Ceramics-Silikáty 70 (1), 42-50 (2026)
www.ceramics-silikaty.cz doi: 10.13168/cs.2025.0050

INFLUENCE OF ALKALI ACTIVATORS ON THE CARBONATION RESISTANCE OF SUPERSULFATED CEMENT

#DŽIGITA NAGROCKIENĖ, ARNOLDAS NORKUS

Vilnius Gediminas Technical University, Saulėtekio av. 11, Vilnius, LT-10223, Lithuania

#E-mail: dzigita.nagrockiene@vilniustech.lt

Submitted August 14, 2025; accepted November 3, 2025

Keywords: Self-healing concrete, Crystalline chemical admixture, Compressive strength, Porosity, Density, Ultrasonic pulse velocity, Freeze-thaw resistance

The article analyses the effect of the crystalline chemical admixture content on the properties of self-healing concrete. The self-healing concrete properties and the effectiveness of crack sealing were tested. The effect of the crystalline chemical admixture content on the following properties of self-healing concrete were tested: the consistency, density, compressive strength, ultrasonic pulse velocity, water absorption, porosity and freeze-thaw resistance. The self-healing concrete was made of cement, a crystalline chemical admixture, sand, gravel, and water. The crystalline chemical admixture was added from 0 to 1.5 % by weight of cement. The test results showed that with the addition of the crystalline chemical admixture, the density, ultrasonic pulse velocity, compressive strength, and water absorption decrease, whereas the resistance to the freeze-thaw cycles increases. The analysis of the crack-sealing effectiveness revealed that the formation of crystals started at 14 days of curing, and, at 42 days, the cracks were totally sealed. Therefore, in the presence of the crystalline chemical admixture added at 1.5 % by weight of cement, the self-healing concrete can bridge the cracks as free cement particles hydrate in contact with water and fill the cracks. The obtained self-healing concrete with better durability properties can be used in concrete structures.

INTRODUCTION

The durability of structures is receiving great attention in many countries. Concrete is one of the basic building materials, but its low resistance to tensile stress is a negative property. Tensile stress causes cracks to appear both in the production phase due to technological inconsistencies and during the service life of concrete structures due to shrinkage or thermal deformation. This factor significantly affects the durability of the structure, as water ingress through cracks leads to reinforcement corrosion and other degradation processes that compromise the integrity of the concrete. Microcracks that develop during the manufacturing process can turn into macrocracks visible to the naked eye. Uncontrolled cracking can go beyond the safety limits as moisture and chemicals penetrating through cracks can reach the rebar surface. In most cases, cracks have to be repaired, but the repair work is often cumbersome and complicated, and these factors increase the structure's maintenance costs.

A reasonable way to increase concrete resistance is to use crystalline admixtures or bacteria that, in the presence of water, precipitate calcium carbonate and in this way seal the microcracks and thereby improve the structure's service life and long-term performance.

Currently, self-healing concrete, which is capable of sealing cracks that appear in structures during their service life, is intensely being researched around the world. Such concrete has been successfully used by the construction industry for several years. The development of cracks decreases the durability of concrete. The destructive process gains momentum with water ingress through the cracks, a sequence of chemical reactions, and the onset of rebar corrosion. Expensive repair work is required to control this negative development. By repairing these cracks, self-healing concrete prevents the development of the factors detrimental to the durability and helps maintain the impermeability of concrete [1].

Mineral admixtures used to induce the autonomous self-healing mechanism are classified into two groups: expanding and crystalline. In the case of expanding admixtures, such as calcium sulfoaluminate (CSA), free lime (CaO), anhydrite ($CaSO_4$), etc., the reaction products have a higher volume than the reagents, similar to the carbonation reaction. Whereas in the case of crystalline admixtures, Na_2CO_3 and similar carbonates, also talc or sodium silicate powder, react with calcium hydroxide $Ca(OH)_2$ and form crystalline compounds [2].

Crystalline admixtures are synthetic substances containing reactive silica dioxide and certain crystalline catalysts. Reactive components of these substances react

with $Ca(OH)_2$ and form a crystalline product that fills the cracks in concrete. However, adequate ambient humidity is essential for the formation of crystalline products. One of the main purposes of using crystalline admixtures is to reduce the water permeability in concrete. The reaction of calcium ions with ambient moisture and atmospheric carbon dioxide leads to the formation of calcium carbonate ($CaCO_3$). Calcium hydroxide ($Ca(OH)_2$), present in the crack area, dissolves in contact with water and produces calcium carbonate deposits on the crack surfaces [3-9].

Researchers have studied the durability and mechanical properties of self-healing concrete modified with crystalline admixtures. The paper does not specify the chemical composition of the admixtures, but it specifies the recommended admixture content of 2 % by weight of binder. Specimens of two compositions – control composition (without the admixture) and modified composition (with a crystalline admixture) – were prepared and the test results were compared. After 28 days, cylindrical samples were tested to determine their compressive strength. The crystalline admixture added at 11% increased the compressive strength of the concrete made of ordinary Portland cement. The mixes with the crystalline admixture also had lower slump values and a higher percentage of entrained air. These results are related to the hydrophilic nature of crystalline admixtures, which attract water molecules during mixing, thus decreasing the workability and preventing air pore leakage [10].

The water permeability indicates lower mechanical properties of concrete and has an effect on the durability of structures. Concrete with lower water absorption values is more durable. The analysis showed that crystalline admixtures reduce the water permeability in concrete by 40 – 50 % [11].

The testing of self-healing concrete revealed that it has the ability to restore the mechanical properties lost due to cracking partially. Researchers have conducted more detailed studies to evaluate this property. The evaluation was performed by conducting a three--point bending test with completely hardened specimens. Artificial microcracks were created in a three-point bending machine and the crack bridging capacity of concrete was observed. The water-cured concrete specimens modified with a crystalline admixture regained a major part of their load-bearing capacity and stiffness compared to the unmodified specimens. The crack bridging lasted much longer in the air-cured specimens and their mechanical properties were restored insignificantly. These tests confirmed the finding that the self-healing concrete admixture becomes effective only after prolonged exposure to water. This study also demonstrates that the use of admixtures contributes to the partial recovery of mechanical properties, which correlates directly with durability improvement in concrete structures [12].

Researchers have tested compressive and tensile strengths, which are the core properties of concrete. However, different results were obtained with different concrete compositions. For example, compressed specimens after treatment in water can regain from 10 to 40 % of their compressive strength. Other studies have shown that self-healing concrete typically exhibited lower early strength; however, at 28 days, it reached a load-bearing capacity very similar to that of unmodified concrete. Studies have shown that, in most cases, chloride ions do not have a negative effect on the crack bridging process in self-healing concrete. It was also noted that closing the gaps retard the intensity of the chloride penetration. Other studies have reported that the water permeability of self-healing concrete decreases over time and depends on the storage conditions of the concrete specimens. Crystalline admixtures react with cement and water and form modified calcium silicate hydrates (C-S-H), which promote crack bridging [13-17].

EXPERIMENTAL

Cement CEM I 42.5 [18] and a crystalline admixture were used for the tests. The chemical composition and characteristics of the cement are presented in Tables 1 and 2. Figure 1 illustrates cement particle size distribution. The average cement particle size is 14.21 μm.

Table 1. Chemical composition of the cement (%).

Chemical composition (%)							
SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	SO_3	Na_2O	Other
20.76	6.12	3.37	63.50	1.00	0.80	0.30	4.15

Table 2. Cement properties.

Properties	CEM I 42,5 R
Specific surface area ($g \cdot cm^{-2}$):	3700
Particle density ($kg \cdot m^{-3}$)	3200
Bulk density ($kg \cdot m^{-3}$)	1200

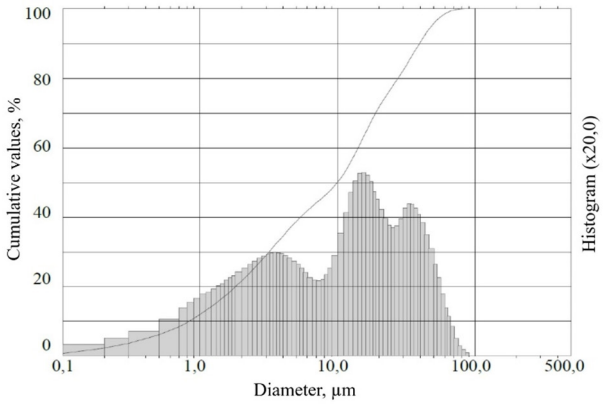


Figure 1. Distribution of the cement particles by size.

Table 3 presents the properties of the sand fraction 0/4, and gravel fraction 4/16, used in the concrete mix [19].

Table 3. Characteristics of the sand and gravel.

Characteristics	Sand	Gravel
Bulk density (kg·m^{-3})	1630	1600
Particle density (kg·m^{-3})	2650	2670

The crystalline admixture was used in a powder form. The admixture characteristics are presented in Table 4.

Table 4. Crystalline chemical admixture characteristics and composition.

Characteristics	Value
Density (kg·m^{-3})	980
Composition	
Portland cement content (%)	25 ± 50
Sodium carbonate content (%)	25 ± 50
Calcium hydroxide content (%)	2.5 ± 10
Chloride content (%)	≤ 0.10
Alkali content, calc. Na_2O equiv. (%)	≤ 8.5

Six self-healing concrete mix designs were prepared, incorporating varying crystalline chemical admixture dosages from 0 to 1.5 % by weight of cement. All the other mix components were kept constant, and the water-to-cement ratio was maintained at 0.52 across all the mixtures. The compositions of the self--healing concrete mixes are presented in Table 5.

The consistency of the mixes was determined by the slump test according to LST EN 12350-2 [20], the density of the hardened specimens was determined according to LST EN 12390-7 [21], and the ultrasonic pulse velocity was measured according to the requirements of the standard in [22]. The compressive strength of the specimen was measured according to LST EN 12390-3 [23], the water absorption and other properties were determined according to the requirements of the standards in [24–25]. The resistance of the modified specimens to the freezing and thawing cycles was determined according to the methodology using porosity parameters in [26].

Determining the crystal formation of the self-healing concrete cracks

Cracks were made mechanically in the concrete to determine the crack bridging effectiveness. The specimens were placed in a hydraulic press and subjected to loading until cracks appeared. The crack formation is illustrated in Figure 2.

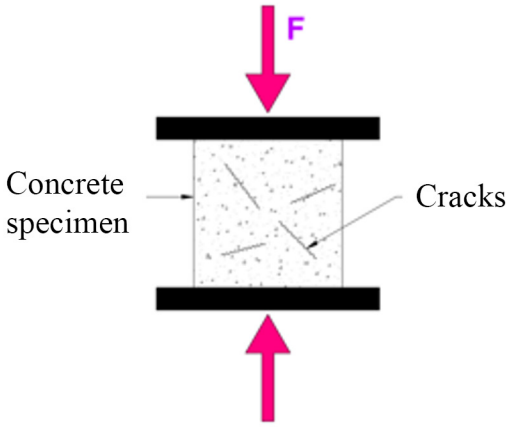


Figure 2. Crack formation.

Table 5. Compositions of the self-healing concrete mixes, 1 m^3.

Batch	1	2	3	4	5	6
Cement (kg)	394	394	394	394	394	394
Sand 0/4 (kg)	676	676	676	676	676	676
Gravel 4/16 (kg)	1089	1089	1089	1089	1089	1089
Water (l)	205	205	205	205	205	205
Crystalline admixture (%)	0	0.30	0.60	0.90	1.20	1.50
Crystalline admixture (kg)	0.00	1.18	2.36	3.55	4.73	5.91
W/C	0.52	0.52	0.52	0.52	0.52	0.52

Constant contact with water is a prerequisite for effective crack bridging in self-healing concrete. The specimens with cracks were placed in a water tub to come into contact with water at 20 °C. The specimens were taken out every 7 – 10 days to visually examine the crack bridging. The testing lasted for 42 days.

RESULTS AND DISCUSSION

An X-ray structure analysis was conducted to determine the mineral composition of the crystalline chemical admixture. The test findings are presented in Figure 3. The crystalline chemical admixture consists of 32.7 % sodium carbonate, 31.4 % quartz, 29.4 % tricalcium silicate, and 6.2 % portlandite. Sodium silicate (Na_2CO_3) accelerates the early strength development in the kinetics of tricalcium silicate hydration reactions [27].

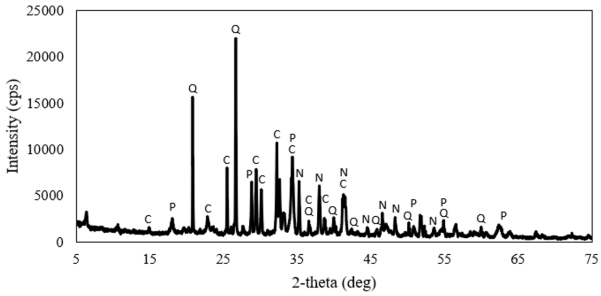
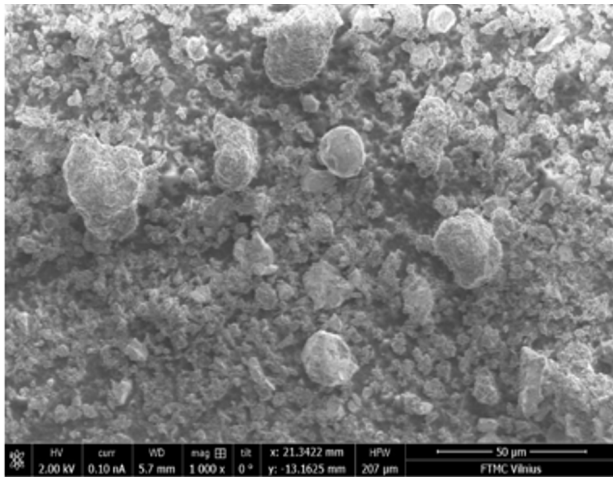


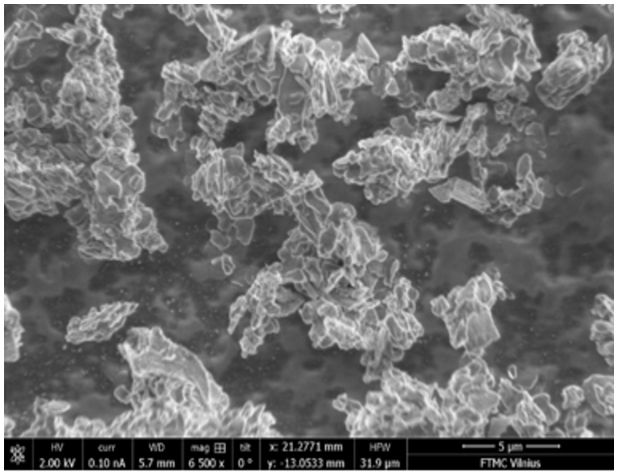
Figure 3. X-ray: N - sodium carbonate (Na_2CO_3), C - tricalcium silicate (Ca_3SiO_4O), Q - quartz (SiO_2), P - portlandite ($Ca(OH)_2$).

The microstructure of the crystalline chemical admixture is presented in scanning electron microscopy (SEM) images in Figure 4. The prevailing irregular shape particles consist of irregular shape crystals distributed in different directions.

Figure 5 illustrates the relationship between the consistency of the fresh self-healing concrete mixes and the crystalline chemical admixture content. The slump tests revealed that the consistency (workability) decreases as the admixture content increases. Following the analysis of the slump test results, it can be concluded that the dosage of the crystalline admixture has a significant influence on the consistency of fresh concrete. As the admixture content increases, the slump values decrease progressively. A comparison between the control mix (without the admixture) and the mix containing the highest dosage (1.5 % by weight of cement) showed a reduction in the slump of 21.5 %. All the tested mixtures fell within class S3 as defined by EN 206. The observed reduction in the slump is attributed to the water-binding properties



a) × 1000 magnification



b) × 6500 magnification

Figure 4. Microstructure of the crystalline chemical admixture.

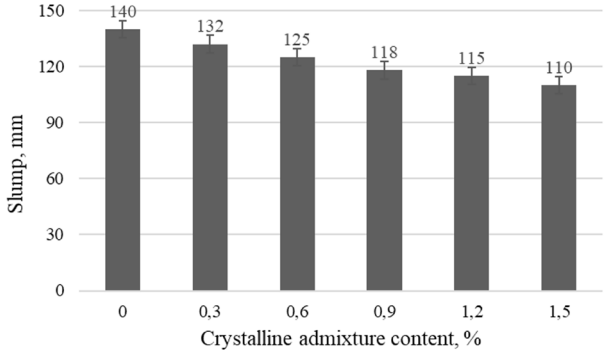


Figure 5. Relationship between the slump and the crystalline chemical admixture content in the self-healing concrete.

of the crystalline chemical admixture, which reduces the free water content and thickens the self-healing concrete mix.

The density is one of the basic properties of self-healing concrete. Figure 6 illustrates the relationship between the self-healing concrete density at 28 days and the crystalline chemical admixture content.

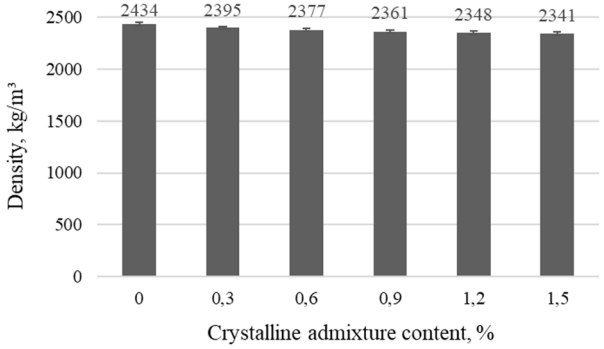


Figure 6. Relationship between the density and the crystalline chemical admixture content in the self-healing concrete.

The density of the specimens tested ranged from 2341 to 2434 kg·m^{-3}. The control specimens had the highest density value, and the specimens with the highest crystalline chemical admixture content had the lowest density value. The tests showed that the crystalline chemical admixture content does not influence the self--healing concrete density. Compared to the reference specimen (without the admixture), the modified self--healing concrete density reduced by 3.8 % when the crystalline chemical admixture content in the mix was increased to 1.5 %. The analysis of the test results showed that the crystalline chemical admixture had no significant effect on the self-healing concrete density.

The relationship between the compressive strength and the crystalline admixture content is illustrated in Figure 7. The control specimens had the highest compressive strength of 55.90 MPa. The lowest compressive strength of 51.0 MPa was found in the specimens with the highest crystalline chemical admixture content.

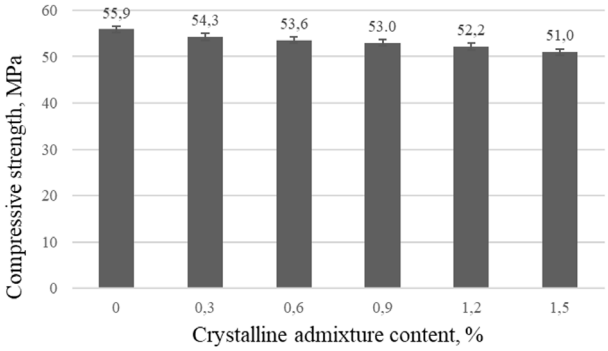


Figure 7. Relationship between the compressive strength at 28 and the crystalline chemical admixture content in the self--healing concrete.

The tests showed that the crystalline chemical admixture content influences the compressive strength of the self-healing concrete, i.e., the compressive strength decreases slightly with the increasing admixture content.

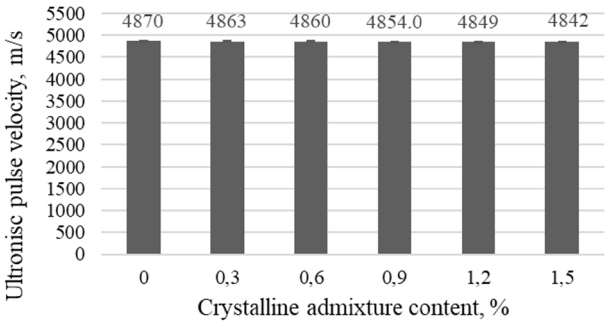


Figure 8. Relationship between the ultrasonic pulse velocity and the crystalline chemical admixture content in the self--healing concrete at 28 days.

The analysis of the test results revealed an 8.8 % drop in the compressive strength values when more crystalline chemical admixture was added to the mix. At 28 days, the ultrasonic pulse velocity reduced with a higher admixture content in the self-healing concrete mix (Figure 8). The same trend was observed with the density and compressive strength values.

The analysis and evaluation of the ultrasonic pulse velocity test results revealed that the crystalline chemical admixture content had no measurable effect on the ultrasonic pulse velocity. The ultrasonic pulse velocity gradually decreased with a higher crystalline chemical admixture content in the self-healing concrete mix. The comparison of the control and modified specimens revealed an insignificant decrease of 0.6 % in the ultrasonic pulse velocity in the specimens with the highest admixture content. Therefore, the ultrasonic pulse velocity remained unaffected by variations in the crystalline admixture content.

Water absorption refers to a material's ability to absorb and retain moisture from its surroundings. This is a critical property of self-healing concrete, as it directly influences its freeze–thaw resistance – higher water absorption typically results in reduced frost durability. The water absorption of the hardened self-healing concrete was determined through tests. The obtained test results are presented in Figure 9.

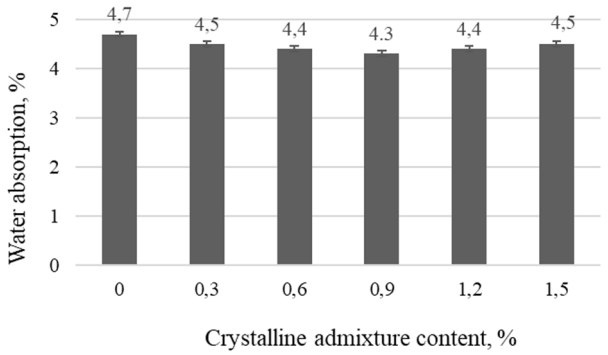


Figure 9. Relationship between the water absorption and the crystalline chemical admixture content in the self--healing concrete.

The figure shows that the reference specimen without the crystalline chemical admixture has the highest water absorption rate. It means that the crystalline chemical admixture lowers the water absorption rate. The water absorption rate decreased with the increase in the admixture content in the concrete mix. Compared to the reference specimen, the water absorption in the specimen with the highest admixture content was reduced by about 14 %.

The porosity was measured according to the specified methodology. Figure 10 illustrates the relationship between the closed, open and total porosity of the self-healing concrete mixes and crystalline chemical admixture content.

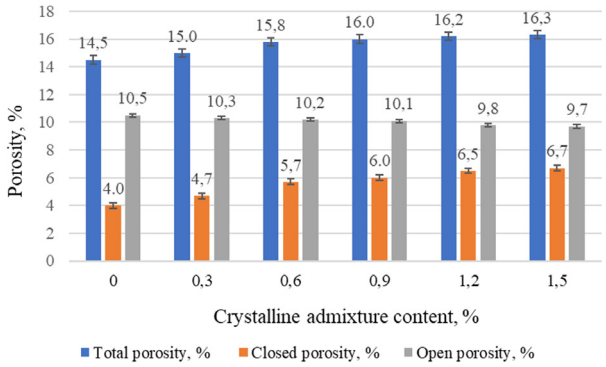


Figure 10. Relationship between the porosity and the crystalline chemical admixture content in the self-healing concrete.

The total porosity values ranged between 14.5 and 16.3 %. The highest total porosity of 16.3 % was found in the concrete modified with the 1.5 % crystalline admixture. The reference specimens without the admixture had the lowest total porosity of 14.5 %.

The open porosity reduced with a higher content of the crystalline chemical admixture. The highest open porosity of 10.5 % was observed in the unmodified specimens, whereas the specimens containing 1.5 % of the crystalline admixture had the lowest open porosity of 9.7 %. The closed porosity increased with a higher content of the crystalline chemical admixture. The highest closed porosity of 6.7 % was observed in the specimens containing 1.5 % of the crystalline chemical admixture, whereas the unmodified specimens had the lowest closed porosity of 4.0 %.

The durability of self-healing concrete is characterised by its resistance to freezing and thawing. The frost resistance of concrete depends on its porosity, because at temperatures below 0 °C, water present in the pores turns into ice. Ice pressure on concrete walls and the movement of the plastic ice during freezing and thawing destroy the concrete structure. Following the testing of the water absorption in the concrete specimens, the open, total, and closed porosity measurement and the determination of the density, the frost resistance factor KF was calculated and used to determine the predicted freeze-thaw resistance of the self-healing concrete. The relationship between the predicted resistance to the freezing and thawing cycles and the crystalline admixture content is presented in Figure 11.

The diagram illustrates that resistance to freezing and thawing cycles grows with a higher crystalline chemical admixture content in the specimens. The lowest number of cycles, i.e., 720 cycles, was observed in the reference specimens without the crystalline admixture. The specimens containing 1.5 % of the admixture sustained 900 freeze-thaw cycles.

The tests showed that the use of crystalline chemical admixtures does not have a significant effect on the density, ultrasonic pulse velocity, and compressive strength of the hardened self-healing concrete; however, the workability of the fresh self-healing concrete deteriorates. Crystalline chemical admixtures reduce the water absorption and increase the predicted resistance to freeze-thaw cycles. The analysis and evaluation of the test results showed that the crystalline chemical admixtures are effective in concretes when the admixture content is 1.5 % by weight of cement.

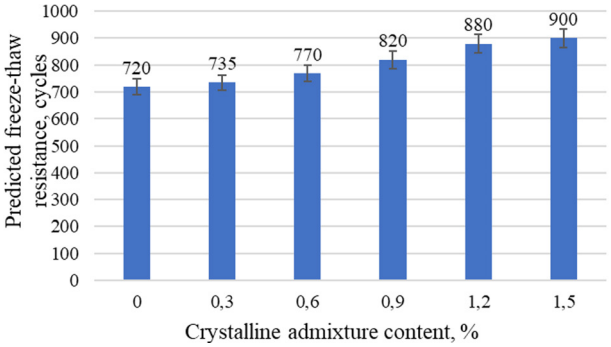
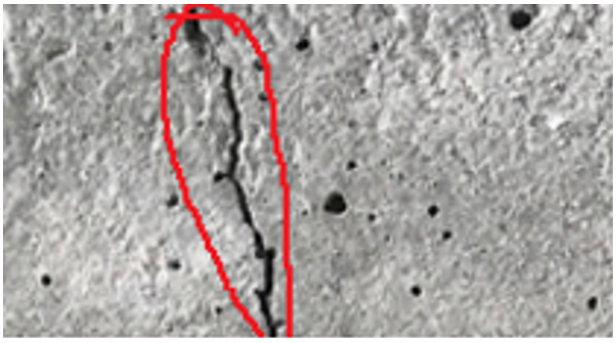
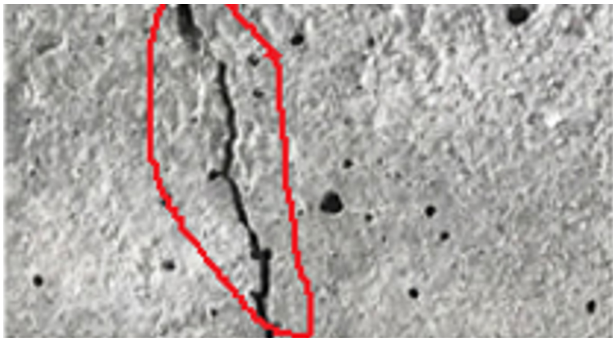


Figure 11. Relationship between the predicted resistance to the freezing and thawing cycles and the crystalline chemical admixture content in the self-healing concrete.

The crack bridging performance of the self-healing concrete was analysed. The effectiveness of the crystalline chemical admixture was tested in the specimens having contact with water. The reference specimen and the specimen containing 1.5 % of the admixture were placed on the grid in a water tub and kept in constant contact with water from 1 to 42 days. The specimens were visually observed after 7, 14, 24, 34, and 42 days. The specimens were taken out from the tub and pictures of the growing crystals were taken. Images of the reference specimen are shown in Figure 12. There is no crack bridging because the specimen has no admixture.



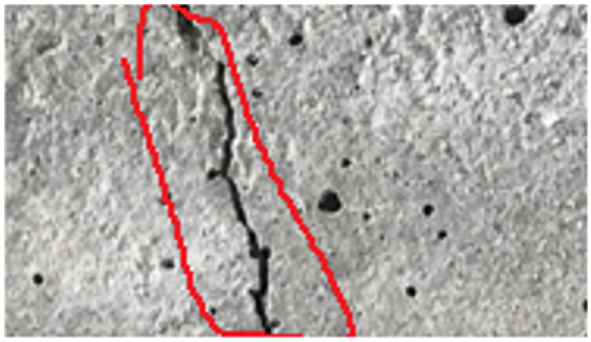
a) 7 days



b) 14 days

c) 24 days

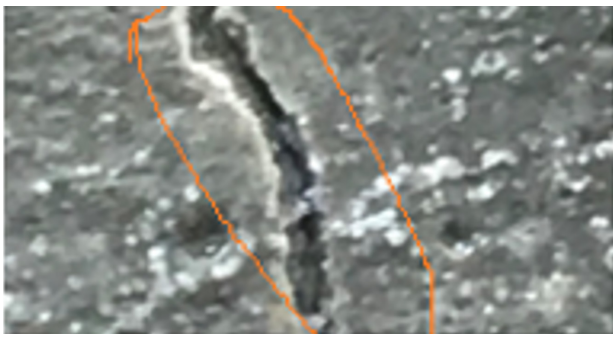
d) 34 days



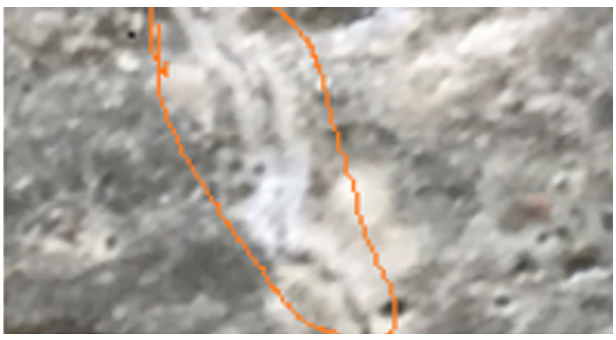
e) 42 days

Figure 12. Concrete reference specimen.

Images of the modified specimen are presented in Figure 13. After 7 days of soaking in water, white deposits were observed in the crack. After 14 and 24 days, crystals started growing in the crack and after 34 and 42 days, the crack was almost completely sealed. The formation of crystals in con-

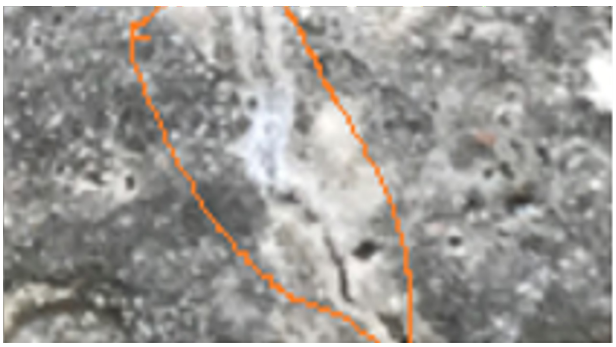


a) 7 days



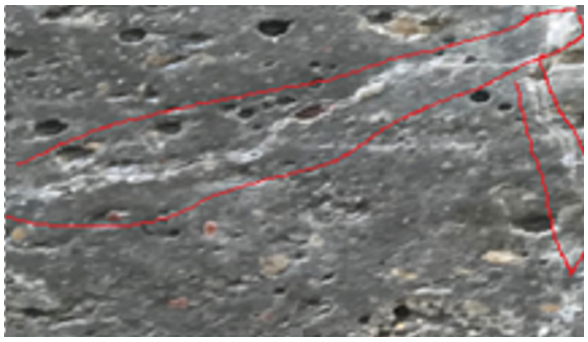
b) 14 days

Figure 13. Self-healing concrete specimen at a crystalline admixture content of 1.5 %. *continued*



c) 24 days

d) 34 days



e) 42 days

Figure 13. Self-healing concrete specimen at a crystalline admixture content of 1.5 %. *continued*

crete is a progressive process that lasts from several days to several weeks. The formed crystals completely sealed the capillaries, pores, and cracks in concrete after 42 days.

It can be said that the concrete has a crack-bridging ability, as it contains free cement particles that hydrate when in contact with water and fill the appearing cracks.

CONCLUSIONS

The tests showed that the crystalline chemical admixture content does not influence the concrete density. The density of the self-healing concrete reduced by 3.8 %, whereas the ultrasonic pulse velocity reduced by 0.6 %.

It was found that the crystalline chemical admixture content has an effect on the compressive strength of the concrete, which reduces with the addition of the admixture up to 1.5 %. The compressive strength dropped 8.8 %, i.e., from 56.0 to 51.0 MPa.

The total porosity of the self-healing concrete ranged from 14.5 to 16.4 %. The highest total porosity of 16.4 % was recorded in the specimens containing 1.5 % of the admixture, whereas the specimens without the admixture had the lowest total porosity of 14.5 %. The highest open porosity of 10.5 % was observed in the unmodified specimens, whereas the specimens containing 1.5 % of the crystalline chemical admixture had the lowest open porosity of 9.7 %. The closed porosity increased with a higher crystalline chemical admixture content. The highest closed porosity of 6.7 % was observed in the specimens containing 1.5 % of the crystalline chemical admixture, whereas the unmodified specimens had the lowest closed porosity of 4.0 %. The relationship between the water absorption and crystalline chemical admixture content was determined. The reference specimen (without the admixture) had the highest water absorption rate of 4.7 % and the lowest water absorption rate of 4.1 % was found in the specimen containing 1.5 % of the admixture. The water absorption decreased with the increasing crystalline chemical admixture content in the mix. The difference in the water absorption rate between the reference specimen and the specimen with the highest admixture content was 14 %.

The freeze-thaw resistance of the self-healing concrete increased up to 900 cycles with an increase in the crystalline chemical admixture content to 1.5 %. The reference specimen without the admixture resisted the lowest number of cycles, i.e., 720. The predicted freeze-thaw resistance increased 20 % between the reference specimen and the specimen with the highest admixture content.

The conducted tests led to the conclusion that self-healing concretes containing up to 1.5 % of the crystalline chemical admixture can bridge the cracks that appear in concrete structures during their service life, as they contain free cement particles that hydrate when in contact with water and fill

the appearing cracks. Such self-healing concrete used in construction work will be more durable and resistant to freeze-thaw cycles.

REFERENCES

1. Augonis A. (2018). Self-healing concrete and its use prospects. Kaunas University of Technology, Kaunas, Lithuania.
2. Yuan Z., Jiang Z., Chen Q. (2019): Permeability modeling of self-healing due to calcium carbonate precipitation in cement - based materials with mineral additives. *Journal of Central South University, 26*, 567-576. doi: 10.1007/s11771-019-4028-4
3. Sisomphon K., Copuroglu O., Koenders E.A. (2012): Self--healing of surface cracks in mortars with expansive additive and crystalline additive. *Cement and Concrete Coimposites, 34*, 566-574. doi: 10.1016/j.cemconcomp.2012.01.005
4. Reddy T. Ch, Ravitheja A. (2019): Macro mechanical properties of self-healing concrete with crystalline admixture under different environments. *Ain Shams Engineering Journal, 10*, 23-32. doi: 10.1016/j.asej.2018.01.005
5. Ali Ammar M., Chegenizadeh A., Arief Budihardjo M., Nikraz H. (2024): The Effects of Crystalline Admixtures on Concrete Permeability and Compressive Strength: A Review. *Building, 14*, 3000. doi: 10.3390/buildings14093000
6. Guzlena S., Sakale G. (2019): Self-healing concrete with crystalline admixture – a review. *Conference Series: Materials Science and Engineering, 660*. doi: 10.1088/1757-899X/660/1/01205
7. Naidenov V., Mironova M. (2020): Investigation on the efficiency of internal crystallization chemical admixtures for cement concrete – structural characteristic. *Machines. Technologies. Materials, 3*, 124-128.
8. Fabiana Ziegler F., Borges Masuero A., Tregnago Pagnussat D., Coitinho Dal Molin D. (2020): Evaluation of internal and superficial self-healing of cracks in concrete with crystalline admixture. *Materials, 13*, 4947. doi: 10.3390/ma13214947
9. Saleh Salem B., Abdul Muhamed M., Noor A., Nor A., Nabilah A., Farah Nora Aznieta Farah A.A. (2021): Feasibility assessment on self-healing ability of cementitious composites with MgO. *Journal of Building Engineering, 34*, 101914. doi: 10.1016/j.jobe.2020.101914
10. Azarsa P., Gupta R.., Biparva A. (2019): Assessment of self-healing and durability parameters of concretes incorporating crystalline admixtures and Portland Limestone Cement. *Cement and Concrete Composites, 99*, 17-31. doi: 10.1016/j.cemconcomp.2019.02.017
11. Ferrara L., Krelani V., Carsana, M. (2014): A "fracture testing" based approach to assess crack healing of concrete with and without crystalline admixtures. *Construction and Building Materials, 68*, 535-551. doi: 10.1016/j.conbuildmat.2014.07.008
12. Muhammad N.Z., Shafaghat A., Keyvanfar A., McCaffer R. (2012): Tests and methods of evaluating the self-healing efficiency of concrete: A review. *Construction and Building Materials, 112*, 1123-1132. doi: 10.1016/j.conbuildmat.2016.03.017
13. Nagrockienė D., Pundienė I., Čepulis A., Pocius E. (2021): The effect of crystallizing admixture on the properties and shrinkage of concrete. *Ceramics – Silikaty, 65*, 273-280. doi: 10.13168/cs.2021.0028
14. Mohd N., Dewangan U.K., Shirish V.D. (2020): Autonomous healing in concrete by crystalline admixture: A review. *Materials Today Proceedings, 32*, 638-644. doi: 10.1016/j.matpr.2020.03.116
15. Zhang G., Cen Liu C., Xiang M., Yu X. (2023): The Effects of Crystalline Admixture on the Self-Healing Performance and Mechanical Properties of Mortar with Internally Added Superabsorbent Polymer. *Materials, 16* (14), 5052. doi: 10.3390/ma16145052
16. Ziegler F., Masuero A.B., Tregnago Pagnussat D., Coitinho Dal Molin D. (2020): Evaluation of internal and superficial self-healing of cracks in concrete with crystalline admixtures. *Materials, 13* (21), 4947. doi: 10.3390/ma13214947
17. LST EN 197-1:2011. Cement. Part 1, Composition, specifications and conformity criteria for common cements. Lithuanian Department of Standardization: Vilnius, Lithuania, 2011.
18. LST EN 12620:2003+A1:2008. Aggregates for concrete. Lithuanian Department of Standardization: Vilnius, Lithuania, 2008.
19. LST EN 12350-5:2019. Testing fresh concrete - Part 5: Flow table test. Lithuanian Department of Standardization: Vilnius, Lithuania, 2019.
20. LST EN 12390-7:2019. Testing hardened concrete - Part 7: Density of hardened concrete. Lithuanian Department of Standardization: Vilnius, Lithuania, 2019.
21. LST EN 12504-4: 2004. Testing concrete – Part 4: Determination of ultrasonic pulse velocity. Lithuanian Department of Standardization: Vilnius, Lithuania, 2004.
22. LST EN 12390-3:2019. Testing hardened concrete - Part 3: Compressive strength of test specimens. Lithuanian Department of Standardization: Vilnius, Lithuania, 2019.
23. LST EN 13369:2018, Annex F: Concrete - Test methods - Determination of water absorption. Lithuanian Department of Standardization: Vilnius, Lithuania, 2018.
24. LST 1974. LST EN 206-1 Application rules and additional national requirements. Lithuanian Department of Standardization: Vilnius, Lithuania, 2024.
25. Skripkiunas, G. (2007). Statybiniu konglomeratu struktura ir savybes. Kaunas: Vitae Litera, 105-115.
26. Dong W., Li W., Tao Z. (2021): A comprehensive review on performance of cementitious and geopolymeric concretes with recycled waste glass as powder, sand, or cullet. *Resources, Conservation and Recycling, 172*, 105664. doi: 10.1016/j.resconrec.2021.105664