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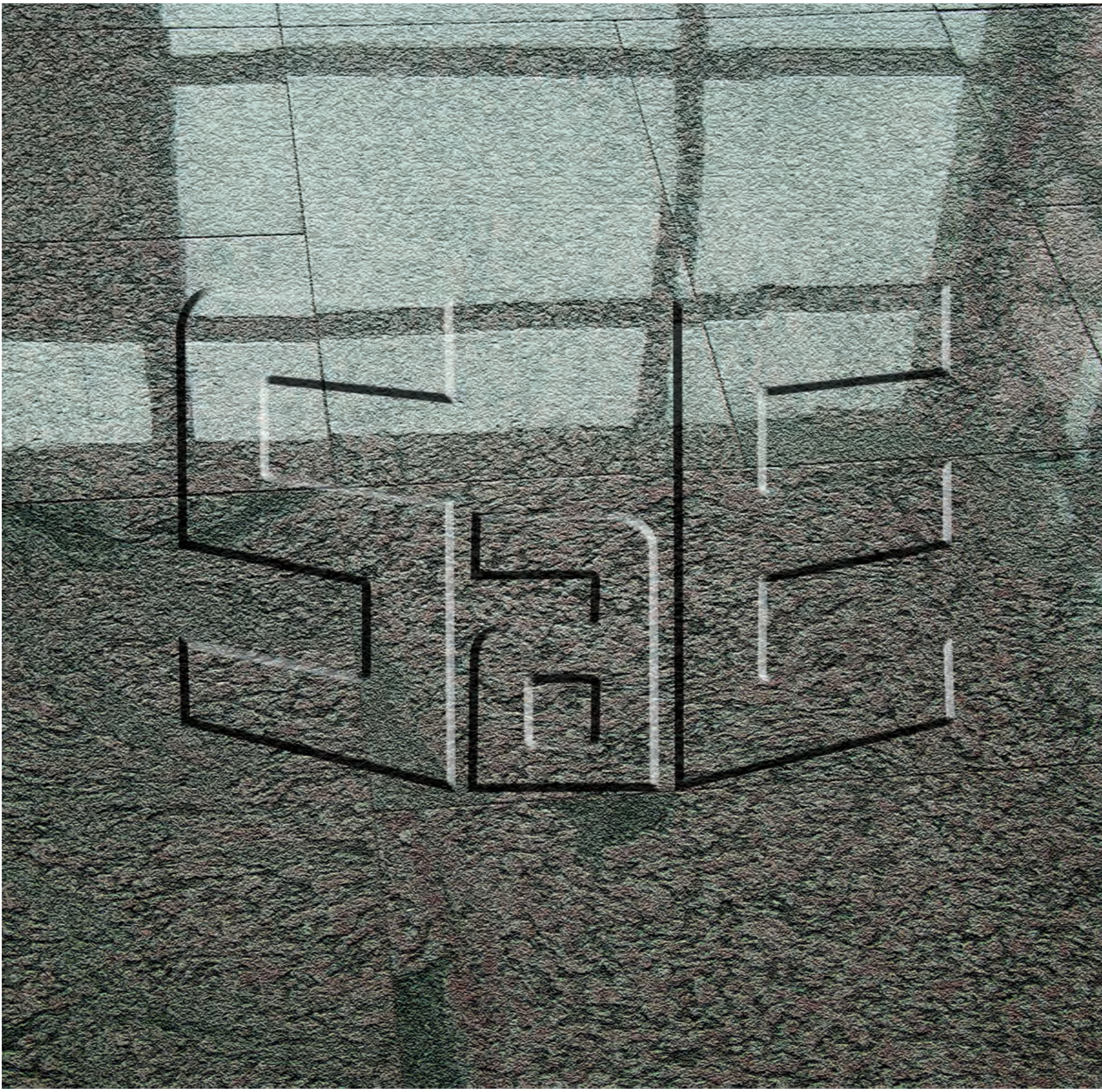

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INFLUENCE OF SODIUM AND POTASSIUM FORMATE ON THE ASR REACTIVITY OF GRANITE AGGREGATE

WPŁYW MRÓWCZANU SODU I POTASU NA PODATNOŚĆ KRUSZYWA GRANITOWEGO NA REAKCJĘ ALKALICZNĄ

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Abstract

Use of de-icing agents is necessary in winter to maintain appropriate quality of road and airport surfaces. Formate or acetate de-icing agents are safer for aircraft and the environment than the commonly used sodium chloride, but may cause an alkali-silica reaction in concrete. The study investigated the influence of sodium formate and potassium formate on the occurrence of ASR (alkali-silica reaction) in mortars with granite aggregate. Accelerated mortar-bar tests at 80°C using various de-icing agents were performed and detailed studies of the SEM-EDS microstructure were carried out.

Keywords: granite aggregate, alkali-silica reaction ASR, sodium formate, potassium formate, alkali-silica gel, microstructure

Streszczenie

Stosowanie środków odladzających jest niezbędne do zimowego utrzymania odpowiedniej jakości betonowych nawierzchni drogowych i lotniskowych. Środki odladzające na bazie mrówczanów lub octanów są bezpieczniejsze zarówno dla środowiska, jak i statków powietrznych niż powszechnie stosowany chlorek sodu, jednak mogą wywoływać reakcję alkaliczno-krzemionkową kruszywa w betonie. W pracy analizowano wpływ mrówczanu sodu i mrówczanu potasu na potencjał wystąpienia ASR (alkali-silica reaction) w zaprawach z kruszywem granitowym. Przeprowadzono badania ekspansji w 80°C z zastosowaniem różnych środków odladzających oraz przeprowadzono szczegółowe badania mikrostruktury SEM-EDS.

Słowa kluczowe: kruszywo granitowe, reakcja alkaliczno-krzemionkowa ASR, mrówczan sodu, mrówczan potasu, żel alkaliczno-krzemionkowy, mikrostruktura

1. INTRODUCTION

Due to climate conditions in Poland, it is necessary to use de-icing agents in winter to ensure appropriate quality of concrete road and airport pavements. Sodium chloride (NaCl) is commonly used for road pavement de-icing due to its effectiveness and low price. However chloride ions can negatively affects concrete pavements as well as the vehicles and the natural environment [1]. For de-icing of airport pavements, alternative agents are used: sodium and potassium formates or acetates [2]. Both formates and acetates are considered to be much more environmentally friendly and they are not harmful to aircraft components. They are easily biodegradable, without emission of toxic products. Formates and acetates are more effective at lower temperatures in comparison to sodium chloride, they work quicker and last longer. The relatively high price is the factor that limits their use only to airport pavements.

Despite a number of advantages, premature damage near the expansion joints and cracks of the concrete airfield pavement has been noticed. There are a few studies describing the influence of de-icing

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*Institute of Fundamental Technological Research of Polish Academy of Sciences, Poland, e-mail: aantolik@ippt.pan.pl agents based on organic salts on concrete durability, especially on alkali-silica reaction [3]. The harmful effects of formate and acetate de-icing agents have been reported by Giebson et al. [4]. They found that the acceleration of ASR by the use of organic salts was associated with an excess supply of alkali and the release of OH^- ions as a result of increased $Ca(OH)_2$ solubility. While Wang et al. [5] found no significant effect of acetate de-icing agents on the ASR acceleration in concrete. The influence of formates and acetates on the occurrence or acceleration of ASR is not clear. Therefore, it was necessary to perform research taking into account the available domestic aggregate deposits.

2. MATERIALS

Three granite aggregates (G1, G2, G3) from Polish mines were selected for testing. Granites aggregates are considered high-quality aggregates and are therefore widely used in concrete pavement construction. Due to the possibility of ASR, granite aggregates are classified as non-reactive [7] or potentially reactive [8] due to the presence of strained and microcrystalline quartz. In the analyzed granite aggregates, the content of reactive minerals was relatively low and ranged from 1.8% to 4.7% (strained quartz) [9]. Portland cement CEM I 52.5 R was used for mortar specimens preparation; the chemical composition is presented in Table 1.

Table 1. Chemical composition of cement determined by the XRF method,% wt.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Na_2O_{eq}	LOI
CEM I 52.5 R	19.42	5.15	2.94	64.10	1.75	3.50	0.29	0.88	0.87	2.43

The water-cement ratio w/c = 0.47 and aggregate-cement ratio a/c = 2.25 were used. Crushing and sieving of granite aggregate was performed according to RILEM AAR-2 [10].

3. TESTING METHODS

The expansion tests of mortars were performed according to the accelerated mortar-bar test RILEM AAR-2 [10]. The specimens (25 x 25 x 285 mm) were exposed to 1 M NaOH and 80°C for 28 days. The method was modified by the usage of deicing agents solutions: 50% HCOOK and 15% HCOONa. The concentration of the solution was related to the simulation of real conditions during defrosting of airport pavements [2]. Reference specimens stored in distilled water were also prepared.

The specimens after the accelerated mortar-bar test were cut into smaller parts (40 x 25 x 10 mm) and prepared for microscopic observations. The specimens were impregnated with epoxy resin, grinded on diamond discs (125, 75, 54, 18 and 9 µm) and polished on polishing pads with diamond pastes (6, 3, 1, 0.25 µm). The prepared specimens were sputtered with a carbon layer (~20 nm), then microscopic observations were performed on a JEOL JSM-6460LV scanning electron microscope (SEM) equipped with an X-ray energy dispersion (EDS) detector. The analysis was performed under high vacuum in the backscattered electron mode (Electron Backscatter Diffraction, EBSD). The SEM was operated with acceleration voltage set to 20 kV and a working distance of 10 mm.

4. RESULTS AND DISCUSSION

The expansion of mortar bars was different depending on the solution used. Results of the expansion over time were presented on Figure 1 and in Table 2. All specimens showed expansion below 0.1% after 14 days of exposure in a 1 M NaOH, which classified the aggregate as non-reactive according to RILEM AAR-2.

Table 2. Expansion [%] of mortar with aggregate G1, G2, G3 after 14 and 28 days of exposure in 80ºC in different solutions (distilled water, sodium hydroxide, sodium formate, potassium formate)

Solution	G1		G2		G3	
	14 days	28 days	14 days	28 days	14 days	28 days
1 M NaOH	0.054 ±0.002	0.097 ±0.002	0.066 ±0.002	0.134 ±0.002	0.086 ±0.03	0.108 ±0.003
H_2O	0.001 ±0.001	0.002 ±0.001	0.003 ±0.001	0.004 ±0.001	0.002 ±0.001	0.004 ±0.001
15% HCOONa	0.004 ±0.001	0.009 ±0.001	0.008 ±0.001	0.013 ±0.001	0.006 ±0.001	0.009 ±0.001
50% HCOOK	0.323 ±0.023	0.645 ±0.032	0.430 ±0.023	0.928 ±0.018	0.459 ±0.002	0.974 ±0.001

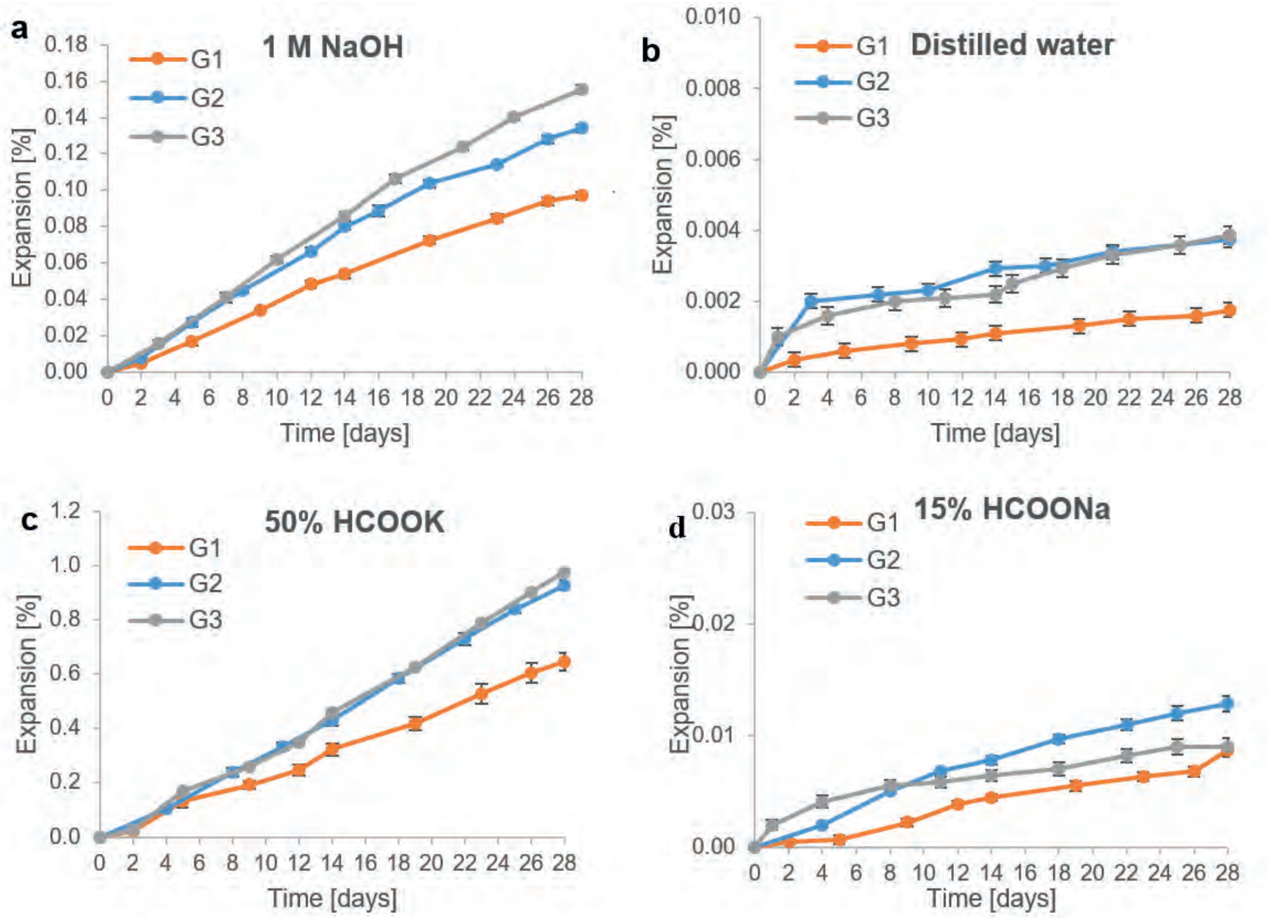

Fig. 1. Expansion of mortar bars with granite aggregate G1, G2, G3 in 80ºC and (a) 1 M NaOH, (b) distilled water, (c) 50% HCOOK, (d) 15% HCOONa (the scales on the vertical axis differ due to a large variation of the results depending on the solution used)

The specimens stored in distilled water at 80°C showed negligible expansion from 0.002% to 0.004% after 28 days. Mortar bars showed no expansion potential under these conditions, similar to the exposure to 15% HCOONa (expansion after 28 days from 0.009% to 0.013%). Significant expansion was observed in the specimens immersed in 1 M NaOH (expansion after 28 days from 0.097% to 0.134%). The greatest expansion was found for mortar bars immersed in 50% HCOOK, ranging from 0.645% to 0.997%. Specimens exposed to potassium formate were highly susceptible to alkali-silica reaction.

Microstructure observations on SEM-EDS confirmed the presence of ASR products in the mortar bars exposed to sodium formate and potassium formate. The results were shown in Figures 2-5.

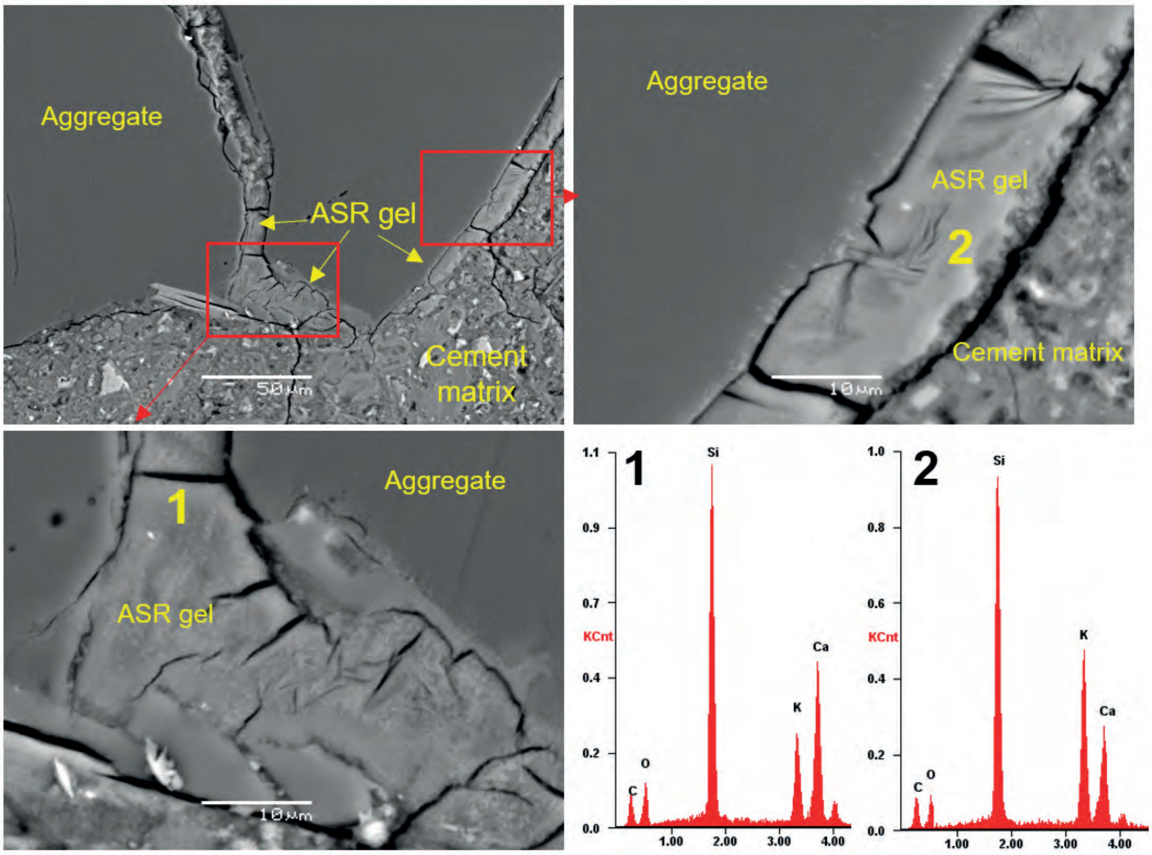

Fig. 2. The microstructure of the mortar with aggregate G3 after 28 days of storage at 80°C in 50% HCOOK, cracks in the aggregate grain filled with ASR gel (1) and ASR gel in the interfacial transition zone aggregate-cement matrix (2)

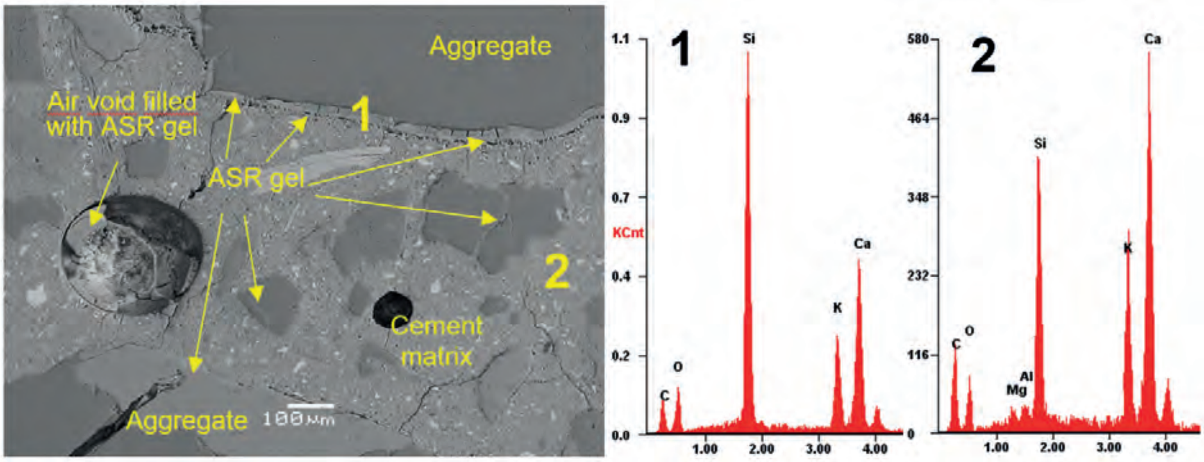

Fig. 3. The microstructure of the mortar with aggregate G2 after 28 days of storage at 80°C in 50% HCOOK, cracks in the aggregate grain filled with ASR gel, ASR gel in the interfacial transition zone between aggregate and cement matrix (1) air void filled with ASR gel, (2) cement matrix with increased potassium amount (2)

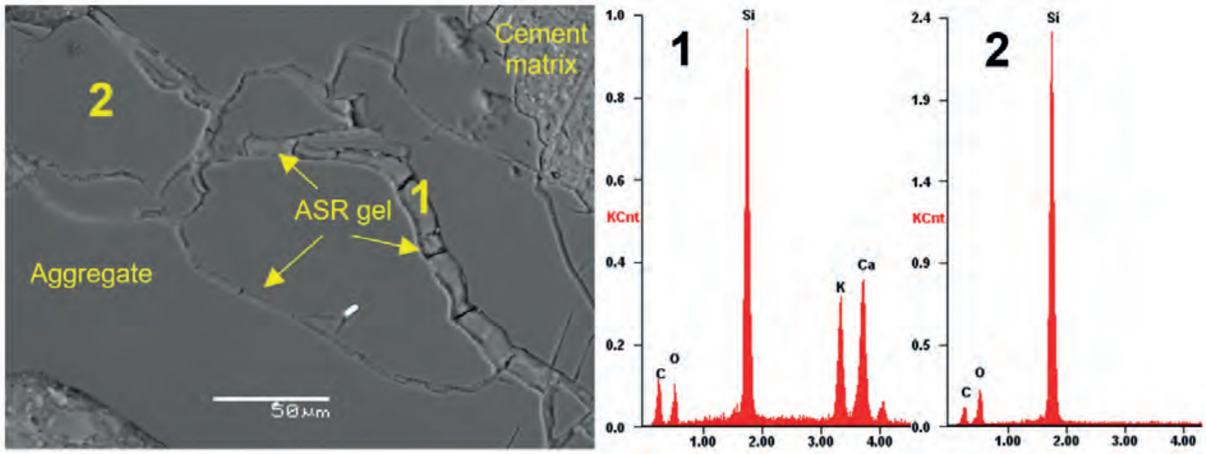

Fig. 4. The microstructure of the mortar with aggregate G1 after 28 days of storage at 80°C in 50% HCOOK, cracks in the aggregate grain filled with ASR gel (1), quartz (2)

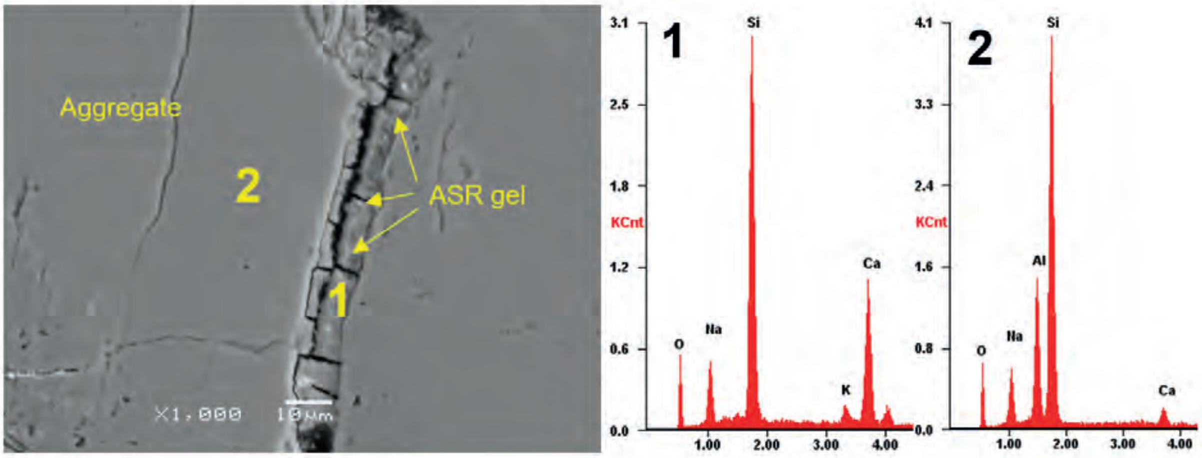

Fig. 5. The microstructure of the mortar with aggregate G2 after 28 days of storage at 80°C in 15% HCOONa, cracks in the aggregate grain filled with ASR gel (1), sodium feldspar (2)

No ASR reaction products were found in the specimens stored in distilled water. An abundance of ASR products was found in specimens exposed to 50% potassium formate. The gel was mainly found in the cracks in the aggregate grains and in the interfacial transition zone. Air voids partially or completely filled with ASR gel were also observed. In the mortar bars exposed to sodium formate, traces of ASR reaction products were found, the gel was recognized in the cracked aggregate grains.

An SEM-EDS microstructure analysis confirmed that the expansion of the specimens stored in a 50% potassium formate solution was related to the ASR reaction. The chemical composition of ASR gel identified in these samples was rich in potassium and was sodium-free. Despite a slight expansion of mortar bars immersed in a 15% sodium formate solution, traces of ASR gel were identified in the microstructure, but in a much smaller amount than in the specimens stored in HCOOK. The ASR gel in the specimens tested in HCOONa contained both sodium and potassium ions, but was characterized by a higher content of Na.

Rangaraju et al. [11] found that the reactive aggregate exposed to potassium acetate showed high susceptibility to ASR. On the other hand, Wang et al. [5], despite the use of a high concentration of potassium acetate (54.5% by weight), did not find the presence of reaction products in concrete subjected to cyclic saturation and drying. Whereas, based on the performed research, it was found that the non-reactive aggregate in the mortar exposed to salts of organic acids, in particular potassium formate, showed a high potential for alkali-silica reaction. Thomas et al. [12]

investigated the possibility of reducing the degree of degradation of concrete treated with a 50% potassium acetate by using the addition of slag or fly ash. However, the effect was not satisfactory and allowed only for a slight delay in the reaction. The authors [12] confirmed the significant effect of potassium acetate on the degradation of concrete as a result of ASR, while in the performed research, the negative effect of potassium formate on the destruction of the mortar due to ASR was also found.

The chemical composition of the ASR gel depended on the de-icing agent used. The content expressed by the ratio of (Na+K)/Si was 0.4-0.6 for gel in mortar stored in potassium formate and 0.3-0.4 for mortar stored in sodium formate, but for specimens exposed to HCOOK, 100% of the alkali was potassium. According to Gholizadeh-Vayghan and Rajabipour [13] ASR gel which contains more alkali, shows greater expansion, which confirms the results obtained in this study and a much higher expansion of mortars stored in HCOOK than in HCOONa. A more detailed analysis of the chemical composition and mechanical properties of the ASR gel will be the subject of further research related to this work.

5. CONCLUSIONS

Based on the conducted research, the following conclusions can be drawn:

- Formate-based de-icing agents promote the occurrence of ASR in granite aggregate.
- A microstructure analysis confirmed that the expansion of the mortars exposed to potassium formate was related to the presence of the ASR gel in the cracks in aggregate grains.
- Despite a slight expansion of mortar bars stored in sodium formate, the presence of ASR reaction products was found.
- The chemical composition of the gel, and thus its properties, depended on the type of de-icing agent used.

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THE IMPACT OF A POLYUREA LAYER ON CRACKING AND PERFORMANCE OF REINFORCED CONCRETE BEAMS UNDER BREAKING LOAD

WPŁYW WARSTWY POLIMOCZNIKA NA ZARYSOWANIE I PRACĘ POD OBCIĄŻENIEM NISZCZĄCYM BELEK ŻELBETOWYCH

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Abstract

The paper discusses the results of laboratory experimental studies on reinforced concrete components (beams) with an outer polyurea layer. The important part of the study is the comparison of the results concerning the load-displacement relation for the reference beams (without the polyurea layer on their external surfaces) and those with the polyurea layer. The main conclusion from this part of the research is that the beam elements covered with a polyurea layer are protected against corrosion processes even in an emergency state. The occurrence of scratches, even of large size, is neutralized by the coating that effectively bridges them.

Keywords: polyurea, corrosion, reinforced concrete beams, breaking load, cracks, durability

Streszczenie

W artykule zaprezentowano wyniki laboratoryjnych badań eksperymentalnych dotyczących elementów żelbetowych (belek) wraz z zewnętrzną warstwą polimocznika. Istotną częścią pracy jest porównanie wyników zależności obciążenie – przemieszczenie dla belek referencyjnych (bez warstwy polimocznika na powierzchniach zewnętrznych) oraz tych taką warstwę posiadającą. Kluczowym wnioskiem płynącym z tej części badań jest ten mówiący o tym, że elementy belkowe pokryte warstwą polimocznika zabezpieczone są przed korozją nawet w stanie awaryjnym. Występowanie rys nawet znacznych rozmiarów jest zneutralizowane poprzez skuteczne ich mostkowanie powłoką.

Słowa kluczowe: polimocznik, korozja, belki żelbetowe, obciążenie niszczące, rysy, trwałość

1. INTRODUCTION

Reinforced concrete (RC) structures that were designed and produced correctly tend to be highly durable. It is commonly assumed that core structural elements, which are critical for the safety of a building facility, should serve their purposes throughout their whole service life. The durability of RC beams and pre-cast concrete products determines (according to a rough estimate) the service life of a whole building. As a result of increasing loads exerted on RC elements, crack formation and propagation, and adverse effects of aggressive media, the ultimate limit state (ULS) and the serviceability limit state (SLS) may eventually be exceeded. Such phenomena are

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indicated in RC structures by excess cracking and deflection of these elements. Cracking states of RC elements are particularly important as they are the main factor determining the durability and safety of structures. Crack formation is actually inherent to the performance of RC structures since this is how these materials naturally respond to the state of strain to which they are subjected. However, the development of wide cracks is very disadvantageous, as they enable penetration by fluids causing corrosion of rebars and affect the rate of concrete degradation, which makes RC elements less durable. As far as cracking is concerned, the safety of structures can be improved by introducing certain design measures (when new elements are designed) or by repairing existing RC elements in the process of filling and closing the cracks. The process of repairing RC structures is often labor- and cost-intensive as well as difficult to complete during the operation of a building facility [1]. There is a number of deeply studied and documented techniques for improving the performance of existing RC elements. Such modifications are introduced by using additional external reinforcing elements (such as steel sections and carbon fiber tapes) and fixing the cracks. A certain disadvantage of these solutions is that they are labor-intensive and an adequate space around an RC element is required to allow the assembly of reinforcements [2, 3].

This paper attempts at providing additional expertise on these topics by introducing polyurea, a material that has not yet been widely recognized. The study shows potential benefits from the application of polyurea on RC beams. The results of experimental research presented in the paper mainly serve to show how polyurea-coated RC beams behave before and after their final failure. Observations and results are also compared to those concerning reference elements (without the additional polyurea layer). Before the study, the authors of the paper defined the following questions:

- Can polyurea be the material that makes it possible to protect RC elements to such extent that their reinforcement is protected against corrosion even if cracks of significant width appear?
- Are there any technical capabilities to maintain the integrity of structural elements even after their final failure?
- Can polyurea be the material that will provide both protection of highly cracked elements against corrosion and their integrity following their failure?

This paper attempts to answer these questions. Note that the paper is not a comprehensive source of information on polyurea and its applications. In fact, it is a continuation of the authors' earlier studies [4].

2. EXPERIMENTAL RESEARCH

Six RC beams were subjected to laboratory bending tests. The elements were made of concrete characterized by an average compression strength of 72.30 MPa (tests of three cube specimens measuring 150x150x150 mm). The RC beams were reinforced with two #10 mm rebars in the compression area (the upper one) and two #14 mm rebars in the tension area (the lower one). The transverse reinforcement of the beams was made of #6 mm rebars in the form of clevises with the main spacing of 15 cm at the beam midspan and with smaller spacing of 10 cm in the support area. The dimensions and arrangement of the reinforcement used in the RC beams are shown in Figure 1.

All the RC beams were divided into two batches. The first batch (three specimens labeled as B.2.1, B.2.2, and B.2.3) were marked as control specimens and had no polyurea coating. The second batch (three specimens labeled as P.2.1, P.2.2, and P.2.3) were polyurea-coated on all their outer surfaces (Fig. 2).

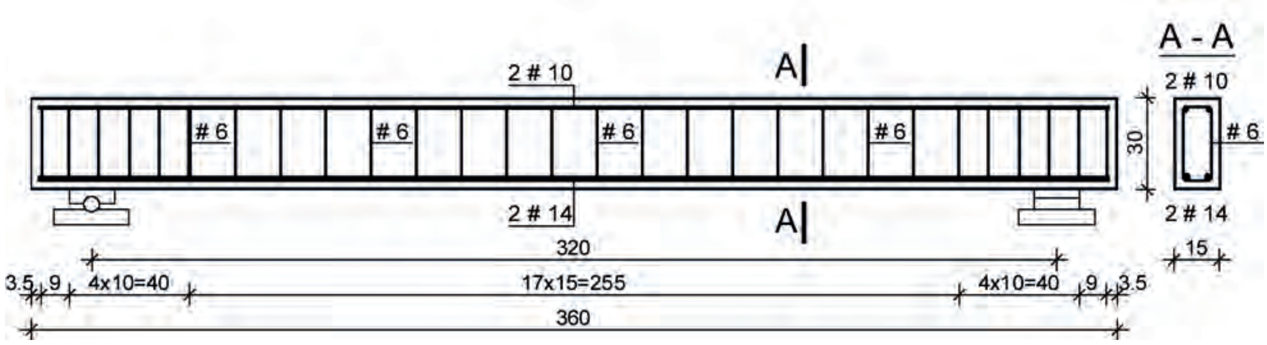

Fig. 1. The dimensions and arrangement of rebars in the RC beams (dimensions in cm)

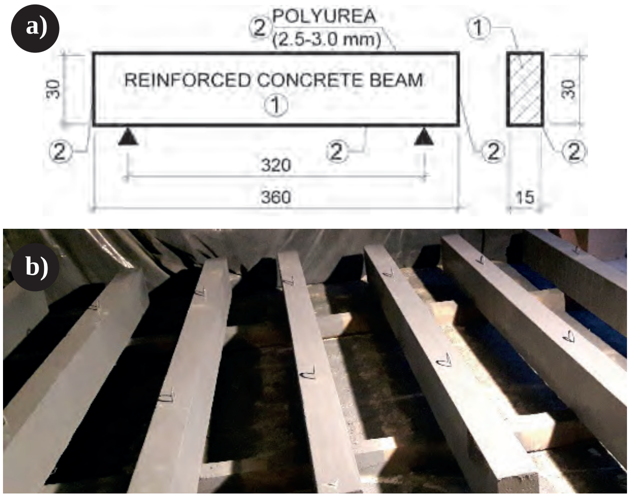

Fig. 2. Polyurea-coated elements: (a) application arrangement; (b) final polyurea-coated elements

The RC beams were coated with aromatic polyurea which is the most common type of coating used in the construction industry. The final product is obtained as a result of the reaction between an isocyanate component and a resin blend component at high temperature (between 65°C and 80°C) and at high pressure (between 120 bar and 200 bar). Aromatic polyurea is the reaction product of the methylenediphenyl diisocyanate (MDI) prepolymers as the isocyanate component and a multifunctional resin blend. The final product is characterized by a short bonding time and high levels of chemical and water resistance, and elasticity. The tensile strength of the coating was 24.08 MPa (at the test speed of 50 mm/min) and 23.03 MPa (at the test speed of 100 mm/min), and its engineering strain was 417% and 391%, respectively. The process of polyurea application involved three main phases: surface preparation of the RC beams (grinding to remove cement wash), prime coat application (two layers of prime coat and dry quartz sand), and polyurea coating application (two layers of the coating were applied with an average total thickness of 2.5 mm to 3.0 mm). Details on preparatory work before laboratory tests are given in the authors' earlier paper [4].

The RC beams of both batches were tested on one test stand whose general arrangement is shown in Figure 3.

The test stand was built using the following components: a steel main frame of the test stand, a steel

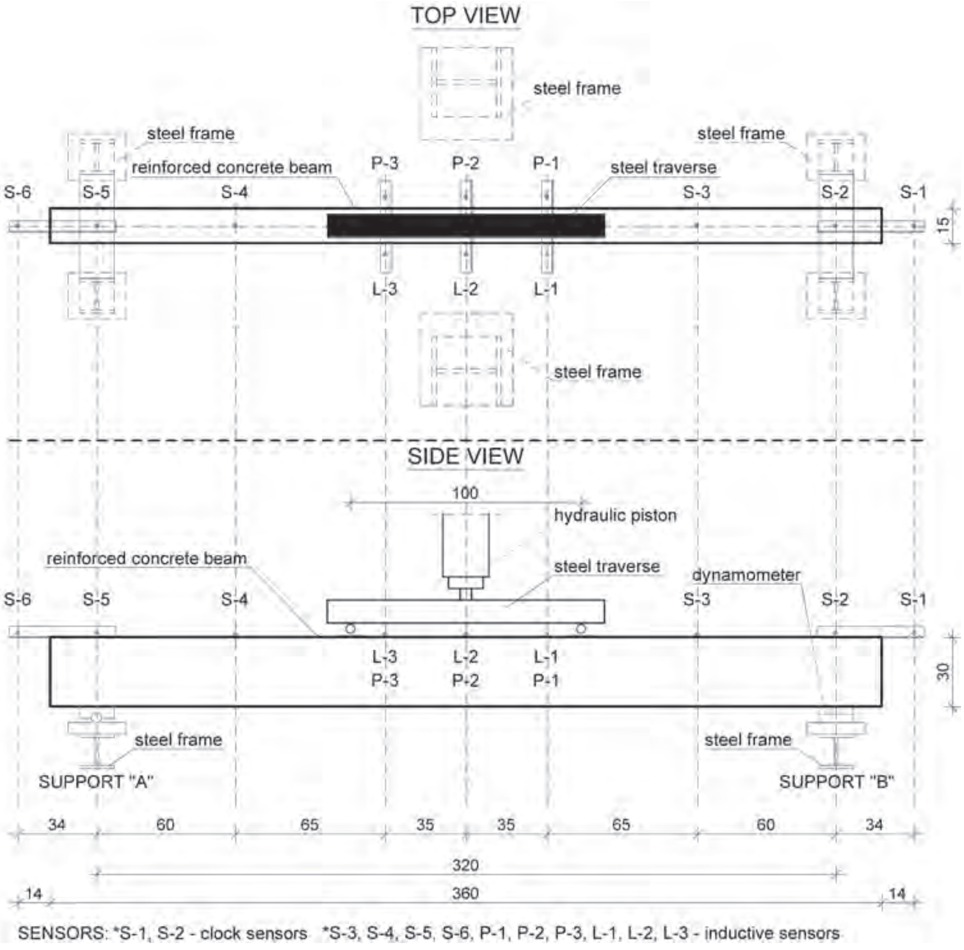

Fig. 3. The test stand

frame providing supports of the RC beams, a stand-alone steel frame supporting strain sensors, a hydraulic piston mounted to the upper part of the frame, a hydraulic pump driving the piston, and a computer workstation for data acquisition. The load was exerted on the RC beams by a steel traverse that was oriented symmetrically to the beam axis and produced load in the form of two concentrated forces 100 cm apart. Test specimens were positioned on the horizontal steel frame and supported pivotally at two points 320 cm apart along the axis. The test stand was also equipped with 12 sensors measuring the displacement of the RC beams while these were subjected to load. The set of 12 sensors included 10 inductive sensors and two dial gauges (marked as S-1 and S-2 in Fig. 3). A force gauge mounted under one of the pivot supports additionally recorded changes in response under each beam.

3. RESULTS

The main results collected during the tests, namely the relation between load and strain, the deflection of the beams, and the cracking state, are provided below.

The following quantities were measured during the tests: vertical displacements, the force exerted by the hydraulic piston, and the response at one of the supports. For the uncoated beams, forces exerted on the beams increased in steps up to a failure; in the case of the polyurea-coated beams, an unloading/loading cycle was applied. The value of the force was obtained from the indication of the device driving the hydraulic piston and also verified with a force gauge mounted between the piston and the traverse.

The relation between the force (exerted by the hydraulic piston) and the deflection of each beam at its midspan is shown in Figures 4 and 5.

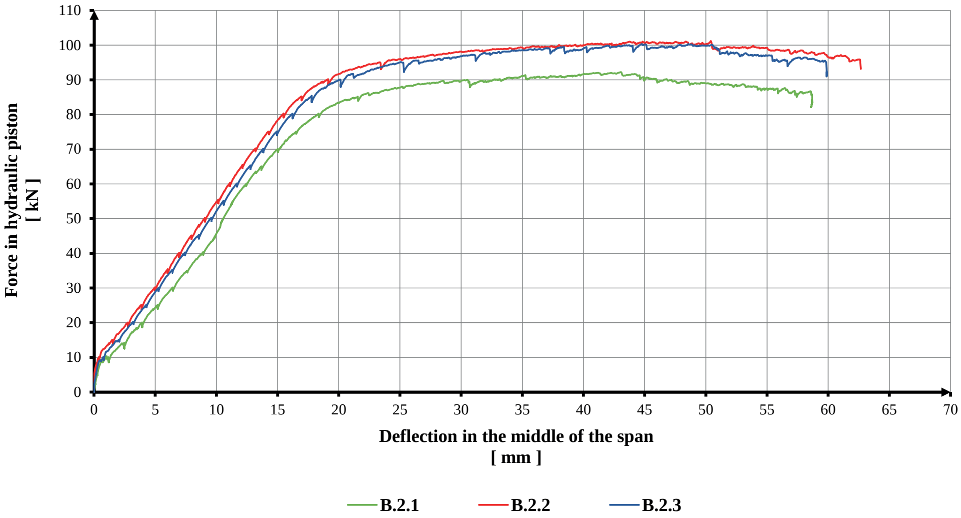

Fig. 4. The relation between the force exerted by the hydraulic piston and the deflection of the beams without any polyurea layer

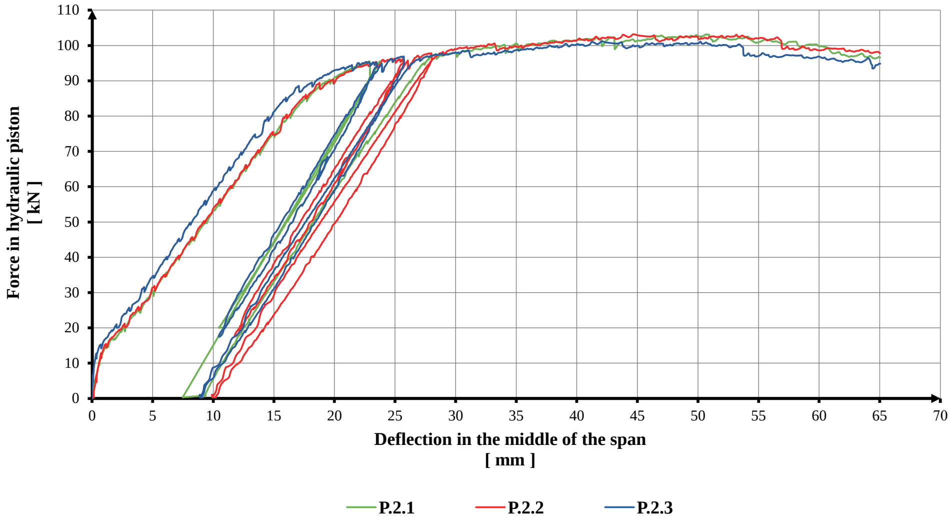

Fig. 5. The relation between the force exerted by the hydraulic piston and the deflection of the beams with a polyurea layer

The first and apparently the most important conclusion from the tests is that the application of the polyurea coating on the RC beams made it possible to additionally subject them to an unloading/loading cycle. The unloading point was set at 90% of the breaking force found for the uncoated reference beams. The load exerted on the specimens (P.2.1 to P.2.3) was removed as soon as it reached 90% of the breaking force obtained for the reference beams. Then, the specimens were again subjected to the load and exhibited their previous bending strength (the one they had before the unloading/loading cycle). The secondary strength (the one after the unloading/loading cycle) of the polyurea-coated RC beams was achieved without any excess increase in the deflection of these elements, i.e. with no loss in bending stiffness (Fig. 5). The following conclusion can be drawn on this basis: the main difference with respect to the behavior of the beams under load close to the breaking one is that polyurea-coated components can be subjected to the load for the second time with only small permanent deformations (very similar behavior was observed in the case of concrete rings [5]).

If we analyse the curves in Figure 6, we will notice that the values and curves of displacements of five out of six RC beams tested are comparable. We can see that in the initial phase of loading, when the beam stiffness mainly depends on properties of concrete, the displacements of the coated beams are smaller than those of the reference specimens. The differences between the curves of deformation of the specimens are smaller under a higher load, i.e. when the beam stiffness is related to characteristics of the reinforcing steel. The diagram (Fig. 6) shows that displacements of beam B.2.1 are the largest. The reason for this is that this beam was the first one that was loaded after the test stand was built, so the settlement of the test stand structure contributed to the deformations of this beam. It should be emphasized that the results for the other specimens are stable and coherent.

All the beams failed in a way that is characteristic of bent elements: the concrete was crushed (debonded) in the compression area of the beam cross-section, or the reinforcement yielded in the tension area of the beam cross-section. The failure of the reference beams occurred when concrete debonded in the upper (compression) area of the element cross-section. During initial phases of loading the reference beams, vertical cracks appeared in the middle part of these beams. As the load increased, the cracks elongated and widened. Finally, in accord with the characteristic failure mechanism of bent elements, the beams underwent a sudden failure as soon as the concrete strength in the upper part of the beam cross-section was exceeded. In contrast to the reference beams, the polyurea-coated ones failed when the reinforcement yielded in the lower (tension) area of these elements. In accord with the characteristic failure mechanism of bent elements, when the bending strength of the RC beams was exceeded, they indicated failure and failed as the reinforcement yielded in the lower part of the cross-section. At the same time vertical cracks widened rapidly near the area where the reinforcement yielded, and beam deflections increased.

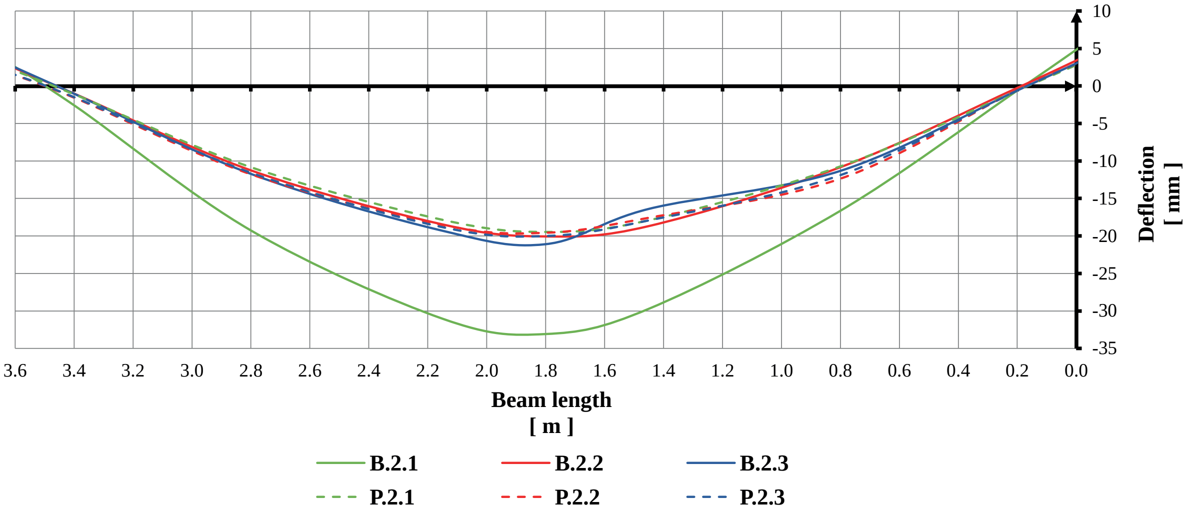

Fig. 6. Deflection of the beams under load equal to 90% of the breaking force

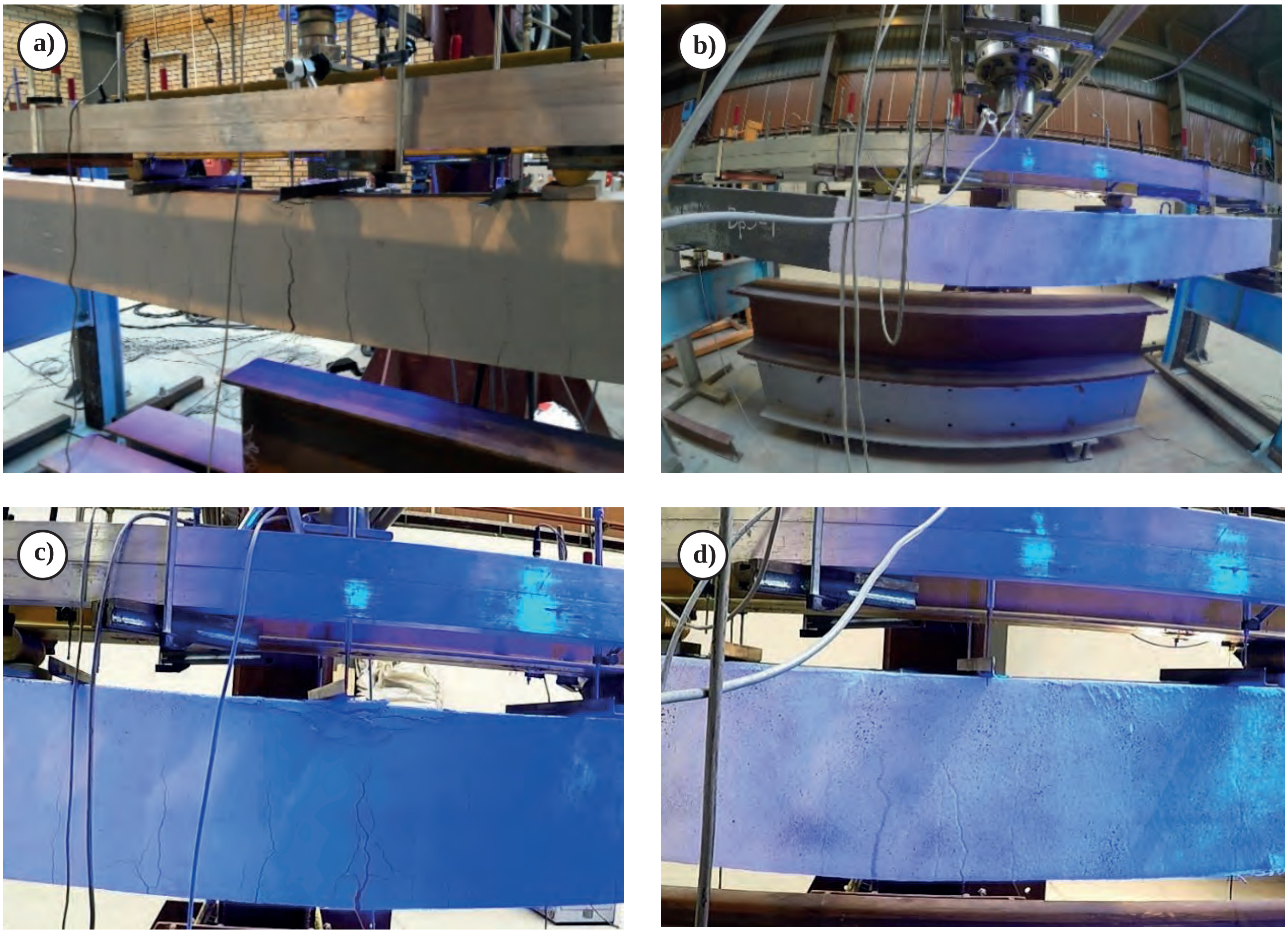

Fig. 7. Visible cracks: (a) (c) beams with no polyurea layer; (b) (d) a beam with a polyurea layer (wide cracks are fully covered)

The polyurea coating remained well bonded to concrete and covered all the cracks until the beams failed completely as a consequence of bending (the cracking states of both types of elements are compared in Fig. 7). Another crucial difference in the behavior of RC beams with and without the polyurea coating can be therefore underlined: in the case of the polyurea-coated elements, even very wide cracks remain impenetrable to factors that make the reinforcement corrode.

4. CONCLUSIONS

The tests described in the paper and the analysis of the results allow us to conclude that:

- The application of polyurea on RC elements makes it possible to subject them to load for the second time (after the load has been removed) even if 90% of the maximum breaking force was achieved.
- The polyurea coating is very efficient at bridging cracks of even significant wideness, limiting the exposure of the internal structure of reinforced concrete (an RC beam) to corrosive factors.
- Polyurea ensures integrity of RC elements even when too much load is exerted on them (no pieces of concrete fall off).

Considering these conclusions and the fact that the research work presented in the paper is only at its initial stage, it can be stated that further research in this area is likely to provide modern building engineering with valuable knowledge.

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TESTS OF SELECTED PROPERTIES OF CONSTRUCTION MORTARS MODIFIED WITH WASTE GYPSUM BINDER OBTAINED IN THE FLUE GAS DESULPHURIZATION PROCESS

BADANIA WYBRANYCH WŁAŚCIWOŚCI ZAPRAW BUDOWLANYCH, W ASPEKCIE ICH TRWAŁOŚCI, Z ODPADOWYM SPOIWEM GIPSOWYM OTRZYMANYM W PROCESIE ODSIARCZANIA SPALIN

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Abstract

The article presents the results of tests of selected properties of plastering mortars that are based on natural gypsum binder, as well as on synthetic gypsum binder from the flue gas desulphurization process. The mortars were analyzed with regards to their durability. For the purpose of the publication, the recipe (quantitative) compositions of the plastering mortars, which differed in terms of the type of used setting retarder (PlastRetard PE and tartaric acid A200), were designed. The mortar recipes were determined experimentally, assuming that the beginning of the setting time was 120 min (the average beginning of the setting time for currently available building mortars), and that the content of the binder was 70%. The assumed research program included tests of flexural and compressive strength, surface hardness, and the adhesion to the substrate. The results of the research confirmed the possibility of modifying the recipe compositions of gypsum plastering mortars.

Keywords: plastering mortars, flue gas desulphurization gypsum, retarders

Streszczenie

W artykule przedstawiono wyniki badań wybranych właściwości zapraw tynkarskich na spoiwie gipsowym budowlanym i syntetycznym pochodzącym z procesu odsiarczania spalin, w aspekcie ich trwałości. Na potrzeby publikacji zaprojektowano składy recepturowe zapraw tynkarskich różniących się rodzajem użytego opóźniacza wiązania (PlastRetard PE i kwas winowy A200). Receptury zapraw zaprojektowano metodą doświadczalną przy założeniu początku czasu wiązania wynoszącym 120 min (średni początek czasu wiązania dla dostępnych zapraw budowlanych) i zawartości spoiwa na poziomie 70%. Założony program badawczy obejmował wykonanie badań wytrzymałości na zginanie i ściskanie, twardości powierzchniowej oraz przyczepności do podłoża. Otrzymane w toku badań wyniki potwierdziły możliwość modyfikowania składu gipsowych zapraw tynkarskich spoiwem syntetycznym pochodzącym z procesu odsiarczania spalin.

Słowa kluczowe: zaprawy tynkarskie, gips z odsiarczania spalin, opóźniacze wiązania

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1. INTRODUCTION

Taking into account the pace of development of innovative technologies, there is a growing demand for combining various industrial branches. A particularly desirable phenomenon is the possibility of using materials that are seen as waste in one industry, but in another fit perfectly into the process of creating “something new”. The chemical industry provides many by-products (waste) that pose a significant problem for a sustainable economy. One of them is synthetic gypsum, which is derived from the flue gas desulphurization process. This gypsum, and the products made from it, seem to be one of the most interesting examples of combining the chemical industry with the construction industry. The paper deals with the problem of the possibility of using gypsum from flue gas desulphurization as a full-value binder in plastering mortars. The storage and recycling of such waste is now a subject that is worth considering, and this is reflected in numerous publications [1-7]. The authors’ experience to date confirms that this type of binder can be a full-value substitute for natural building binders in the recipes of building mortar. The strength parameters of such mortars are similar, or sometimes even exceed the parameters of mortars that are developed based on natural binders.

The scope of the undertaken research activities included the designing of quantitative and qualitative compositions of gypsum plastering mortars that meet the standard requirements for these materials. Moreover, the conducted studies involved the testing of selected properties of plastering mortars that were prepared based on building and synthetic gypsum. Flexural and compressive strength, surface hardness, and the adhesion to the substrate were analyzed during the testing.

2. THE RECIPE COMPOSITIONS OF THE DESIGNED MORTARS

The compositions of the designed plastering mortars included: gypsum binder (synthetic gypsum from the flue gas desulphurization process and building gypsum), setting retarders, lime powder, methylcellulose, perlite, and hydrated lime. The proportions of the individual components were determined experimentally, assuming that the beginning of the setting time was 120 min (the average beginning of the setting time for currently available building mortars), and that the binder content was at the level of 70%.

The synthetic gypsum that was used in the recipes came from a petrochemical plant located in Poland. In order to obtain a full-value binder, it was calcined at a specific temperature and for a specific time. After the calcination process, the synthetic binder lost, on average, approximately 25% of its weight. Figure 1 shows the synthetic gypsum before and after the calcination process.

Fig. 1. The synthetic gypsum before and after the calcination process

In order to reach the assumed beginning of the setting time (approx. 120 min), it was necessary to use setting retarders. For this purpose, two retarders were used: PlastRetard PE and A200 tartaric acid. Unfortunately, the correct dosage of retarders during the execution of mortars poses a problem. The amounts of retarders, which were declared by the manufacturers with regards to extending the setting time, did not coincide with the actual extension that was obtained in the study. Additionally, the matter was complicated by the fact that e.g. a difference of only 0.0002% of PlastRetard PE retarder per 1 kg of mortar could delay the setting time by even 10 ÷ 15 minutes. A similar relationship was observed in the case of the A200 tartaric acid.

A list of the prepared mortars (with the adopted designations) is presented in Table 1, while the recipe compositions are shown in Table 2.

Table 1. List of the made plastering mortars

Type of mortar	Adopted designation	Used retarder
Plastering mortars based on building gypsum (reference mortars)	AK.GB.TR	PlastRetard PE
	AK.GB.TK	Tartaric acid A200
Plastering mortars based on synthetic gypsum (experimental mortars)	AK.GS.TR	PlastRetard PE
	AK.GS.TK	Tartaric acid A200

Table 2. Recipes of the made plastering mortars

Mortar designation	The content of ingredients of the gypsum plastering mortars [g]						
	binder	lime powder	methyl cellulose	perlite	hydrated lime	retarder	water
Plastering mortars based on the building gypsum							
AK.GB.TR	700.00	245.95	3.00	29.00	50.00	1.03	620.00
AK.GB.TK		245.93				0.40	
Plastering mortars based on the synthetic gypsum							
AK.GS.TR	700.00	245.95	3.00	29.00	50.00	1.05	620.00
AK.GS.TK		245.91				0.41	

3. RESEARCH ON THE PROPERTIES OF THE GYPSUM PLASTERING MORTARS

The adopted research program included testing of plastering mortars with regards to flexural strength, compressive strength, surface hardness, and the adhesion to the substrate. The mortars were prepared on the basis of building and synthetic gypsums, and with the addition of different setting retarders: PlastRetard PE and A200 tartaric acid. The research was carried out in the Laboratory of the Institute of Building Engineering of Warsaw University of Technology (Branch in Płock).

3.1. Flexural strength

The test was carried out in accordance with PN-EN 13279-2 [8] on 6 bar samples with dimensions of 40x40x160 mm. The samples were subjected to standard treatment – 7 days at a temperature of 23°C ±2°C and a relative air humidity of 50% ±5%, followed by drying to a constant weight in a temperature of 40°C ±2°C (Fig. 2).

Fig. 2. A sample during the flexural strength test

During the study, it was noticed that the samples containing the PlastRetard PE binding retarder achieved a constant mass in a faster time. The average results of the flexural strength test for the mortars based on the building gypsum, as well as those based on the synthetic gypsum that was obtained in the flue gas desulphurization process, are shown in Figure 3.

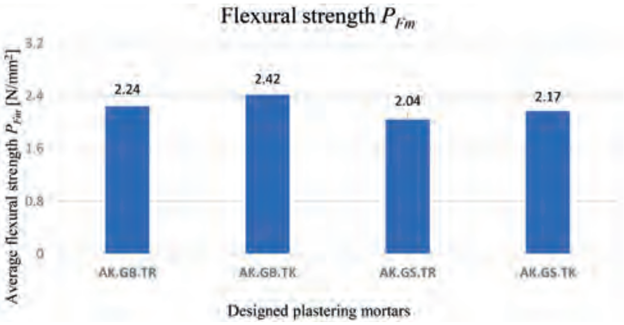

Fig. 3. Results of the average flexural strength of the plastering mortars

The study of the flexural strength of the gypsum plaster mortars that were modified with setting retarders showed slight differences in terms of results – ranging from 2.04 to 2.42 N/mm^2. The use of the synthetic gypsum in the designed mortars allowed for the obtaining of results similar to those based on the building gypsum. Importantly, for all the recipes, the achieved results were not lower than the standard value, which is equal to 2 N/mm^2.

3.2. Compressive strength

The test was carried out in accordance with PN-EN 13279-2 [8] on 12 halves of bars, which were obtained after the flexural strength test. After the samples were dried to a constant weight, they were placed into a testing machine and examined (Fig. 4).

Fig. 4. A sample during the compressive strength test

The average results of the compressive strength test for the mortars that were prepared based on the building gypsum, as well as those based on the synthetic gypsum obtained in the flue gas desulphurization process, are shown in Figure 5.

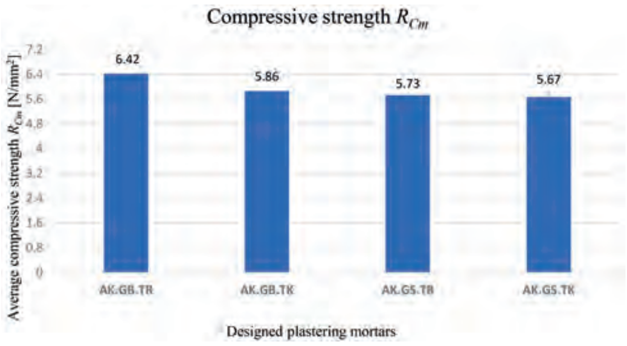

Fig. 5. Results of the average compressive strength of the plastering mortars

After the samples were destroyed, the obtained type of damage was compared and the results were recorded. The sample destruction patterns were very similar. The distinguishing of the mortars based on the building gypsum binder from the mortars based on the synthetic gypsum binder after damage was only possible thanks to the color of the binder. As in the case of the flexural strength test, the obtained results did not differ from each other. The best results were obtained for the samples with the use of the building gypsum as the binder, and the most durable samples were those with the PlastRetard PE retarder – the average compressive strength was equal to 6.42 N/mm^2.

3.3. Surface hardness

Surface hardness was tested in accordance with PN-EN 13279-2 [8]. Its determination involved the measuring of the depth of the indentation made using a hardened steel ball (with a diameter of 10 mm) on rectangular specimens with dimensions of 40x40x160 mm (3 samples, 6 indentations each) (Fig. 6). The results of the average surface hardness are shown in Figure 7.

Fig. 6. A sample during and after the surface hardness test

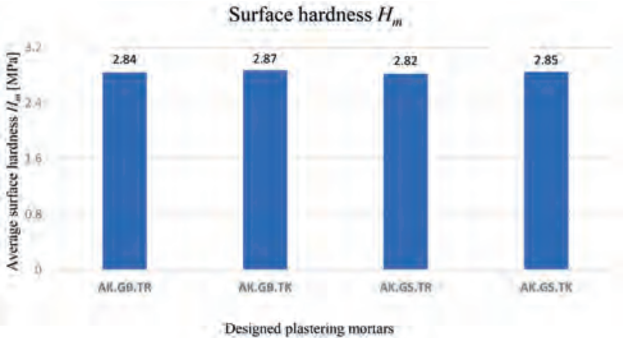

Fig. 7. Results of the average surface hardness of the plastering mortars

In terms of the durability of the plastering mortars, this test is very important due to the nature of their use. The results of the determination of the surface hardness for all the recipes were similar. The difference in the test results was only equal to 0.05 MPa. When studying literature concerning the subject [9], it can be noticed that the variable firing temperature of synthetic binder affects the results of the surface hardness test. Due to the fact that the tested samples contained a binder fired at a constant temperature, the test results did not differ from each other.

3.4. Pull-of adhesion to the substrate

The interlayer adhesion test was carried out in accordance with PN-EN 13279-2 [8]. For this purpose, concrete slabs with dimensions of 50 x 25 cm and a thickness of 50 mm were used. They were seasoned for at least two months. In the first stage, mortar (5 mm) was spread on the entire surface of the slabs. Afterwards, incisions were made in the plaster in order to separate the measuring areas, onto which metal discs (with a surface corresponding to these areas) were glued using epoxy resin. The sample's pull-off force in relation to the contact surface was taken as a measure of the adhesion of the mortar to the substrate (Fig. 8). After testing the samples, the nature of their destruction was compared (cohesive – in the binder, adhesive – between the mortar and the concrete substrate).

Fig. 8. A sample during the pull-off tests

The results of the average value of pull-off adhesion are shown in Figure 9.

The obtained nature of the destruction – cohesive (in the binder) – for all the tested mortars indicates that their pull-off adhesion is greater than the tensile strength of the mortars. The mortars prepared on the basis of the synthetic binder with the PlastRetard PE retarder obtained the best results. This confirms that their addition has a positive effect on the pull-off adhesion between the mortars and the substrate.

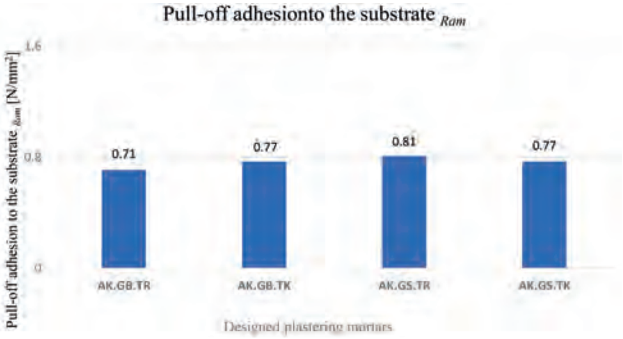

Fig. 9. Results of the average value of the pull-off adhesion between the substrate and the plastering mortars

4. CONCLUSIONS

The obtained test results confirmed the possibility of modifying the composition of gypsum plastering mortars with different setting retarders and with the addition of a synthetic binder derived from the flue gas desulphurization process.

Regarding the conducted research, it seems advisable to carry out further tests of gypsum plaster mortars (with e.g. different contents of gypsum binder in the mixtures, or with the addition of other retarders or admixtures) in order to especially improve the tensile strength of mortars. Such an extension of the research program will significantly improve the pull-off adhesion between the plaster and the substrate, and will also contribute to the achievement of a change in the nature of damage from cohesive to adhesive.

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METHODOLOGY FOR MEASURING THE CARBONATION DEPTH OF CONCRETE – STANDARD AND NON-STANDARD ASPECTS

METODYKA POMIARU GŁĘBOKOŚCI KARBONATYZACJI BETONU – ASPEKTY NORMOWE I POZANORMOWE

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Abstract

Carbonation of concrete is a complex phenomenon, depending on many factors, including the heterogeneity of concrete, which results in an uneven carbonation front. The assessment of the depth of the carbonation front depends on the measurement technique adopted. The article summarizes the standard techniques for measuring the depth of carbonation and proposes an alternative measurement technique based on the measurement of the fields of the carbonated and noncarbonated surfaces, and then converting to the averaged depth of carbonation. For an example sample, the results obtained with different standard techniques and the proposed off-standard technique were compared.

Keywords: carbonation, research technique, carbonation front, cement concrete

Streszczenie

Karbonatyzacja betonu jest zjawiskiem złożonym, zależnym od wielu czynników, między innymi niejednorodności betonu, z czego wynika nierównomierny front karbonatyzacji. Ocena głębokości frontu karbonatyzacji zależy od przyjętej techniki pomiaru. W artykule podsumowano normowe techniki pomiaru głębokości karbonatyzacji oraz zaproponowano alternatywną technikę pomiaru opartą na pomiarze pól powierzchni skarbonatyzowanej i nieskarbonatyzowanej, a następnie przeliczeniu na uśrednioną głębokość karbonatyzacji. Dla przykładowej próbki porównano wyniki otrzymane różnymi technikami normowymi oraz zaproponowaną techniką pozanormową.

Słowa kluczowe: karbonatyzacja, technika badawcza, front karbonatyzacji, beton cementowy

1. INTRODUCTION

Carbonation is physicochemical phenomenon occurring under the influence of carbon dioxide contained in the air. It is the most common mechanism of threat to the durability of reinforced concrete structures [1-4]. The phenomenon of carbonation takes place in any surface-unprotected concrete structure, since almost every building object is completely or partially immersed in an atmosphere whose component is CO_2 with a concentration sufficient to initiate and progress this process. Carbonation of concrete is a process with a complex, determined by many factors, course and equally complex impact on concrete and its properties [5-7]. The course of carbonation over time is associated with a number of factors of a material, technological and environmental nature. Concrete is a heterogeneous material and therefore the carbonation front does not have a linear waveform. Standard methods for determining the average carbonation front are

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differentiated algorithms. They differ in the way of taking into account the occurrence of aggregate grains on the front of carbonation line and local reductions of the carbonation front. They also differ in the number and location of measurement lines. Such differentiated approaches result in variability in the result of determining the average carbonation front, and at the same time is characterized by randomness of the results. The aim of this paper is to present an alternative method of measurement based on the determination of the surface of the noncarbonated area, and then convert it into an averaged carbonation depth and compare the obtained result with those obtained using standard measurement techniques.

2. STANDARDIZED TEST METHODS FOR CONCRETE CARBONATION

Current and previously standardized test methods of resistance to carbonation of concrete differ not only in the method of sample preparation (conditioning time, temperature, humidity, paraffin protection, size and shape of samples), the carbonation conditions (exposure time, CO_2 concentration, humidity) but also in the technique of measuring the carbonation range. The differences concern: the method of plotting the front line of carbonation (taking into account the grains of coarse aggregate, porous aggregatesa or air voids, rejection from corner measurements), the number of measuring points and their distribution and the accuracy of results presentation (Tab. 1).

Table 1. Comparison of selected standard methods for determining the depth of the carbonation frontline

No.	Standard	Carbonation conditions	Shape and method of sample preparation	Depth measurement method
1.	PN-EN 13295: 2005 Products and systems for the protection and repair of concrete structures – Test methods – Determination of resistance to carbonation [8]	Accelerated laboratory examination. The samples are treated with an atmosphere containing 1% CO_2 at (21 ±2)°C, humidity RH (60 ±10)%.	In the case of paste, mortar or concrete with $D_{max} \leq 10$ mm sample are beams of 40 mm x 40 mm x 160 mm size, in the case of concretes with $D_{max} > 10$ mm minimum sample dimensions are 100 mm x 100 mm x 400 mm. Before the test, storage under dry conditions for 14 days. Samples not protected by paraffin.	The depth of carbonation is measured by applying a phenolphthalein index to the surface of the fresh sample break. The same sample can be used several times to measure the increasing depth of carbonation over time, before each measurement a thin layer of the sample is removed. For each successive side, the length of the colour limit parallel to the edge of the sample shall be divided into four equal sections, thus determining the 5 measuring points. At each of these points, a measurement shall be made to the nearest 0.1 mm. When the carbonation front is broken with coarse aggregate, the carbonation line should be carried out through the aggregate, connecting the border on both sides of it. In places where there are voids in concrete or fragments of porous aggregate, a greater depth of carbonation may occur. If the values of the maximum carbonation cavity are less than 4 mm for concrete or 1.5 mm for mortar, the results may not be taken into account. If they are larger, the estimated maximum depth of carbonation shall be reported. The average carbonation result is determined with an accuracy of 0.5 mm.
2.	PN-EN 12390-10: 2019-02 Testing hardened concrete – Part 10: Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide [9]	Carbonation in natural conditions Carbonation under chamber conditions: concentration of CO_2 (0.040 ±0.001) % The sample is stored under laboratory conditions (T = (20 ±2)°C; RH = (65 ±5)%) for (16 ±2)h prior to the test.	The standard provides for the testing of rectangular samples with a length of at least 350 mm and shorter sides of at least 4 lengths of the maximum dimension of the aggregate grain. Samples not protected by paraffin.	The depth of the carbonation front is determined in 3 points for each of the walls of the sample. The length of the side of the sample should be divided into four equal parts and then measured in 0.25; 0.5 and 0.75 side lengths of the sample. The results shall be recorded to the nearest 0.5 mm. The average measurement result shall be given to the nearest 0.1 mm. When the carbonation front is broken with coarse aggregate, the carbonation line should be carried out through the aggregate, connecting the border on both sides of it. If the values of the maximum carbonation cavity are less than 4 mm, the results may be disregarded. If they are larger, the estimated maximum depth of carbonation shall be reported.
3.	PN-EN 12390-12: 2020-06 Testing hardened concrete – Part 12: Determination of the carbonation resistance of concrete – Accelerated carbonation method [10]	Accelerated laboratory examination. Before the test, the samples are conditioned in laboratory conditions for 14 days (temp from 18°C to 25°C, relative humidity from 50% to 65%). The measurement is made after 7, 28 and after 70 days of storage in the chamber at a temperature of (20 ±2)°C, with a humidity RH (57 ±3)% containing (3.0 ±0.5)% CO_2.	The standard provides for the testing of samples: 2 rectangular or 5 cylindrical with a length of at least 280 mm and shorter sides of at least 3 lengths of the maximum dimension of the aggregate grain or 8 cubic ones with a side length of at least 3 lengths of the maximum grain size. The reference sample size is 100 mm. Samples not protected by paraffin.	The depth of carbonation is measured at 3-5 points on each of the 4 surfaces of the prism, half of the cube or the dissected surface of the cylinder. To locate these points, the length of the edges should be divided into about 4 equal sections. The measurement shall be made with an accuracy of 0.5 mm. When the carbonation front is broken with coarse aggregate, the carbonation line should be carried out through the aggregate, connecting the border on both sides of it. If the values of the maximum carbonation cavity are less than 4 mm, the results may be disregarded. If they are larger, the estimated maximum depth of carbonation shall be reported. The average measurement result shall be given to the nearest 0.1 mm.

4.	PN EN 12390 – 12 Project valid from 2010 to 2020 [11]	The test proceeds as above with the exception of CO_2 concentration during the test, which should be (4.0 ±0.5)%.	Samples as above except for the possibility of securing two parallel sides with paraffin.	The measurement shall be as above, except for samples which have been secured with paraffin, in which case the measurement shall be made perpendicular to the unprotected walls of the sample. The design of the standard does not increase the number of measurements on one wall for protected samples, but at the same time requires 20 measurements for one sample.
5.	ISO 1920-12: 2015 Testing of concrete. Part 12: Determination of the carbonation resistance of concrete. Accelerated carbonation method [12]	Accelerated laboratory examination. The storage time in the carbonation chamber is 70 days. The samples are conditioned before the test for 14 days under laboratory conditions. In the chamber at (22 ±2)°C, at a humidity RH (55 ±5)% containing (3.0 ±0.5)% CO_2. In the case of locations in hot climates, the conditions in the chamber may change to the temperature (27 ±2)°C, with humidity RH (65 ±5)%. The depth of carbonation is measured on the 56th, 63rd and 70th day of storage in the chamber.	The test is carried out on 2 cubic or rectangular samples. The dimension of the samples in cross-section should be at least 100 mm and the length of the rectangular samples should be at least 400 mm. Before the test, two parallel walls may be paraffinized.	The depth of carbonation is measured at five locations on each wall where the sample has not been protected with paraffin or at 10 sites at each of the unsaffin-protected walls where the sample has been protected with paraffin. In order to locate the measurement points, divide the sides of the sample into 6 or 11 sections, respectively. The measuring points are the central points. The measurement shall be made with an accuracy of 0.5 mm.

3. CARBONATION DEPTH MEASUREMENT TECHNIQUE USING ALKALINE INDICATORS

All discussed standard methods are based on qualitative chemical analysis. The basis of this method are chemical indicators for assessing the reaction of concrete, which change coloration at a certain pH limit. A number of different alkaline indicators can be used to determine the course of the pH limits in concrete.

The natural pH of concrete is approx. 12.5÷13.0 and this is the level that ensures the passivating effect of the coating in relation to the reinforcement. It is considered that already lowering the pH below 11.0 is the beginning of the threat of corrosive processes in reinforcement, and pH values at the level of 9,0÷10,0 are considered to be the limits below which the protective capacity of the coating is lost [1]. In measurement practice, mainly four types of indicators are used: phenolphthaleic ("deep purple test", pH limit value = ~8.5), timolophthaleic (limit pH = ~10.5), timolophenolphthaleic (limit pH = ~9.5) and the so-called "rainbow test", which allows to identify at the turn of the sample the approximate pH range in the interval every 2 (i.e. approximate pH limits = 12, 10, 8) [1, 13-15]. The rainbow indicator is used in the diagnosis of operated structures, and the interpretation of the result is often difficult, due to the blurred boundaries of color zones and the smooth transition of one color into another with a change in pH at the depth of concrete. In the analyzed standard methods, phenolphthalein is used. As a result of using this indicator, clearly outlined color areas are obtained (an uncarbonated purple zone with a pH of < 8.5 and a carbonated zone of uncolored concrete). The border of these two zones is clearly outlined, which allows to plot a clear front line of carbonation.

4. PROPOSAL FOR AN ALTERNATIVE MEASUREMENT TECHNIQUE

Cement concrete is a heterogeneous material, and the standard methods for determining the average depth of carbonation are based on point measurements, including different numbers of measurements depending on the standard. The greater the number of measuring points, the more accurate the result can be obtained. The proposed new measurement technique is based on the adoption of an infinite number of measurements, which is possible by measuring the total area of the sample (A_{tot}) and measuring uncarbonated area (A_{ns}), followed by conversion to the averaged depth of carbonation (d) according to formula:

$$d = \frac{\sqrt{A_{tot}} - \sqrt{A_{ns}}}{2} \quad (1)$$

where:

A_{tot} – area of total specimen cross – section,
A_{ns} – area of noncarbonated zone.

The proposed measurement technique involves measurement by the method of image analysis at the sample break after the application of phenolphthalein.

The proposal for an algorithm for calculating the field of noncarbonated and carbonated areas was placed on Figures 1-3. It should be emphasized that the proposed method is not universal and is applicable only in the case of testing laboratory samples. It cannot be used in the case of testing forgings of structures elements.

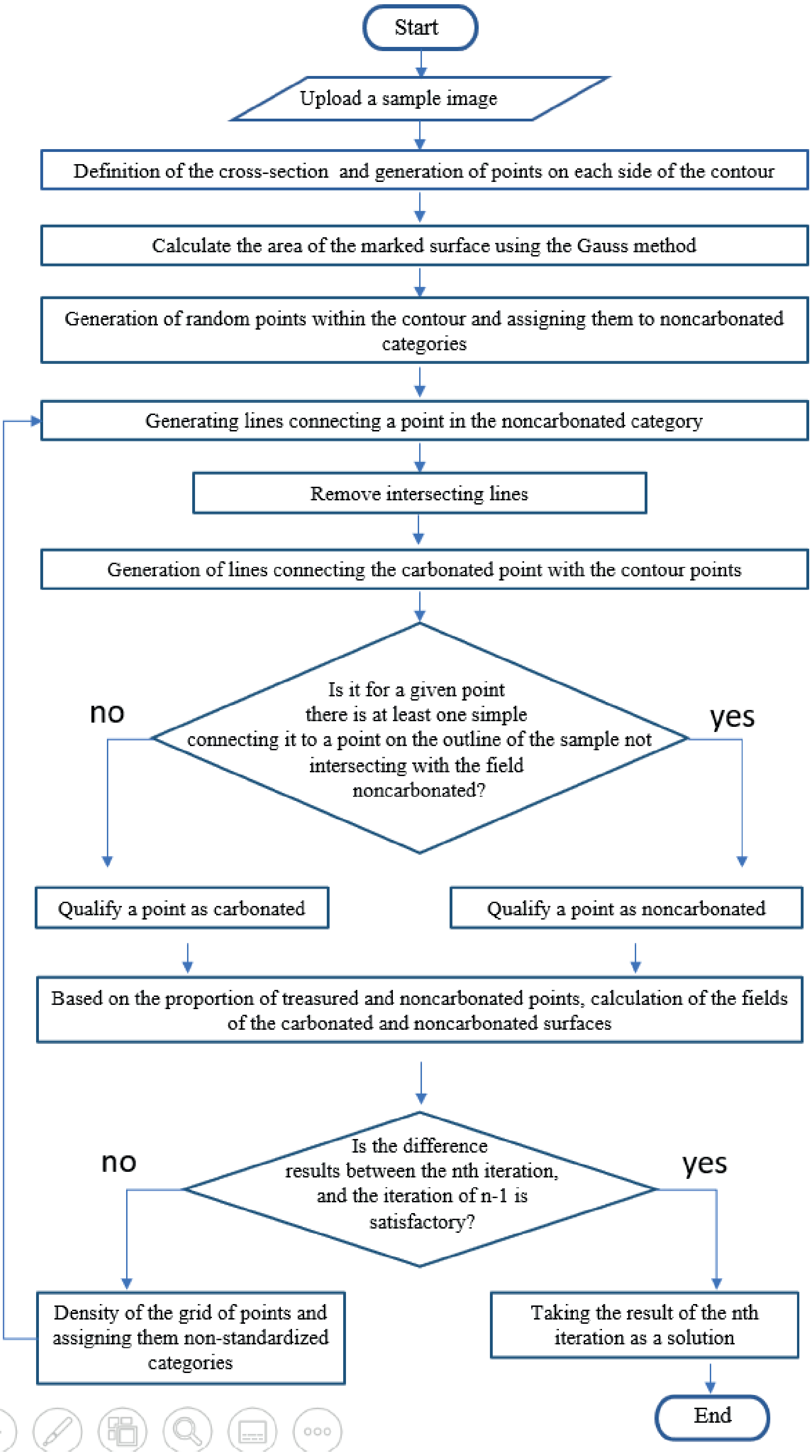


Fig. 1. Algorithm for determining the carbonated and noncarbonated area based on the sample image

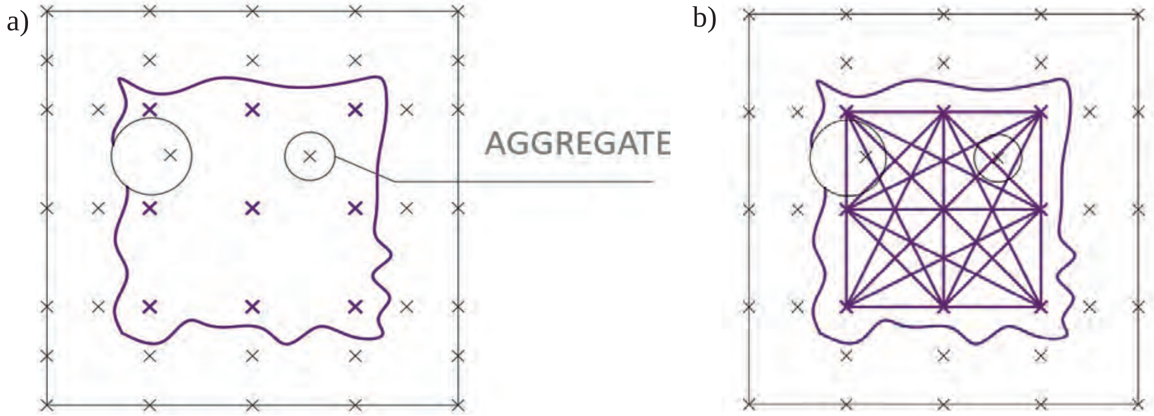


Fig. 2. Schematic of the algorithm: a) generation of random points to which the category of the noncarbonated is assigned, b) the lines connecting the noncarbonated points are generated

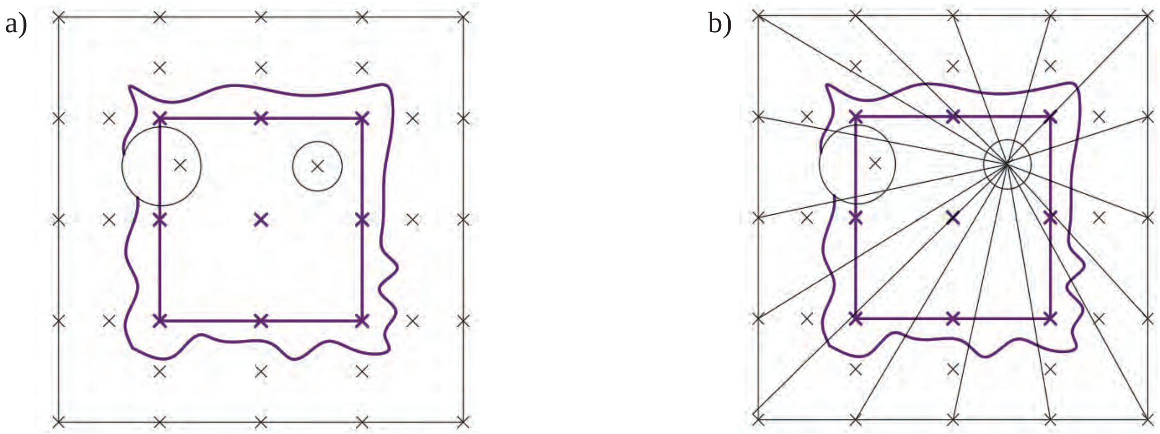


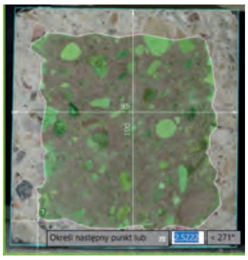
Fig. 3. Schematic of the algorithm: a) removal of intersecting lines, b) generation of lines connecting carbonated points to contour points

5. COMPARISON OF THE RESULT OF THE STANDARD AND ALTERNATIVE MEASUREMENT

As part of the comparison of the results of the depth of the carbonation front obtained using the measurement techniques described in the analyzed standards for the sample image after the carbonation test, image analysis was carried out. The carbonation depths were measured in accordance with the standards and the average carbonation depth was determined in accordance with the proposed algorithm. The results of the standard measurements are summarised in Table 2. After applying the discussed algorithm, the following results were obtained: total sample cross-section area (A_{tot}) equal to 9441 mm^2, noncarbonated area (A_{ns}) equal to 5539 mm^2 (Tab. 2) After applying the formula (1), an average depth of the carbonation front of 11.4 mm was obtained.

Comparing the measurement results with three standard methods (Table 2) and a new method using image analysis, it can be concluded that all methods give a comparable final result, i.e. in the range from 10.4 mm to 11.5 mm. The result of the image analysis method is the closest to the result obtained by the PN-EN12390-10 method, which assumes the most even distribution of measuring points along the edges of the sample. Statistical confirmation of the convergence of results obtained by different methods would require measurements on a larger population of samples, which at the current stage of research was not planned. Previous analyses suggest that the convergence of the image analysis method and the standard methods will be very high.

Table 2. Measurement of carbonation depth using standard methods: PN-EN 12390-10: 2019-02, PN-EN 12390-12: 2020-06 and PN EN 12390-12, ISO 1920-12: 2015 and proposed method

	PN-EN 12390-10: 2019	**PN-EN 12390-12: 2020-06**	**ISO 1920-12: 2015**	**Proposed method**
Sample image with unlabeled measurement lines or area				
Measurement	11.5 mm	10.8 mm	10.4 mm	11.4 mm

6. SUMMARY

The method of measuring the depth of carbonation presented in the article is a certain improvement in standard procedures. In the point measurement, performed with a linear measure, the precision of the person making the measurement is of great importance, but also the interpretation of the local course of the boundary line between the purple noncarbonated area and the gray carbonated area. The analysis of the consolidated image proposed in the new method is the most representative way of averaging the measurement. The simplicity of processing the photo and obtaining the result based on the proposed algorithm significantly speeds up and facilitates the study. The authors are aware that the key aspect of the representativeness of the method is the method of taking the photo of the sample break, including especially the angle of the lens axis relative to the plane of the fracture, which should be 90 degrees. Despite this caveat, the new method seems interesting and should be evaluated by statistical methods and then described in the form of a detailed measurement procedure.

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MAINTENANCE PROBLEMS OF UNDERGROUND GARAGES IN RESIDENTIAL AND PUBLIC UTILITY BUILDINGS

PROBLEMY EKSPLOATACYJNE GARAŻY PODZIEMNYCH W OBIEKTACH MIESZKALNYCH I UŻYTECZNOŚCI PUBLICZNEJ

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Abstract

The article presents selected maintenance problems of underground garages in residential and public buildings. Numerous examples from the authors' engineering practice are presented. The characteristics of the most common failures and problems related to the repair of objects are discussed. The aim of the article is to emphasize the importance of proper diagnostics preceding an effective repair of damage.

Keywords: durability, underground garages, damages, maintenance, repairs

Streszczenie

W artykule przedstawiono wybrane problemy eksploatacyjne garaży podziemnych w obiektach mieszkalnych i użyteczności publicznej. Przedstawiono liczne przykłady z praktyki inżynierskiej autorów. Omówiono charakterystykę najpowszechniej występujących uszkodzeń oraz problemy związane z wykonywaniem napraw obiektów. Celem artykułu jest podkreślenie znaczenia właściwej diagnostyki poprzedzającej skuteczną naprawę uszkodzeń.

Słowa kluczowe: trwałość, garaże podziemne, uszkodzenia, utrzymanie, naprawy

1. INTRODUCTION

Due to the high costs of investment areas and more and more intensive development in urban agglomerations, contemporary collective residence facilities and public utility facilities usually have one or more underground floors. There may be located technical facilities for the service, storage rooms or parking spaces and communication routes for parking vehicles, which are occupying the largest surfaces. Underground garages are often treated by residents or property managers as a specific showcase of the facility, hence any shortcomings, especially the visible ones, of these spaces are the subject of frequent warranty claims and repairs. The issues described in the article largely result from errors and omissions in design, materials and workmanship that were present much earlier, and appeared only during the operation of the commissioned facilities.

2. TYPICAL OPERATIONAL PROBLEMS OF UNDERGROUND GARAGES

The underground storeys of structures are exposed to a quite specific system of impacts, usually significantly different from those located above the ground level.

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In particular, it may be related to the presence of groundwater, obstructed ventilation, accumulation of loads on the structure, high intensity of use and, very often, neglect in the area of maintenance and proper operation of the facility. Due to the above conditions, the degradation of the building's elements is accelerated. Particular nuisances include water leaks, deterioration of plasters, damage and wear of floors, corrosion of system components and drains. Structural damage indicates more serious technical problems and is an alarm signal for the facility manager that the safety of use may be endangered.

2.1. Moisture

Moisture is a particularly troublesome operational problem in underground garages. It may be more or less intense, depending on the source of the penetrating water and the characteristics of the structure. The most common leaks occur at the contact of the floor/concrete slab with the walls of the building (Fig. 1) or through the external walls at cracks (Fig. 2a) or improperly made structural expansion joints (Fig. 2b, 2c). If, for economic reasons, the structure was founded on continuous footings instead of the foundation slab, a much higher intensity of leakage and much higher repair costs can be expected. Also common are leaks through the places where the installation passes between floors (Fig. 2d) and leaks through floors (Figs. 3a, 3b, 3c) and ceilings, especially in the areas of the storey beyond the outline of the above-ground part of the structure. Leaks within the lift shafts (Fig. 3d) pose a serious threat. Moisture in the underground parts of the building may also be related to improperly functioning ventilation – in the period of high temperatures, water vapor may condense on the inner surfaces of the walls.

Fig. 1. Water rising at the joint between the floor and walls (a, b) and corrosion of steel elements (c) exposed to permanent moisture

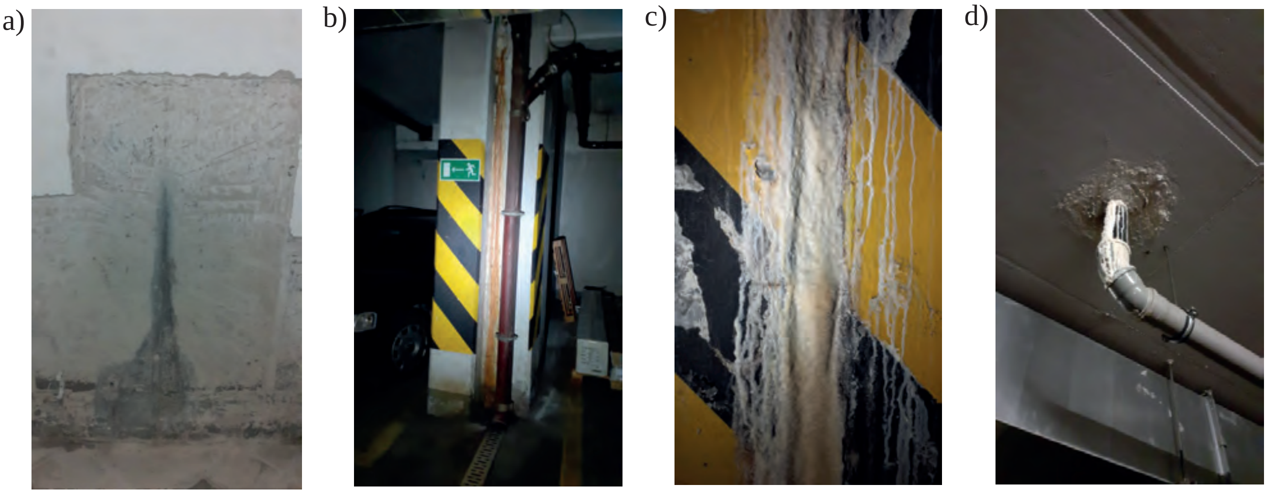


Fig. 2. Leaks through external walls (a), expansion joints (b, c) or installation penetration points (d)

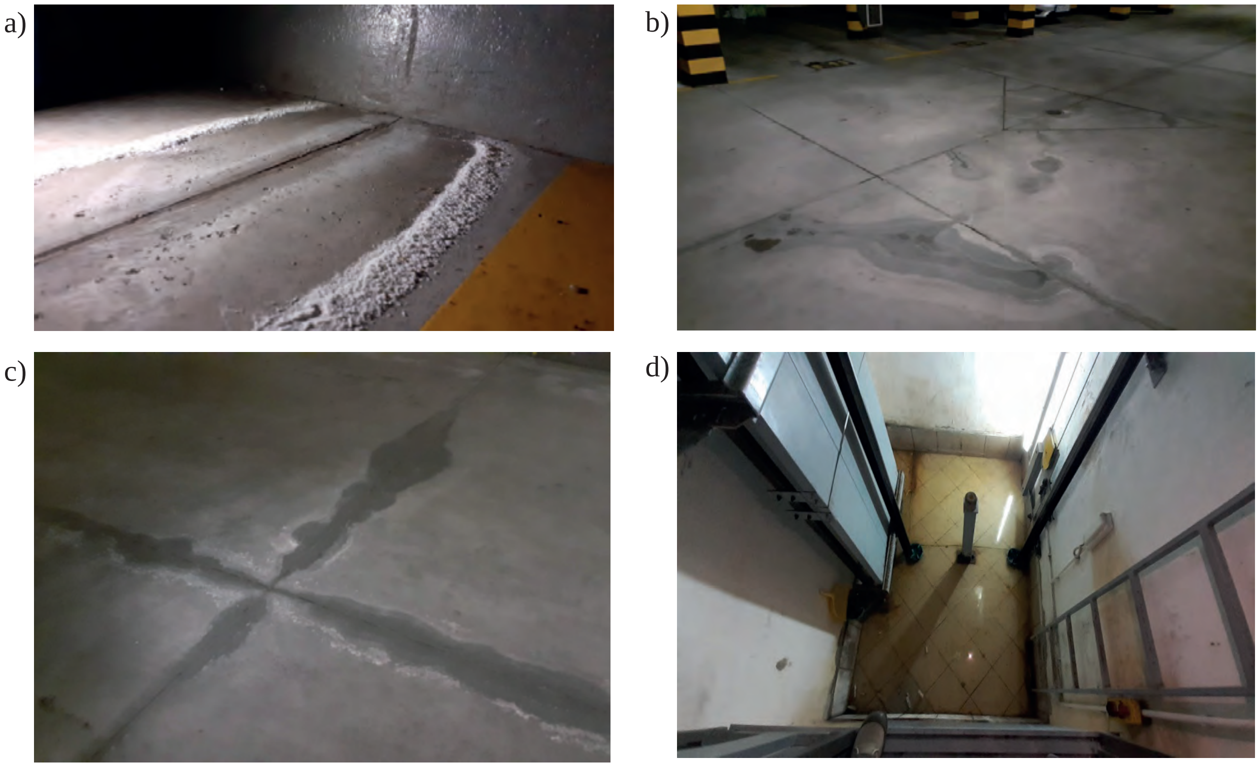


Fig. 3. Leaks through (a, b, c) floor / foundation slab, (b) lift shaft

2.2. Wear of the floor

The wear layer of garage floors is the area most exposed to damage related to mechanical, physical and chemical impacts. Water ingress, the presence of slush deposited by vehicles with de-icing agents (risk of chloride corrosion), intense abrasion (especially on ramps and curves) in the presence of sand and debris cause surface degradation. Surfaces in underground garages are usually finished in the DST (Dry Shake Topping) surface hardening technology or in the coating technology, less often as an additional unfinished surface, but only obliterated during concrete laying.

Floor wear is usually manifested as loosening (Fig. 4a), abrasions, extensive flaking or craters (Fig. 4b). Execution errors intensify the image of destruction, often manifested in the form of a regular grid of cracks (e.g. consistent with the location of the reinforcement mesh, Fig. 4c), surface heterogeneity or extensive cracks, e.g. in the vicinity of expansion joints.

Fig. 4. Damage to the usable floor layer: detachment of the resin coating (a), extensive concrete chipping (b), surface scratches (c)

Drainage is an important element of the floors in underground garages. Usually they are made in the form of linear or point drainage. Practice shows that this element of the garage surface is particularly sensitive. The maintenance of this system is often underestimated and neglected (Fig. 5a), and subsequent repairs are, unfortunately, extremely expensive and constitute a significant inconvenience for users. Common types of damage are channel cracks (Fig. 5b), corrosion (Fig. 5c, 5d) or deformations (Fig. 5e).

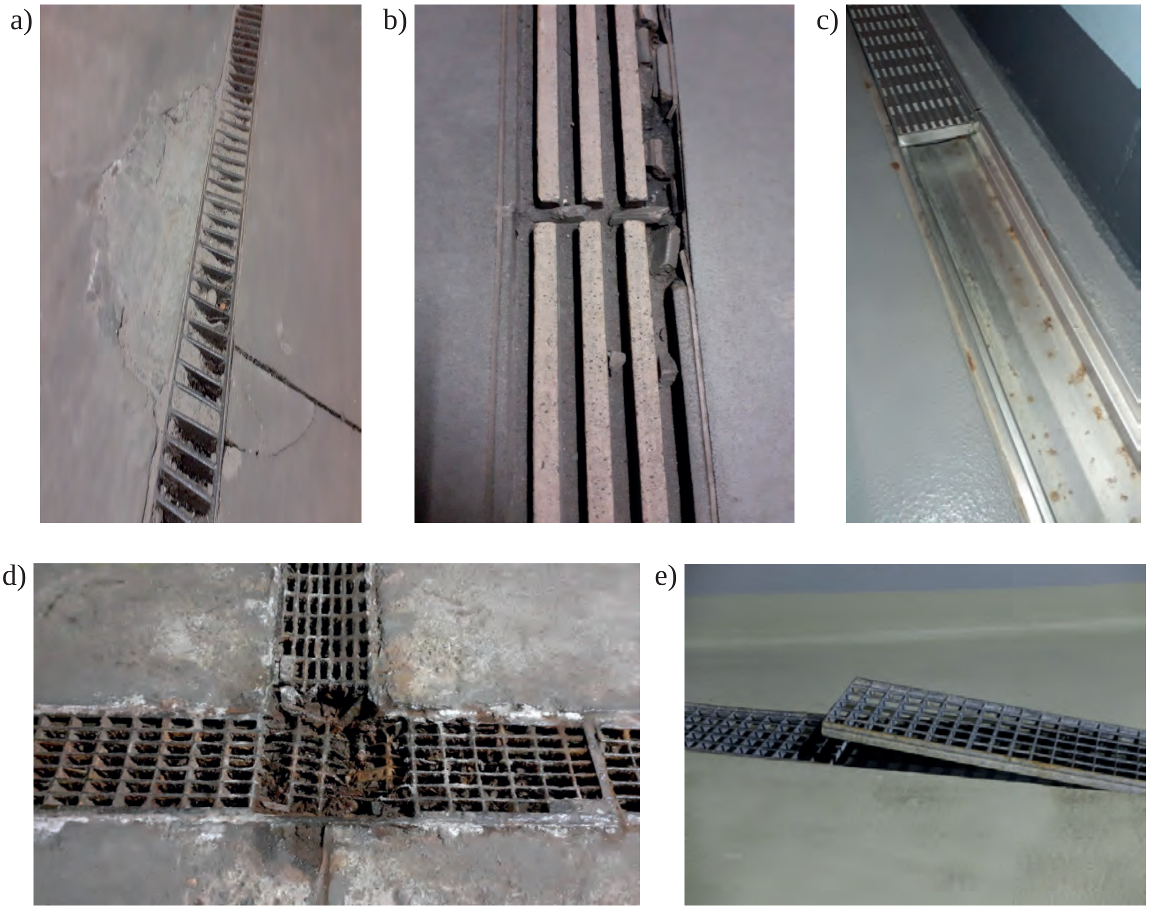


Fig. 5. Operational problems of linear drainage troughs: deformation (a), advanced corrosion of grates (b), negligence in maintenance (c), mechanical damage (d), corrosion of troughs (e)

2.3. Structural damage

Damage to the load-bearing system of garages, i.e. ceilings and binders, as well as walls and columns, usually appear in the form of scratches (Fig. 6a, 6b) and cracks (Fig. 6c). More serious symptoms appear as deformations or detachments of material. Such a state of the structure may indicate that the limit states of use or load capacity have been exceeded and should prompt the manager to take preventive measures. Contrary to the previously discussed damage, structural damage is usually identified only during the inspection of the object carried out by specialists in the course of periodic or ad hoc diagnostics of the object.

Fig. 6. Scratches in the ceilings (a), binders and columns (b) and cracks in the floor slabs (c)

3. REMEDIAL PROCEEDINGS

Remedial proceedings is a complex issue and each time requires a separate analysis covering a number of material, construction and functional issues [1, 5, 8, 9]. Practice shows that remedial proceedings are often carried out in the reverse order than it would follow from the rules of construction practice and technical knowledge. It happens that repairs are performed without prior analysis of the causes of damage or analysis of the actual impacts. Such action results in incorrect selection of materials and technical solutions and, consequently, ineffective repair (Fig. 7). The repair itself is sometimes performed only locally and not comprehensively, so the actual problem is not solved but only hidden. This generates even greater subsequent repair costs and organizational nuisance for the users of the facility. Correctly carried out corrective actions [2-6] should be preceded by an assessment of the condition of the object or its elements, which will allow to identify the scope and course of necessary remedial actions, and the principles and methods of repair should follow the concept of the PN-EN 1504 standard series. The scope of the analysis should include the assessment of design, material and construction reasons [10, 11]. The initial, indispensable stage of repair is, however, the diagnostics of the object [1, 5, 8, 9], which should be selected each time depending on the technical condition of the object and the expected scope of repairs and maintenance [12, 13].

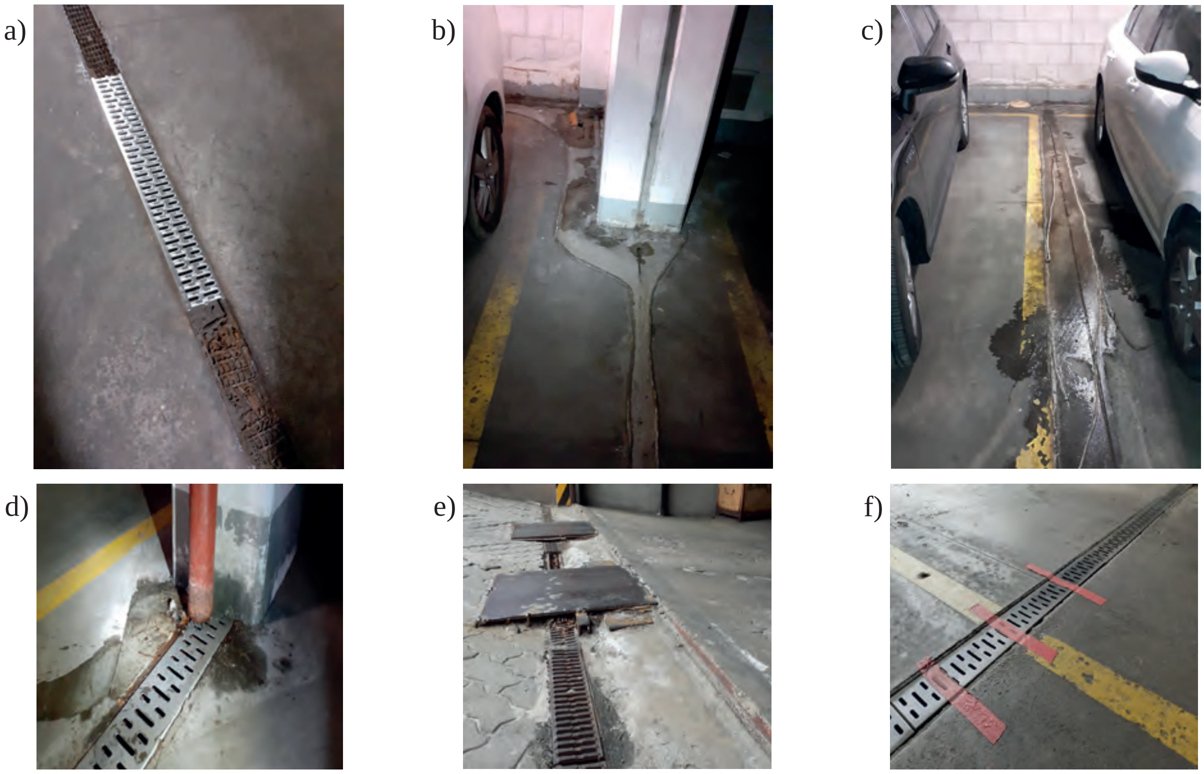
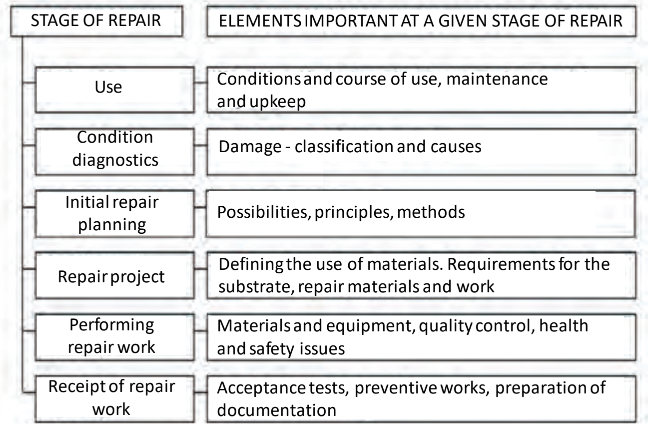


Fig. 7. Examples of unsuccessful repairs performed only partially (a) or not in accordance with the construction practice (b-f)

4. SUMMARY

Problems at the operation stage of underground garages usually result from a combination of design, material, construction and functional reasons.

Correctly conducted remedial actions should be preceded by an in-depth analysis of the condition of the object or its elements, which will allow to identify the scope and course of necessary remedial actions, and the principles and methods of repair should follow the concept of the PN-EN 1504 standard series (Fig. 8). The initial, indispensable stage of repair, however, is the facility diagnostics, which should be selected each time depending on the technical condition of the facility and the expected scope of repairs and maintenance.



STAGE OF REPAIR	ELEMENTS IMPORTANT AT A GIVEN STAGE OF REPAIR
Use	Conditions and course of use, maintenance and upkeep
Condition diagnostics	Damage - classification and causes
Initial repair planning	Possibilities, principles, methods
Repair project	Defining the use of materials. Requirements for the substrate, repair materials and work
Performing repair work	Materials and equipment, quality control, health and safety issues
Receipt of repair work	Acceptance tests, preventive works, preparation of documentation

Fig. 8. Stages of repair according to PN-EN 1004-9 with the assignment of particularly important elements [6, 7]

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METHODS OF MITIGATING ALKALI REACTIVITY OF GRAVEL AGGREGATE

SPOSOBY OGRANICZENIA REAKTYWNOŚCI KRUSZYWA ŻWIROWEGO

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Abstract

Effectiveness of selected chemical admixtures and mineral additives to mitigate alkali-silica reaction was compared based on reactive gravel aggregate. Lithium compounds in the form of nitrate and lithium polysilicate were used as chemical admixtures. Natural pozzolans containing zeolite were used as mineral additive. Efficiency of the additive was enhanced by modification with ammonium ions. Linear changes of mortars with crushed gravel aggregates were studied with the accelerated and long-term methods. Additionally, scanning electron microscopy was used for microstructural observations. It was demonstrated that at elevated temperatures the application of lithium compounds provided better protection. Under conditions similar to those in the field, 20-30% of natural pozzolans proved to be more effective in inhibiting the expansion. Regardless of the method of protection applied, the presence of alkali-silica reaction products was detected in the microstructure of the mortars.

Keywords: alkali-silica reaction, lithium compounds, natural pozzolana, zeolite, expansion, reaction inhibition

Streszczenie

Na przykładzie reaktywnego kruszywa żwirowego porównano efektywność ograniczenia reakcji alkalia-kruszywo przy pomocy wybranych domieszek chemicznych i dodatków mineralnych. Jako domieszki chemiczne zastosowano związki litu w postaci azotanu i polikrzemianu litu. W przypadku dodatków mineralnych zastosowano naturalną pucolanę, zawierającą zeolit, której efektywność zwiększano poprzez modyfikację jonami amonowymi. Wykonano badania zmian liniowych zapraw z rozdrobnionym kruszywem żwirowym metodą przyspieszoną i długoterminową. Dodatkowo wykonano obserwacje mikrostruktury z wykorzystaniem elektronowego mikroskopu skaningowego. Wykazano, że w warunkach podwyższonej temperatury lepsze zabezpieczenie uzyskano po zastosowaniu związków litu. W warunkach zbliżonych do eksploatacyjnych zastosowanie 20-30% pucolany naturalnej skuteczniej hamowało ekspansję zapraw z kruszywem reaktywnym. Niezależnie od sposobu zabezpieczenia, w mikrostrukturze zapraw wykryto obecność produktów reakcji alkalia-krzemionka.

Słowa kluczowe: reakcja alkalia-krzemionka, związki litu, pucolana naturalna, zeolit, ekspansja, inhibicja reakcji

1 INTRODUCTION

The alkali-silica reaction causes significant swelling and deterioration of various elements of concrete infrastructure, such as dams, sidewalks, bridges, walls, barriers and structural elements of nuclear power plants [1, 2] and represents a significant problem in the context of the durability of concrete all over the world. The reaction begins with the dissolution of

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reactive silica due to the high pH value of the pore solution, which subsequently leads to the creation of alkali-silica gel. The absorption of more calcium ions causes gelation and/or crystallization, which leads to the creation of amorphous and/or crystalline products of the alkali-silica reaction. The products of the reaction can differ greatly, depending on the composition of the pore solution, the stage of reaction and the temperature [3, 4, 5]. The exact stages and mechanisms of expansion due to the alkali-silica reaction have not been fully identified and explained yet. It is generally assumed that expansion caused by the alkali-silica reaction is connected with the swelling of products in aqueous environments, because more damage has been observed in the presence of high relative humidity [6, 7]. However, recently published papers [3, 8] have revealed that neither amorphous, nor crystalline products of the alkali-silica reaction that contain Na, K, Ca and silica, experience swelling because of the presence of water. The absorption of water by the products of the alkali-silica reaction was lower than in the case of the C-S-H phase, which would suggest that expansion is not caused by swelling, but rather by some other mechanisms, which would suggest that more research is urgently needed.

The suppression of the alkali-silica reaction in existing structures is difficult and costly and may require the application of water insulation layers. The alkali-silica reaction may be allowed to continue, however, because the amount of water present in concrete may be sufficient for its continuation even in insulated concrete structures. In new structures, the use of non-reactive aggregate is a relatively cheap and effective method of avoiding the alkali-silica reaction. However, local aggregates are often used for environmental and economic reasons, and in some distant locations, especially in the case of massive structures such as dams, they may represent the only choice. The effective mitigation (limitation) of the alkali-silica reaction effects is of key importance in the context of the safe use of reactive aggregates in the production of durable concrete.

The use of mineral cement additives and chemical admixtures, such as lithium salts, in order to prevent concrete expansion resulting from the alkali-silica reaction, was first reported over 80 years ago, soon after the discovery of this effect in the 1940s. In the case of the production of concrete elements, an effective way to minimise the risk of their damage as a result of the alkali-silica reaction is to use cement with mineral additives (containing main components other than Portland clinker), in order to reduce its pH and the concentration of sodium and potassium ions in the concrete's pore solution. Low soluble sodium and potassium content and a low pH value reduce the risk of the generation of alkali-silica reaction (ASR) products [5], reducing also the speed of reaction by inhibiting the dissolution of reactive phases of the silica [9]. Mineral additives in the form of waste products from other manufacturing processes, such as fly ash or blast-furnace slag, are sometimes difficult to obtain, therefore additives obtained from natural sources, such as zeolite or metakaolin, are used.

Contrary to mineral additives, which can be introduced only during the production of concrete, lithium salt solutions can be applied directly onto a concrete structure that demonstrates the effects of an alkali-silica reaction, and can also be used as a chemical admixture during the production of concrete. Different types of lithium salts have been tested in the past in order to reduce the effects of the alkali-silica reaction [10-13]. Certain problems with the application of lithium salts have been encountered, because the dosage of different types of lithium salts varies greatly depending on several factors, such as the mineral structure of reactive aggregates and the content of alkali in concrete [14, 15]. Additionally, the operating mechanisms of different types of lithium salts are complicated and produce different types of alkali-silica reaction products that contain lithium and lithium silicates [16-18].

The understanding of the mechanisms that alleviate the effects of the alkali-silica reaction through the use of mineral additives as well as lithium compounds, is important in the context of the optimum use of these materials, as well as the assurance of their long-term effectiveness in the protection of concrete structures. This has posed a significant challenge for many decades, mainly due to problems with the specification of the products of alkali-silica reaction generated in small quantities and volumes using conventional laboratory techniques. It is also difficult to characterise Li containing products of the reaction, mainly due to their chemical composition.

This article presents the results of tests aiming to establish the effectiveness of reducing the effects of alkali-aggregate reaction in reactive gravel aggregate using selected chemical admixtures and mineral additives. Lithium compounds in the form of lithium nitrate and lithium polysilicate were used as chemical admixtures. As for mineral additives, natural pozzolana with zeolite content was used and its effectiveness was enhanced by modifying it with ammonium ions.

Linear changes for mortars with fine-crushed gravel aggregate were investigated using the accelerated and long-term method. Additionally, their microstructure was analysed using a scanning electron microscope.

2 MATERIALS AND METHODS

Samples needed for the tests were prepared using CEM I 42.5R Portland cement and gravel aggregate with confirmed reactivity [19, 20]. Lithium nitrate and lithium polysilicate, together with natural Transcarpathian zeolite, were used in order to reduce the degradation of mortar as a result of the alkali-silica reaction. Some of the zeolite was modified by replacing exchangeable cations with ammonium cations. Ion exchange was carried out by immersing natural zeolite in a 2M solution of NH_4Cl for 24 hours [21]. During this time, some of the sodium and potassium ions were replaced with ammonium ions, in accordance with the cation selectivity sequence for clinoptilolite [22, 23]. Chlorine was removed by rinsing with distilled water.

The chemical composition of cement and zeolite has been listed in Table 1. As a result of the ion exchange, the content of Na_2O and K_2O in modified zeolite was reduced to 0.46% and 1.41%, respectively. The SiO_2/Li_2O molar module of the used lithium polysilicate was 3.5, the density was 1.190 g/cm^3. The molar ratio of lithium to the total content of sodium and potassium in the cement was 0.74. The lithium compounds were added to the mix with the mixing water.

Because Polish cements have higher levels of potassium content, K_2SO_4 was used to raise the content of Na_2O_{eq} in the cement to 1.1%.

6 mortar batches were made using the described materials and their chemical composition has been listed in Table 2. In the case of samples containing zeolite as an additive, their w/s ratio was increased from the normative 0.47 to 0.49, due to the high water demand of zeolite which resulted in the lower flowability of mortar.

Table 1. Chemical composition of cement and zeolite, % w/w

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	TiO_2	MnO	P_2O_5	LOI	Cz. n.r.
Cement	20.20	4.,80	3.00	61.70	1.80	2.70	0.78	0.15	0.45	–	–	3.00	1.00
Zeolite	67.07	12.,40	0.90	2.09	0.72	–	2.80	2.05	0.19	0.04	0.014	–	–

LOI – Loss on ignition, Cz.n.r. – non soluble residue

Table 2. Composition and indication of mortars

Indication of samples	Content [g]				[Li/Na+K]	w/s
	Cement	Sand	Zeolite	Modified zeolite		
CEM	525	1175	0	0	0	0.47
Z20	420	1175	105	0	0	0.49
Z30	367.5	1175	157.5	0	0	0.49
Zm20	420	1175	0	105	0	0.49
LiN*	525	1175	0	0	0.74	0.47
LiS**	525	1175	0	0	0.74	0.47

*LiN – samples with lithium nitrate **LiS – samples with lithium polysilicate

The main measurable effect of the alkali-aggregate reaction, both in concrete as well as in mortar, is expansion. In order to examine the efficiency of its reduction through the application of lithium compounds and the addition of zeolite, mortar bars measuring 25×25×250 mm were prepared with the application of reactive gravel aggregate. They were then tested in order to establish the rate of expansion using the accelerated method (according to the methodology of standard ASTM C 1260) and using the long-term method (according to the methodology of standard ASTM C 227) [24, 25]. Additionally, during the tests, a sample was taken from each mortar after 28 days in the case of samples tested in accordance with procedure described in standard ATM C1260, and after 360 days in the case of samples tested in accordance with procedure described in standard ATM C227, in order to examine their microstructure under a scanning electron microscope. Such tests were carried out on mortar fracture samples.

3 RESULTS

3.1. Results of accelerated tests according to the methodology of ASTM C1260

The results of linear changes in mortars tested in accordance with ASTM C1260, demonstrated in Figure 1, confirm that the used gravel aggregate contributes to the degradation of mortar as a result of the alkali-silica reaction. Simultaneously, all of the applied methods of mitigating this reaction have contributed to the reduction of expansion. Lithium compounds were the most effective in this regard. All of them had a similar effect that limited the expansion to no more than 0.025%. After 12 days in the case of lithium nitrate, and after 16 days in the case of lithium polysilicate, the expansion of the samples was stabilised.

In the case of all other mortars, the stabilisation of the volume of their samples was not observed during the entire 30-day testing period. Mortars with different kinds of zeolite additives demonstrated significant differences in terms of the rate of expansion. The most effective use of zeolite in order to reduce expansion entailed the replacement of 30% of cement in the mortar with zeolite. Such addition of zeolite reduced the expansion of mortar during the normative 16-day testing period to a level of less than 0.1%. This allowed us to conclude that mortar was not subject to the negative effects of an alkali-silica reaction. Other 20% additives of natural and modified zeolite only facilitated the reduction of expansion to a level of less than 0.2% during this period. This would allow us to classify such mortars as potentially exposed to the negative effects of an alkali-silica reaction.

On this basis we can also observe the effectiveness of modification of zeolite with ammonium ions, which improve the efficiency of zeolite as an expansion-inhibiting factor in the context of the alkali-silica reaction. Modified zeolite reduces expansion by more than 30% in comparison with non-modified zeolite used in the same quantity.

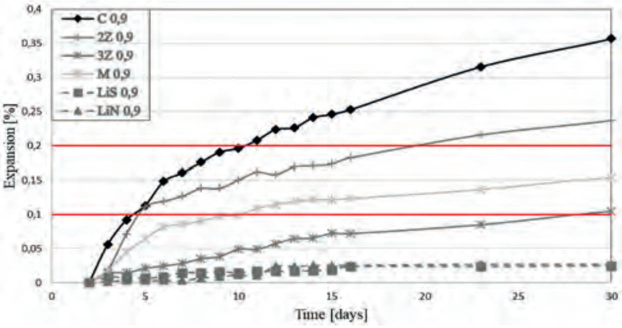

Fig. 1. The expansion of mortars during testing in accordance with ASTM C1260

3.2. Results of long-term tests according to the methodology of ASTM C227

Figure 2 shows the results of long-term testing of expansion. These results allow us to conclude that all implemented methods of the reduction of expansion caused by the alkali-silica reaction gave satisfactory results. Whether lithium compound additives were used, or mineral additives in the form of natural and modified zeolite were applied, the expansion of mortars never exceeded the 0.04% threshold. In the course of these tests, unlike during the accelerated tests, zeolite additives proved to be more effective than lithium compound admixtures in limiting the expansion of mortars. A 30% natural zeolite additive and a 20% modified zeolite additive proved to be the most effective in inhibiting the expansion of mortars. In both cases, the shrinkage of samples was observed instead of their expansion. This test allows us to conclude that by modifying zeolite by way of an ion exchange, it is possible to reduce its quantity in the binder, which can also contribute to the improvement of its consistency [26-28].

The 20% natural zeolite additive proved to be less effective. In this case, no significant changes in the measurements of the tested samples were observed. Lithium compound-based chemical admixtures were also less effective. In both cases expansion was observed and its rate was similar to the one observed for lithium admixtures.

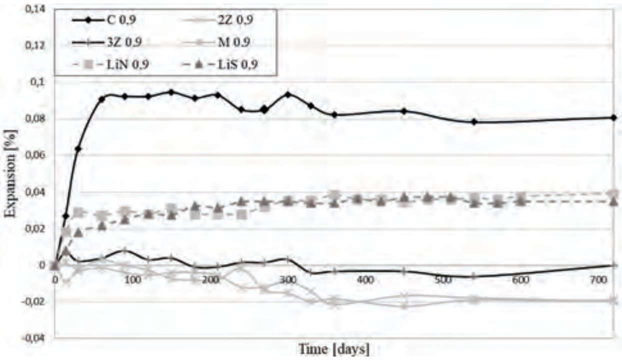

Fig. 2. The expansion of mortars during testing in accordance with ASTM C227

3.3. Microstructure analysis

Short-term research of the microstructure of all mortars containing zeolite has revealed the presence of damages that could be attributed to the alkali-silica reaction (Fig. 3). They demonstrated visible signs of local cracking that could be the result of the expansion of alkali silica gel. In the case of sample Zm20 (with a 20% additive of modified zeolite), the damage mechanism shown in Figure 3c has been thoroughly detailed in the Czapik paper [20]. Apart from visible cracking, the alkali-silica reaction generates reaction products of variable swelling and stress-inducing characteristics. They can be observed on the enclosed drawings (Fig. 3a, 3b), inside air voids situated near areas of intense cracking. In the case of mortar with a lower natural zeolite content (Fig. 3a), they form agglomerates of compacted gel [29]. The fibrous character of the gel, which is typical for alkali-silica reaction products, is demonstrated by the sample with higher zeolite content (Fig. 3b). The reason for this could be that reaction products generated in smaller quantities have more space to fill up freely and will thus generate less stress in the mortar, which leads to lower expansion of the samples. Alkali-silica reaction products concentrated in voids are fractured, which can be considered as typical for these products [30].

The introduction of lithium nitrate into mortars effectively reduces the harmful reaction of aggregate with alkali, which is confirmed by the low number of fractures observed in the microstructure of the mortars. However, the presence of highly porous reaction products on the surface of the grains (pt 1; Fig. 4a) and fine gels (pt 2; Fig. 4a) has been observed, which may be proof of the process of dissolution of silica and thus the reaction of alkali from the cement (Fig. 4a). The products of the reaction can also have a fibrous form, but this is limited mainly to the surface of the grains and can generate only low stresses (Fig. 4b). None of the analysed samples have revealed the presence of reaction products in the form of crystalline lithium silicate that could protect the grains of reactive silica against reaction with the alkali. However, it was not possible to definitely determine that reaction products observed on the surface of the aggregate grains do not contain any lithium ions. The limitations of the EDS technique did not allow for the detection of lithium compounds, which greatly restricted the analysis of test results.

Mortars containing lithium polysilicate demonstrated fractures of the aggregate grains. Figure 4c demonstrates the separation of carbonate envelopes of bioclasts filled with chalcedony, which has been indicated as one of the minerals responsible for the reactivity of the analysed polymineral aggregate, from fine grains [20, 31].

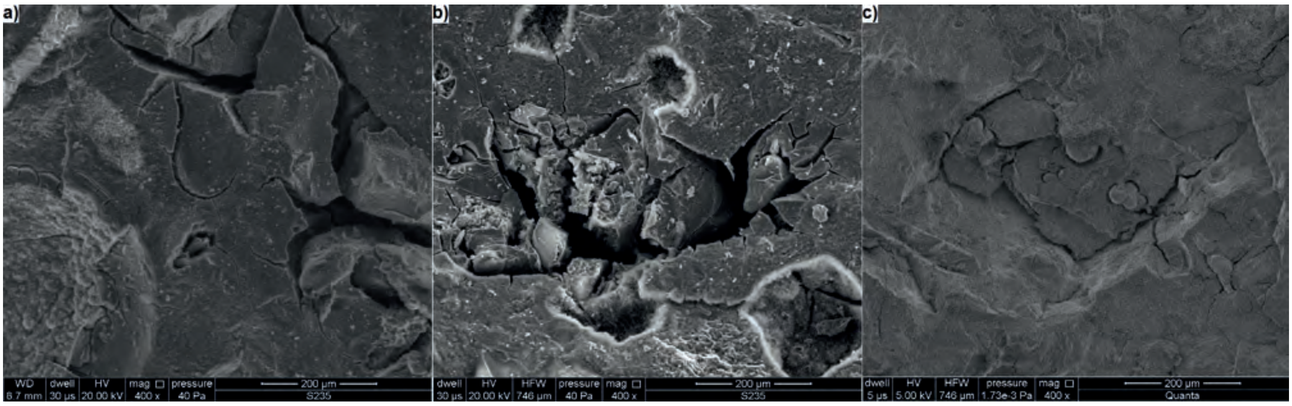

Fig. 3. The microstructure of mortars with zeolite after tests acc. to ASTM C 1260, a) Z20 (20% of zeolite), b) Z30 (30% of zeolite), c) Zm20 (20% of modified zeolite)

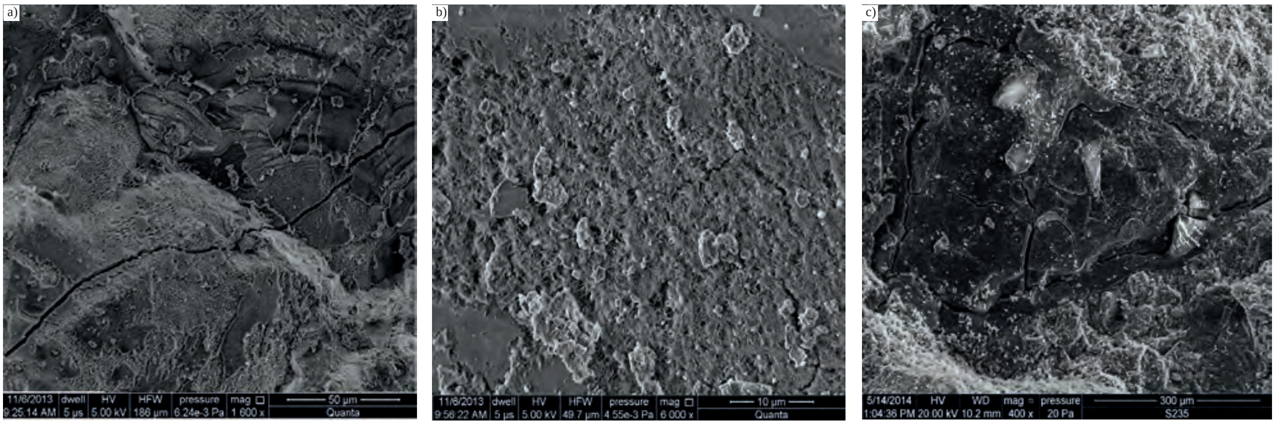

Fig. 4. The microstructure of mortars with lithium compounds after tests acc. to ASTM C1260, a-b) LiN, c) LiS

The microstructure of mortars with lithium nitrate, stored in conditions as defined by standard ASTM C227, indicates the presence of centres of corrosion, which has been confirmed by the appearance of microfractures and the presence of alkali silica gel in the area of reactive grains and partially in the cement paste. Figure 5a demonstrates the presence of sponge-like gel in the reactive grains (pt 1), next to the solid, amorphous gel (pt 2). The visible differences in appearance are a result of the texturisation of the gel with time, mainly because of the higher content of calcium in the reaction products [32]. Mortars with lithium polysilicate demonstrate the presence of highly fractured gels resulting from the total reaction of aggregate grains (Fig. 5b).

Another characteristic feature was the presence of fractures caused by the reaction of only the reactive minerals in the non-reactive matrix, as visible in Figure 5c. The presence of reaction products that cause the fracturing of the grains and the matrix of the cement paste proves that harmful degradation of the gravel aggregate takes place in the presence of lithium compounds.

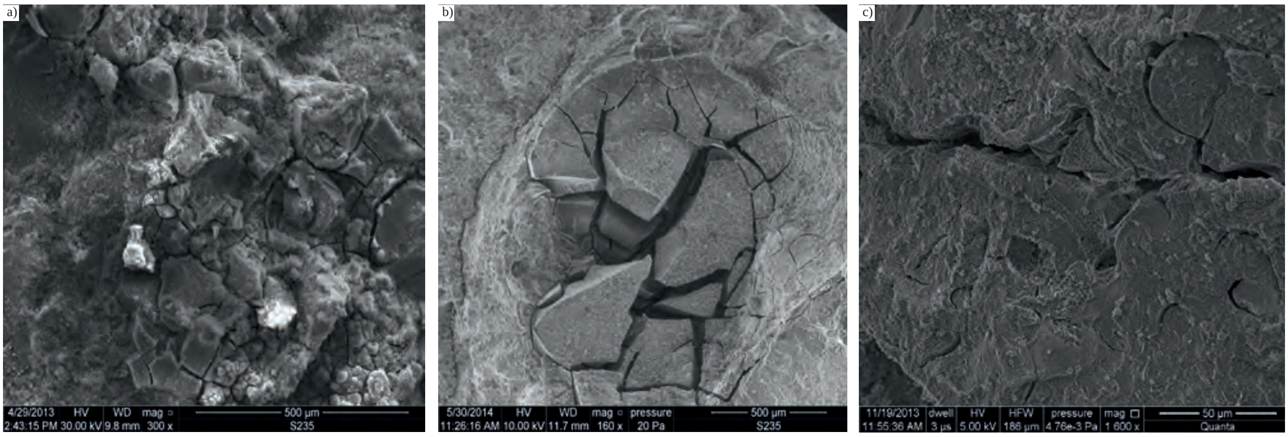

Fig. 5. The microstructure of mortars with lithium compounds after tests acc. to ASTM C227, a) LiN, b-c) LiS

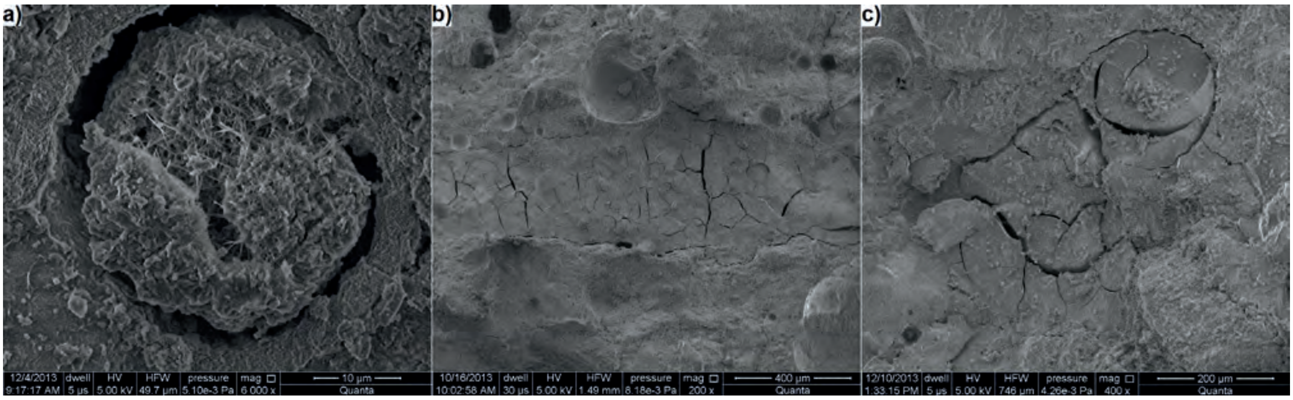

Fig. 6. The microstructure of mortars with zeolite after tests acc. to ASTM C 227, a) Z20, b) Z30, c) Zm20

The microstructures of all mortars with a zeolite additive tested using the long-term method demonstrated the presence of microstructural changes caused by the alkali-silica reaction, despite the fact that the effect of expansion was avoided (Fig. 6).

The presence of gel clusters (Fig. 6a), that may have formed in the place of fine reactive grains, has been observed. In this case, fibrous products of the alkali-silica reaction were present under the external envelope of compacted gel. In other locations, highly fractured aggregate grains of the size of more than 200 µm have been observed (Fig. 6b, 6c). Whereas large aggregate grains can cause the degradation of samples in the course of the alkali-silica reaction, small grains may limit the alkali-silica reaction as a result of pozzolanic activity. The microstructure of the tested samples with modified zeolite also revealed the presence of higly fractured, compacted alkaline gel (Fig. 6c).

4. CONCLUSIONS

The results of the performed tests have revealed:

- differences in the effectiveness of the use of a zeolite additive or admixtures containing lithium compounds in the limitation of the effects of the alkali with gravel aggregate reaction, depending on the implemented testing method (short-term or long-term);

- in the case of the short-term method, lithium compounds – both lithium polysilicate as well as lithium nitrate – were the most effective in reducing the extension of the length of mortar bars. A zeolite additive was less effective in limiting mortar expansion, however the use of a 30% additive may be considered as an effective way of limiting the effects of alkali-silica reaction. A 20% additive of non-modified and modified zeolite has also visibly reduced expansion, but it still exceeded the first threshold value (0.1%);
- in the case of the long-term method, a zeolite additive, irrespective of its content and modification, has proved to be a fully effective way of limiting expansion caused by the alkali-silica reaction. In the case of lithium-containing compounds, expansion was limited to a level considered in the ASTM C227 standard as safe;
- irrespective of the type of lithium compound, the results of expansion tests using the short- and long-term methods were similar;
- in the case of samples containing zeolite, the results of expansion achieved using the short- and long-term methods were different;
- the analysis of the microstructure of samples, both in the case of zeolite as well as lithium-containing additives, has revealed the presence of the products of the alkali-silica reaction, but these products did not cause any extensive expansion of the mortar samples;
- in the context of the conditions of long-term tests, which more closely resemble real operating conditions, the application of a zeolite additive can be considered as a more effective way of limiting the alkali-silica reaction than lithium salt-based admixtures. However, the explanation of the observed differences in the effectiveness of these materials, tested using different methods, still requires further research.

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INFLUENCE OF SODIUM AND POTASSIUM FORMATE ON THE ASR REACTIVITY OF GRANITE AGGREGATE

WPŁYW MRÓWCZANU SODU I POTASU NA PODATNOŚĆ KRUSZYWA GRANITOWEGO NA REAKCJĘ ALKALICZNĄ

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Structure and Environment vol. 14, No. 3/2022, p. 69

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Abstract

Use of de-icing agents is necessary in winter to maintain appropriate quality of road and airport surfaces. Formate or acetate de-icing agents are safer for aircraft and the environment than the commonly used sodium chloride, but may cause an alkali-silica reaction in concrete. The study investigated the influence of sodium formate and potassium formate on the occurrence of ASR (alkali-silica reaction) in mortars with granite aggregate. Accelerated mortar-bar tests at 80°C using various de-icing agents were performed and detailed studies of the SEM-EDS microstructure were carried out.

Streszczenie

Stosowanie środków odladzających jest niezbędne do zimowego utrzymania odpowiedniej jakości betonowych nawierzchni drogowych i lotniskowych. Środki odladzające na bazie mrówczanów lub octanów są bezpieczniejsze zarówno dla środowiska, jak i statków powietrznych niż powszechnie stosowany chlorek sodu, jednak mogą wywoływać reakcję alkaliczno-krzemionkową kruszywa w betonie. W pracy analizowano wpływ mrówczanu sodu i mrówczanu potasu na potencjał wystąpienia ASR (alkali-silica reaction) w zaprawach z kruszywem granitowym. Przeprowadzono badania ekspansji w 80°C z zastosowaniem różnych środków odladzających oraz przeprowadzono szczegółowe badania mikrostruktury SEM-EDS.

HE IMPACT OF A POLYUREA LAYER ON CRACKING AND PERFORMANCE OF REINFORCED CONCRETE BEAMS UNDER BREAKING LOAD

WPŁYW WARSTWY POLIMOCZNIKA NA ZARYSOWANIE I PRACĘ POD OBCIĄŻENIEM NISZCZĄCYM BELEK ŻELBETOWYCH

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Abstract

The paper discusses the results of laboratory experimental studies on reinforced concrete components (beams) with an outer polyurea layer. The important part of the study is the comparison of the results concerning the load-displacement relation for the reference beams (without the polyurea layer on their external surfaces) and those with the polyurea layer. The main conclusion from this part of the research is that the beam elements covered with a polyurea layer are protected against corrosion processes even in an emergency state. The occurrence of scratches, even of large size, is neutralized by the coating that effectively bridges them.

Streszczenie

W artykule zaprezentowano wyniki laboratoryjnych badań eksperymentalnych dotyczących elementów żelbetowych (belek) wraz z zewnętrzną warstwą polimocznika. Istotną częścią pracy jest porównanie wyników zależności obciążenie – przemieszczenie dla belek referencyjnych (bez warstwy polimocznika na powierzchniach zewnętrznych) oraz tych taką warstwę posiadającą. Kluczowym wnioskiem płynącym z tej części badań jest ten mówiący o tym, że elementy belkowe pokryte warstwą polimocznika zabezpieczone są przed korozją nawet w stanie awaryjnym. Występowanie rys nawet znacznych rozmiarów jest zneutralizowane poprzez skuteczne ich mostkowanie powłoką.

TESTS OF SELECTED PROPERTIES OF CONSTRUCTION MORTARS MODIFIED WITH WASTE GYPSUM BINDER OBTAINED IN THE FLUE GAS DESULPHURIZATION PROCESS

BADANIA WYBRANYCH WŁAŚCIWOŚCI ZAPRAW BUDOWLANYCH, W ASPEKCIE ICH TRWAŁOŚCI, Z ODPADOWYM SPOIWEM GIPSOWYM OTRZYMANYM W PROCESIE ODSIARCZANIA SPALIN

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Abstract

The article presents the results of tests of selected properties of plastering mortars that are based on natural gypsum binder, as well as on synthetic gypsum binder from the flue gas desulphurization process. The mortars were analyzed with regards to their durability. For the purpose of the publication, the recipe (quantitative) compositions of the plastering mortars, which differed in terms of the type of used setting retarder (PlastRetard PE and tartaric acid A200), were designed. The mortar recipes were determined experimentally, assuming that the beginning of the setting time was 120 min (the average beginning of the setting time for currently available building mortars), and that the content of the binder was 70%. The assumed research program included tests of flexural and compressive strength, surface hardness, and the adhesion to the substrate. The results of the research confirmed the possibility of modifying the recipe compositions of gypsum plastering mortars.

Streszczenie

W artykule przedstawiono wyniki badań wybranych właściwości zapraw tynkarskich na spoiwie gipsowym budowlanym i syntetycznym pochodzącym z procesu odsiarczania spalin, w aspekcie ich trwałości. Na potrzeby publikacji zaprojektowano składy recepturowe zapraw tynkarskich różniących się rodzajem użytego opóźniacza wiązania (PlastRetard PE i kwas winowy A200). Receptury zapraw zaprojektowano metodą doświadczalną przy założeniu początku czasu wiązania wynoszącym 120 min (średni początek czasu wiązania dla dostępnych zapraw budowlanych) i zawartości spoiwa na poziomie 70%. Założony program badawczy obejmował wykonanie badań wytrzymałości na zginanie i ściskanie, twardości powierzchniowej oraz przyczepności do podłoża. Otrzymane w toku badań wyniki potwierdziły możliwość modyfikowania składu gipsowych zapraw tynkarskich spoiwem syntetycznym pochodzącym z procesu odsiarczania spalin.

METHODOLOGY FOR MEASURING THE CARBONATION DEPTH OF CONCRETE – STANDARD AND NON-STANDARD ASPECTS

METODYKA POMIARU GŁĘBOKOŚCI KARBONATYZACJI BETONU – ASPEKTY NORMOWE I POZANORMOWE

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Structure and Environment vol. 14, No. 3/2022, p. 89
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Abstract

Carbonation of concrete is a complex phenomenon, depending on many factors, including the heterogeneity of concrete, which results in an uneven carbonation front. The assessment of the depth of the carbonation front depends on the measurement technique adopted. The article summarizes the standard techniques for measuring the depth of carbonation and proposes an alternative measurement technique based on the measurement of the fields of the carbonated and noncarbonated surfaces, and then converting to the averaged depth of carbonation. For an example sample, the results obtained with different standard techniques and the proposed off-standard technique were compared.

Streszczenie

Karbonatyzacja betonu jest zjawiskiem złożonym, zależnym od wielu czynników, między innymi niejednorodności betonu, z czego wynika nierównomierny front karbonatyzacji. Ocena głębokości frontu karbonatyzacji zależy od przyjętej techniki pomiaru. W artykule podsumowano normowe techniki pomiaru głębokości karbonatyzacji oraz zaproponowano alternatywną technikę pomiaru opartą na pomiarze pól powierzchni skarbonatyzowanej i nieskarbonatyzowanej, a następnie przeliczeniu na uśrednioną głębokość karbonatyzacji. Dla przykładowej próbki porównano wyniki otrzymane różnymi technikami normowymi oraz zaproponowaną techniką pozanormową.

MAINTENANCE PROBLEMS OF UNDERGROUND GARAGES IN RESIDENTIAL AND PUBLIC UTILITY BUILDINGS

PROBLEMY EKSPLOATACYJNE GARAŻY PODZIEMNYCH W OBIEKTACH MIESZKALNYCH I UŻYTECZNOŚCI PUBLICZNEJ

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Abstract

The article presents selected maintenance problems of underground garages in residential and public buildings. Numerous examples from the authors' engineering practice are presented. The characteristics of the most common failures and problems related to the repair of objects are discussed. The aim of the article is to emphasize the importance of proper diagnostics preceding an effective repair of damage..

Streszczenie

W artykule przedstawiono wybrane problemy eksploatacyjne garaży podziemnych w obiektach mieszkalnych i użyteczności publicznej. Przedstawiono liczne przykłady z praktyki inżynierskiej autorów. Omówiono charakterystykę najpowszechniej występujących uszkodzeń oraz problemy związane z wykonywaniem napraw obiektów. Celem artykułu jest podkreślenie znaczenia właściwej diagnostyki poprzedzającej skuteczną naprawę uszkodzeń.

METHODS OF MITIGATING ALKALI REACTIVITY OF GRAVEL AGGREGATE

SPOSOBY OGRANICZENIA REAKTYWNOŚCI KRUSZYWA ŻWIROWEGO

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Structure and Environment vol. 14, No. 3/2022, p. 102

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Abstract

Use of de-icing agents is necessary in winter to maintain appropriate quality of road and airport surfaces. Formate or acetate de-icing agents are safer for aircraft and the environment than the commonly used sodium chloride, but may cause an alkali-silica reaction in concrete. The study investigated the influence of sodium formate and potassium formate on the occurrence of ASR (alkali-silica reaction) in mortars with granite aggregate. Accelerated mortar-bar tests at 80°C using various de-icing agents were performed and detailed studies of the SEM-EDS microstructure were carried out.

Streszczenie

Stosowanie środków odladzających jest niezbędne do zimowego utrzymania odpowiedniej jakości betonowych nawierzchni drogowych i lotniskowych. Środki odladzające na bazie mrówczanów lub octanów są bezpieczniejsze zarówno dla środowiska, jak i statków powietrznych niż powszechnie stosowany chlorek sodu, jednak mogą wywoływać reakcję alkaliczno-krzemionkową kruszywa w betonie. W pracy analizowano wpływ mrówczanu sodu i mrówczanu potasu na potencjał wystąpienia ASR (alkali-silica reaction) w zaprawach z kruszywem granitowym. Przeprowadzono badania ekspansji w 80°C z zastosowaniem różnych środków odladzających oraz przeprowadzono szczegółowe badania mikrostruktury SEM-EDS.

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