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Autogenous Shrinkage of Concretes from Highly Mobile and Self-Compacting Mixtures

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Abstract

Introduction. The influence of the chemical and mineralogical composition of Portland cements and the chemical base of superplasticizers on the magnitude and kinetics of autogenic (contractional) shrinkage of concretes from highly mobile and self-compacting concrete mixtures has been revealed. The relevance of the issue is due to the commonly overlooked role of autogenic shrinkage in the formation of the field of temperature-shrinkage stresses in the early hardening period of massive monolithic structures. In order to calculate intrinsic stresses, data on the magnitude and kinetics of autogenic shrinkage are required, and the insufficiency and some inconsistency of data on the effect of superplasticizing additives on the magnitude and kinetics of autogenic shrinkage, depending on the material composition of cement and the chemical and mineralogical composition of clinker, are critical to the expediency of obtaining new data on the issue. The objective of the work is to develop scientific ideas about the influence of prescription factors and material properties on the quantitative and qualitative parameters of autogenic shrinkage using the example of materials commonly used in the production of monolithic reinforced concrete structures in the Rostov region.

Materials and methods. Experimental studies were conducted using six Portland cements from four manufacturers that are fast-hardening according to GOST 31108-2020 classification. Superplasticizing additives based on polycarboxylate esters and naphthalene formaldehydes in a dosage of 0.5% of the commercial product were employed. The properties of cements are identified according to GOST 30744-2001 and GOST 310.5-88. Deformations of the hardening cement paste (stone) were determined by means of the Le Chatelier method. The amount of autogenic shrinkage of concrete was determined by the calculation method based on the amount of autogenic shrinkage of cement, taking into account the true value of the I/C of concrete and the concentration of aggregate in concrete.

Results. The ratio of "autogenic shrinkage/total contraction" of the investigated cements with additives at the age of 5 days was 0.37–0.74, the quantitative values of the total contraction of the studied cements in combination with additives at the age of 5 days ranged from 2.93 to 3.43 ml/100 g of cement, which does not contradict the available data. Change in the amount of autogenic shrinkage in the presence of additives at the age of 5 days was from 0.64 to 1.65 relative to the non-additive standard. The effect of additives on the kinetics of autogenic shrinkage was manifested both in acceleration or deceleration, and in the absence of any effect. The calculated value of autogenic shrinkage of concretes of classes B25–B35 from highly mobile and self-sealing mixtures at the age of 5 days ranged from 0.36 to 1.18 mm/m.

Discussion and Conclusion. Scientific ideas about the kinetics of autogenic shrinkage have been developed depending on the type of cements and additives. In order to describe the change in autogenic shrinkage over time, a formula similar to the formula EN 1992-1-1 for the change in concrete strength over time is set forth. The classification of concretes according to the kinetics of autogenic shrinkage is suggested. The patterns of changes in the amount of autogenic shrinkage of concretes from highly mobile and self-compacting concrete mixtures have been clarified considering the influence of the composition and properties of cements in combination with several superplasticizing additives. The most probable value of the indicator of the degree d = 1.6 – 1.8 is determined in the well-known formula for calculating the autogenic shrinkage of concrete.

Keywords: general contraction, contractional shrinkage, autogenic shrinkage, superplasticizing additives, highly mobile concrete mixtures

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Оригинальное эмпирическое исследование

Контракционная усадка бетонов из высокоподвижных и самоуплотняющихся смесей

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Аннотация
Введение. Выявлено влияние особенностей химико-минералогического состава портландцементов и химической основы суперпластифиуаторов на величину и кинетику аутогенной (контракционной) усадки бетонов из высокоподвижных и самоуплотняющихся бетонных смесей. Актуальность вопроса обусловлена часто игнорируемой ролью аутогенной усадки в формировании поля температурно-усадочных напряжений в ранний период твердения массивных монолитных конструкций. Для расчета собственных напряжений требуются данные о величине и кинетике аутогенной усадки, а недостаточность и некоторая противоречивость данных о влиянии суперпластифицирующих добавок на величину и кинетику аутогенной усадки в зависимости от вещественного состава цемента и химико-минералогического состава клинкера предопределяют целесообразность получения новых данных по данному вопросу. Цель работы состоит в развитии научных представлений о влиянии рецептурных факторов и свойств материалов на количественные и качественные параметры аутогенной усадки на примере широко применяемыми при производстве монолитных железобетонных конструкций в Ростовской области материалов.
Материалы и методы. Экспериментальные исследования выполнены с использованием шести быстротвердеющих по классификации ГОСТ 31108-2020 портландцементов четырех производителей. Использованы суперпластифицирующие добавки на основе эфиров поликарбоксилатов и нафталинформальдегидов в дозировке 0,5 % по товарному продукту. Свойства цементов определены по ГОСТ 30744-2001 и ГОСТ 310.5-88. Деформации твердеющего цементного теста (камня) определялись по методу Ле-Шателье. Величина аутогенной усадки бетона определялась расчетным методом по величине аутогенной усадки цемента с учетом истинного значения В/Ц бетона и концентрации заполнителя в бетоне.
Результаты исследования. Соотношение «аутогенная усадка/общая контракция» исследованных цементов с добавками в возрасте 5 сут. составило 0,37–0,74, количественные значения общей контракции исследованных цементов в сочетании с добавками в возрасте 5 сут. составили от 2,93 до 3,43 мл/100 г цемента, что не противоречат известным данным. Изменение величины аутогенной усадки при наличии добавок в возрасте 5 сут. составило от 0,64 до 1,65 относительно бездобавочного эталона. Влияние добавок на кинетику аутогенной усадки проявилось как в ускорении либо замедлении, так и в отсутствии влияния. Расчетная величина аутогенной усадки бетонов классов В25–В35 из высокоподвижных и самоуплотняющихся смесей в возрасте 5 сут. составила от 0,36 до 1,18 мм/м.
Обсуждение и заключение. Развиты научные представления о кинетике аутогенной усадки в зависимости от вида цементов и добавок. Для описания изменения аутогенной усадки во времени предложена формула, подобная формуле EN 1992-1-1 изменения прочности бетона во времени. Предложена классификация бетонов по кинетике аутогенной усадки. Уточнены закономерности изменения величины аутогенной усадки бетонов из высокоподвижных и самоуплотняющихся бетонных смесей с учетом влияния состава и свойств цементов в сочетании с некоторыми суперпластифицирующими добавками. Определено наиболее вероятное значение показателя показателя степени d = 1,6 – 1,8 в известной формуле для расчета аутогенной усадки бетона.

Ключевые слова: общая контракция, контракционная усадка, аутогенная усадка, суперпластифицирующие добавки, высокоподвижные бетонные смеси

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Introduction. The risk of premature cracking of massive monolithic reinforced concrete structures is caused by tensile stresses resulting from temperature and shrinkage deformations [1, 2]. They are frequently overlooked while assessing the level of tensile stresses [3, 4]. Shrinkage deformations are generally not the dominant factor contributing to premature cracking of massive monolithic reinforced concrete structures, but taking them into consideration enables a more reliable assessment of the level of stresses that take place [5], particularly with a considerable overlap time and in the case of concrete mix supplies from different concrete mixing plants, since with the possible use by manufacturers of different cements and additives, during the early hardening period there might be significant differences in shrinkage deformations of the same concrete grade. In order to reliably assess the role of shrinkage deformations, it is essential to take their nature, magnitude and patterns of development into account. The hydration and hardening of Portland cement is known to be accompanied, among other things, by its own deformations caused by mass exchange processes with the external environment (shrinkage during drying or "drying shrinkage" including carbonation shrinkage, hereinafter referred to as DS) and changes in the volume of the hardening system due to hydration, which occur as a result of a decline in the volume of neoplasms during hydration relative to the total volume of the reacting substances. This is historically known as "contraction" or "general contraction" (from the Latin la contraddizione, hereinafter referred to as OK) and consists of contractional porosity (CP) and contraction shrinkage (CS) [6]. V.V. Nekrasov was the first Russian researcher to have meticulously investigated the OK [7]. For more than 30 years, the terms "chemical shrinkage" have been largely used in foreign literature to denote OK and "autogenous shrinkage" to denote CS [5, 8–10]. One of the earliest mentions of the term "autogenous shrinkage" can be found in [11]. In the Russian literature, the terms "general" and "external" contraction or chemical shrinkage are found to denote OK and CS, respectively [12]. In this paper, the terms OK (general contraction = "chemical shrinkage") and CS ("autogenous shrinkage") will be used further on.

The first mention of CS dates back to 1933. (Nilender Yu.A.), and according to [9] — to 1934 (Lyman), whereas in [9] it is noted that the value of CS depends on the type of cement and can vary up to 3 times. There is some information about the changing ideas about the role of CS in the process of premature cracking of concrete in Table 1.

Table 1

Some ideas about the role of CS in the formation of the concrete structure

Data	CS
Nilender Yu.A. (1933)	5-10 times lower than DS
Spindel M. (1936)	Considerably higher than DS
Aleksandrovskiy S.V. (1962)	Low compared to DS and is not involved in crack formation
Mikhailov V.V. (1974)	Fairly considerable (1 mm/m per day)
Bazhenov Yu.M. (1987)	Does not change the size but rather a porous structure
Kholmyanskiy M.M. (1997)	Low compared to DS and has no significant impact on crack formation
Larrard Roy (1993)	DS 0,42, КУ 0,58 of the total one
Tazawa, Miyazawa (1997)	DS 0,17–0,5, КУ 0,83–0,5 of the total one[1]
Persson (1998)	DS 0,49–0,54, КУ 0,32–0,38 of the total one
Nesvetaev G.V., Timonov S.A. (2001)	DS 0,27–0,87; КУ 0,72–0,13[1, 2] of the total one

Note: 1 — depending on W/C; 2 — 8 supplies of cement from 6 manufacturers.

The value of CS depends on the properties of cement, the strength of concrete, and the presence of additives. According to EN 1992-1-1, CS (according to EN $\varepsilon_{ca}(\infty)$) is identified using the formulas depending on the strength of concrete f_{ck} and time t:

$$\varepsilon_{ca}(\infty) = 2{,}5(f_{ck} - 10)10^{-6}, \quad (1)$$

$$\varepsilon_{ca}(t) = \beta_{as}(t)\cdot\varepsilon_{ca}(\infty), \quad (2)$$

$$\beta_{as}(t) = 1 - exp(-0{,}2t^{0{,}5}). \quad (3)$$

As the strength of concrete is known to depend on W/C, CS obviously depends on W/C:

$$\frac{\varepsilon_{\text{ку},W/C}}{\varepsilon_{\text{ку},\frac{W}{C}=0{,}27}} = k\cdot exp\left(b\frac{W}{C}\right), \quad (4)$$

where k = 3,6 and 2,9 respectively according to the averaged data EN 1992-1-1 and some experimental data (Malinina L.A, Nesvetaev G.V. and Timonov S.A., Persson B.) with b = –4,7 and –4,0 and and the indicator of the accuracy of the approximation R^2 respectively 0,99 and 0,54, which, according to the experimental data, indicates a strong influence on the dependence (4) of other factors — first of all, the properties of cement and the presence of additives — apart from W/C.

Fly ash has almost no effect on CS, and the effect of microcrosilicon depends on the dosage — both an increase and a decrease in CS are possible. According to [13], at the age of 4 days, slag increases CS up to 1.5 times. According to [14], 10% of silica increases shrinkage by up to 1.33 times, and depending on the dose of the superplasticizer, CS varies from 0.75 to 1.25. The hardening accelerator reduces CS by about 13%, and the setting retarder increases it by up to 1.5 times. The air-entrapping additive greatly reduces CS.

The largest divergence of opinions in the literature is regarding the size of CS. Some data is shown in Table2. It should be remembered that the CS values shown in Table 2 were obtained using a variety of methods.

Table 2

Some literature data on CS

Data	CS, mm/m						
	cement dough (stone)			concrete or a solution			
	72 h	120 h	no data	24/48 h	72 h	120 h	no data
[15]	1.2	1.47			0.12–0.24	0.147–0.295	
[16]	0.6 0.3	0.75 0.39			0.060–0.120 0.030–0.060	0.075–0.15 0.039–0.078	
[17]					0.8–1.0 0.44–0.55 0.238–0.475 0.18–0.225		
[18]	0.25	0.275			0.025–0.050	0.0275–0.055	
[19]							0.1–0.5
[13]			0.75–1.2				
[14]							0.4–1.05
[20]							0.35–1.25
[21]					0.071–0.817		
[22]						0.14–0.53	
[23]				0.203/0.235			
[24]					0.4–0.62		

According to [13], the CS/CP ratio at the age of 10 hours was 0.3. According to [6], while examining 5 supplies of cement from 4 manufacturers, the CS/CP ratio was 0.32–0.5 and as SP was introduced, it ranged from 0.3 to 0.8.

We assume the large variation in the values of CS according to some literature data is largely due to the lack of a unified methodology for measuring it [19, 20, 25]. The key point is certainly the time of the beginning of the CS measurement as the development of contraction occurs immediately after the start of cement hydration. CS starts being measured at considerably different times depending on a method chosen. According to [19], with reference to the recommendations of RILEM and DIN 1045-1, CS starts being measured at the age of 1 day, but studies also indicate the beginning of measurement immediately following setting. On top of that, samples of different shapes and sizes can be used [19, 25].

Fig. 1 schematically shows the development of OK, CS, and CP over time [6]. At the first stage (1 in Fig. 1), prior to the formation of a crystalline aggregate, there are deformations of the cement paste in the plastic stage prior to setting. In some foreign sources [14], it is noted that this is an induction period and that of the start of intense hydration, with OK = CS at the first stage. Further on, due to the start of the formation of a crystalline intergrowth (skeleton), the deformations of the uninsulated (CP) and isolated (CS) mixtures start differing, and CA = CS + CP. It is from this moment on that the countdown should start while measuring CS, i.e. following setting, as noted in, e.g., in [8], and a change in the timing of the start of crystal cluster formation affects the CS/OK ratio [6].

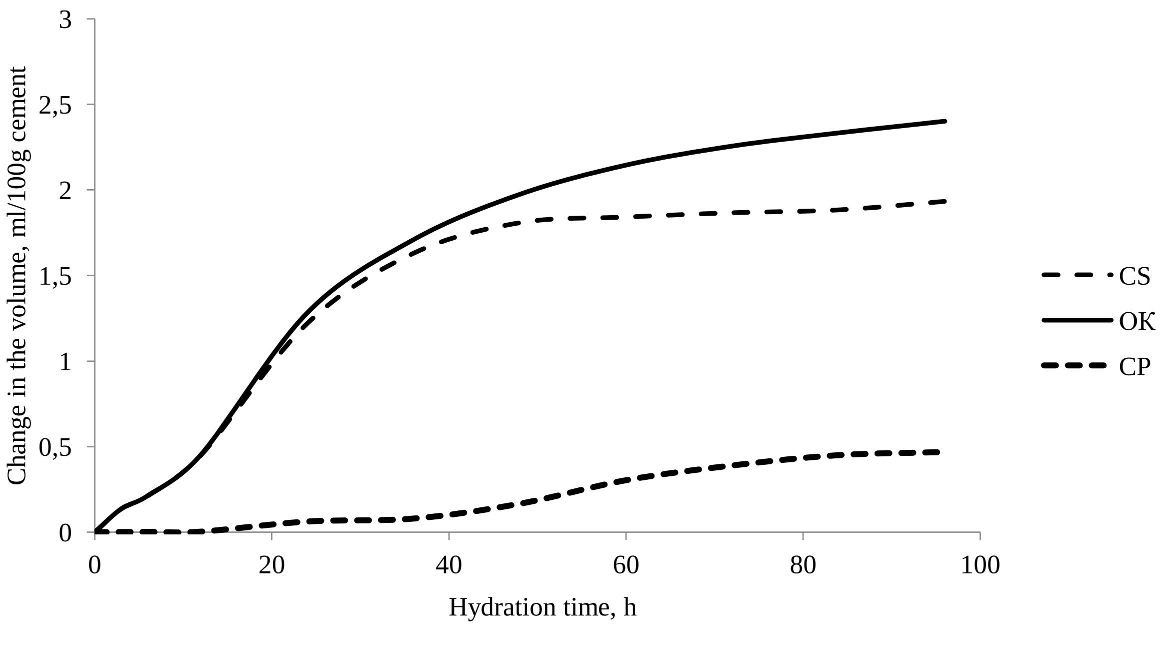

Fig. 1. Scheme of the development of OK, CS and CP over time

Highly mobile and self-sealing concrete mixtures commonly used in the production of massive monolithic reinforced concrete structures are characterized by an increased content of binder dough and the presence of modern effective diluent additives [26, 27]. Significant differences in the estimation of CS and insufficient data on the effect of superplasticizers (SPs) on CS and kinetics given the chemical and mineralogical composition of clinker and the material composition of cement, are central to the essence of research in this area. Therefore the objective of the study is to clarify the patterns of changes in the magnitude and kinetics of CS of concretes from highly mobile and self-sealing mixtures considering the influence of the composition and properties of cements in combination with some compounds commonly used in the production of monolithic reinforced concrete structures in the Rostov region.

Materials and Methods. Experimental studies were conducted using six Portland cements from four manufacturers (Table 3).

Table 3

Some properties of the investigated cements

№	PC	Properties of the cements			
		Strength, MPa, at the age of		НГ, %	НС, min.
		2 days	28 days		
1	CEM I 42,5N[1, 5]	22.4	51.5	22.75	115
2	CEM II/A-Sh 42,5N[1, 5]	23.4	55.3	25,0	150
3	CEM I 42,5N[2, 5]	28.5	50.9	26,5	150
4	CEM 0 52,5N[3, 5]	35.9	62.9	30,0	180
5	CEMI 42,5N[3, 5]	30.1	55.6	26,25	170
6	CEM II/A-P 42,5N SS[4,6]	23.5	54.6	27,25	150

Notes: 1–4 — manufacturers; 5 — GOST 31108-2020; 6 — GOST 22266-2013

All the investigated cements are classified as fast-hardening ones according to GOST 31108-2020. SP was used in a dosage of 0.5 % by weight of cement for a commercial product:

– POLYPLAST SP-4 according to TU 5745-026-58042865-2007 — a a mixture of naphthalenesulfonic acid-based copolymers;

– LINAMIX PC II according to TU 5745-033-58042865-2008 — based on polyoxyethylene derivatives of polycarboxylic acids and polyethylene glycol.

The properties of cements were identified according to GOST 30744-2001 and GOST 310.5-88. Deformations of hardening cement paste (stone) were identified using the Le Chatelier method by means of an uninsulated scheme for identifying OK and an isolated scheme (in an elastic shell) for CS [12]. CS took 120 hours (5 days) to measure, as it is this period posing the greatest threat of premature cracking of lots of massive monolithic structures. In order to switch from volumetric deformations of cement stone ΔV, %, to linear ones $\varepsilon_{\mathrm{CS}}$, mm/m, while measured using an isolated scheme due to the small values, the following dependence was used:

$$\varepsilon_{\mathrm{CS}} = 3{,}33\Delta V. \quad (5)$$

The CS of concrete ε_{con} was identified using a calculation method based on the CS of cement ε_{cem} considering the actual W/C of concrete and filler content V_a in concrete using the formula [28]:

$$\varepsilon_{con} = \varepsilon_{cem}(1 - V_a)^d, \quad (6)$$

where d = 1,2–1,7 — according to the data by Sheikin A.Ye. ; d = 1,4–1,8 — according to the data by Scherbakov Ye.N. [29]; d = 1,7 — according to the data [8, 10, 30]; V_a is assumed to be 0,7 in accordance with the recommendations [8, 28].

Research Results. Table 4 shows the data on the CS/OK ratio of the investigated cements with additives.

Table 4

CS/OK ratio in the investigated cements with additives

Composition	CS/OK ratio at 120 h for PC based on Table 3					
	1	2	3	4	5	6
PC	0.37	0.53	0.48	0.59	0.54	0.56
PC + Linamix	0.61	0.49	0.48	0.4	0.6	0.7
PC + SP-4	0.49	0.68	0.34	0.57	0.61	0.74

Almost all of the results agree with the previously specified range of 0.3–0.8. The values OK are shown in Table 5.

Table 5

OK of the investigated cements with additives

Composition	OK, ml/100 g cement , at 120 h for PC based on Table 3					
	1	2	3	4	5	6
PC	2,93	3,43	3,0	3,24	3,32	3,42
PC + Linamix	2,98	2,3	4,3	3,5	3,35	3,06
PC + SP-4	3,35	3,46	3,61	4,17	3,75	3,95

Formulas are known for identifying OK based on the mineralogical composition of clinker and the material composition of cement [20, 29]:

$$\text{OK} = aC_3S + bC_2S + cC_3A + dC_4AF + eSO_3. \tag{7}$$

For PC №1 according to Table 3, for which all the essential calculation data were known, Table 6 shows the calculated values according to a variety of formulas.

Table 6

Calculated and measured values of OK at 120 h

Value	Formula					
	Danyushevskiy V.S.	Volzhenskiy A.V.	Powers T.S.	Nekrasov V.V.	Nesvetaev G.V.[2]	Paulini P.
Calculated	2,73 0,93[1]	4,17 1,42	3,52 1,2	5,1 1,74	2,99 1,02	4,17 1,42
Measured	2,93					

Notes: 1 — in relation to the measured value ; 2 — based on (8).

The best correspondence between the calculated and measured values was obtained using the formula by Nesvetaev G.V. [29]:

$$OK = 0{,}0364C_3S + 0{,}021C_2S + 0{,}1474(C_3A - 2{,}67SO_3) + 0{,}1C_4AF + 0{,}433SO_3 \tag{8}$$

In order to describe the change in CS over time, a dependence similar to the formula for the change in concrete strength over time is employed according to EN 1992-1-1:

$$R_\tau(CS_\tau) = R_{[\tau]}\big(CS_{[\tau]}\big)\cdot exp, \tag{9}$$

where R_τ, CS_τ — the compressive strength and CS at the time τ, days, respectively; $R_{[\tau]}$, $CS_{[\tau]}$ — compressive strength and CS in 28 (R) and 5 (CS) days, respectively; k, d —coefficients shown in Table 7.

Table 7

Coefficients k and d (9)

Properties of concrete (Y)	Coefficients (9)	Cement solidification rate — criterion R_2/R_{28} based on EN 206.1			
		quick > 0.5	normal 0.3–0.5	slow 0.15–0.3	very slow < 0.15
Compressive strength, R	k	< 0.25	0.25–0.43	0.43-0.7	≥ 0.7
	d	0,5			
	$[\tau]$	28 сут.			
Autogenous shrinkage, $\varepsilon_{КУ}$	k	≲ 0.33	0.3–0.4	> 0.4	–
	d	≲ 0.65	0.66–0.9	> 0.9	–
	$[\tau]$	5 сут			–

As both the compressive strength of concrete and CS depend on the degree of cement hydration, they naturally change over time according to similar laws allowing one to set forth a classification of concretes according to CS kinetics as shown in Table 7 apart from the well-known classification of concretes according to the rate of hardening based on EN 206.1.

Fig. 2–7 shows the measurement results the values of the CS of the cement stone of the cements according to Table 1 for 120 hours, including with SP.

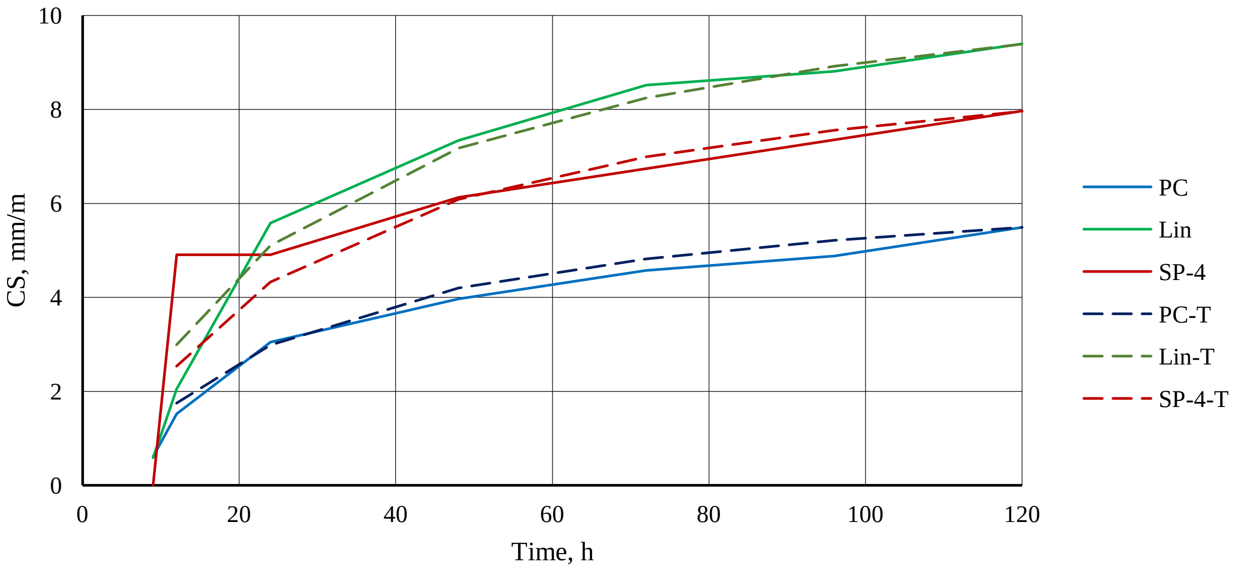

Fig. 2. Change of CS of PC № 1 over time based on Table 3:
PC, Lin, SP-4 — the additive-free standard, with Linamix and SP-4 additives respectively ;
with index T (9) — for a quick hardening rate based on Table 7 (k = 0,33; d = 0,65)

It is obvious from the results in Fig. 2 that
– the kinetics of CS of PC № 1 is almost perfectly described by formula (9) at k = 0,33, d = 0,65 (Table 7);
– if there is SP Linamix, CS grows by 1.71 times at the age of 5 days and SP-4 by 1.45 times ;
– SP has almost no effect on the kinetics of CS, k = 0,33/0,33, d = 0,65/0,65 according to SP Linamix/SP-4.

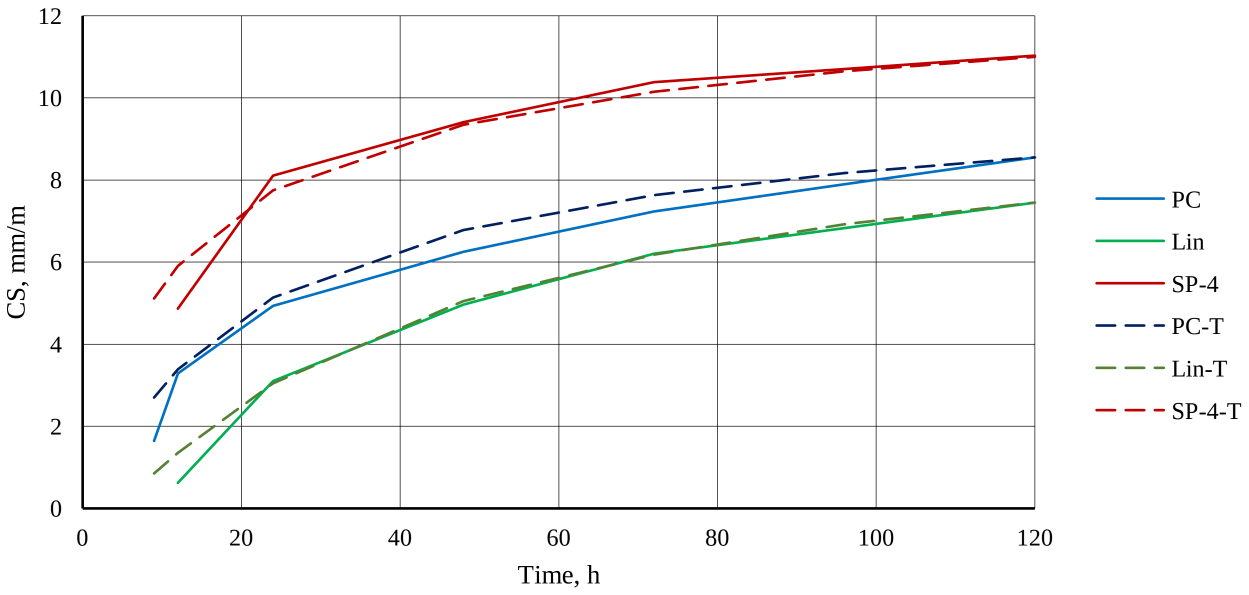

Fig. 3. Change of CS of PC № 2 over time based on Table 3:
the same designations as in Fig. 2

From the results in Fig. 3 it is obvious that
– the kinetics of CS of PC № 2 (contains slag as a mineral additive) is quite well described by formula (9) at k = 0.33, d = 0.65 (Table 7);
– if there is SP Linamix, CS at the age of 5 days is 0.87 of the standard and at SP-4 — 1.29;
– SP-4 slightly increases the kinetics of CS of k = 0.26, d = 0.53, SP Linamix slows down the kinetics of CS, k = 0.45, d = 0.68.

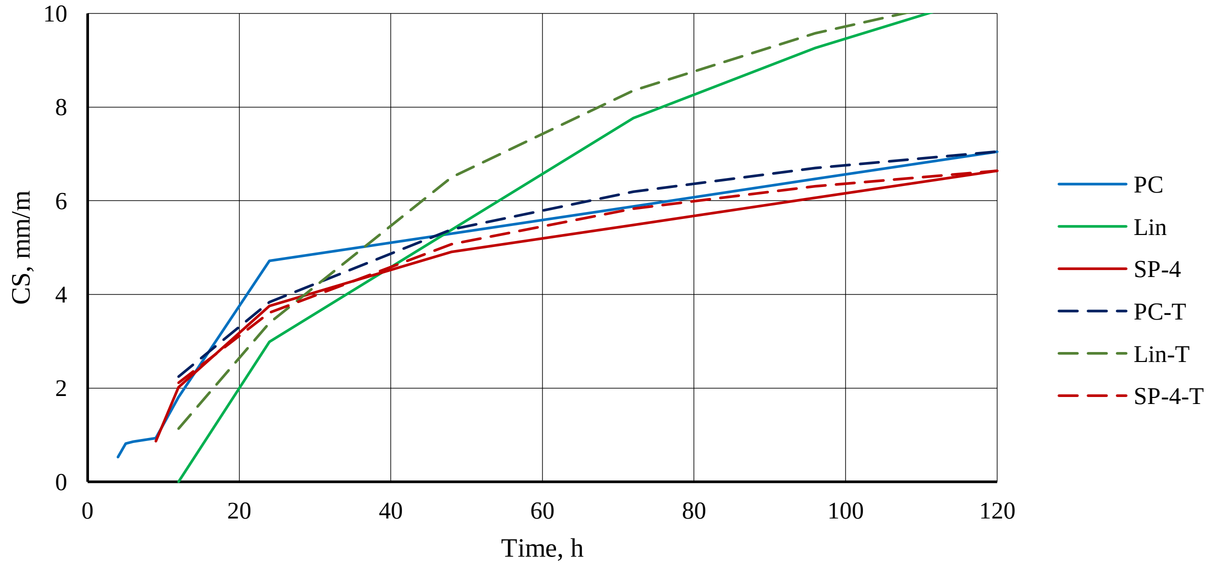

Fig. 4. Change of CS of PC № 3 over time based on Table 3:
the same designations as in Fig. 2

From the results in Fig. 4 it is obvious that

– the kinetics of CS of PC № 3 is quite well described by formula (9) at k = 0.33, d = 0.65 (Table 7);

– if there is SP Linamix, CS at the age of 5 days grows by 1.48 times and at SP-4 drops to 0.94 in relation to the additive-free standard;

– SP Linamix greatly slows down the kinetics of CS of k = 0.48, d = 0.75, SP-4 has almost no effect on the kinetics of CS of k = 0.33, d = 0.65.

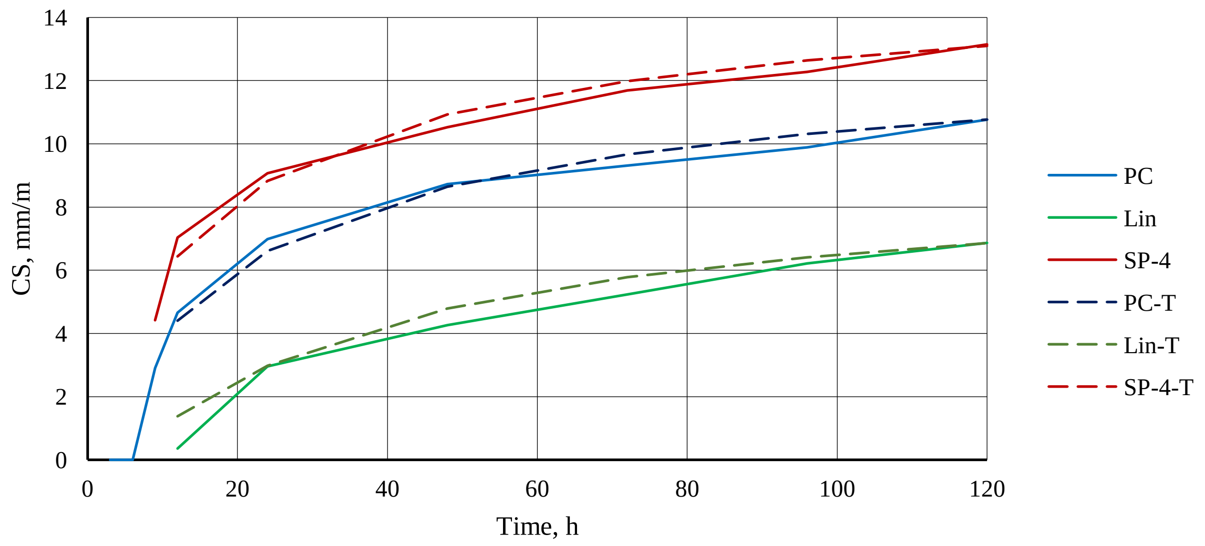

Fig. 5. Change of CS of PC № 4 over time based on Table 3:
the same designations as in Fig. 2

From the results in Fig. 5 it is obvious that

– the kinetics of CS of PC № 4 (cement grade 52.5) is quite well described by formula (9) at k = 0.3, d = 0.6 (Table 7);

– if there is SP Linamix, CS at the age of 5 days drops to 0.64 in relation to the additive-free standard and at SP-4 it grows by 1.22 times;

– SP Linamix slows down the kinetics of CS, k = 0.4, d = 0.77, SP-4 at the age of up to 48 h greatly increases the kinetics of CS of k = 0.27, d = 0.56.

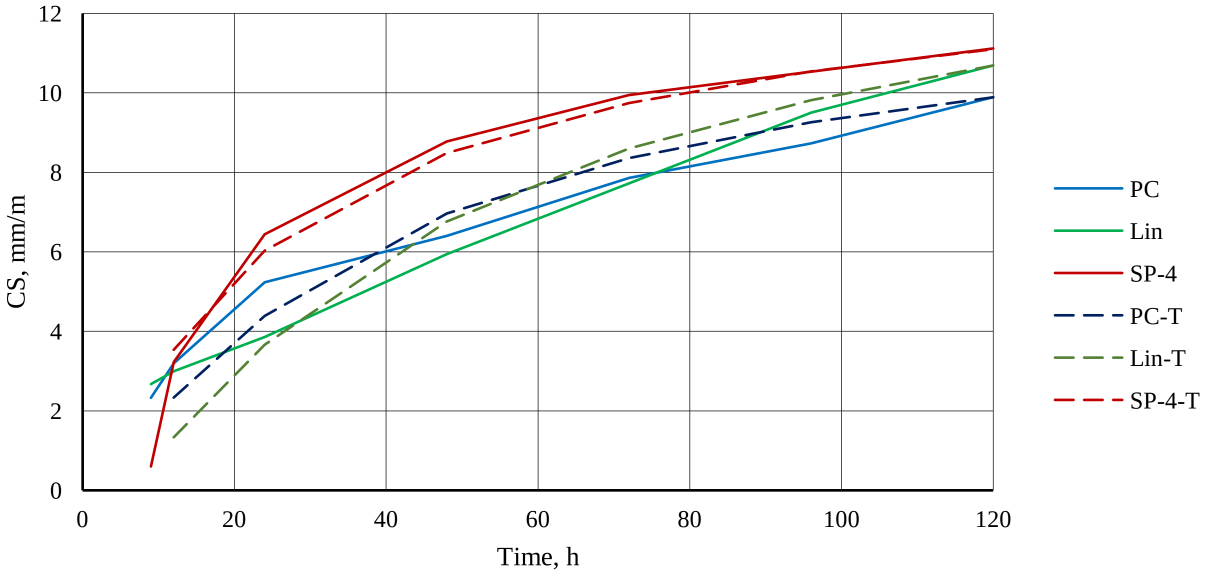

Fig. 6. Change of CS of PC № 5 over time based on Table 3:
the same designations as in Fig. 2

From the results in Fig. 6 it is obvious that

– the kinetics of CS of PC № 5 is fairly well described by formula (9) at k = 0.36; d = 0.70 (Table 7);

– if there is SP Linamix, CS at the age of 5 days grows by 1.08 times and at SP-4 by 1.12 times in relation to the additive-free standard;

– SP Linamix slows down the kinetics of CS, k = 0.49, d = 0.72, SP-4 somewhat increases the kinetics of CS of k = 0.33, d = 0.65.

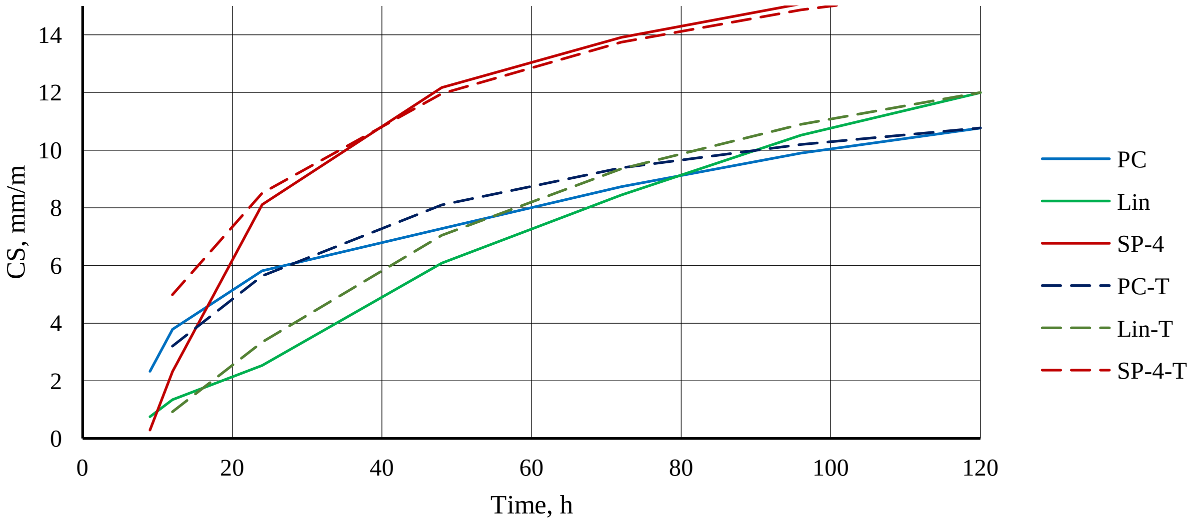

Fig. 7. Change of CS of PC № 6 over time based on Table 3: the same designations as in Fig. 2

From the results in Fig. 7 it is obvious that

– the kinetics of CS of PC № 6 (contains flask as a mineral supplement) is quite well described by formula (9) at k = 0.35; d = 0.65 (Table 7);

– if there is SP Linamix, CS at the age of 5 days grows by 1.11 times and at SP-4 by 1.45 times in relation to the additive-free standard;

– SP Linamix greatly slows down the kinetics of CS, k = 0.51, d = 0.78, SP-4 has almost no effect on the kinetics of CS, k = 0.33, d = 0.65.

The final analysis of the effect of SP on the kinetics of CS is shown in Table 8.

Table 8

Effect of SP on CS of the investigated cements

Cements based on Table 3	Index of cement stone with additives	
	$CS_{SP}/CS_{Э}$ at 120 h	Kinetics of CS
1	1,71/1,45[1]	no effect/no effect
2	0,87/1,29	slows down/somewhat increases
3	1,48/0,94	greatly slows down/no effect
4	0,64/1,12	slows down/increases
5	1,08/1,12	slows down/increases
6	1,11/1,45	greatly slows down/almost no effect

Note: 1 — in the numerator with Linamix, in the denominator with SP-4.

Fig. 8 shows the calculated CS values of concretes of grades B25–B35 commonly used for the construction of monolithic reinforced concrete structures in accordance with the obtained CS measurement results of the investigated cements, including those with additives, at various values of *d* in (5).

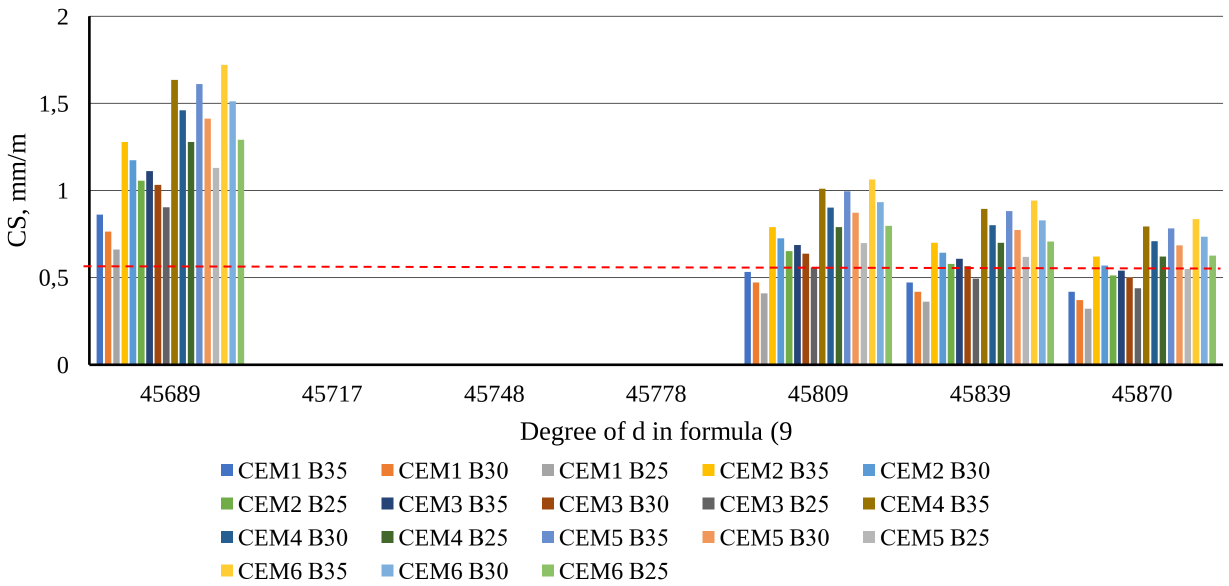

Fig. 8. Calculated values of CS of the concrete grades on the investigated cements at different values of *d* in (5)

In Fig. 8, the red dotted line indicates the maximum (1.25 mm/m) and minimum (0.4 mm/m) CS values of concrete according to some literature data (Table 2). Obviously, the most probable value of *d* in (6) is 1.6–1.8. Research in the field of experimental identification of the CS of concretes requires a follow-up.

Discussion and Conclusion. The patterns of changes in the value and kinetics of CS of concretes from highly mobile and self-sealing mixtures have been clarified considering the effect of the composition and properties of cements in combination with some SPs commonly used for the production of monolithic reinforced concrete structures in the Rostov region. The studies conducted on six different Portland cements from four manufacturers in combination with the commonly used SP of various chemical compositions POLYPLAST SP-4 and LINAMIX PK II have proved the hypothesis of a considerable effect of the chemical and mineralogical composition of cements and the chemical base of superplasticizers on the kinetics and numerical values characterizing contraction, particularly, autogenous shrinkage, which is essential for assessing the stress-strain in the early hardening period of massive monolithic structures.

The CS values of the investigated cements at 120 h have been obtained in the range from 2.93 to 3.43 ml/100 g of cement, which is in good agreement with the available literature data. The obtained values of the CS/OK ratios in the range of 0.37–0.74 at 120 h do not contradict the known data. When the SP was introduced into the concrete, CS at the age of 120 hours ranged from 0.64 to 1.71 in relation to the additive-free standard. The effect of SP on the kinetics of CS depends on both the type of cement and the SP composition.

The calculated values of the CS of concretes of grades B25–B35 from highly mobile and self–compacting concrete mixtures at 120 hours, depending on the type of cement and joint venture, were 0.32-1.06 mm/m, which is in good agreement with some available literature data.

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