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Shrinkage of ultra-high performance concrete with superabsorbent polymers

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Abstract. During the period of hydration and hardening in ultra-high performance concrete (UHPC), a number of destructive processes occur that affect the formation of the structure of the material, which ultimately seriously affects its technical properties and performances. In this regard, the article explores the possibility of increasing the effectiveness of UHPC through the use of polymineral binders (PB) and superabsorbent polymers (SAP). For this, such characteristics as the effect of SAP on the plastic shrinkage of cement paste were investigated; hydration and hardening of cement in the presence of SAP; rheological and physical-mechanical properties of the cement system with the addition of SAP; shrinkage deformations of UHPC. It has been proven that SAP is an effective means of reducing shrinkage deformations of the cement system at the initial stage of structure formation, which helps to reduce the number of destructive phenomena of cement paste. The additive with a dispersion of more than 200 µm reduced vertical deformations by approximately 30%, and with a dispersion of less than 200 µm, by 50%. Despite the fact that SAP does not have a chemical effect on the process of cement hydration. However, the introduction of an additive in an amount of more than 0.1% by weight of PB leads to a significant increase in the setting time (period of active hydration) through the absorption and desorption of water. After 17 and 24 hours after watering, the crystals of neoplasms in the control samples without additives developed more rapidly and had a larger size. However, 41 hours after mixing with water, the larger size of hydration products is typical for samples containing SAP. The introduction of SAP into the composition of cement paste leads to the formation of closed pores filled, depending on storage conditions, with water or air, and a decrease in mechanical properties (by 10-20%). A technological line for the production of UHPC based on polymineral binders using SAP has been developed, it consists of three main stages - the preparation of the polymineral binder, UHPC with desired properties and the manufacture of products from it.

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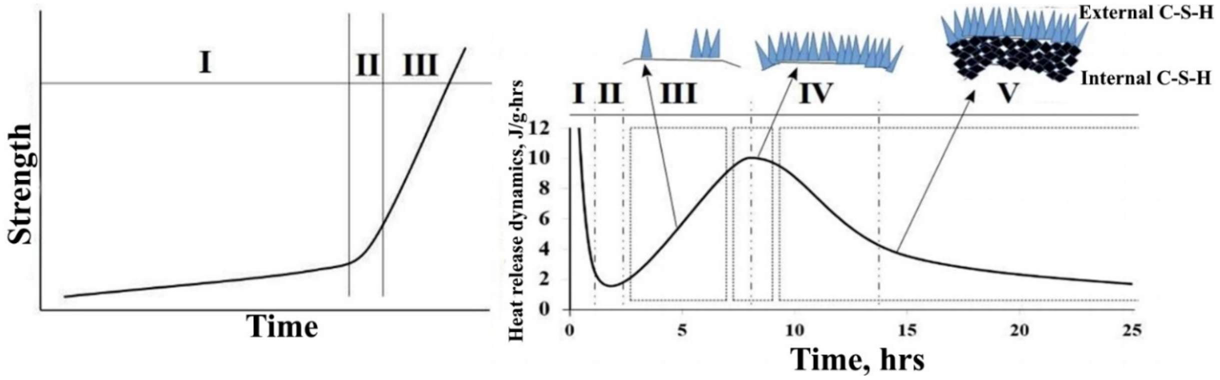
1. Introduction

Hydration and hardening of the cement system is accompanied by a number of destructive processes that affect the formation of the structure of the material, which ultimately seriously affects its physico-mechanical properties and performances [1]. Processes such as the occurrence of internal stresses, the formation of structural microcracks, changes in geometric dimensions, etc., are mainly due to shrinkage phenomena of cement paste, which in most cases leads to concrete cracking [2]. According to the results of previous works, compensation for these negative phenomena is carried out mainly due to the introduction of modifiers of a different spectrum of action, however, the methods used are not always effective when using traditional types of binders [3].

The increase in the strength of the hardening cement paste is the result of structural transformations, expressed in crystallization, development and intergrowth of crystalline hydrates, in the accumulation and compaction of the resulting gel [4], [5]. There are several theories of hydration and structure formation of Portland cement and materials based on it such a three-stage one, which uses the kinetics of structural strength (Fig. 1a) [6] and a five-stage one that explains the process in terms of heat release dynamics (Fig. 1b) [7], [8].



a) b)

Figure 1. Increase in the structural strength of Portland cement: a) three-stage theory (kinetics of structure formation) [6], b) five-stage theory (heat release dynamics) and the relationship of the main peak of heat release with an increase in C-S-H [8].

The difference lies in the fact that in the first, the chemical process (hydrolysis of calcium silicates with the release of $Ca(OH)_2$) is carried out immediately after the contact of the reagents, and in the second, after the time (induction) interval I + II, culminating in the main exothermic effect [9]. From the point of view of the dynamics of heat release (Figure 1 *b*), in the initial period (up to 24 hours), characteristic of heat release during cement hydration, two exothermic effects are separated by an induction period (II) [10], [11]. The first effect (I) is associated with adsorption and chemical interactions [12], [13]. At this stage, there is a rapid increase in the concentration of Ca^{2-} ions in the liquid phase, and after a few minutes from the moment of mixing, supersaturation is reached. After that, the leaching of calcium sharply slows down [14], [15]. This period does not characterize structural transformations [16], [17]. The growth of hydration products nuclei to critical sizes with a gradual increase in calcium supersaturation of the liquid phase can serve as one of the probable reasons for the presence of an induction period [18]. The induction period is the nucleation stage, the duration of which is determined by the nucleation rate, and then hydration passes through the new growth stage, which corresponds to the second exothermic effect [19]. The accelerated period of heat release (III) coincides with the intensive crystallization of hydrolytic lime [20]. Hydration in the accelerated period is a process of accumulation of new growths, going at a constant rate until the deceleration period (IV) [21]. Further monotonic decay of the rate of heat release and hydration (V) is due to the accumulation of reaction products that hinder the access of water to the initial phase and thereby reduce the intensity of their interaction [22]. These periods are characterized by a change in the completeness of hydration and the value of the reaction rate constants [23]. The main structural transformations take place during these periods [24].

In this regard, the working hypothesis of the research is the assumption that it is possible to increase the effectiveness of ultra-high performance concrete (UHPC) through the use of polymineral binders and superabsorbent polymers. The tasks for confirming the proposed hypothesis were: study of the effect of SAP on the plastic shrinkage of cement paste; study of hydration and hardening of cement in the presence of SAP; assessment of rheological and physical-mechanical properties of the cement system with the addition of SAP; study of UHPC shrinkage.

2. Materials and Methods

2.1. Characteristics of the raw materials used

Fig. 2 shows appearance of the materials used. Portland cement CEM I 42.5 N (Verkhnebakansky cement plant, Russia) was used as the base of the polymineral binder. Fly ash from the Novotroitskaya thermal power plant (Russia) and microsilica (StroKorporatsia 74, Russia) were used as supplementary cementitious materials. Glenium 51 (BASF, Germany) was used as a superplasticizer.

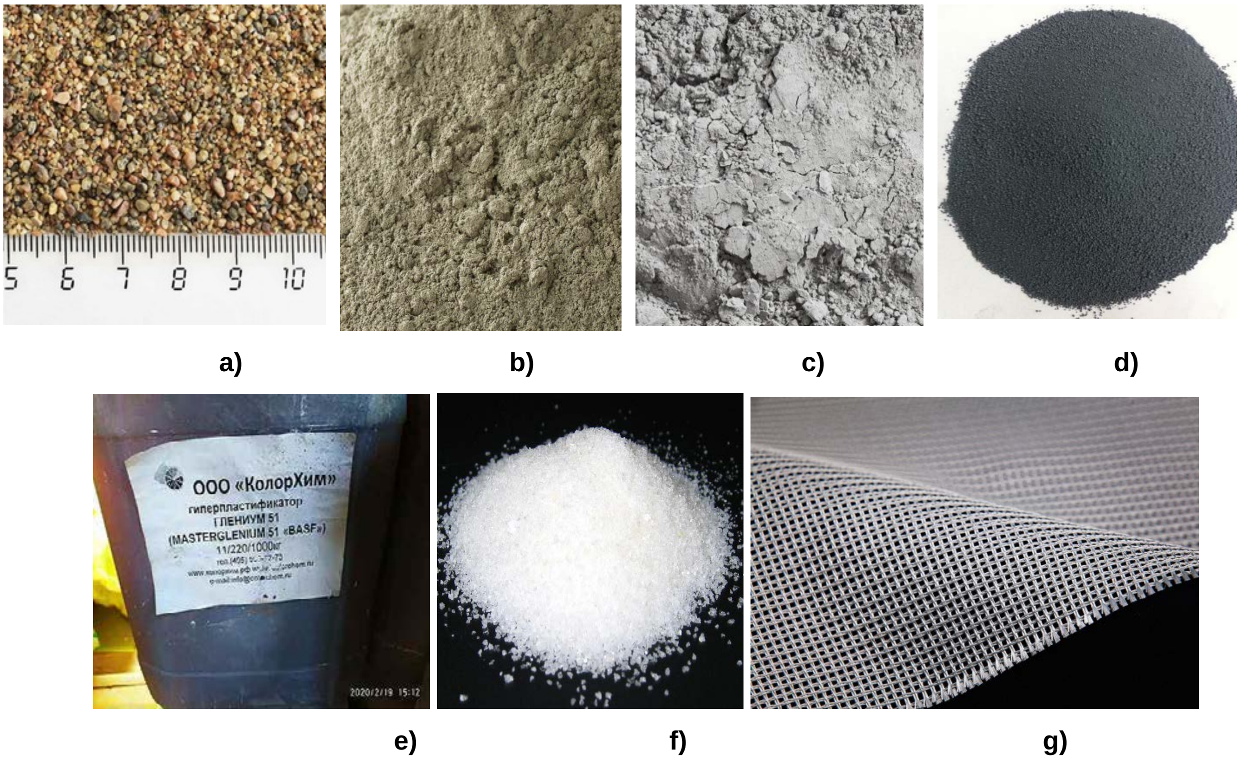


Figure 2. Appearance of the materials used: a) sand, b) fly ash, c) Portland cement, d) microsilica e) superplasticizer, f) SAP, g) glass mesh.

As a filler, fractionated enriched quartz sand of fractions from the Podgorenskoye deposit (Russia) with a fineness modulus of 2.9 was used. The sand characterization is shown in Table 1.

Table 1. The sand characterization.

Type	Fineness modulus	Partial sieve residues, wt. %					Passage through a 0.14 mesh sieve, wt. %
		2.5	1.25	0.63	0.315	0.14	
large	2.9	0	0.1	94.8	4.4	0.7	0

Superabsorbent polymers are a new generation of superabsorbent additives based on high water absorption, retention and release. The additives are cross-linked polyelectrolytes (sodium polyacrylates) that swell upon contact with water or moisture-containing solutions, resulting in the formation of a hydrogel. SAP is used as a dry chemical additive as it absorbs water during the mixing process. The characterization of the superabsorbent polymers used in the paper are presented in Table 2.

Table 2. SAP characterization.

Brand	Modification	Partical size, μm	Designation in the article
Floset	B3	<200	SAP B3 fine
		200-500	SAP B3 coarse
	B4	<200	SAP B4 fine
		200-500	SAP B4 coarse

Article used a textile mesh made of alkali-resistant AR-glass fibers, it is bidirectional (2D), leno weave, has a mesh size of 10×10 mm, and fiber consumption is 520 g/m^2. Alkali-resistant glasses are produced on the basis of the ZrO_2-SiO_2-Na_2O system. The content of expensive zirconium oxide in them varies from 15 to 23%. Since the melting point of pure zirconium oxide is quite high (2715°), alkali metal oxides are added to the glass, most often Na_2O (from 12 to 16%). Table 3 shows the chemical composition of the AR glass used for fiberglass production.

Table 3. AR-glass chemical composition, wt. %.

SiO_2	ZrO_2	Na_2O	TiO_2	K_2O	Al_2O_3
58.3–60.6	18.1–21.2	13.0–14.1	0–2.8	0–2.8	0.2

2.2. Mix design

Table 4 lists investigated mixes of UHPC. The amount of binder for all mixtures was 855 kg per 1 m^3. SAP additives were introduced in a dry state in an amount of 0.1% by weight of the binder. Compositions were prepared at water-to-binder ratios of 0.3 (without SAP) and 0.35 (with SAP) according to the regime that provides the best mixing of the components (Table 5).

Table 4. Investigated mixes of UHPC, kg per 1 m^3.

Feedstock	Mix ID					
	C1	CS1	CSM1	C2	CS2	CSM2
Portland cement	700	700	700	600	600	600
Fly ash	120	120	120	180	180	180
Microsilica	35	35	35	75	75	75
Sand	1190	1190	1190	1400	1400	1400
Superplasticizer	6	6	6	6	6	6
SAP B3 (<200 μm)	-	-	1.8	-	-	-
SAP B3 (200-500 μm)	-	0.9	-	-	-	-
SAP B4 (<200 μm)	-	-	-	-	0.9	-
SAP B4 (200-500 μm)	-	-	-	-	-	1.8
Water	262	262	306	262	262	306
Mash layers	-	-	2	-	-	2

Table 5. Mode of preparation of concrete mixture using a mixer.

Total time, min.	Stage	Stage duration, min.
00.00–02.00	Mixing of dry components	2
02.00–03.00	Addition of 80% water	1
03.00–04.00	Mixing in normal mode	1
04.00–05.00	Mixing in fast mode	1
05.00–06.00	Scraping off the walls by hand	1
06.00–06.30	Adding the remaining 20% water	0.5
06.30–08.30	Mixing in normal mode	2

2.3. Laboratory equipment and research methods

Granulometry of binder systems and used raw materials was carried out using an ANALYSETTE 22 NanoTec plus laser particle size analyzer. The rheological properties of the test cement paste were determined by measuring the diameter of a slump flow from a mold in the form of a truncated cone (h = 60 mm, D =100 mm, d = 70 mm) on a smooth surface immediately after preparation.

Shrinkage tests were carried out in a climate chamber under two operating modes simulating normal hardening conditions (moisture evaporation rate 0.25 kg/m^2·h) and hot climate (0.75 kg/ m^2·h) (Fig. 3). The experimental setup consists of four plastic molds with internal dimensions of 300×300×20 mm and is equipped with special sensors necessary to identify the physical quantities that affect the cement system during the test period (Fig. 4). Due to the prefabricated design of the formwork, it is possible to change the thickness of the test samples. The setup allows to carry out researches in the specified operating modes of the climatic chamber, due to changes in environmental factors (temperature and humidity, wind speed) and to record the parameters of vertical and horizontal deformations.

Mode	Air temperature, °C	Air humidity, %	Air speed, m/s	Moisture evaporation rate, kg/m^2·h
Normal	20	65	4	0.25
Hot	35	40	5.5	0.75

Figure 3. Climate chamber operating modes.

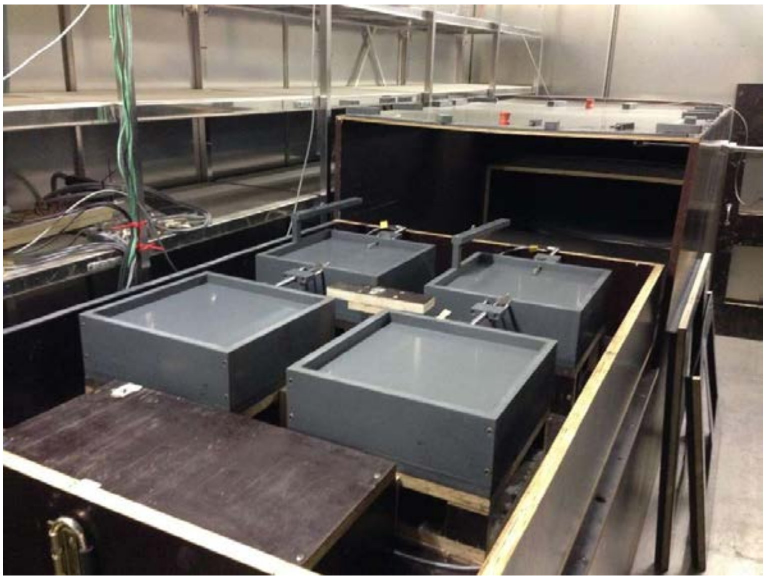


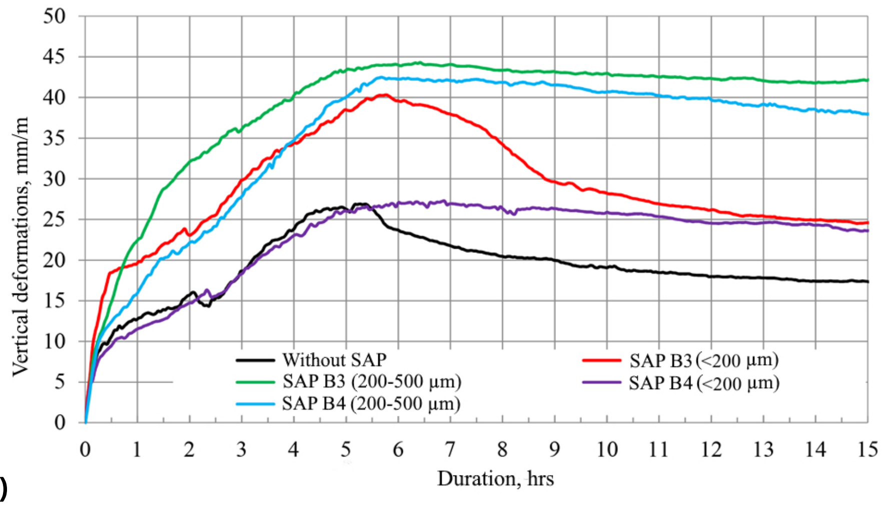
Figure 4. Appearance of the setup for determining the plastic shrinkage of cement systems inside the climatic chamber.

The nature of the effect of superabsorbent polymers on cement hydration was established by determining the dynamics of heat release, expressed by the dependence $dQ / dt = f(t)$, during 24 hours of testing, and the total amount of heat released, described by the function $Q = f(t)$, for 70 hours, using a differential calorimeter. A comparison was made of the results of a control sample of cement without additives, and samples containing SAP in an amount of 0.3% by weight of cement with sizes less than 200 mμ and more than 200 mμ, and also, in an amount of 0.6%, particle sizes less than 200 mμ. Cement samples weighing 10 g were prepared, the amount of water introduced was 5 g. It is also found that within 48 hours after mixing the cement with water, using a TESCAN MIRA 3LMU scanning electron microscope, the morphology of hydration products was studied and a comparative analysis was made.

3. Results and Discussion

3.1. Effect of SAP on the cement paste plastic shrinkage

The effect of SAP additives on vertical deformations is ambiguous (Fig. 5). It is found that when tested in normal climatic conditions (Fig. 5a), all the studied types of additives contributed to an increase in vertical deformations. This effect can be explained by the reduction in the volume of SAP particles, due to water desorption, and filling the free space with cement paste, resulting in a decrease in the volume of the test samples. The best effect was achieved by adding SAP B4 with a dispersion of less than 200 µm. However, when tested in a hot climate mode (Fig. 5b), the introduction of SAP led to a significant reduction in vertical deformations. The greatest effect was achieved by the introduction of SAP B4, while the addition of a dispersion of more than 200 µm reduced vertical deformations by about 30%, and a dispersion of less than 200 µm by 50%, in turn, SAP B3 with a dispersion of less than 200 µm reduced deformations by 28%. Thus, as a result of studying the nature of the influence of the type and dispersion of superabsorbent polymers on plastic shrinkage in cement paste, it was found that SAP is an effective means of reducing shrinkage deformations of the cement system at the initial stage of structure formation, which helps to reduce the number of destructive phenomena of cement paste.



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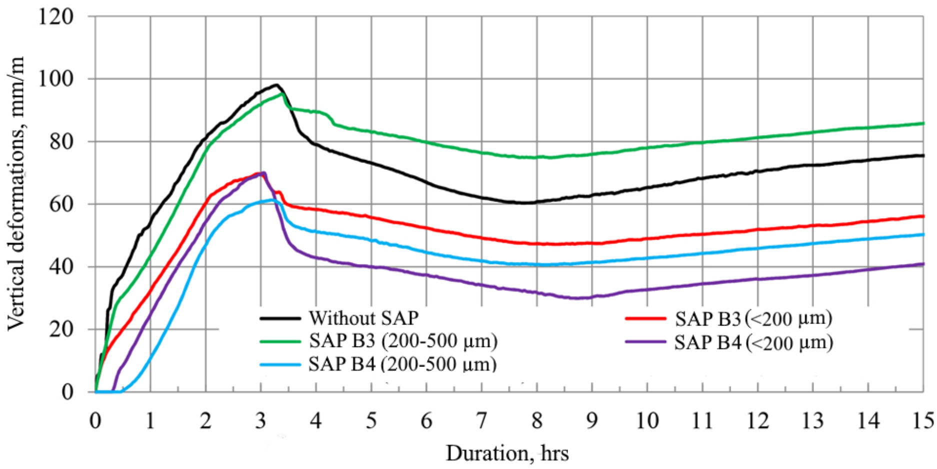


b)

Figure 5. Curves of changes in vertical deformations: a) normal climatic mode, b) hot climatic mode.

The obtained results regarding effect of SAP on the cement paste plastic shrinkage correlate with the works of other authors [25], [26], confirming the potential of using superabsorbent polymers for self-healing building cement materials.

3.2. Hydration and hardening of cement in the presence of SAP

It was established that SAP does not have a chemical effect on the process of cement hydration. However, the introduction of an additive in an amount of more than 0.1% by weight of the binder leads to a significant increase in the setting time (period of active hydration) through the absorption and desorption of water (Fig. 6)

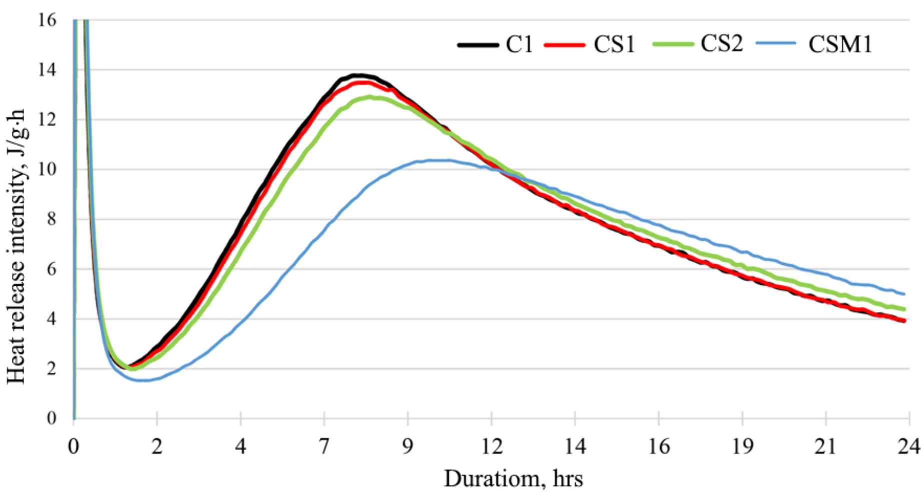


Figure 6. Curves of dynamics of heat release during cement hydration in the presence of SAP.

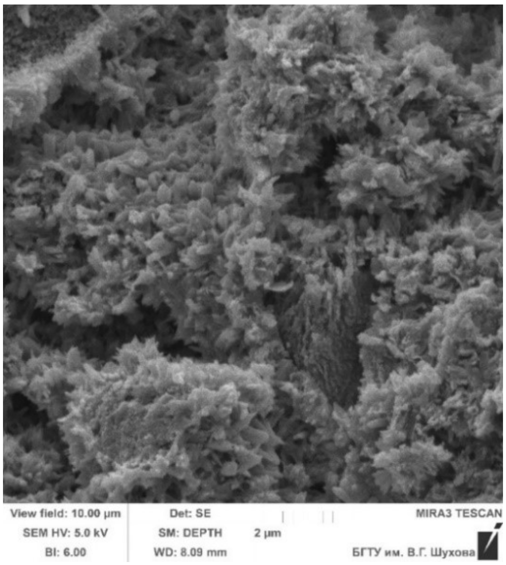
Moisture retention in the first hours after mixing leads to incomplete hydration of the binder, since not all cement particles can be fully provided with the necessary water. However, the subsequent water loss leads to an additional reaction, which is confirmed by the elongated curves of the heat release dynamics of the samples, which contain additives. Based on the total amount of heat released during 70 hours of testing samples containing SAP compared to the control composition, it can be judged that all the water was involved in the cement hydration process (Table 6).

Table 6. Amount of heat released during testing for 70 h, J/g.

Amount of SAP, wt. % of binder			
0	0.1 (200–500 µm)	0.1 (<200 µm)	0.2 (<200 µm)
280.03	279.80	286.03	281.13

To establish the effect of water loss of additives on the growth of hydration products in the early stages of hardening, samples were prepared at w/b = 0.3, with a content of 0.1 wt. % SAP (dispersion less than 200 µm) and control ones without additives. After disassembly, the samples were stored open in laboratory conditions.

It was established that after 17 and 24 hours after water mixing, the crystals of new growths in the control samples without additives developed more rapidly and had a larger size (Fig. 7a - 7d). However, 41 hours after mixing with water, a larger size of hydration products is characteristic of samples containing SAP (Fig. 7e-7f)



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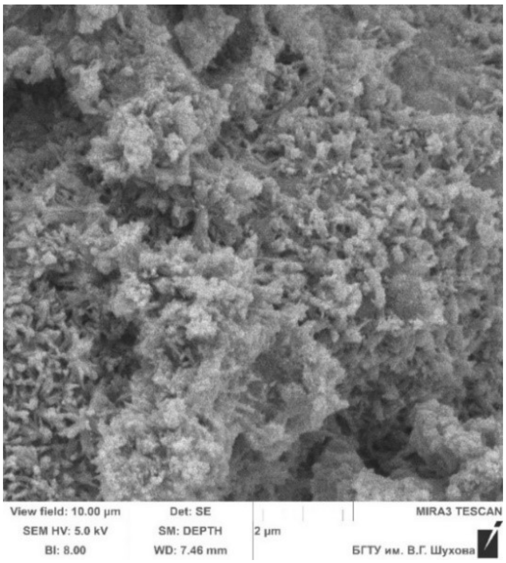

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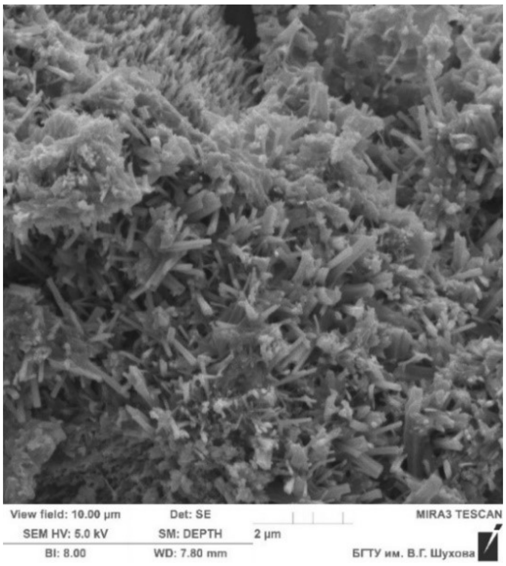
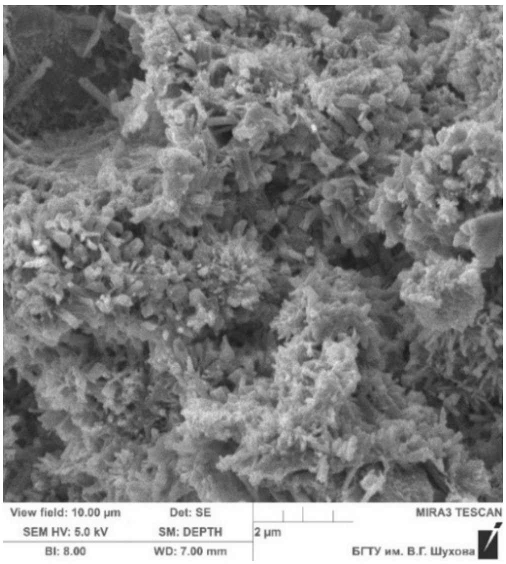


c)



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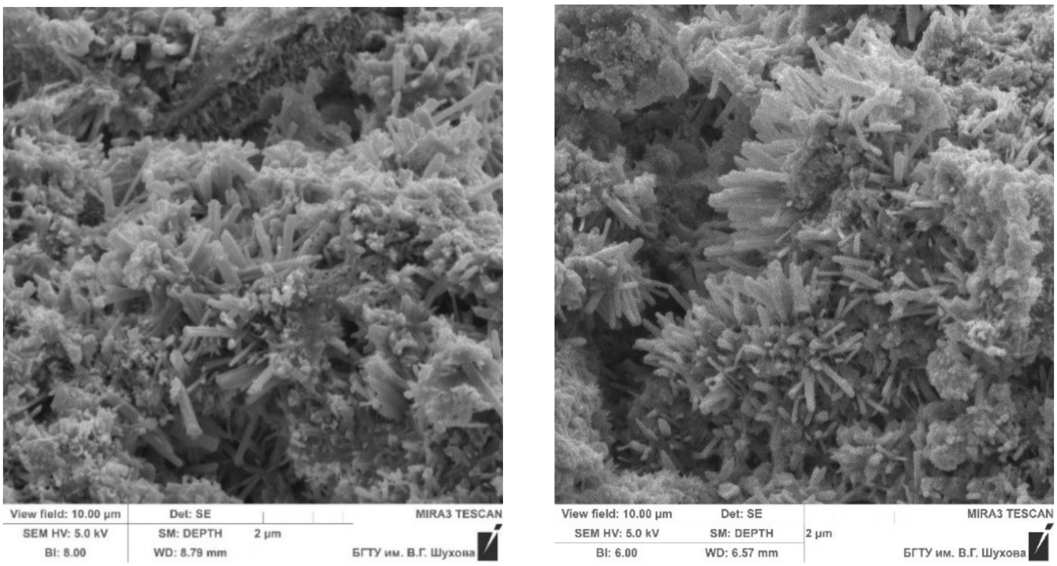

e) **f)**

Figure 7. SEM images of hydration products crystals: 17 hours after mixing with water – a) without SAP, b) with SAP; 24 hours after mixing with water – c) without SAP, d) with SAP; 41 hours after mixing with water – e) without SAP, f) with SAP

This effect is achieved as a result of the participation in the hydration process of additional water released from the SAP hydrogel approximately after the maximum exothermic reaction has been reached.

The obtained results regarding hydration and hardening of cement in the presence of SAP correlate with the works of other authors [27], [28], confirming the potential of using superabsorbent polymers for self-healing building cement materials.

3.3. Rheological and physical-mechanical properties of the cement system with the addition of SAP

The test results the *concrete* mix slump flow and the concrete 28-days average density are presented in Table 7. SAP B3 additives, regardless of dispersion, do not have significant moisture saturation in the first 8.5 minutes after contact with water (duration of mixture preparation). However, SAP B4 (<200 µm) reduces the concrete slump flow by 24%, and SAP B4 (200–500 µm) by 14%. The difference in the slump flow of samples containing SAP B4 indicates that with an increase in the dispersion of the additive, the rate of its moisture saturation increases. Further moisture saturation with water will depend on the sorption capacity of the polymer, its size and the amount of free water present. The relative amount of water consumed can be determined from the value of the average density of the concrete.

The effect of superabsorbent polymers on the physical and mechanical properties was established by testing concrete samples prepared in standard forms 40×40×160 mm on days 3, 7 and 28. Tests and processing of results were carried out according to the Russian Standard GOST 30744-2001.

Table 7. The effect of SAP on fresh mix consistency and average concrete density.

Mix ID	Slump flow, mm	Average density, kg/m^3
C1	215	1920
CSM1	206	1880
C1	210	1880
C2	164	1870
CSM2	180	1870

The introduction of additives leads to a decrease in the average density of the concrete. During the period of water mixing and up to solidification, SAP particles absorb water and turn into a hydrogel, thereby reducing the density of the mixture. After the cement stone hardens, SAP particles form a closed pore filled with water, which leads to a decrease in the average density of the samples.

There is a trend between the moisture saturation of SAP additives and the value of the average density of the concrete. The more water a polymer particle is able to absorb, the lower the average density and the greater the pore volume created in the concrete. The same regularity can be traced when establishing the influence of SAP on the strength properties of the concrete (Fig. 8).

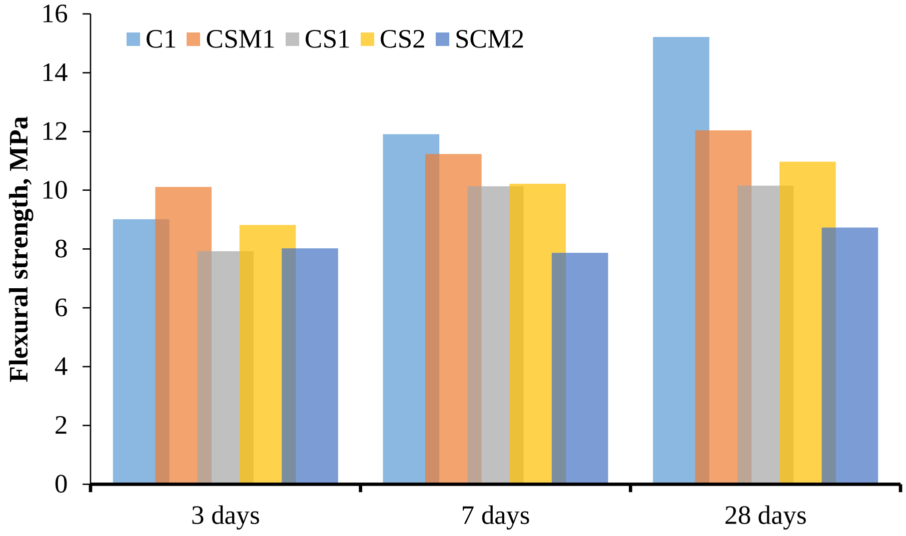

Figure 8. The effect of SAP on the concrete flexural strength.

In the early stages of strength development (day 3), concrete samples containing SAP B3 and SAP B4 of smaller particle size (<200 μm) showed an increase in flexural strength by 12.21 and 8.99%, respectively. However, in subsequent periods of testing, the strength decreases. So, on average, on the 7th and 28th day of testing samples containing SAP B3, in comparison with control samples, there is a decrease in flexural strength by 5.71 and 14.19%, respectively, and when testing samples containing SAP B4 by 20.84 and 27.88% respectively.

There is also a decrease in flexural strength depending on the dispersion of additives. For concrete samples with SAP B3, the difference in flexural strength on days 3, 7 and 28 is 21.56, 9.80 and 15.61%, respectively, and for concrete samples containing SAP B4 9.07, 22.99 and 20.42%, respectively. The increase in the pore size due to the introduction of larger SAP leads to a decrease in the resistance of concrete to flexural loads.

A similar trend can be traced when establishing the effect on the compressive strength. So on the 3rd, 7th and 28th day of testing samples containing SAP B3, in comparison with control samples, there is a decrease in compressive strength by an average of 4.73, 13.24 and 16.18%, respectively, and when testing samples containing SAP B4 by 16.74, 17.50 and 16.68%, respectively (Fig. 9).

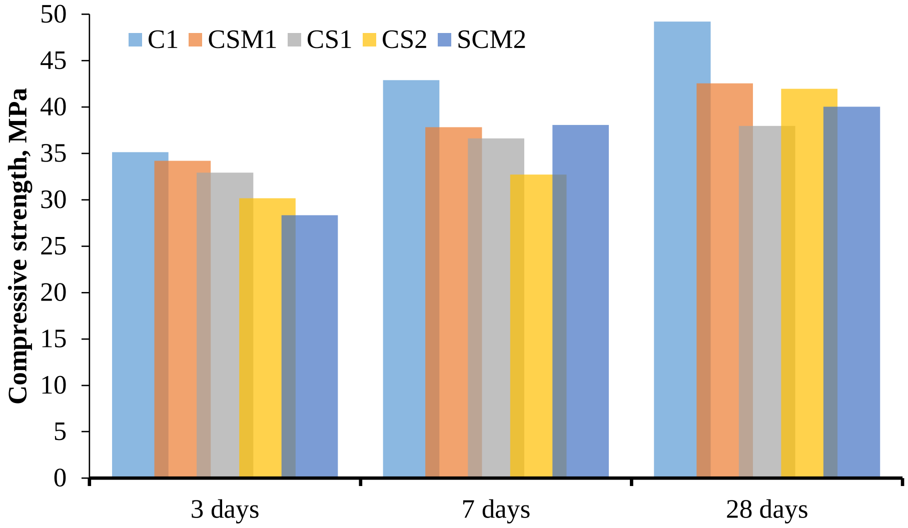

Figure 9. The effect of SAP on the concrete compressive strength.

An increase in SAP particle size results in a decrease in compressive strength. For concrete samples containing SAP B3 on days 3, 7 and 28, the difference in compressive strength is 3.77, 3.17 and 10.77 %, respectively, and for samples in the presence of SAP B4 is 6.10, 16.35 and 4.62 % respectively. Thus, the introduction of superabsorbent polymers into the composition of concrete leads to the formation of closed pores filled, depending on storage conditions, with water or air, and a decrease in physical and mechanical properties. At the same time, an increase in the size of SAP particles leads to the greatest decrease in strength indicators.

The obtained results regarding rheological and physical-mechanical properties of the cement system with the addition of SAP correlate with the works of other authors [29], [30], confirming the potential of using superabsorbent polymers for self-healing building cement materials.

3.4. Shrinkage deformations of concrete

The influence of the type of superabsorbent polymers and reinforcing meshes on the shrinkage deformations of the developed UHPC compositions in the early stages of hardening was studied. The most cost-effective type of reinforcing mesh was used, made of alkali-resistant glass of the AR type, with a fiber consumption of 520 g/m^2 and a mesh size of 10×10 mm. The tests were carried out on a special installation for the study of plastic shrinkage of cement systems in two modes of operation of the climatic chamber.

During the tests, it was found that the introduction of SAP into the composition of UHPC in all cases leads to a reduction in horizontal deformations caused by plastic shrinkage. When tested under normal conditions (moisture evaporation rate 0.25 kg/m^2.h) in the first 15 hours after water mixing, UHPC compositions with different SAPs have almost equal values of horizontal deformations (Fig. 10a). Due to the peculiarities of hydration and hardening of the polymineral binder, in subsequent periods of testing, a small number of structural defects are observed in concrete.

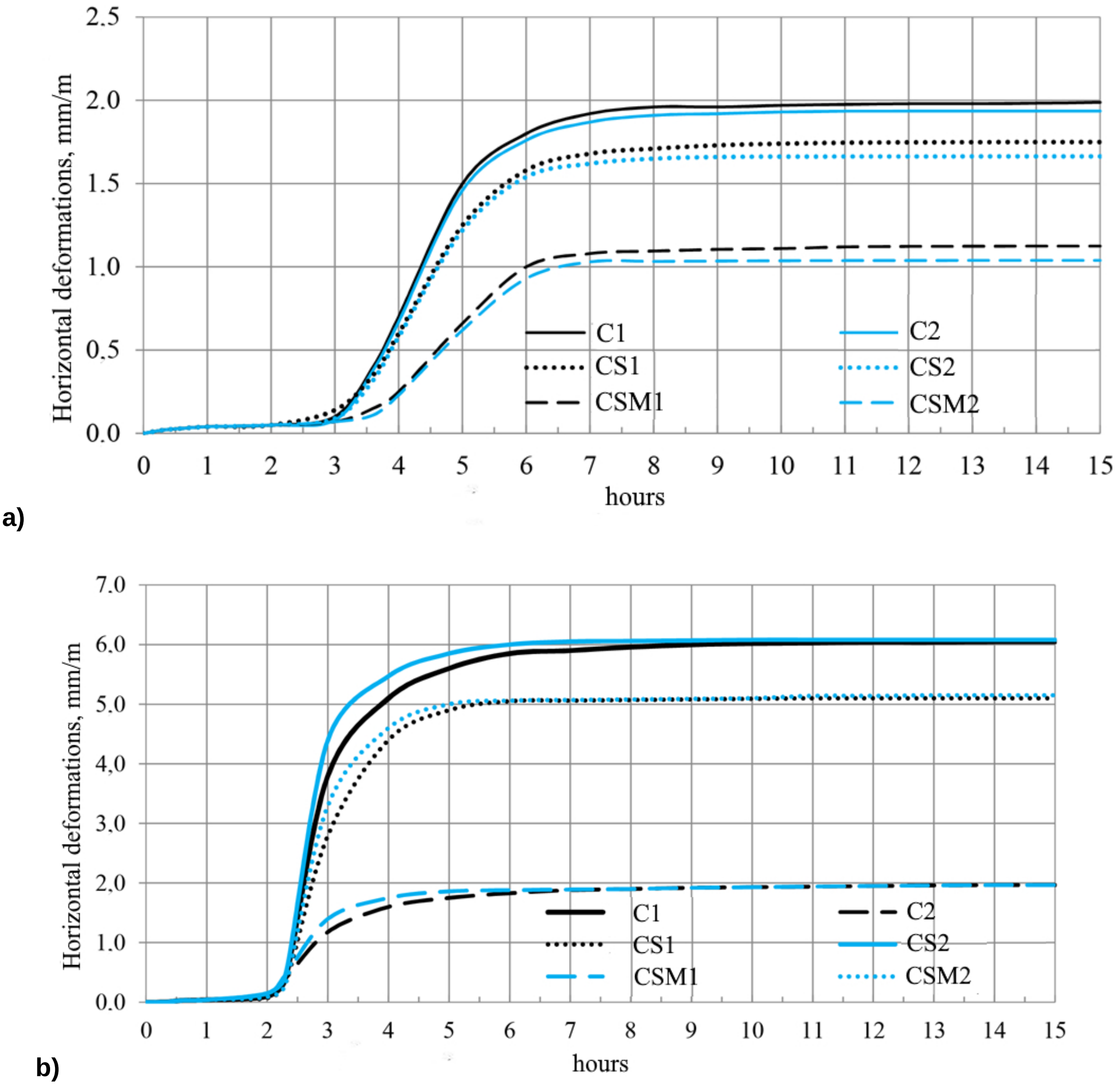

Figure 10. Influence of concrete components on the change in horizontal deformations when tested in normal climatic conditions (a) and hot climatic conditions (b).

When tested in hot climatic conditions (evaporation rate 0.75 kg/m^2.h), due to more intensive evaporation of moisture from the surface of the concrete mix, volumetric deformations in the first hours, caused by the formation of negative capillary pressure, due to the lack of structural strength of the binder, develop more rapidly (Fig. 10b). Since the setting of Portland cement occurs somewhat earlier than that of supplementary cementitious materials, the deformations of C1, CS1 and CSM1 upon reaching 3 hours are less than C2, CS2 and CSM2. However, in the future, the hydration of the polymineral binder increases, which leads to a reduction in horizontal deformations. When comparing the test results of UHPC and cement stone, a decrease in horizontal deformations by more than a factor of two is observed. This is due to the restraining effect of the filler and fillers during the development of plastic shrinkage of UHPC. A well-chosen ratio of coarse and fine fractions reduces the size of capillary pores, prevents concrete delamination and forms a framework that prevents the development of volumetric deformations. As can be seen from the graphs (Fig. 10), reinforcing mesh is of great importance in curbing shrinkage deformations in the early stages of hardening. When tested under normal conditions, two layers of reinforcing meshes together with SAP in UHPC reduce horizontal deformations by more than 40%, and when tested in hot climates, by more than 60%. As a result of the tests, it was found that the introduction of superabsorbent polymers in an amount of 0.1% by weight of the binder leads to a reduction in shrinkage deformations of the concrete mix, regardless of the type of binder, under normal and hot hardening conditions by 20 and 16 %, respectively, and concrete by 40 and 60% respectively. The effectiveness of the use of polymineral binders will be in the formation of the UHPC structure with increased resistance to destructive processes, manifested in the form of microcracks.

The obtained results regarding shrinkage deformations of concrete correlate with the works of various authors [29–32], confirming the potential of using superabsorbent polymers for self-healing building cement materials.

3.5. Technological line for the production of UHPC

The technological scheme for the production of products from Ultra high performance concrete, based on polymineral binders using superabsorbent polymers, consists of three main stages such the preparation of a binder, the preparation of fine-grained concrete of given properties and the manufacture of products from UHPC, depending on the method adopted (Fig. 11).

Portland cement, fly ash and microsilica in the accepted ratio are subjected to joint grinding in a ball mill for a period of time necessary to achieve a specific surface area of the mixture equal to 550 m^2/kg. The preparation of the concrete mixture is carried out in accordance with the requirements of the relevant standards and regulations for mixtures of fine-grained concrete. To achieve a uniform consistency, it is recommended to use forced-action concrete mixers (blade). After the ready-mixed concrete is fed into the hopper of the mix distributor, dosing and filling of the molds is carried out with the help of a movable manual distributor, depending on the method of preparation of the UHPC. Molded products are delivered to the storage warehouse. The method of preparing products from UHPC, in each case, is selected depending on the design features. The developed technological line implies three methods of preparing textile-concrete: lamination method (layer-by-layer laying of the concrete mixture), casting method (filling the mold with a rolling stock of the concrete mixture) and shotcrete (layer-by-layer laying of the concrete mixture by spraying using shotcrete equipment).

The developed technological line for the production of self-healing concrete is more efficient than similar ones.

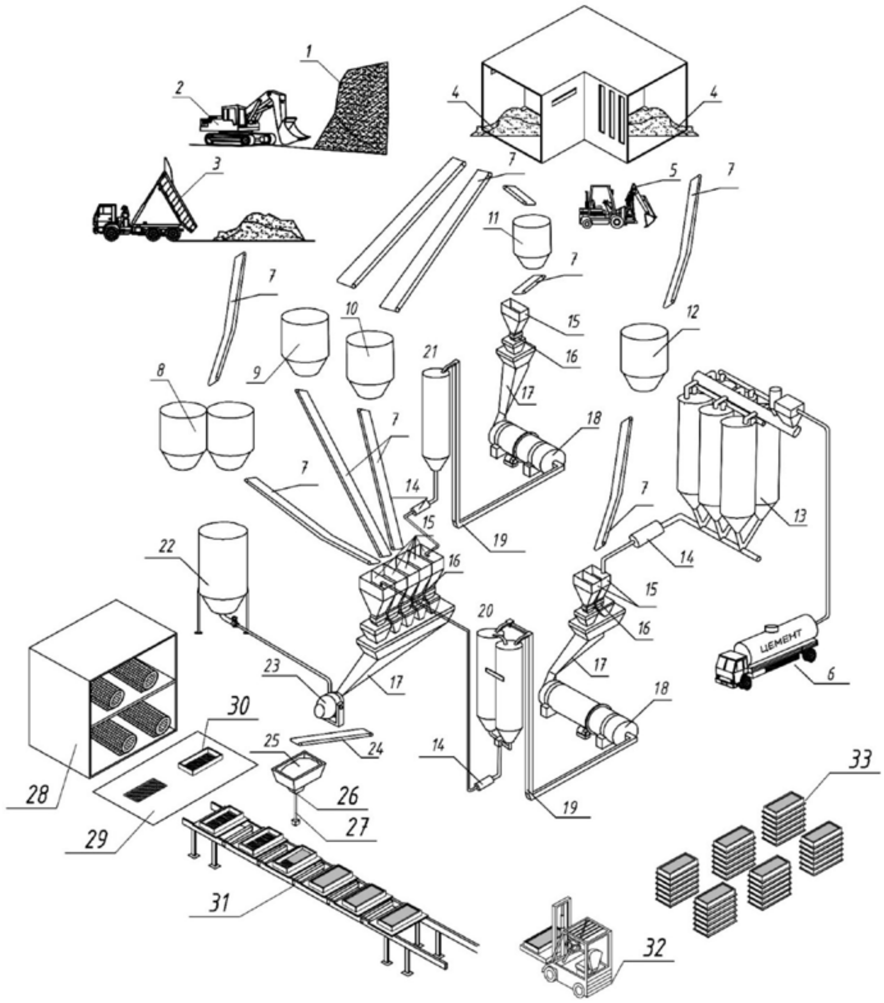

Figure 11. Technological scheme for the production of UHPC products: 1 – sand quarry; 2 – excavator; 3 – vehicles; 4 – warehouse for storage of fly ash and microsilica; 5 – loader of raw materials; 6 – cement carrier; 7 – belt conveyor; 8 – sand storage bunker; 9 and 10 – fly ash storage bunkers; 11 and 12 – microsilica storage bunker; 13 – cement storage bin; 14 – chamber pump; 15 – collection bunker; 16 – weight dispensers; 17 – receiving funnel; 18 – ball mill; 19 – elevator; 20 and 21 – polymineral binder silos; 22 – water tank; 23 – concrete mixer; 24 – belt feeder; 25 - storage bin; 26 – rotary supercharger; 27 – manual mixture distributor; 28 – storage of glass mesh; 29 – point for cutting and laying glass mesh into the formwork; 30 – formwork; 31 – belt conveyor; 32 – unloader; 33 – storage warehouse for molded products.

4. Conclusions

During the period of hydration and hardening, a number of destructive processes occur in the cement system that affect the formation of the structure of the material, which ultimately seriously affects its technical and operational properties. In this regard, the working hypothesis of the research is the assumption that it is possible to increase the effectiveness of UHPC through the use of polymineral binders and superabsorbent polymers. The tasks for confirming the proposed hypothesis were: study of the effect of SAP on the plastic shrinkage of cement paste; study of hydration and hardening of cement in the presence of SAP; assessment of rheological and physical-mechanical properties of the cement system with the addition of SAP; shrinkage study of UHPC. As a result of solving these tasks, the following main conclusions were drawn:

– SAP is an effective means of reducing shrinkage deformations of the cement system at the initial stage of structure formation, which helps to reduce the number of destructive phenomena of the cement stone. The greatest effect was achieved by the introduction of SAP B4, while the addition of a dispersion of more than 200 μm reduced vertical deformations by about 30%, and a dispersion of less than 200 µm by 50%, in turn, SAP B3 with a dispersion of less than 200 µm reduced deformations by 28%.

- SAP does not have a chemical effect on the cement hydration process. However, the introduction of an additive in an amount of more than 0.1 wt. % by weight of the binder leads to a significant increase in the setting time (period of active hydration) through the absorption and desorption of water.
- After 17 and 24 hours after watering, the crystals of new growths in the control samples without additives developed more rapidly and had a larger size. However, 41 hours after mixing with water, the larger size of new growths is typical for samples containing SAP.
- The introduction of superabsorbent polymers into the composition of cement paste leads to the formation of closed pores filled, depending on storage conditions, with water or air, and a decrease in physical and mechanical properties. At the same time, an increase in the size of SAP particles leads to the greatest decrease in strength indicators.
- Ultra high performance concrete, based on polymineral binders using superabsorbent polymers, consists of three main stages - preparation of binder and mineral modifier, preparation of fine-grained concrete of given properties and production of UHPC products, depending on the adopted method

5. Compliance with Ethical Standards

The authors declare no conflict of interest. The research does not involving Human Participants and/or Animals.

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