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REPORT - Nº 190/2020

ON PHYSICAL-MECHANICAL PROPERTIES AND DURABILITY OF ULTRA HIGH PERFORMANCE CONCRETE ForteCrete150 REINFORCED WITH STEEL FIBERS (UHPSFRC)

Client	**Spajić d.o.o.** Koroglaska br. 13 19300 NEGOTIN
Subject	Tests for determination of physical-mechanical properties and durability of **ForteCrete150** premix reinforced with high strength steel fibers (UHPSFRC)
Nº of contract / offer	Quotation no. 132217/2-20 dated 22.06.2020. (number of Faculty of Civil Engineering in Belgrade)

The report approved by

Technical Manager of the Laboratory:

Associate Prof. Dimitrije Zakić, Ph.D.B.C.E.

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CONTENT

Based on The Law on Planning and Construction ("Official Gazette of the Republic of Serbia", no. 72/09, 81/09, 64/10 US, 24/11, 121/12, 42/13 US, 50/13 US, 54/13, 98/13 US, 132/14 and 145/14) is issued a

CONFIRMATION

Members of the Institute of Materials and Structures, employees of Faculty of Civil Engineering, University of Belgrade

Responsible person:	V. prof. dr Dimitrije Zakić, dipl.građ.inž.
Execution of tests:	Savo Stavnjak, lab technician
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have created TECHNICAL DOCUMENTATION titled:

REPORT - Nº 190/2020

ON MECHANICAL AND DURABILITY PROPERTIES OF ULTRA HIGH PERFORMANCE CONCRETE ForteCrete150 (UHPC) REINFORCED WITH HIGH STRENGTH STEEL MICROFIBER

This report is prepared upon Clinet's request and complies with above mentioned clauses of Law

Belgrade, June 2020

IMK INSTITUTE MANAGER

Prof. Zlatko Marković, Ph.D.B.C.E..

DEAN OF THE FACULTY OF CIVIL ENGINEERING

Prof. Vladan Kuzmanović, Ph.D.B.C.E.

R E P O R T

1. INTRODUCTION

The Institute for Materials and Construction of the Faculty for Civil Engineering University of Belgrade, in line with the Offer No. 132217/2-20 dated 22.06.2020. addressed to Spajic d.o.o (referred to as the "Client" from here on out), has carried out tests on Physical-Mechanical properties and durability parameters of the UHPC specimens made using the ForteCrete150 premix provided by the Client. The report was prepared based on the test results.

ForteCrete150 was supplied in bags as blended premix (all dry constituents) that included the proprietary proportions of portland cement, microsilica, fine quartz, and quartz sand already pre-mixed. (Picture 1.1, Annex 1). The premix was then mixed with water and additives in two stages for an appropriate period of time as recommended by the Client. Two mixes were tested, with and without steel fibers (Picture 1.2, Annex 1), i.e with specific volume percentage of microfiber reinforcement of 0%, 1% and 2%.

The specimens were prepared in the forms of standard cubes, prisms, cylinders and plates as required by Standards for different tests. The tests were performed at different ages (1, 3 and 28 days), and according to the standards listed below. The tests were done according to the following parameters: bulk density, compressive strength, tensile strength, "Pull-off" method, water tightness, freez-thaw resistance and salt attack resistance, resistance to carbonation and penetration of chloride ions. Based on the test results the report has been prepared and photos of the samples and the tools used for testing shown as part of the attachments at the end of the report.

2. BASIC PHYSICAL-MECHANICAL PROPERTIES

The basic physical-mechanical characteristics of the tested materials (Volume mass, compressive and bending strength) were found using the standard method by testing standard cubes and prisms with dimensions of 10x10x10 cm and 4x4x16cm. The specimens were 24 hours, 3 days and 28 days old. The test results are shown in table 1.
The procedure to find out the bulk density of samples involved: Determining the volume of the sample, the mass of the mold and the fresh concrete that was poured in. After all of these steps were complete, the density was found out by taking the mass that was obtained and dividing by the volume, giving the bulk density of fresh concrete. The same procedure is repeated for the hardened state where specimens were kept in a humid environment for 24 hours.

The compressive strength was tested according to SRPS EN 12390-3:2014 Standard. (*Testing hardened concrete- Part 3: Compressive strength of test*). The sample testing was performed with and without the steel fibres (0%, 1% and 2%), at different ages of 1 day, 3 days and 28 days. The test was performed on a cube crushing machine that was manufactured by the company *Matest* (Capacity 2000 kN), where pressure was applied constantly until the subject sample crushed (Figures 2.1 and 2.3, Annex 2). Testing was done on two series of secimens and results shown in tables 1 and 2. Series 2 specimens reinforced with 2% of steel microfiber by volume were tested earlier for compressive strengths after 4, 14 and 28days.

The flexural strength was tested according to the standard SRPS EN 1015-11:2008 (*The method to test the mortar specimens- part 11- Investigating the Tensile strength and compressive strength of the hardened mortar specimens*). The testing was carrid out on samples with and without the addition of microfiber reinforcement (1% and 2%), on the standard prisms with size 4x4x16 cm. The tests were performed on the jack manufactured by *Amsler* (Figure 2.2 Annex 2), where the force applied was controlled until sample failure (Figure 2.2 and 2.4, Annex 2)

Table 1. Basic physical-mechanical properties of examined material- Series 1

Sample number	Flexural strength (MPa) 0%	Flexural strength (MPa) 1%	Flexural strength (MPa) 2%	Compressive strength (MPa) 0%	Compressive strength (MPa) 1%	Compressive strength (MPa) 2%
	f_{zs}			f_p		
Sample age 24 hours						
1	6.8	12.5	13.0	82.4	91.6	82.8
2	7.3	12.5	11.7	83.2	85.5	84.7
3	7.0	12.5	12.5	90.0	93.3	-
Average	**7.0**	**12.5**	**12.4**	**85.2**	**90.1**	**83.7**
Sample age 3 day						
1	14.5	19.8	18.8	91.2	93.2	96.2
2	17.8	18.3	17.0	87.7	-	94.4
3	14.3	16.3	20.5	85.7	94.6	103.2
Average	**15.5**	**18.1**	**18.7**	**88.2**	**93.9**	**99.7**
Sample age 28 day						
1	21.8	19.5	23.5	-	123.9	130.0
2	22.8	17.5	25.5	115.9	114.4	-
3	23.0	19.0	24.5	112.1	113.5	129.7
Average	**22.5**	**18.6**	**24.5**	**114.0**	**117.3**	**129.9**

Table 2. Basic physical-mechanical properties of examined material- Series 2

Sample number	Compressive strength (MPa) 2% age 4 days	Compressive strength (MPa) 2% age 14 days	Compressive strength (MPa) 2% age 28 days
	f_p		
1	110.3	133.2	151.2
2	114.0	132.1	-
3	-	-	-
Average	**112.2**	**132.7**	**151.2**

Mean value of density in wet and dry states are presented in table 2.1 Annex 2**. Based on results shown in tables 1 & 2 mean value of compressive strengths obtained at 28 days is 140.6 MPa, while specimens cured for 24h in steam curing chamber at 90 degrees Celsius developed mean compressive strength value of 144.4 MPa. Maximum flexural strength obtained was 25.5 MPa while mean value was 24.5 MPa for specimens t aged 28 days.**

3. "Pull off" TEST RESULTS

The "Pull off" test was carried out to check bond stress. Concrete plates and cubes with dimensions 15x15x5cm and 10x10x10cm respectively, aged 28 days , were glued to metal plate of Dia 50mm (Figure 3.1, Annex 3). Specimens were reinforced with (0% ,1% and 2%) steel fiber. It is noted that the tests were performed using the apparatus *Controls* (Figure 3.2, Annex 3) and that for each age, a group of 3 samples were tested and results presented in table 3.

Tabela 3. "Pull off" test results

Sample number	0% fibres	1% fibres	2% fibres
Sample age 28 day [MPa]			
1	5.7	6.6	6.7
2	5.5	6.9	6.5
3	6.2	6.8	-
Average	**5.8**	**6.8**	**6.6**

As can be seen from the table 3 above, **the average bond strength is significantly higher than for normal concrete. Furthermore, the bond strength is even higher on specimens with steel fibers (1% and 2%) than without (0%).**

4. RESULTS OF WATER ABSORBTION TEST

Test for watertigthness is carried out according to the SRPS EN 12390-8:2010 Standard (the Investigation of hardened concrete – part 8: Depth of water penetration under pressure). Examination of water penetration was performed on plate specimens that measured 15x15x5cm without fiber additions (0%) at the age of 28 days. Standard apparatus for water penetration test was used. The specimens were placed and exposed to water with an average pressure of 5 bars for a 72 hour period (Figure 4.1, Annex 4). After splitting the sample in halves, the maximum water penetration on each sample was measured (Figure 4.1 and 4.2, Annex 4). The test results are shown in the table below in table 4:

Table 4. Results of water absorbtion test

Sample	V1		V2		V3	
Side	Left	Right	Left	Right	Left	Right
Depth of water penetration[mm]	5.5	5.0	4.4	4.3	8.9	9.5

Mean vaule of water penetration was measured at **6.3mm** and tit can be concluded: **tested concrete belongs to class V-III as per SRPS U.M1.203: 2013 standard - very low water permeability.**

5. RESULTS OF FREEZ-THAW AND SALT ATTACK TEST

The investigation of the samples resistance to frost and salt is carried out according to the standard SRPS U.M1.055:1984 (concrete – investigating the resistance of the concrete's surface to frost and salt for defrosting). The investigation was carried out on plate samples that measeured 15x15x5cm without any added fibres (0%), at the age of 28 days in a chamber with regulated temperatures (Figure 5.1, Annex 5). The samples whose upper surface were treated with a 3% solution of NaCl, were placed in altering temperatures for 16-18 hours, freezing at a temperature of -20°C and defrosting at a temperature of 6-8°C. After 25 cycles a visual inspection was conducted on all samples (Figure 5.2, Annex 5). On the basis of visual-macroscopic examination of the samples, the following can be concluded : **No damages were observed on the surface of the samples, concrete samples belong to the highest class –MS0 (without peeling) in terms of resistance when both frost and salts acted simultaneously.**

6. ADDITIONAL DURABILITY PARAMETERS

Added parameters for durability (apart from water tightness and resistance to freez-thaw cycles and chemical aggressive agents), are defined by investigating the resistance of the samples for carbonisation and penetration of chloride ions.

6.1 Resistance to carbonation

The investigation for the resistance to carbonisation was completed using an accelerated test according to fib Bulletin No.34: Model Code for Service Life Design (2006). The samples used for this test were prisms with no added fibres (0%), broken at the age of 28 days. The samples were put into a chamber (picture 6.1, attachment 6) in which they were exposed to CO2 with a concentration of 2% for the next 28 days at the constant temperature of 20°C and humidty of 65%. After this period, the samples were split apart and tested using phenolphthalein solution C20H14O4 and left to dry for 30 mins. After the aforementioned time, the samples treated surfaces were entirely pink (picture 6.2, attachment 6), which indicates the following: **there is no decrease in the alkalinity of the concrete, specifically the depth of carbonation was measured at 0.00mm. Carbonation has been found to be negligible. The tested concrete belongs to the highest class to carbonation resistance, which corresponds to the exposure class XC4- as defined by the standard SRPS EN 206.**

6.2 Resistance to Chloride Ion Penetration

The Investigation for the resistance of chloride ion penetration was completed using concrete cylinder specimens Dia 100mm and 100mm long with no added Fibres (0%),: at the age of 28days. The test was carried out according to the standard NT Build 42 (Non-Steady State Chloride Migration, 1999). Cylinders measuring 50mm after splitting were curred in water for 28 days. The samples were, after being submerged in water for 24h of which 3h were kept in a vacuum, were put into the testing apparatus (Figure 7.1, Annex 7). In the testing apparatus, the samples were stored for 120h, where the temperature was measured before and after the testing, during the testing the initial resistance was based on the duration of the test and the voltage which the sample was exposed to during the test. After the prescribed time, the samples were taken out and split in half, and then their inner surfaces treated with the silver nitrate solution (AgNO3 and were left to dry for 30min. After the treatment, the penetration of the chloride ions in the form of a layer of silver paint on the surface of the sample could clearly be seen on the treated surface (Figure 7.2 Annex 7).
The chloride penetration was measured at seven points, excluding edges, where the values obtained were used to determine the chloride ion migration coefficient. The test results are shown in Table 5:

Table 5. Result of chloride ion penetration resistance test

Sample number	Voltage [V]	L1[mm]	I_{30}	t_p	t_k	t[h]	x_{av}[mm]	D_{nssm}[m^2/s]
1	60	51.0	1.82	18.60	19.10	120	2.57	$10.002*10^{-14}$
2	60	51.5	1.73	18.30	19.10	120	1.79	$6.888*10^{-14}$

The mean value of the chloride migration coefficient is $\mathbf{D_{nssm} = 8.454 * 10^{-14}\ m^2/s}$. Based on this, the following conclusion can be drawn: **the resistance of the tested concrete is 8-10 times higher than of ordinary concrete, which according to the classification of the mentioned standard classifies it in the group "very good", i.e in the highest exposure class of concrete regarding the penetration of chloride ions *XD4*- as defined by SRPS EN 206 - superior resistance to chloride penetration.**

7. CONCLUSION

Based on the results of the tests conducted, it can be concluded that the tested composite can be classified as Ultra High Performance Concrete (UHPC), reinforced by steel Fibres (micro reinforced concrete – FRC). During installation, the liquid consistency of the fresh concrete was observed, which allowed installation without vibration or with short-term compaction of the mixture, which classifies this concrete in the group of self-compacting Concretes (SCC).

It was shown that the mean valuee of the concrete compressive strength after 28 days was **140.6 MPa** and after steam-curing it was **144.4 MPa**, which corresponds to concrete with Ultra High Strength. Also, the flexural strength is significantly larger (**4-6 times larger**) than normal concrete and measured on average **24.5 MPa**. Test resuts show that the tested concrete belongs to the highest class of water tightness ***V-III***, as well as the highest class ***MS0 (without peeling)*** in a simulated freez-thaw environment and salt attack test. Additional tests show that the concrete also meets expectations of the highest classes ***XC4*** and ***XD4*** in terms of resistance to carbonization and the penetration of chloride ions.

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COMPILED:

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- END OF REPORT -

The REPORT has 7 appendix (1-7)

APPENDIX 1

Prepaation and treatment of samples

Figure 1.1.Preparation of components for making the mixture and precise weight measurement

Figure 1.2. Mixture with fiber content during mixer operation and poured samples

APPENDIX 2

Examination of basic physical-material properties

Figure 2.1. Equipment for compressive strength test Matest

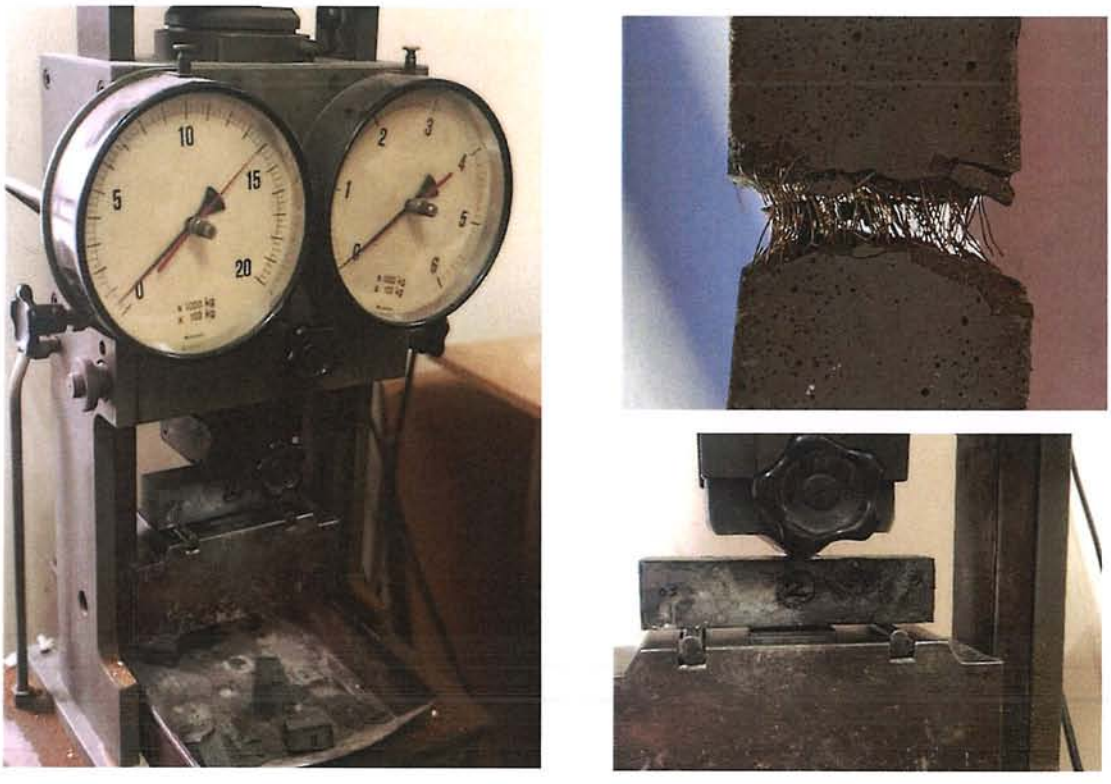


Figure 2.2. Equipment for bending strength test Amsler and broken samples with the addition of steel fibers (2%) after testing

Table 2.1. Density of concrete with and without steel fibers in fresh and hardened state (kg/m^3)

State	0% fibers	1% fibers	2% fibers
Fresh	2281.9	2339.3	2529.2
Hardened (after 24h)	2270.2	2329.1	2489.6

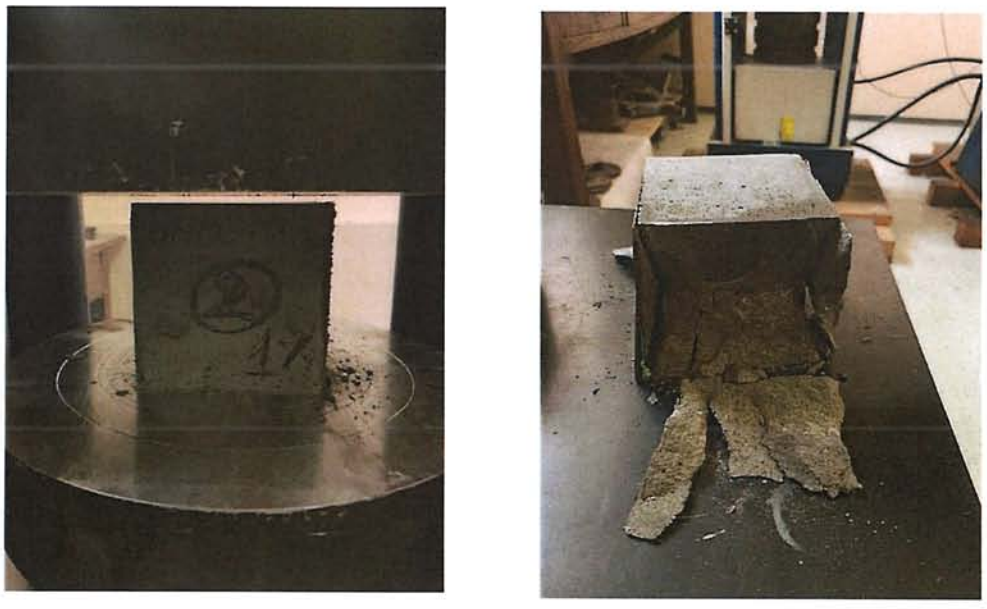


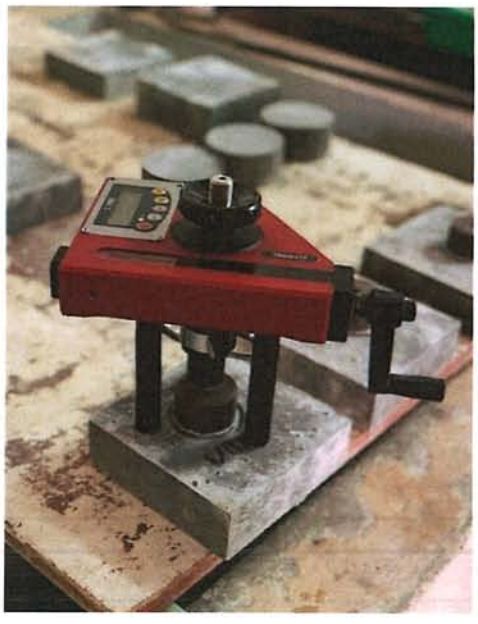
Figure 2.3. Prepared sample in equipment for compressive strength test and broken samples after test

Figure 2.4. Appearance of samples with the addition of steel fibers after flexural strength test

APPENDIX 3

"Pull off" test

Figure 3.1. Piece of concrete from surface of the sample



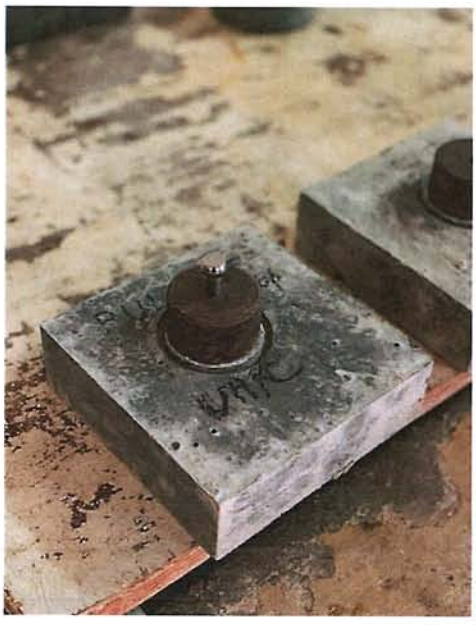


Figure 3.2. Equipment for „Pull off" test

APPENDIX 4

Water absorbtion test

Figure 4.1. Equipment and prepared samples for water absorbtion test. Inside of the sample V3 after testing

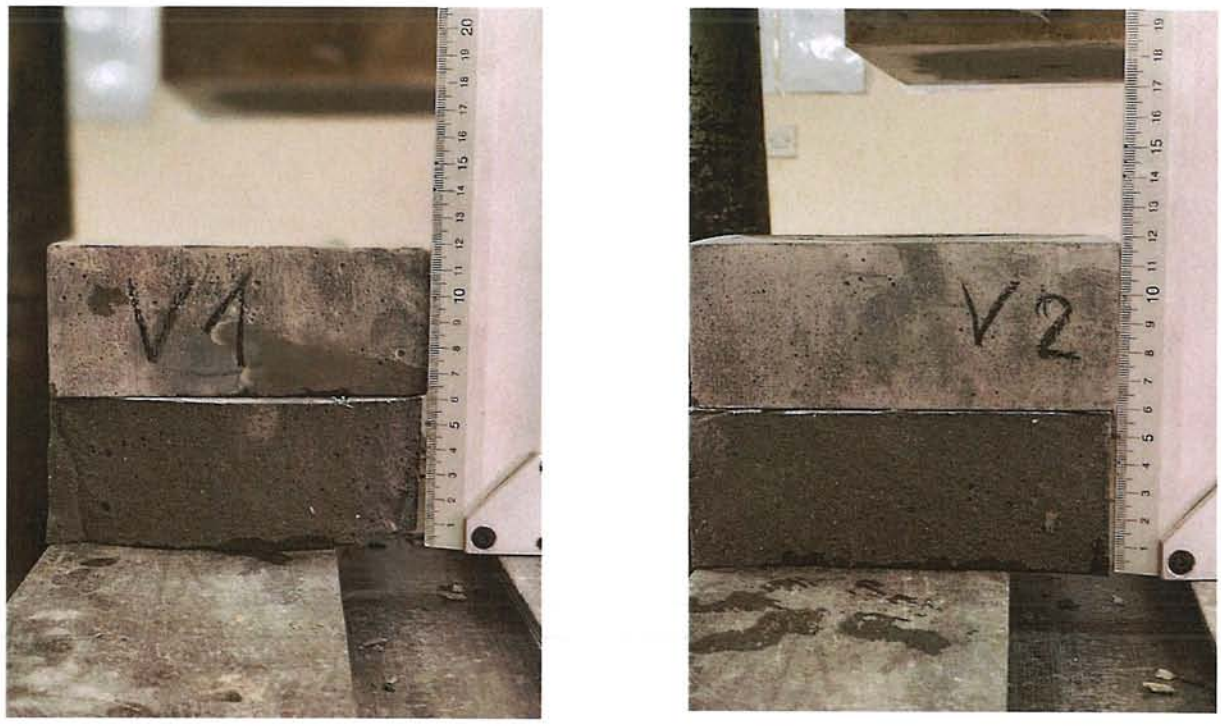


Figure 4.2. Measurement of water penetration depth on samples V1 and V2

APPENDIX 5

Freez-thaw and salt attack test

Figure 5.1. Prepared samples before test in environmental chamber

Figure 5.2. Samples after 25 cycles in the environmental chamber

APPENDIX 6

Carbonation resistance test

Figure 6.1. Environmental chamber for carbonation resistance test with set parameters (CO_2, temperature and humidity)

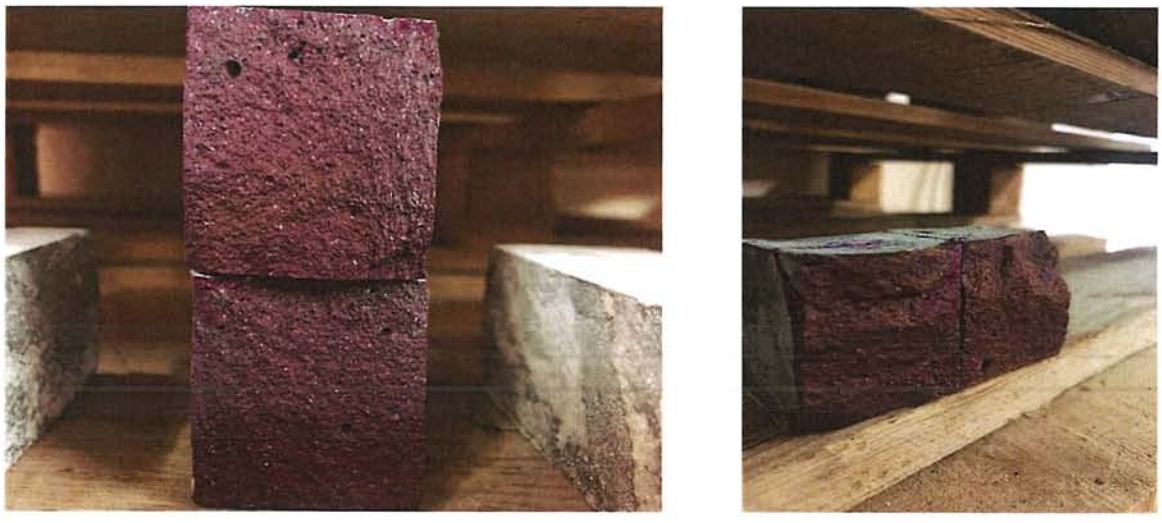


Figure 6.2 Appearance of the sample surface after treatment with phenolphthalein solution

APPENDIX 7

Chloride ion penetration resistance test

Figure 7.1. Equipment and prepared samples for test

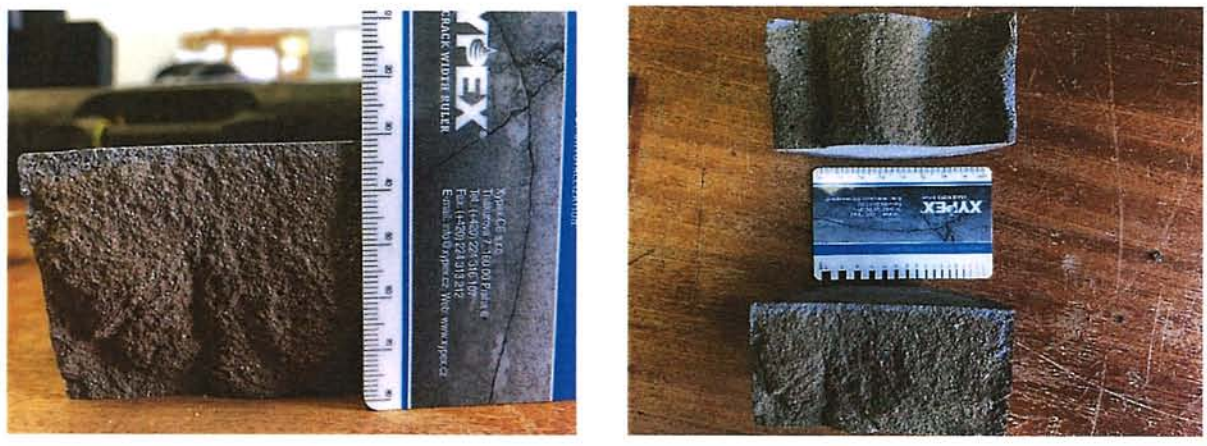


Figure 7.2. Appearance of the sample sufrace after treatment with silver nitrate solution