UDC 691.535 DOI: 10.31650/2786-6696-2022-1-55-62

COMPARATIVE ANALYSIS OF THE USE OF EXPANSION AGENTS IN REPAIR SOLUTIONS OF DRY BUILDING MIXTURES FOR IMPROVING HARDENING CONDITIONS

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Abstract. The article examines the possibility of increasing the compatibility of repair solutions based on dry mixes with damaged concrete and reinforced concrete structures by improving the curing conditions of such materials through comparative analysis of adhesive strength and linear shrinkage of cement samples using different types of superabsorbents, namely SAP Newsorb based on sodium polyacrylates from the Japanese manufacturer Newstone, Chinese MNC-SAP based on potassium polyacrylates from MUHU Construction Materials and AquaGel based on cross-linked copolymer of acrylamide and potassium acrylate from the Australian Baroid.

The data obtained during experimental studies show that the use of investigated SAP superabsorbents additives due to the improvement of hydration conditions in the cement matrix of the repair material can partially compensate the growth of shrinkage deformations, which, in turn, slightly improves the indicators of the adhesive strength of the bond with the surface of the damaged structure.

A positive effect of the use of the specified polymer admixtures on the investigated cement solutions was established. Compared to the base sample, on average, for each of the studied days of hardening, the shrinkage rate of all samples containing SAP was reduced by 35%, which justifies their use in order to facilitate the creation and further high-quality functioning of the repair system. The addition of the studied SAPs allows to improve the adhesion index by 1.5-2.3 times compared to the basic one, which should ensure the maximum ability of the repaired system to perceive the workload.

The optimal contents of SAP additives in the composition of the studied cement mortars to reduce shrinkage and increase the adhesive strength were determined. The compositions of non-structural repair cement mortars of class RM3 and R1-R2 in terms of adhesive strength and classes RM1-RM2 in terms of shrinkage deformation in accordance with Ukrainian and European standards were obtained.

Keywords: repair solutions, dry mixes, expansion agents, superabsorbent, adhesion, linear shrinkage.

Introduction. Nowadays, carrying out repair and restoration works of damaged concrete and reinforced concrete structures is of particular importance. Structures that have undergone partial destruction require local restoration works using modern repair materials to restore their operational characteristics without decommissioning them and in a short period of time.

Repair solutions based on dry construction mixtures are powder compositions based on mineral or polymer binders with the use of finely dispersed fillers, fine fractional aggregates and a complex of chemical additives, intended for the restoration and protection of structurally damaged horizontal, vertical and ceiling elements of structures when performing all types of repair and restoration works at civil, industrial and special construction sites [1-3].

In recent years, the regulatory framework for such materials has expanded in the direction of increasing the set of requirements for solutions and accounting for the parameters of joint work when creating compatible systems (in technological and physicochemical terms) [4-8], while in practice it becomes necessary to ensure additional properties. In addition to the appropriate

indicators of strength, rheological properties and reduction of setting and hardening time to reduce the period of repair work and to put the facility into operation as soon as possible, one of the most important characteristics of such materials is the increase of adhesion to the base (substrate) being repaired to create conditions for compatible work with a damaged structure and reduction of shrinkage deformations to prevent cracking of the material and the occurrence of defects in the contact zone between solution and substrate, which can be achieved by improving the hardening conditions when using polymer additives for internal care of the hardening material [9-11].

Analysis of research and publications. Along with the classic methods of reducing shrinkage deformations [12-15], expanding polymeric agents (superabsorbents) of various chemical nature are increasingly used recently [9, 16].

Superabsorbent (Super Absorbent Polymer, SAP) is a polymer humectant that absorbs and retains certain amounts of water, which is subsequently released into the cement matrix of the repair solution and provides the highest quality hydration process, thereby reducing the appearance of internal stresses and reducing the possibility of autogenous shrinkage in the solution, especially at very low W/C rates. Based on the concept of the repair system [4, 5, 8], which includes the idea of the joint operation of the repair material through the contact layer with the substrate being repaired, the increase in shrinkage deformations in the thickness of such material will be negatively reflected on the adhesion indicators [17-20]. In the hydrated form, the superabsorbent granule is a water-saturated gel, which has the property of easy return of absorbed water. Absorbent molecules contain a set of polymer chains parallel to each other, which are regularly connected by crosslinking agents, forming a network [16]. When the water contained in the solution comes into contact with the SAP, it is drawn into the polymer molecule by osmosis [21]. Thus, stored water quickly migrates inside the polymer mesh. In the process of hardening of the repair material, water encapsulated in SAP moves back into the solution, ensuring a normal hydration process and improving the conditions of hardening of the repair material [9, 16, 21].

For such materials and systems for the repair and restoration of damaged concrete and reinforced concrete structures the European standard [22] singles out the concepts of adhesive strength and general shrinkage as indicators that are of particular importance for successful repair work. The standards [4, 23] stipulate that the amount of deformation of repair composites that harden, according to the corresponding classes, should not exceed 1.2-2 mm/m, and adhesion to the concrete substrate should be ensured at the level of 0.8-2 MPa.

Problem statement. The purpose of this work is to investigate the possibility of increasing the compatibility of repair solutions based on dry building mixtures with damaged concrete and reinforced concrete structures by the improvement of the hardening conditions of such materials through a comparative analysis of indicators of adhesive strength and linear shrinkage of cement samples using different types of superabsorbents, namely SAP Newsorb based on sodium polyacrylates from the Japanese manufacturer Newstone, Chinese MNC-SAP based on potassium polyacrylates from MUHU Construction Materials and AquaGel based on a cross-linked copolymer of acrylamide and potassium acrylate from Australian Baroid.

Research materials and methodology. European CEM I 42.5 R was used as a binder for the preparation of samples, and quartz sand with a fraction of 0.125-0.63 was used as a fine aggregate. To control the rheological properties of the solutions, a powder superplasticizer based on polycarboxylate CABR CCS from the manufacturer Luoyang Tongrun was used. The selection of the amount of water to maintain the necessary working consistency, which is the same for all investigated solutions, was carried out according to the method specified in [4]. For the completeness of the comparative analysis, a solution without superabsorbents was used as the base composition. The compositions of the studied samples are shown in Table 1.

For all investigated compositions of cement samples, adhesive strength indicators were determined using the DYNA Z16 adhesiometer in accordance with [22] and linear shrinkage using the Controls 62-L0009/F mold and the Controls Nirois 62-L0035/A comparator in accordance with [24].

For the study of adhesion parameters, washer samples Ø50 mm and a material thickness of 10 mm were produced, as well as reference concrete slabs in accordance with [25] (PC II/A-S-400,

gravelly sand 0-8 mm, W/C rate 0.45, without using grease for molds, water absorption on the surface of 3.2 cm^3 after 4 hours). In order to obtain the most reliable data on the quality of adhesion of repair composites to concrete slabs, the results of AF-S and CF-S types of adhesive bond loss only were taken into account. In accordance with [26], the polymer primer Acryl-Putz GP 41 was used as a contact layer. To determine the parameters of linear shrinkage, samples-beams of size 40×40×160 mm with embedded end elements were used.

Table 1 – Compositions of the studied samples

No.	Cement, g/kg	Sand, g/kg	CABR CCS, g/kg	SAP Newsorb, g/kg	MNC-SAP, g/kg	AquaGel, g/kg	Water, ml
1	435.00	563.11	1.89	–	–	–	72.40
2		560.11		3.00	–	–	81.28
3		558.11		5.00	–	–	94.22
4		561.11		–	2.00	–	79.36
5		559.11		–	4.00	–	99.74
6		561.61		–	–	1.50	88.17
7		560.11		–	–	3.00	102.97

Research results. During the experimental studies, data were obtained on the indicators of adhesive strength and linear shrinkage of cement samples of repair mortars based on dry building mixes for repair and restoration of concrete and reinforced concrete structures and structures using various types of superabsorbents.

As can be seen from Table 1, it should be noted that with the same working consistency of all solutions, the water consumption in all compositions containing SAP expanding polymer agents is higher than the basic composition by an average of 22%, which is explained by the high absorption capacity of free SAP granules due to the ionic nature, internal linked structure and the formation of secondary chemical bonds [9-11]. The largest amount of water while maintaining the working consistency indicator was required for composition 7 with a content of 3 g/kg of AquaGel superabsorbent, which can be explained by the fact that, unlike most polymer products that absorb water, the superabsorbent based on the cross-linked copolymer of acrylamide and potassium acrylate has a lower amount of crosslinking agent than the other two SAPs in the study. A more cross-linked polymer has a denser network, which reduces its capacity and reduces the property of easy return of absorbed water, but increases the stability of the polymer over time [10].

Table 2 shows the obtained indicators of shrinkage deformations of the studied samples.

Table 2 – Shrinkage deformations of the studied samples

No.	Sample marking	Shrinkage rate per day of hardening, mm/m		
		1	5	10
1	Basic without SAP	0.202	0.823	1.318
2	SAP Newsorb, 3 g/kg	0.126	0.597	1.088
3	SAP Newsorb, 5 g/kg	0.094	0.449	0.756
4	MNC-SAP, 2 g/kg	0.128	0.622	1.240
5	MNC-SAP, 4 g/kg	0.107	0.508	1.103
6	AquaGel, 1.5 g/kg	0.114	0.559	0.998
7	AquaGel, 3.5 g/kg	0.079	0.466	0.779

Sample 7 with a content of 3.5 g/kg of AquaGel superabsorbent shows the lowest shrinkage rates (Fig. 1), taking into account the dosage – 41% less compared to the rate of the base sample on the 10^{th} day of curing.

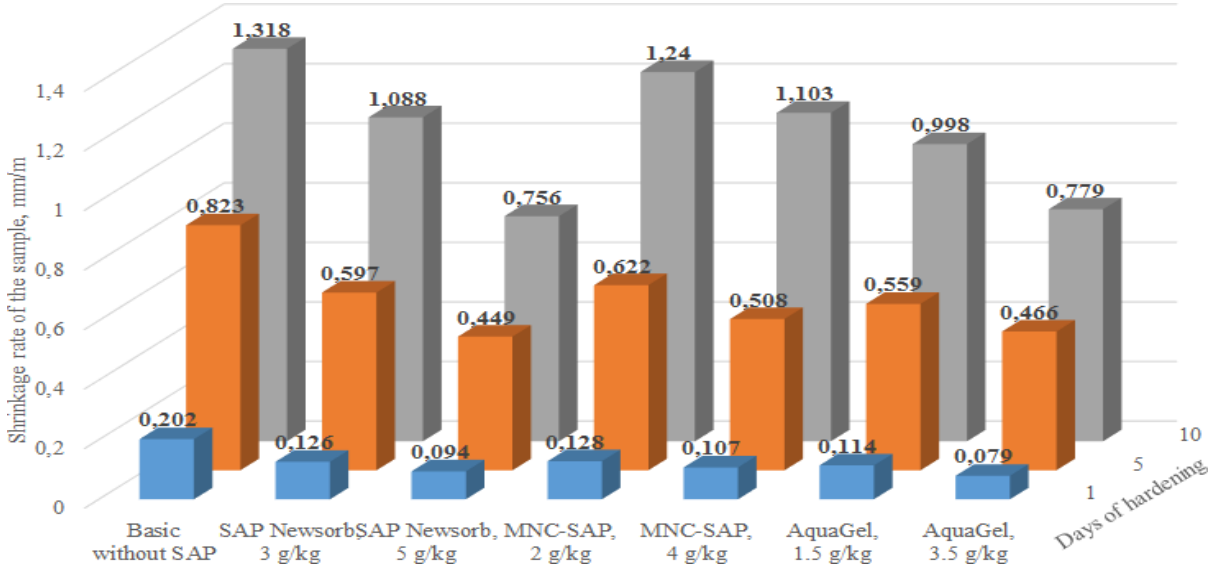

Fig. 1. Shrinkage rates on the 1st, 5th, and 10th days of samples' hardening

It should be noted that due to the dense polymer network and, as a result, high stability in the "feeding" of the cement matrix of the hardening sample, SAP Newsorb superabsorbent based on sodium polyacrylates in the amount of 5 g/kg reduces the rates of shrinkage deformations, showing lower indicators especially in the later curing days – on the 5th and 10th days.

Taking into account the average value of shrinkage deformations of PC binder of 3-5 mm/m and indicators of the base composition, it is necessary to note the overall positive effect of the use of expanding polymer agents to reduce shrinkage deformations of repair materials based on PC binders. On average, for each of the studied hardening days, the shrinkage rate of all samples containing SAP was reduced by 35%, which justifies their use in order to facilitate the creation and further high-quality functioning of the repair system. All tested samples of cement mortar containing SAP expanding agents, except for sample 4, according to the index of shrinkage deformations, correspond to the repair material class RM1-RM2 according to [23].

According to the standard [22], the concept of adhesion strength is defined as the bond strength of the applied repair product or system with the concrete substrate, the strength of contact at the boundary of the distribution of two materials. Based on the micro rheological theory of adhesion [27], the quality of this boundary directly depends on the deformation background of the material that hardens in the zone of formation of the contact zone of the repair system [28-33].

When studying the adhesive strength index, samples of the tested cement mortars were applied to the primed surface of reference concrete slabs, kept for a day in a normal hardening chamber and for another day in air-dry conditions. The obtained results of measurements of the adhesion of repair solutions to the concrete substrate through the contact layer are shown in Table 3.

Table 3 – Adhesion indicators of the studied samples to the concrete substrate

No.	Sample marking	Adhesion index f_A, MPa					
		For each sample					$\overline{f_A}$
1	Basic without SAP	0.66	0.57	0.64	0.59	0.62	0.62
2	SAP Newsorb, 3 g/kg	1.21	1.18	1.08	1.27	1.22	1.19
3	SAP Newsorb, 5 g/kg	1.44	1.49	1.33	1.38	1.54	1.44
4	MNC-SAP, 2 g/kg	0.88	0.92	0.87	0.85	0.99	0.90
5	MNC-SAP, 4 g/kg	1.06	1.19	1.21	1.11	1.19	1.15
6	AquaGel, 1.5 g/kg	1.08	0.98	1.17	1.06	1.01	1.06
7	AquaGel, 3.5 g/kg	1.32	1.49	1.36	1.44	1.33	1.39

The highest adhesion values (Fig. 2) of 1.44 MPa and 1.39 MPa were observed in samples with 5 g/kg of SAP Newsorb and 3.5 g/kg of AquaGel, respectively. Taking into account the dosage, the superabsorbent based on sodium polyacrylates increases the adhesive properties of the material by 24% compared to the base sample.

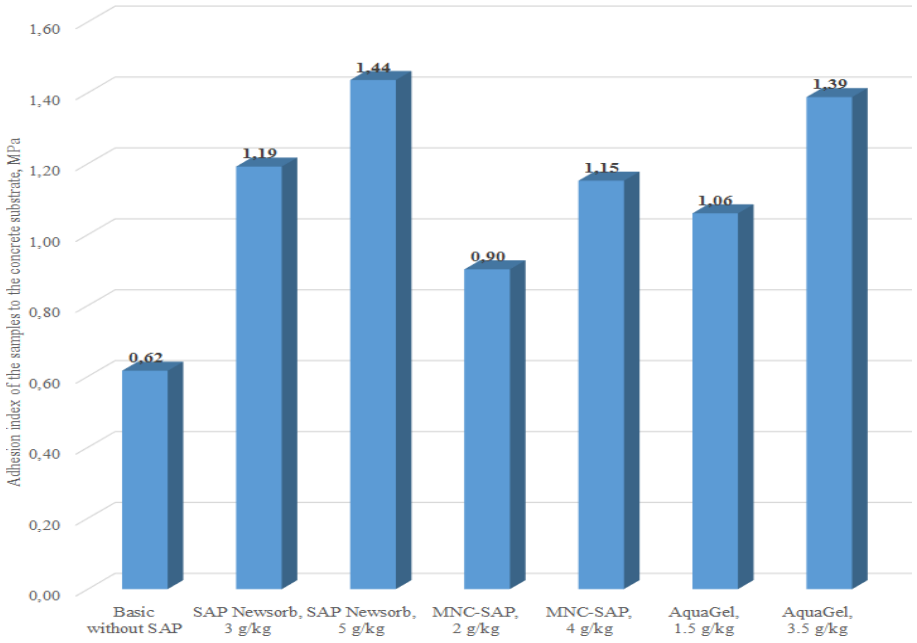

Fig. 2. Indicators of adhesion of the samples to the concrete substrate

In general, the introduction of the studied SAPs into the composition of solutions for carrying out repair work based on PC binder allows to improve the adhesion index by 1.5-2.3 times, which should ensure the maximum ability of the repaired system to absorb the workload. It should also be noted the rather high level of correlation (Fig. 3) of the obtained indicators of adhesive strength and shrinkage deformations of the samples throughout the entire period of their measurement.

All tested cement mortar samples containing SAP expanding agents correspond to the repair material class RM3 according to [23] and classes R1-R2 according to [4] according to the adhesion index. The base sample without SAP content according to [4] and [23] cannot be used as a repair material.

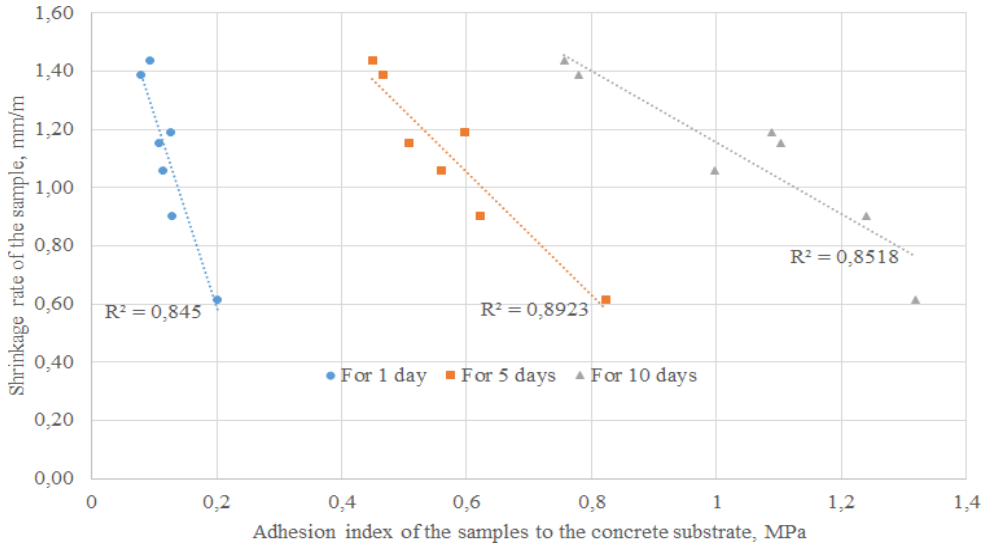

Fig. 3. Dependence of indicators of adhesion of samples to the concrete substrate on shrinkage deformations

Conclusions. The use of investigated SAP superabsorbent additives due to the improvement of hydration conditions in the cement matrix of the repair material can partially compensate for the growth of shrinkage deformations, which, in turn, slightly improves the indicators of the adhesive strength of the bond with the surface of the damaged structure.

With the same working consistency of all tested solutions, the water consumption of all compositions containing SAP expanding polymer agents is higher than the base composition by an average of 22%. The largest amount of water while maintaining the working consistency index was needed for the cement sample with a content of 3 g/kg of AquaGel superabsorbent.

Compared to the base sample, on average, for each of the studied days of hardening, the shrinkage rate of all samples containing SAP was reduced by 35%, which justifies their use in order to facilitate the creation and further high-quality functioning of the repair system. The sample with a content of 3.5 g/kg of AquaGel superabsorbent shows the lowest shrinkage rates, taking into account the dosage – by 41% less compared to the rate of the base sample on the 10^{th} day of curing.

The introduction of the investigated SAPs allows to improve the adhesion index by 1.5-2.3 times compared to the basic sample without expansion agents, while maintaining a fairly high level of correlation of this index with the index of shrinkage deformations of the samples for each of the studied days of hardening, which should ensure the maximum possibility of perception of the repaired workload system.

The highest adhesion values of 1.44 MPa and 1.39 MPa were observed in samples with 5 g/kg of SAP Newsorb and 3.5 g/kg of AquaGel, respectively. Taking into account the dosage, the superabsorbent based on sodium polyacrylates increases the adhesive properties of the material by 24% compared to the base sample.

All tested samples of cement mortar containing SAP expansion agents, except for sample 4, according to the adhesion index correspond to the repair material class RM3 according to [23] and classes R1-R2 according to [4], according to the index of shrinkage deformations correspond to the classes RM1-RM2 according to [23], and can be used as non-structural repair systems.

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ПОРІВНЯЛЬНИЙ АНАЛІЗ ВИКОРИСТАННЯ РОЗШИРЮВАЛЬНИХ АГЕНТІВ У РЕМОНТНИХ РОЗЧИНАХ З СУХИХ БУДІВЕЛЬНИХ СУМІШЕЙ ДЛЯ ПОКРАЩЕННЯ УМОВ ТВЕРДІННЯ

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Анотація. В статті наведене дослідження можливості підвищення сумісності ремонтних розчинів на основі сухих будівельних сумішей з пошкодженими бетонними та залізобетонними конструкціями та спорудами за рахунок покращення умов твердіння таких матеріалів через порівняльний аналіз показників адгезійної міцності та лінійної усадки цементних зразків з використанням різних типів суперабсорбентів, а саме SAP Newsorb на основі поліакрилатів натрію японського виробника Newstone, китайського MNC-SAP на основі поліакрилатів калію від MUHU Construction Materials та AquaGel на основі зшитого сополімеру акриламіду та акрилату калію від австралійської Baroid.

Отримані під час експериментальних досліджень дані показують, що використання досліджуваних домішок суперабсорбентів SAP внаслідок покращення умов гідратації в цементній матриці ремонтного матеріалу може частково компенсувати зростання деформацій усадки, що, в свою чергу, дещо покращує показники адгезійної міцності зчеплення з поверхнею пошкодженої конструкції.

Встановлений позитивний вплив використання зазначених полімерних домішок на досліджувані цементі розчини. У порівнянні з базовим зразком в середньому на кожні з досліджуваних діб твердіння показник усадки всіх зразків, що містили SAP, знижений на 35%, що виправдовує їх застосування з метою полегшення створення та подальшого якісного функціонування ремонтної системи. Введення досліджуваних SAP дозволяє покращити показник адгезії у 1,5-2,3 рази порівняно із базовим, що має забезпечити максимальну можливість сприйняття відремонтованою системою робочого навантаження.

Визначено оптимальні вмісти домішок SAP у складі досліджуваних цементних розчинів для зниження показників усадкових деформацій та підвищення адгезійної міцності. Отримано склади неконструкційних ремонтних цементних розчинів класу РМ3 та R1-R2 за адгезійної міцністю та класів РМ1-РМ2 за показником усадкових деформацій відповідно до українських та європейських норм.

Ключові слова: ремонтні розчини, сухі будівельні суміші, розширювальні агенти, суперабсорбенти, адгезія, лінійна усадка.

Стаття надійшла до редакції 21.06.2022