for the benchmark concrete (designated with R) river aggregate divided into three fractions from the South Morava river was used. Apart from the benchmark concrete, two batches of concrete were made – one with all three fractions of crushed aggregate and the other with the combination of fine river and coarse crushed aggregate. The following crushed aggregates were used: limestone from the quarry "Koreni" near Pirot (concrete designation K), andesite from the quarry "Velika Bisina" near Raška (concrete designation A), diabase from the quarry "Tavani" near Ruma. (concrete designation D) and basalt from the quarry "Zebrnik" near Kumanovo (designation B). In those cases when the concrete was mad with the mixture of river and crushed aggregate, the letter R was added in the designation [19].

All aggregate types were divided into three basic fractions 0/4, 4/8 and 8/16 mm. Particle size distribution of the mixture for making concrete was equal, with acceptable deviations. It was corresponding to the mean value of standard particle size distributions A and B compliant to the standard SRPS U.M1.057:1984 [20].

Table 2 contains: aggregate particle density, water absorption and fine particle (particles smaller than 0.09 mm) content for the aggregate fractions.

Three water/cement ratios 0.45, 0.55 and 0.65 were used for making concrete, which covered all the concrete consistencies: from S1 to S4 according to the standard SRPS ISO 4109:1997 [21] and from V0 to V4 according to the standard SRPS ISO 4110:1997 [22] i SRPS ISO 4103:1997 [23].

In Table 3 are given actual quantities of material for all concrete mixtures.

3.2 Experiment results

In Tables 4, 5 and 6 are given the consistency values measured by Vebe method and Abrams cone for all concretes according to the standard SRPS ISO 4109:1997 [21], SRPS ISO 4110:1997 [22] i SRPS ISO 4103:1997 [23].

In Table 7 are given the pressurized water penetration values according to SRPS U.M1.015:1998 [24] and compressive strengths according to SRPS ISO 4012:2000 [25] of the composed concrete mixtures at the age of concrete of 90 days. The testing was conducted on the cube shape specimens having 200 mm long edges. The specimens were exposed to pressure of 100 kPa within 48 h, a then 24 h to pressure of 300 kPa and then 24 h to pressure of 700 kPa. After that the average depth of water penetration was calculated and most extreme depth of water penetration was measured. The results have been rounded to the closest 5 mm.

Table 1

Approximate concrete curing period required to achieve a certain degree of hydration when the capillary pores in hardened cement paste become segmented / *Aproximarea vârstei betonului la care gradul de hidratare a cimentului produce întreruperea porilor capilari ai matricei liante*

Water/cement ratio *Raport apă /ciment*	Degree of hydration [%] *Gradul de hidratare [%]*	Required curing period *Vârsta betonului*
0.40	50	3 days
0.45	60	7 days
0.50	70	14 days
0.60	92	6 months / *luni*
0.70	100	1 year /*an*
> 0.70	100	impossible / *imposibil*

Table 2

Aggregate particle density, water absorption and fine particles content for aggregate fractions
Densitatea, absorbția apei şi fracția de particule fine a agregatelor

Fraction *Fracția granulară* [mm]	Aggregate particle density *Densitatea particului de agregat* [kg/m³]	Water absorption *Absorbția apei* [%]	Fine particle content *Conținutul de parte fină* [%]
Aggregate type: river aggregate – South Morava / *Agregat de râu – South Morava*			
0 – 4	2539	2.100	1.598
4 – 8	2577	1.479	0.378
8 – 16	2576	1.268	0.242
Aggregate type: limestone crushed – Koreni / *Calcar concasat – Koreni*			
0 – 4	2524	2.805	13.582
4 – 8	2708	0.584	0.380
8 – 11,2	2710	0.583	0.186
11.2 – 16	2837	0.435	0.264
Aggregate type: andesite crushed – Velika Bisina / *Andezit concasat – Velika Bisina*			
0 - 2	2541	2.672	7.730
2 - 4	2565	2.344	1.528
4 - 8	2742	2.897	1.492
8 – 11,2	2698	1.565	0.453
11.2 - 16	2757	2.655	0.292
Aggregate type: basalt crushed – Zebrnik */ Bazalt concasat – Zebrnik*			
0 - 4	2720	2.299	12.727
4 - 8	2862	2.134	1.174
8 – 11,2	2806	2.433	0.678
11.2 - 16	2830	1.912	0.464
Aggregate type: diabase crushed – Tavani / *Diabaz concasat – Tavani*			
0 - 2	2636	2.298	4.085
2 - 4	2633	2.353	0.502
4 - 8	2636	1.455	0.635
8 – 11,2	2808	0.580	0.270
11.2 - 16	2833	0.594	0.364

Table 3

Actual quantities of material for all concrete mixtures
Compoziția betoanelor (kg /m³)

No. *Nr.*	Concrete mix code *Cod beton*	Cement *Ciment* m_c [kg/m³]	Aggregate *Agregat* m_a [kg/m³]	Water *Apă* m_v [L/m³]	Density of fresh concrete *Densitatea betonului proaspăt* ($_{b,s,st}$ [kg/m³]	Paste volume *Volumul de pastă* V_{cp} [m³]
1	R/0.45	383.19	1865.81	172.40	2421	0.298
2	R/0.55	370.52	1803.69	203.78	2378	0.325
3	R/0.65	358.23	1743.90	232.85	2335	0.350
4	K/0.45	384.93	1873.84	173.22	2432	0.299
5	K/0.55	377.5	1837.80	207.62	2423	0.331
6	K/0.65	362.30	1763.67	235.49	2361	0.354
7	A/0.45	378.76	1843.79	170.44	2393	0.295
8	A/0.55	370.87	1805.39	203.93	2380	0.326
9	A/0.65	358.31	1744.28	232.90	2335	0.350
10	B/0.45	390.31	1900.00	175.64	2466	0.304
11	B/0.55	381.27	1856,02	209.70	2447	0.334
12	B/0.65	368.21	1792.45	239.39	2400	0.360
13	KR/0.45	389.50	1896.08	175.27	2461	0.303
14	KR/0.55	374.08	1821.04	205.74	2400	0.329
15	KR/0.65	364.18	1772.85	236.71	2374	0.356
16	AR/0.45	381.17	1855.55	171.52	2408	0.296
17	AR/0.55	370.20	1802.17	203.61	2376	0.325
18	AR/0.65	360.32	1754.08	234.20	2348	0.352
19	DR/0.45	396.92	1932.22	178.61	2507	0.309
20	DR/0.55	383.72	1867.97	211.04	2462	0.337
21	DR/0.65	373.67	1819.05	242.88	2435	0.365
22	BR/0.45	391.85	1907.55	176.33	2476	0.305
23	BR/0.55	377.76	1838.90	207.76	2424	0.332
24	BR/0.65	365.89	1781.15	237.82	2384	0.358

Table 4

Consistency of all concrete mixtures measured by Vebe and Abrams for water/cement ratio value 0.45
Consistența măsurată prin tasare şi Vebe a betoanelor cu raport apă/ciment de 0,45

Design mix code *Cod beton*	ω_c	Vebe *Timpul Vebe* [second]	Consistency type by Vebe *Clasa de consistență*	Slump *Tasarea* [mm]	Consistency type by Abrams *Clasa de consistență*
R/0.45	0.45	18	[V0]	0	[S1]
K/0.45	0.45	32.3	[V0]	0	[S1]
A/0.45	0.45	51.8	[V0]	0	[S1]
B/0.45	0.45	57.7	[V0]	0	[S1]
KR/0.45	0.45	18.9	[V2]	0	[S1]
AR/0.45	0.45	14.5	[V2]	0	[S1]
BR/0.45	0.45	16.0	[V2]	0	[S1]
DR/0.45	0.45	13.7	[V2]	0	[S1]

Table 5

Consistency of all concrete mixtures measured by Vebe and Abrams for water/cement ratio value 0.55
Consistența măsurată prin tasare şi Vebe a betoanelor cu raport apă/ciment de 0,55

Design mix code *Cod beton*	ω_c	Vebe *Timpul Vebe* [second]	Consistency type by Vebe *Clasa de consistență*	Slump *Tasarea* [mm]	Consistency type by Abrams *Clasa de consistență*
R/0.55	0.55	4.4	[V3]	70	[S2]
K/0.55	0.55	9.2	[V3]	30	[S1]
A/0.55	0.55	7.9	[V3]	20	[S1]
B/0.55	0.55	16.4	[V2]	10	[S1]
KR/0.55	0.55	4.3	[V3]	70	[S2]
AR/0.55	0.55	5.1	[V3]	60	[S2]
BR/0.55	0.55	8.1	[V3]	30	[S1]
DR/0.55	0.55	2.0	[V4]	100	[S3]

Table 6

Consistency of all concrete mixtures measured by Vebe and Abrams for water/cement ratio value 0.65
Consistența măsurată prin tasare şi Vebe a betoanelor cu raport apă/ciment de 0,65

Design mix code *Cod beton*	ω_c	Vebe *Timpul Vebe* [second]	Consistency type by Vebe *Clasa de consistență*	Slump *Tasarea* [mm]	Consistency type by Abrams *Clasa de consistență*
R/0.65	0.65	1.0	[V4]	230	[S4]
K/0.65	0.65	1.0	[V4]	170	[S4]
A/0.65	0.65	1.0	[V4]	180	[S4]
B/0.65	0.65	7.1	[V3]	50	[S2]
KR/0.65	0.65	1.0	[V4]	230	[S4]
AR/0.65	0.65	1.0	[V4]	240	[S4]
BR/0.65	0.65	1.0	[V4]	190	[S4]
DR/0.65	0.65	1.0	[V4]	250	[S4]

Table 7

Value of pressurized water penetration and values of compressive strength for the made concrete mixes at the age of 90 days / *Valorile penetrației apei sub presiune şi ale rezistenței la compresiune a betoanelor încercate la vârsta de 90 de zile*

Design mix code *Cod beton*	Water/cement ratios *Rapoarte apă/ciment*			Water/cement ratios *Rapoarte apă/ciment*		
	0.45	0.55	0.65	0.45	0.55	0.65
	Pressurized water penetration [mm] *Adâncimea de penetrare a apei sub presiune* [mm]			f_p [MPa] *rezistența la compresiune*, f_{c90} [MPa]		
K	25	40	40	55.1	42.7	36.4
A	50	130	140	48.2	41.2	36.9
B	15	30	95	58.4	51.4	45.1
R	40	25	80	60.4	46.2	40.9
KR	20	10	25	51.0	47.8	33.4
AR	25	25	20	54.7	50.4	35.2
BR	15	25	10	70.8	55.4	47.3
DR	10	25	10	65.1	58.6	44.4

Graphic display of the pressurized water absorption dependence on the type of aggregate used for making concrete of identical water/cement ratios, in the function of the aggregate type, for the concrete mixtures is given in figures 3, 4 and 5.

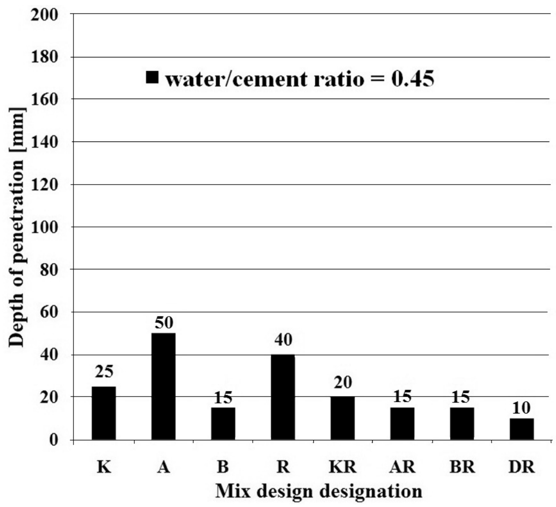

Fig. 3 - Graphic display of the pressurized water absorption dependence on the type of aggregate used for making concrete for water/cement ratio 0.45 / *Dependența adâncimii de pătrundere a apei sub presiune de tipul de agregat, în betonul cu raportul A/C de 0,45*

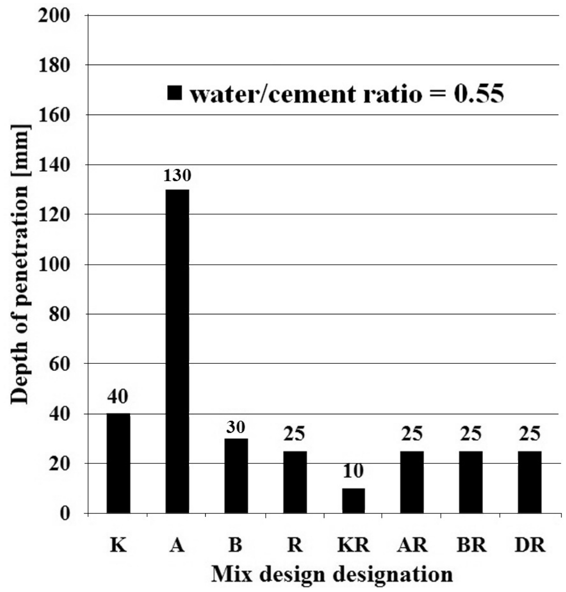

Fig. 4 - Graphic display of the pressurized water absorption dependence on the type of aggregate used for making concrete for water/cement ratio 0.55 / *Dependența adâncimii de pătrundere a apei sub presiune de tipul de agregat, în betonul cu raportul A/C de 0,55*

Micro-porosity of hardened concrete of the mixtures with water/cement ratios: 0.45, 0.55 and 0.65 made with fine river aggregate and coarse limestone aggregate was observed with optical stereo-zoom microscope Krüss (Germany), with the maximum magnification of 180x (Figure 6, 7 and 8).

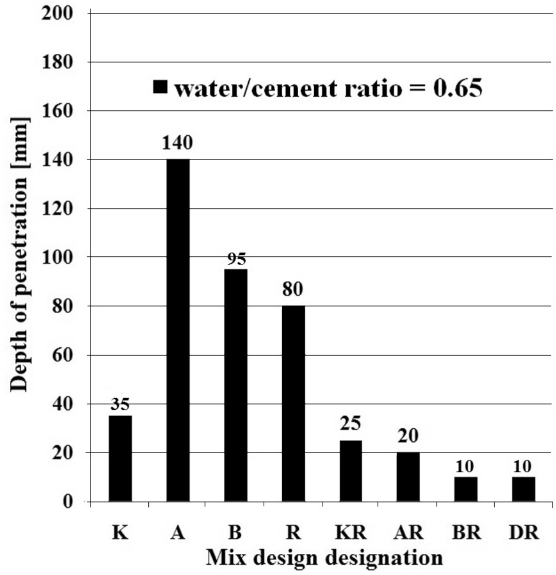

Fig. 5 - Graphic display of the pressurized water absorption dependence on the type of aggregate used for making concrete for water/cement ratio 0.65 / / *Dependența adâncimii de pătrundere a apei sub presiune de tipul de agregat, în betonul cu raportul A/C de 0,65*

The recorded images were analyzed using the specialized software for image processing, that is, for the analysis of micro-porosity of specimens (Image Pro Plus®) [26].

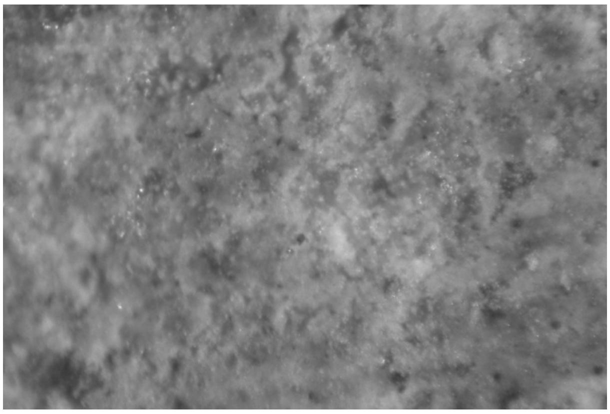

Fig. 6 - Microstructure of concrete with water/cement ratio 0.45 made with fine river aggregate and coarse limestone aggregate under the optical stereo-zoom microscope at magnification of 180x / *Microstructura betonului cu raport A/C de 0,45, preparat cu nisip de râu şi agregat grosier calcaros, imagine la microscop optic stereo-zoom, 180 x*

Only that part of concrete containing no aggregate, (i.e. only the cement stone) was observed. Simultaneously, the digital photographs were taken, and later processed using the mentioned software. The image processing provided number and size of pores in the cement stone, in all of the three previously mentioned concrete mixtures.

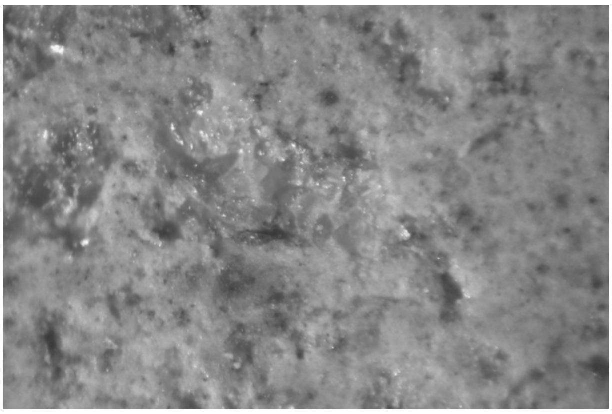

Fig. 7 - Microstructure of concrete with water/cement ratio 0.55 made with fine river aggregate and coarse limestone aggregate under the optical stereo-zoom microscope at magnification of 180x / *Microstructura betonului cu raport A/C de 0,55, preparat cu nisip de râu şi agregat grosier calcaros, imagine la microscop optic stereo-zoom, 180 x*

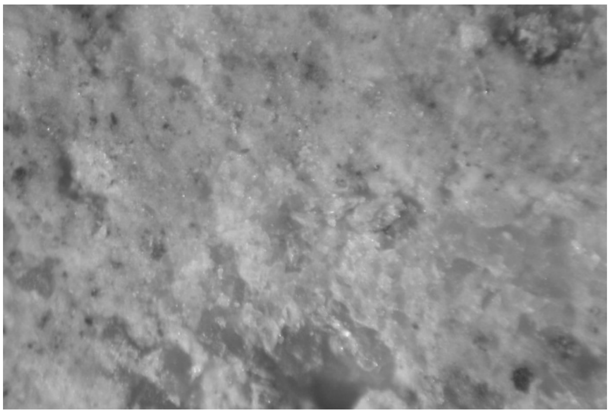

Fig. 8 - Microstructure of concrete with water/cement ratio 0.65 made with fine river aggregate and coarse limestone aggregate under the optical stereo-zoom microscope at magnification of 180x / *Microstructura betonului cu raport A/C de 0,65, preparat cu nisip de râu şi agregat grosier calcaros, imagine la microscop optic stereo-zoom, 180 x.*

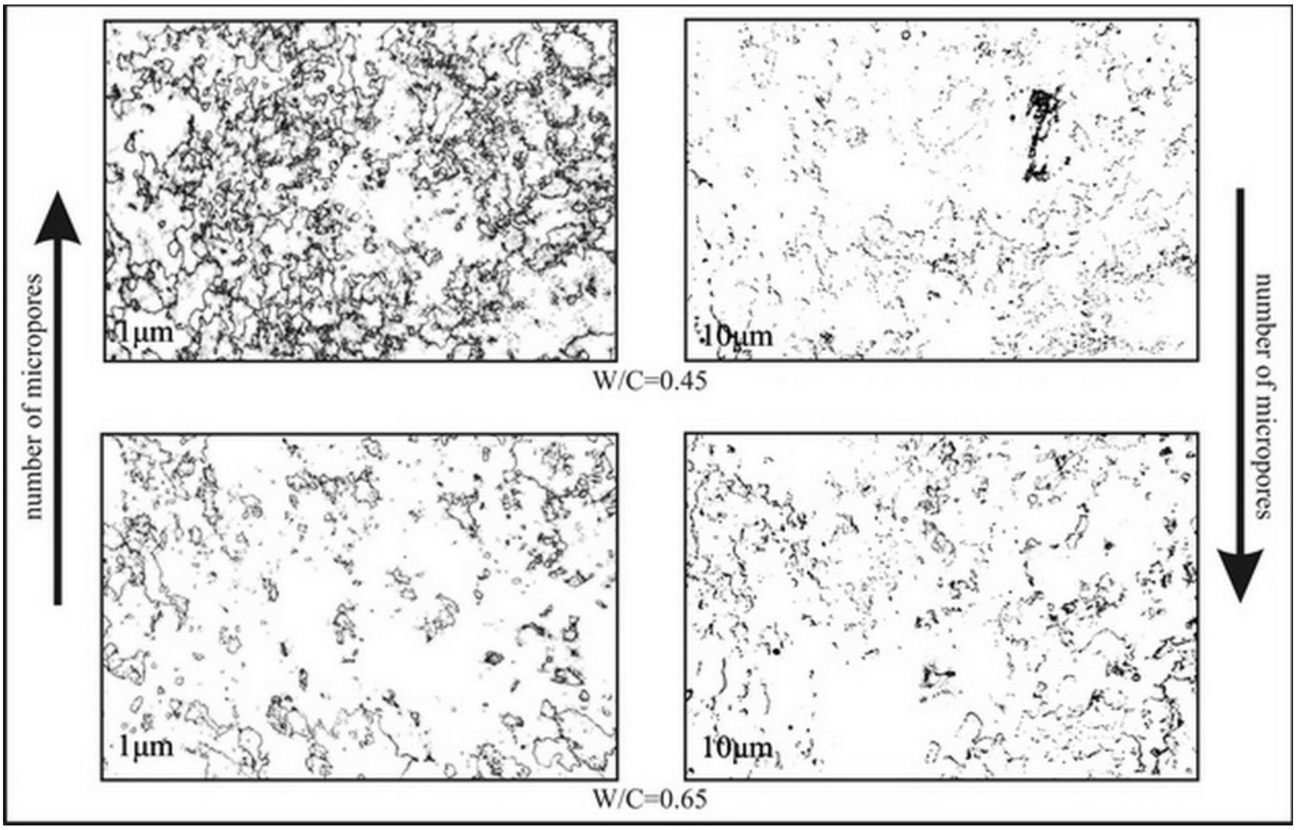

Fig. 9 - Processed images of cement stone with the pores having sizes ≤1μm and ≥10μm of the concrete mixtures produced with fine river and coarse crushed limestone aggregate with water/cement ratios 0.45 (designation KR/0.45) and 0.65 (designation KR/0.45)/ *Imagini ale porilor, ≤1μm şi ≥10μm, în matricea betoanelor cu nisip de râu şi agregat grosier calcaros şi rapoarte A/C de 0,45 KR/0,45) şi 0.65 (KR/0,45)*

Distribution and size of the ≤1 μm and ≥10 μm pores in cement stone of the concrete made with water/cement ratios 0.45, 0.55 and 0.65 are displayed in figure10 as histogram.

4. Discussion of results

For those concretes made only with crushed aggregate and water/cement ratio 0.45 the least water absorption of 15 mm was measured when basalt was used (designation B/0.45), Figure 3. The highest water penetration for the same water/cement ratio (0.45) was measured for the concrete made with andesite. With the increase of water/cement ratio from 0.45 through 0.55 to 0.65, resulted in the increase of water penetration in those concretes made with andesite and basalt

Such pattern of variation of water penetration height was not observed in the con-

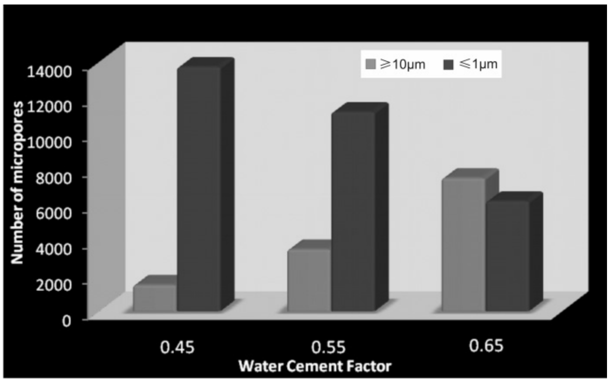

Fig. 10 - Histogram of dependence of the number of micropores (size ≤1 μm and ≥10 μm) on the various water/cement ratios (0.45, 0.55 and 0.65) of the concrete mixtures KR/0.45, KR/0.55 and KR/0.65 / *Histograma cu variația numărului de micropori (dimensiunea ≤1 μm şi ≥10 μm) în funcție de raportul A/C (0,45; 0,55 şi 0,65) din betoanele KR/0,45, KR/0,55 şi KR/0,65.*

cretes with crushed limestone and in the benchmark concrete. The concretes with limestone crushed aggregate and water/cement ratio 0.55 (designation B/0.55) and 0.65 (designation B/0.65) have almost equal water penetrations (35 to 40mm).

In the benchmark concretes, the lowest value of water penetration of 25 mm was found when the concrete with water/cement ratio 0.55 was made (designation R/0.55).

Substitution of crushed fine aggregate by the fine river aggregate in overall terms contributed to decreasing of water penetration value. This was prominent in concretes made with all water/cement ratios, and particularly with water/cement ratio 0.65. In those concretes made with water/cement ratio 0.55 this effect is the least prominent. However, it should be noted that all the concretes made with water/cement ratio 0.55, except that made with andesite (designation A/0.55), had low values of water penetration (Figure 4).

From the images presented in Figure 9 it can be seen that the share of the pores smaller than ≤1μm decreases with the increase of water/cement ratio. As opposed to that, the share of the pores larger than ≥10μm increases with the increase of water/cement ratio. The variation of the number of pores depending on their size for water/cement ratios 0.45, 0.55 and 0.65 was displayed with histogram, Figure 10.

It was determined that the share of the small diameter pores (≤1 μm) was 88%, while the share of the pores with diameter ≥10 μm was around 12% in the hardened concrete cement matrix for the concrete made with water/cement ratio 0.45 (designation KR/0.45). With the increase of water/cement ratio, the share of the small diameter pores (≤1 μm) decreases, while the share of the large diameter pores (≥10 μm) increases. Therefore, for the hardened concrete cement matrix in the concrete made with water/cement ratio 0.55 the share of small diameter pores and large diameter pores is 74% : 36%, and in the concrete with water/cement ratio 0.65 this share amounts to 45% : 55%.

5. Conclusion

The general conclusion on the basis of obtained results is that the depth of pressurized water penetration depends both on water/cement ratio and on the aggregate type.

Substitution of fine crushed aggregate by the adequate river aggregate contributes to reduction of the water penetration height. This effect is most pronounced in the concretes with high water/cement ratio 0.65 and in the concretes with andesite aggregate (designation AR/0.65) and basalt aggregate (designation BR/0.65).

The values of the water penetration depth are considerably uniform for the concretes made with the crushed limestone aggregate, which can be ascribed to the presence of fine limestone particles (filler). The chemical activity of fine particles reduces porosity of cement matrix and improves the quality of the interface of cement matrix and the aggregate in the transition zone.

The structure of pores in the hardened cement paste changes significantly with the change of water/cement ratio. The share of the pores finer than 1 μm decreases with the increase of water/cement ratio from 0.45 to 0.65, while the opposite is true for the pores larger than 10 μm.

In the further experimental research, the attention will focused on the detailed analysis of pores in the hardened cement paste, by taking into consideration the sizes of the pores which were not considered on this occasion.

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