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The impact of superplasticizers on the radiation changes in Portland cement stone and concretes

Влияние суперпластификаторов на радиационные изменения портландцементного камня и бетонов

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Key words: superplasticizers; Portland cement stone; concretes; civil engineering; radiation changes in volume, strength and deformation modulus; effect of neutron radiation from nuclear reactors

Ключевые слова: суперпластификаторы; портландцементный камень; бетоны; радиационные изменения объема; прочности и модуля деформации; действие нейтронного излучения ядерных реакторов

Abstract. The authors have estimated the effect of advanced superplasticizers of types Muraplast, Reamin, Weiss SM, Polyplast SP-1 and Melflux on radiation changes in Portland cement stone and concretes of radiation protection, based on experimental data from available literature, about the effect of such superplasticizers on thermal changes of Portland cement stone and the known analogy between thermal and radiation changes in Portland cement stone exposed to neutrons. The estimate of radiation changes in volume and compression strength of Portland cement stone used proposed ratios between the effect of superplasticizers on thermal and radiation changes in Portland cement stone, obtained through processing the published experimental results about the effect of superplasticizers S-3 and S-4 on radiation and thermal changes in Portland cement stone. Radiation changes in volume, crack formation, compression strength and deformation modulus of concretes, were measured with developed and tested methods for analysis of radiation changes in concretes based on information on changes of their components (aggregates and Portland cement stone). It has been established that advanced superplasticizers generally diminish radiation changes in Portland cement stone and concretes. The authors have demonstrated the extent by which such changes are reduced depending on various factors. It has been found that the effect of superplasticizers is in inverse proportion to the water-to-cement ratio of the mix as cement stone is made, by increasing the content of superplasticizer in the mix (for water reducing), and it depends on the fluency of fast neutrons.

Аннотация. Выполнено расчетное определение влияния современных суперпластификаторов Muraplast, Reamin, Weiss SM, Полипласт СП-1 и Melflux на радиационные изменения портландцементного камня и бетонов радиационной защиты на основании имеющихся в литературе экспериментальных данные по влиянию этих суперпластификаторов на термические изменения портландцементного камня и известной аналогии между термическими и радиационными изменениями портландцементного камня под действием нейтронов. Расчетное определение радиационных изменений объема и прочности на сжатие портландцементного камня выполнено с использованием предложенных коэффициентов связи между влиянием суперпластификаторов на термические и на радиационные изменения портландцементного камня, полученных на основании обработки имеющихся в литературе экспериментальных данных по влиянию суперпластификаторов С-3 и С-4 на радиационные и термические изменения портландцементного камня. Радиационные изменения объема, трещинообразования, прочности при сжатии и модуля деформации бетонов проведено на основании имеющихся разработанных и апробированных методов аналитического определения радиационных изменений бетонов по данным об изменениях их составляющих (заполнителей и портландцементного камня). Установлено, что современные суперпластификаторы в основном уменьшают радиационные изменения портландцементного камня и бетонов. Показано, в какой степени уменьшаются эти изменения в зависимости от различных факторов. Установлено, что эффект влияния суперпластификаторов возрастает с уменьшением водоцементного отношения смеси при изготовлении цементных камней за счет увеличения содержания суперпластификатора в смеси (при водоредуцировании) и зависит от флюенса быстрых нейтронов.

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Introduction

Among the main objectives within the Russian Federation 2035 energy strategy in nuclear power is the objective to reduce specific costs of building new nuclear power plants (NPP) as a financial competitive edge, with safety as top priority. One way to address the issue is that NPP construction, including the structures of nuclear reactor radiation protection, should use concrete mixes and concretes with properties modified as required for the purpose.

In order to modify and improve the construction technology and operation properties of concretes, manufacturers use a whole range of chemical additives, particularly superplasticizers, primarily polycarboxylates [1–11]. Published works executed in the Russian Federation [12–19] contain evidence that superplasticizers are also able to raise thermal and radiation resistance of concretes to neutrons, because they mainly reduce thermal and radiation changes in Portland cement stone as a key component of concrete. With this as basis, the paper [18] validates the possibility of concretes with high radiation resistance for nuclear power plants by using superplasticizers based on polycarboxylate ethers.

Among the publications of foreign authors of works devoted to the study of the influence of superplasticizers on the radiation changes in Portland cement stone and concrete, weren`t found. Not considered these issues and in most major foreign reviews [20–25].

At the same time, both in early studies [13, 14], as summarized in [15], and in later studies [16–18], the effect of superplasticizers and other chemical additives on radiation resistance of concretes, was assessed based on how the additives change the properties of Portland cement stone as a component of concrete. In fact, only papers [14–15] gave some results from research of superplasticizer effects on radiation changes in Portland cement stone exposed to the most harmful ionizing radiation neutron radiation that emanates from nuclear reactors. However, those studies only covered superplasticizers S-3 and S-4 (Dophen) – polycondensates, based on sulfonated naphthaleneformaldehyde, developed during 1970s. In [16–18], the effect of superplasticizers on radiation resistance of Portland cement stone was researched based on the resulting thermal changes in Portland cement stone heated to high temperatures. This was done using the fast method – proposed and validated in [14], then improved in [16–18] – of finding (or rather, verifying) the radiation resistance of cement stone [19]. The method is based on comparing the relative changes of the properties of the investigated cement stone with addition, with change of properties of the radiation-resistant cement stone without additives (reference sample) after short-term heating. Modify the properties of each of the compositions is determined in relation to the properties until it is warm. The results of comparing the changes in the properties of the composition with the additive and without the additive composition are judged on the influence of additives on the radiation changes and radiation resistance of cement stone.

Essentially, the studies covered in [13, 14] and summarized in [15] helped to do the following:

- to learn, how specific studied superplasticizers S-3 and S-4 influence on thermal and radiation changes in Portland cement stone (exposed to neutrons);
- to set an analogy in the mechanisms of radiation and thermal changes in Portland cement stone, which temperatures cause which results of radiation, up to researched level of fast neutron fluency;
- based on the above analogy, developing a method to quickly measure radiation resistance of Portland cement stone by results of heating test, after 5 hours at temperatures 150, 350, 600 and 900 °C.

Nevertheless, at the papers [13, 14] researchers never examined the quantitative relation between the effect of chemical additives on radiation and thermal changes in Portland cement stone, as necessary to identify radiation changes after the thermal test. They merely found approximate temperatures that correspond to certain neutron fluency levels in terms of concurrent processes. In addition, they failed to demonstrate how radiation changes of concretes change/decrease when the researched additives are used.

Research represented in studies [16–18] demonstrates that modern superplasticizers either increase thermal change immaterially or decrease it, and thus they must either slightly increase or decrease radiation changes in Portland cement stone; therefore they can be used to raise radiation resistance of concretes. However, the studies never established the extent of radiation changes in Portland cement stone and concretes caused by the use of said superplasticizers.

Among the publications of foreign authors of works devoted to the study of the influence of superplasticizers on the radiation changes in Portland cement stone and concrete, weren`t found. Not considered these issues and in most major foreign reviews [20–25].

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The purpose of present article is estimation of effects of modern superplasticizers on radiation changes in Portland cement stone and concretes based on experimental data [16–18] about effect of such superplasticizers on thermal changes in Portland cement stone. Perfomed calculations are based on processed and analyzed available experimental data [12–15] about the effects of superplasticizers S-3 and S-4 on radiation and thermal changes in Portland cement stone, and also based on available designed and tested analytical methods of measuring radiation changes in concretes based on data on changes in their components (aggregate and Portland cement stone) [15, 26–28]. From the given publications [12–15] used the data about change of the sizes and volume of Portland cement stones without additives with water cement relation W/C = 0.255-0.26 and with superplasticizers S-3 (0.5–0.8 %) and S-4 (0.8–1.1 %) with W/C = 0.225 after an irradiation in nuclear reactor IBR-2 to fluency of fast neutrons in IBR-2 reactor, from $0.1x10^{24}$ neutron/m^2 to $1.4x10^{24}$ neutron/m^2 and after heating within 5 hours at temperatures 150 °C, 350 °C, 600 °C and 900 °C.The paper also examines purely radiation-related changes in Portland cement stone and concretes exposed to neutrons, because radiation from nuclear reactors causes not only radiation changes, but also thermal changes by heating, along with neutron radiation, as can be demonstrated by the results of heating.

Research Methodology

According to the summary contained in [15, 29], vital effects of radiation on Portland cement stone include shrinking size and volume as concrete shrinks when it loses water, and also change of strength, mainly towards weakening. Changes of density and thermal conductivity coefficient, as reviewed in [15], are immaterial. According to [15, 29], change of mass by dehydration and change of strength correlate with changing size and volume, while intensity of gas release can be calculated based on figures that represent change of material weight with dehydration and condition of radiation, as discussed in [30, 31]. Therefore, the focus was on volume change.

To estimate radiation changes in Portland cement stone with superplasticizers, we considered the analogy of the processes of radiation and thermal changes in Portland cement stone, as demonstrated in [14].

We used coefficient K_{RT} to describe the ratio between the effect of superplasticizer additives on change of volume Portland cement stone caused by radiation and heat (according to [19] after 5 hours of heating), expressed as:

$$K_{RT} = \frac{1-(\Delta V_{CSR}/V_{CS0})_A/(\Delta V_{CSR}/V_{CS0})_{WA}}{1-(\Delta V_{CST}/V_{CS0})_A/(\Delta V_{CST}/V_{CS0})_{WA}}, \quad (1)$$

where $(\Delta V_{CSR}/V_{CS0})_A$ and $(\Delta V_{CSR}/V_{CS0})_{WA}$ – relative change of volume of Portland cement stone with and without additive after exposure to radiation, %;

$(\Delta V_{CST}/V_{CS0})_A$ and $(\Delta V_{CST}/V_{WC0})_{WA}$ – relative change of volume of Portland cement stone with and without additive after 5 hours of heating, %.

Values of coefficients K_{RT} were found by processing the experimental data available in [12, 14, 15] on effect of superplasticizers S-3 and S-4 on thermal [12] and radiation [14, 15] changes in Portland cement stone.

For all data used herein, relative change of volume of Portland cement stone after heating $\Delta V_{CST}/V_{CS0}$ and radiation $\Delta V_{CSR}/V_{CS0}$, was found by relative change of size $\Delta h/h_0$ and was assumed to be $3\Delta h/h_0$.

Based on the resulting coefficients K_{RT} calculates radiation change in Portland cement stone with various modern superplasticizers, whose effects were studied in [16–18], after heating with the method recommended resistance in [14, 19] to measure radiation.

Radiation change of volume of Portland cement stone without additives were found using the formula found in [15, 29], proving that dependency of radiation change of volume $\Delta V_{ЦКР}/\Delta V_{ЦК0}$ of Portland cement stone (pure radiation, no thermal changes by heating that goes along with radiation) on the fluency of neutrons with energy greater than 0.8 MeV regardless the type of Portland cement, W/C ratio and age of stone, can be approximated with the expression:

$$\Delta V_{CSR}/V_{CS0} = a_R(F_{FN}k_F)^{b_R}, \quad (2)$$

where $a_R = -3.31\%$; $b_R = 1.22$;

F_{FN} – fluency of fast neutrons with energy above 0.8 MeV, neutron/m^2;

k_F = 10^{-24} m^2/neutron – normalizing factor.

For Portland cement stone without additives, we assumed $a_R = -3.31\%$, $b_R = 1.22$.

For Portland cement stone with additives, following the analogy of mechanisms of radiation and thermal changes in Portland cement stone established in [14], value a_R was adjusted by coefficient K_{PT} and then found with the formula:

$$a_R = -3.31\{1 - K_{RT}\left[1 - (\Delta V_{CST}/V_{CS0})_A / (\Delta V_{CST}/V_{CS0})_{WA}\right]\}, \quad (3)$$

Radiation changes in strength of Portland cement stone, within and without additives, were found using the formula recommended in [15, 29], which connects the relative residual strength of Portland cement stone after both radiation and heating, with change of volume:

$$R_{CSR}/R_{CS0} = 1/(A + B\Delta V_{CSR}/V_{CS0}), \quad (4)$$

where R_{CSR}/R_{SC0} – relative weakening of Portland cement stone caused by radiation impact, as ratio of strength after radiation R_{CSR} and strength before radiation R_{CS0}, fractional unit;

A and B – parameters, assumed for aged Portland cement stone (8 months and more, considering time it takes to erect nuclear reactors and NPP buildings) under [15, 23]: $A = 1$; $B = -0.23\%^{-1}$.

Use of ultrasound passing time to measure changes in strength proved impractical, because according to data analysis of [14, 15], no reliable correlation exists between change of ultrasound penetration time and change of compression strength after irradiation in the reactor. Besides, according to data analysis offered in [13–18], correlation observed between changes in size and velocity of ultrasound is even less dependable, while their averaged ratios differ greatly for exposure to radiation and heat.

Based on data on radiation changes in Portland cement stone with various modern superplasticizers, we calculated relative radiation-induced change of volume, relative cracking ratio, relative loss of strength and deformation modulus of concretes. We used analytical methods to measure radiation changes in concretes by data on radiation changes of their components, as described in [15, 26–28].

To estimate material influences on radiation changes of concrete aggregate, this research calculated and compared net contributions of radiation changes in Portland cement stone. Such calculations assumed that the aggregate is made of specific material whose volume and properties are not changed by exposure to radiation.

Our calculations treated a typical concrete with averaged production mix with relative aggregate content by volume (sand + crushed rock) $V_{s+cr} = 0.70$.

The approximation was that the true W/C ratio (considering the water need of the aggregate) of Portland cement in the concrete is the same as in the researched mixes of Portland cement stones.

Using the methodology described in [15, 26–28], change of volume, relative crack ratio, changes in compression strength and elasticity modulus of the concrete, due to radiation shrinkage and weakening of Portland cement stone (with and without additives), for aggregates not changed by radiation, is found using these formulas:

$$\frac{\Delta V_{CR}}{V_{C0}} = 100\left\{\left[1-(C_{comp}^{s+cr})^{1/3}\right]\left(1+\frac{\Delta V_{CSR}}{V_{CS0}}\frac{1}{100}\right)^{1/3}\right\}^3 - 100 \approx \left[1-(C_{comp}^{s+cr})^{1/3}\right]\frac{\Delta V_{CSR}}{V_{CS0}} \quad (5)$$

$$V_{CRRC} = \Delta V_{CR} / V_{C0} - (1 - V_{s+cr})\Delta V_{CSRP} / V_{CS0}, \quad (6)$$

$$R_{CR} / R_{C0} = (R_{CSR} / R_{CS0}) / [1 + (A_C V_{CRRC})^2] \quad (7)$$

$$E_{CR} / E_{C0} = 0{,}85(R_{CR} / R_{C0})^{1.8} + 0.15, \quad (8)$$

where $\Delta V_{CR} / V_{C0}$ – radiation-induced relative change of volume of concrete, as ratio of absolute change of volume of concrete ΔV_{CR} to volume prior to radiation exposure V_{C0}, % ;

V_{CRRC} – radiation-induced relative crack ratio in concrete due to radiation impact, as the ratio of cracks caused by radiation impact, to the material's volume before radiation impact, %;

R_{CR} / R_{C0} – radiation-induced relative weakening of concrete due to radiation impact, as the ratio of strength after radiation R_{CR} to strength before radiation R_{C0}, fractional unit;

E_{CR} / E_{C0} – radiation-induced relative change in deformation modulus of concrete due to radiation impact, as the ratio of deformation modulus after radiation E_{CR}, to initial deformation modulus E_{C0}, fractional unit;

C_{comp}^{s+cr} – degree of aggregate consolidation (sand and crushed rock) in concrete, by the formula:

$$C_{comp}^{s+cr} = V_{s+cr} / V_{comp}^{s+cr} \quad (9)$$

where V_{s+cr} – relative content of aggregate (sand and crushed rock) by volume in concrete, assumed herein to be 0.70, as mentioned above;

V_{comp}^{s+cr} – relative volume that the aggregate such as sand and crushed rock can have in packed state (without layers of Portland cement), measured by bulk density of vibration-packed aggregate.

From [15], our calculations assumed $V_{comp}^{s+cr} = 0.86$ as the approximated mean value.

As discussed in [16–18], the mixes of Portland cement stone, additives of superplasticizers used, respective batch ratios and water-to-cement ratios (W/C) are listed in Tables 1 and 2 below.

Thermal changes in samples of such mixes, after they were heated to different temperatures for 5 hours, are quoted from [16–18] and listed in Tables 3 and 4.

Table 1.Information on composition of Portland cement stone, as discussed in [16–18]

No.	Additive marking	Superplasticizer group by [1]*	Manufacturer	Batch ratio recommended, %	Batch ratio used, %	W/C ratio, rel. units
0	No additive	–	–	–	–	0.26
1	Muraplast FK 48	II (NF)	MC-Bauchemie	0.2–2.0	0.6	0.24
2	Muraplast FK 63	IV (P)	MC-Bauchemie	0.2–2.5	0.6	0.25
3	Reamin MF-100	I (MF)	Kuban Polymer	0.3–1.0	0.4	0.24
4	Weiss SM	IV (P)	Weiss Reagens	No data	0.4	0.24
5	Poliplast SP-1 (S-3)	II (NF)	OOO Poliplast-Uralsib	0.4–0.8	0.4	0.24

*MF – based on sulfonated melamin-formaldehyde polycondensates; NF – based on sulfonated naphthalene-formaldehyde polycondensates; P – polycarboxylate-based.

Table 2. Information on composition of Portland cement stone, as discussed in [18]

No.	Additive marking	Superplasticizer group by [1]	Lateral chain length, and steric effect, by [18]	Batch ratio recommended, %	Batch ratio used, %	W/C ratio, rel. units
0	No additive	–	–	–	–	0.26
1.1	Melflux 1641f	IV (P)	Short lateral chains, minor steric effect	0.05–0.50	0.05	0.25
1.2					0.50	0.20
2.1	Melflux 4930f	IV (P)	Very long lateral chains, very high steric effect	0.05–1.00	0.05	0.25
2.2					1.00	0.20
3.1	Melflux 5581f	IV (P)	Long lateral chains, high steric effect	0.03–0.50	0.03	0.26
3.2					0.50	0.20
4.1	Melflux 6681f	IV (P)	Medium lateral chains, medium steric effect	0.05–1.00	0.05	0.25
4.2					1.00	0.19

Table 3. Thermal changes in Portland cement stone, according to [16–18], after brief heating for 5 hours to temperatures 150 °C to 900 °C

Mix No. by Table 1	Average relative change in size $\Delta h / h_0$, weight $\Delta m / m_0$ and ultrasound velocity $\Delta v / v_0$ in samples after 5 hours of heating to different temperatures											
	150 °C			350 °C			600 °C			900 °C		
	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %
Portland cement stone, without additives												
0	0.02	–3.28	0.13	–1.06	–6.32	–3.23	–1.97	–6.59	–5.61	–2.43	–11.95	–15.00
Portland cement stone, with different groups of superplasticizers												
1	–0.29	–4.31	–0.98	–1.13	–7.39	–5.26	–2.19	–8.17	–5.41	–2.57	–13.39	–13.00
2	–0.27	–4.85	–1.98	–1.00	–8.12	–5.79	–2.02	–9.06	–4.62	–2.53	–14.09	–15.50
3	–0.32	–4.47	–2.60	–1.06	–7.65	–6.40	–2.10	–8.70	–6.65	–2.66	–13.90	–9.71
4	–0.30	–4.91	–2.10	–0.96	–7.75	–2.32	–1.95	–8.82	–4.80	–2.41	–14.09	–13.20
5	–0.30	–4.38	–0.16	–1.06	–7.13	–1.53	–2.09	–8.25	–6.04	–2.59	–13.47	–13.30

Table 4. Information on thermal changes in Portland cement stone, according to [18], after brief heating for 5 hours to temperatures 150 °C to 900 °C

Mix No. by Table 2	Average relative change in size $\Delta h/h_0$, weight $\Delta m/m_0$ and ultrasound velocity $\Delta v/v_0$ in samples after 5 hours of heating to different temperatures											
	150 °C			350 °C			600 °C			900 °C		
	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %	$\frac{\Delta h}{h_0}$, %	$\frac{\Delta m}{m_0}$, %	$\frac{\Delta v}{v_0}$, %
Portland cement stone without additives												
0	–0.17	–1.65	–1.35	–0.76	–4.89	–8.38	–1.58	–9.28	–20.33	–2.18	–11.11	–22.37
Portland cement stone, with various superplasticizers based on polycarboxylate ethers												
1.1	–0.14	–1.81	–2.16	–0.75	–5.48	–3.63	–1.36	–9.85	–9.78	–1.83	–11.40	–15.25
1.2	–0.11	–1.43	–2.31	–0.54	–4.22	–4.94	–1.10	–6.89	–6.78	–1.31	–9.01	–15.62
2.1	–0.18	–1.87	–1.94	–0.76	–5.54	–7.18	–1.63	–10.04	–14.66	–2.38	–11.69	–18.81
2.2	–0.14	–1.00	–2.31	–0.54	–3.60	–7.49	–1.15	–6.22	–9.76	–1.45	–8.66	–15.58
3.1	–0.15	–1.73	–2.63	–0.81	–5.58	–6.76	–1.76	–10.12	–16.97	–2.67	–11.84	–21.34
3.2	–0.14	–1.95	–1.34	–0.63	–5.68	–4.73	–1.33	–9.24	–8.30	–1.70	–11.41	–15.80
4.1	–0.14	–1.59	–1.79	–0.80	–5.39	–4.11	–1.68	–9.97	–13.20	–2.47	–11.72	–17.77
4.2	–0.11	–1.30	–1.28	–0.50	–4.22	–3.33	–1.20	–7.15	–5.27	–1.55	–9.55	–17.16

Results of Research and Discussion

Examination of data offered in [12, and 14, 15] reveals that coefficient K_{RT} of the connection between effects of additives on thermal and radiation-induced changes in Portland cement stone with and without superplasticizers, were 2.5 to 0.5, and depended on the temperature in relation to which the connection is established, and on neutron fluency (Fig. 1). Effects of the superplasticizer type (S-3 or S-4) were not observed.

Analysis demonstrates that the dependency can be described with this expression:

$$K_{RT} = a_r(k_F F_{IBR})^2 + b_r(k_F F_{IBR}) + c_r\,, \tag{10}$$

where F_{IBR} – fluency of fast neutrons in IBR-2 reactor, neutron/m^2;

k_F =1×10^{-24} m^2/neutron – normalizing factor;

a_r, b_r and c_r – coefficients dependent on the heating temperature compared to effect of the additives on radiation-induced changes, whereof the received values are:

- a_r = -0.383, b_r = -0.003, c_r = 1.25 – taking as basis the results after 5 hours of heating at 150 °C;
- a_r = -0.522, b_r = -0131, c_r = 1.922 – taking as basis the results after 5 hours of heating at 350 °C;
- a_r = -0.750, b_r = -0.094, c_r = 2.534 – taking as basis the results after 5 hours of heating at 600 °C;
- a_r = -0.282, b_r = 0.370, c_r = 1.674 – taking as basis the results after 5 hours of heating at 900 °C.

Calculations with formula (10) considered the following circumstances:

1. According to [15, 29], radiation-induced changes in Portland cement stone are mainly caused by neutrons with energy charges above 0.8 MeV, so radiation changes in Portland cement stone should be bound to the fluency value of such neutrons.
2. According to [15], there is apparent difference between Portland cement stone exposed to radiation in an impulse reactor such as IBR-2 and the results of other reactors. The results

presented in [16] prove that by efficient influence on Portland cement stone, fluency of fast neutrons in IBR-2 impulse reactors is equivalent to that of neutrons with charges greater than 0.8 MeV in other reactors, the ratio being 0.3 approximately. This may be explained by the impulse operation principle of reactor IBR-2 as different for the constant mode in other reactor; another possible explanation is the specific nature of the neutron spectrum in the channel of reactor IBR-2 where exposure is done, as compared to the spectra in the channels of other reactors.

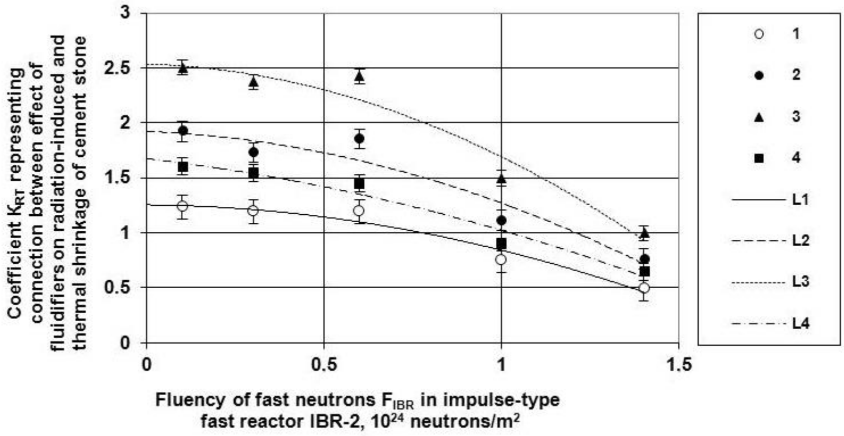

Fig. 1. Dependence of coefficient K_{RT} representing the effect of superplasticizers on radiation-induced and thermal change of volume of Portland cement stone, on fluency of fast neutrons in impulse-type fast reactor IBR-2, based on comparison of Portland cement stone exposed to radiation in reactor with same briefly (5 hours) heated at 150, 350, 600 and 900 °C

We used test results with Portland cement stone of various mixes with superplasticizers S-3 and S-4 and also ones without additives treated in impulse reactor IBR-2 at 30–40 °C, as described in [14, 15], plus test results of the same mixes briefly (5 hours) heated at 150, 350, 600 and 900 °C, as presented in [12].

1 – on the data at 150 °C; 2 – on the data at 350 °C; 3 – on the data at 600 °C; 4 – on the data at 900 °C;

L1 – approximation line by data after 150 °C; L2 – approximation line by data after 350 °C;

L3 – approximation line by data after 600 °C; L4 – approximation line by data after 900 °C.

Therefore, respective to fluency of neutrons with charge above 0.8 MeV in typical reactors coefficient K_{RT} was found with the adjusted formula:

$$K_{RT} = a_r (k_F F_{FN} / 0.3)^2 + b_r (k_F F_{FN} / 0.3) + c_r , \quad (11)$$

where F_{FN} – fluency of fast neutrons with charge above 0.8 MeV, neutron/m^2.

Because we assumed the results presented in [14,15] for impulse reactor IBR-2 as basis to find coefficients K_{PT}, the radiation-induced changes in Portland cement stone with different modern superplasticizers had to be found for the following fluency of neutrons, the effects of which were covered in [14, 15], but converted to fluency of neutrons with charge above 0.8 MeV in other reactors: 0.1 × 10^{24} × 0.3 = 0.03 × 10^{24} neutron/m^2; 0.3 × 10^{24} × 0.3 = 0.09 × 10^{24} neutron/m^2; 0.6×10^{24} × 0.3 = 0.18 × 10^{24} neutron/m^2; 1 × 10^{24} × 0.3 = 0.3×10^{24} neutron/m^2; 1.4×10^{24} × 0.3 = 0.42 × 10^{24} neutron/m^2.

Calculated radiation changes in Portland cement stones with different superplasticizers taking as basis the results of heating for 5 hours at 350 °C are presented in Tables 5 and 6, and in Figures 2–5.

Tables 5 and 6, and Figures 2–5 make it obvious that in the fluency range of fast neutrons with charges above 0.8 MeV between 0.03×10^{24} and 0.42×10^{24} neutron/m^2, radiation-induced changes in Portland cement stones tend to increase along with growing fluency of fast neutrons, specifically:

– -relative decrease of volume from 0.016 %–0.052 % to 0.867 %–1.203 %;

- relative residual strength from 0.99–0.996 to 0.783–0.834, which corresponds to relative decrease of strength by the value range of 0.4–1 % to 21.7–16.6 %.

Table 5. Calculated radiation-induced changes in Portland cement stones with and without different superplasticizer additives, examined in [16–18]

Mix No. in Table 1.	Relative changes in volume $\Delta V_{CSR}/V_{CS0}$ and relative residual strength R_{CSR}/R_{CS0} of Portland cement stone radiation-treated with various fluency of fast neutrons with charge above 0.8 MEV									
	F_{FN} = 0.03×10²⁴ neutron/m²		F_{FN} = 0.09×10²⁴ neutron/m²		F_{FN} = 0.18×10²⁴ neutron/m²		F_{FN} = 0.3×10²⁴ neutron/m²		F_{FN} = 0.42×10²⁴ neutron/m²	
	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units
0	-0.046	0.990	-0.175	0.961	-0.409	0.914	-0.762	0.851	-1.149	0.791
1	-0.052	0.988	-0.197	0.957	-0.453	0.906	-0.826	0.840	-1.203	0.783
2	-0.041	0.991	-0.157	0.965	-0.370	0.922	-0.707	0.860	-1.102	0.798
3	-0.046	0.990	-0.175	0.961	-0.409	0.914	-0.762	0.851	-1.149	0.791
4	-0.038	0.991	-0.145	0.968	-0.345	0.927	-0.671	0.866	-1.071	0.802
5	-0.046	0.990	-0.175	0.961	-0.409	0.914	-0.762	0.851	-1.149	0.791

Table 6. Calculated radiation-induced changes in Portland cement stones with and without various superplasticizers based on polycarboxylated ethers. examined in [18]

Mix No. in Table 2.	Relative changes in volume $\Delta V_{CSR}/V_{CS0}$ and relative residual strength R_{CSR}/R_{CS0} of Portland cement stone radiation-treated with various fluency of fast neutrons with charge above 0.8 MeV									
	F_{FN} = 0.03×10²⁴ neutron/m²		F_{FN} = 0.09×10²⁴ neutron/m²		F_{FN} = 0.18×10²⁴ neutron/m²		F_{FN} = 0.3×10²⁴ neutron/m²		F_{FN} = 0.42×10²⁴ neutron/m²	
	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units	$\frac{\Delta V_{CSR}}{V_{CS0}}$, %	$\frac{R_{CSR}}{R_{CS0}}$, rel. units
0	-0.046	0.990	-0.175	0.961	-0.409	0.914	-0.762	0.851	-1.149	0.791
1.1	-0.045	0.990	-0.171	0.962	-0.400	0.916	-0.749	0.853	-1.138	0.793
1.2	-0.021	0.995	-0.082	0.981	-0.212	0.953	-0.482	0.900	-0.911	0.827
2.1	-0.046	0.990	-0.175	0.961	-0.409	0.914	-0.762	0.851	-1.149	0.791
2.2	-0.021	0.995	-0.082	0.981	-0.212	0.953	-0.482	0.900	-0.911	0.827
3.1	-0.052	0.988	-0.197	0.957	-0.453	0.906	-0.826	0.840	-1.203	0.783
3.2	-0.031	0.993	-0.120	0.973	-0.293	0.937	-0.597	0.879	-1.008	0.812
4.1	-0.051	0.989	-0.192	0.958	-0.444	0.907	-0.813	0.842	-1.192	0.785
4.2	-0.016	0.996	-0.065	0.985	-0.177	0.961	-0.431	0.910	-0.867	0.834

Where superplasticizers are used, relative radiation change of volume of Portland cement stone with superplasticizer, compared to changes in that without additives typically fall 1.0–2.8 times, though strength is lost to a lesser degree: mainly by up to 6 %.

At water-cement ratio W/C = 0.25 – 0.26 radiation-induced changes in Portland cement stones with superplasticizers of group I (MF) and group II (NF) tend to be somewhat above the radiation changes in Portland cement stone without additives, but in the case of superplasticizers of group IV (P) are either commensurable or weaker than the changes in Portland cement stone without additives.

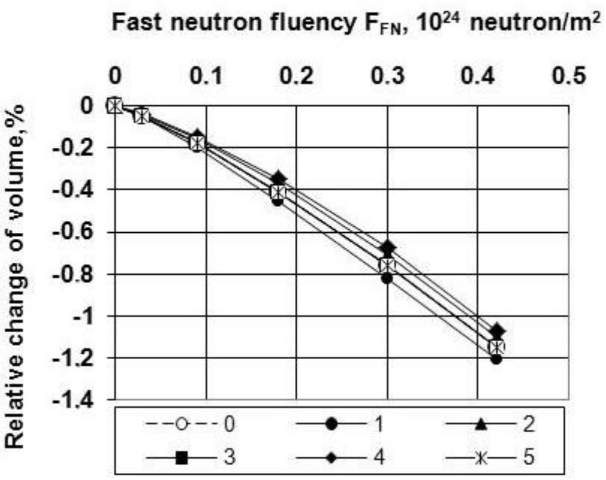

Figure 2. Dependence of calculated radiation change in volume of Portland cement stones with and without various superplasticizers, on fluency of fast neutrons with charge above 0.8 MeV

0, 1, 2, 3, 4, 5 – numbers of Portland cement stone mix in Table 1.

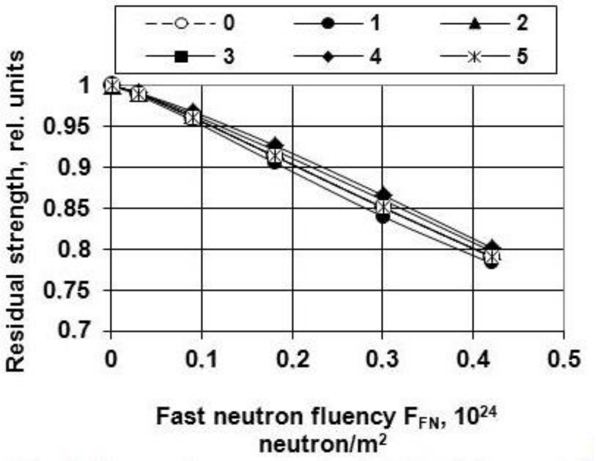

Figure 3. Dependence of calculated relative residual strength to compression in Portland cement stones with and without various superplasticizers, on fluency of fast neutrons with charge above 0.8 MeV

0, 1, 2, 3, 4, 5 – numbers of Portland cement stone mix in Table 1.

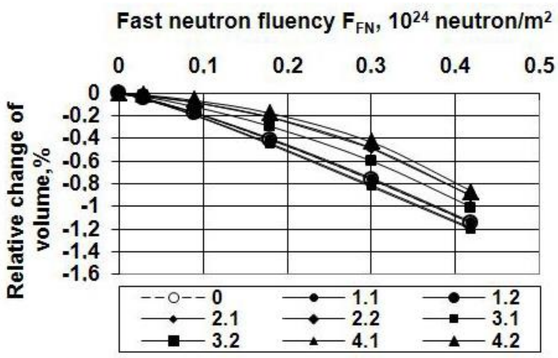

Figure 4. Dependence of calculated radiation change in volume of Portland cement stones with and without various superplasticizers based on polycarboxylated ethers, on fluency of fast neutrons with charge above 0.8 MeV

0, 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2 – numbers of Portland cement stone mix in Table 2.

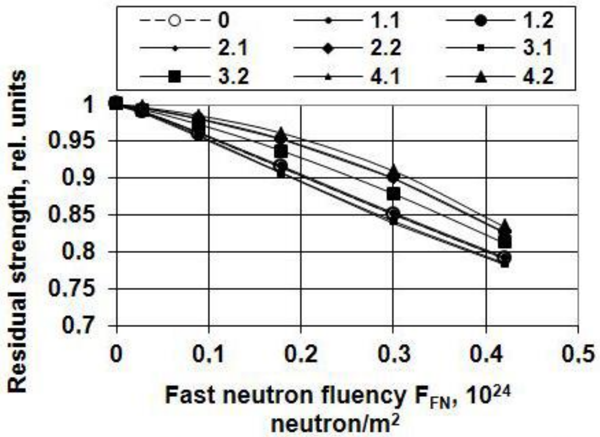

Figure 5. Dependence of calculated relative residual strength to compression in Portland cement stones with and without various superplasticizers based on polycarboxylated ethers, on fluency of fast neutrons with charge above 0.8 MeV

0, 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2 – numbers of Portland cement stone mix in Table 2.

The reducing effect on radiation change of volume of Portland cement stone is increased by superplasticizers, if higher content of superplasticizer in the mix lowers the water-to-cement ratio of manufactured Portland cement stone in the range between 0.25–0.26 and 0.19–0.20 (Fig. 6). Such W/C ratio dependency was also observed with the heating test results (Fig. 7).

From composition of Portland cement stone investigated at low W/C = 0.19-0.20 the greatest drop in radiation change was observed with superplasticizers Melflux 1641f, Melflux 4930f, and Melflux 6681f.

Thus we observed immaterial influence of superplasticizers on radiation-induced but especially on thermal changes in volume and strength of Portland cement stone with a constant W/C ratio, but we saw a decrease of radiation and thermal changes in cement stone with lower W/C ratios, and the decrease was in inverse proportion to the W/C ratio. This means that the effect of superplasticizers on radiation and thermal changes in Portland cement stone is mainly explained by their influence on the material’s general porosity. We know from [1–3, 6, 10] that although superplasticizers added at a constant W/C ratio does decrease capillary porosity, the gel porosity will increase, and so general porosity remains practically unchanged, therefore the effect of superplasticizers is immaterial. With the W/C ratio lower, both the capillary and the gel porosity will go down [32], so the effect of the superplasticizer will grow.

The factor of porosity can be explained by the fact that after Portland cement stone is heated to less than 550 °C and treated with neutron radiation, change of volume (shrinkage) is caused by water oozing from the material’s pores.The lower the material’s porosity, the less will be the meaning stretching forces and material deformations around pores, which were water-saturated prior to heating or radiation. Since such forces and deformations are weakened by dehydration, this causes reduction of volumes (shrinkages) of Portland cement stone. The lower porosity, the less will the material shrink with dehydration and the loss of strength will become lower. Certainly, loss of chemically bound water (decomposition of portlandite and other crystalline hydrates around 550–600 °C) and decomposition of tiff (at 800–900 °C) represents a different shrinkage mechanism of Portland cement, but seen the results of heating described in [17–19] (Table 3, 4) at 600 °C and 900 °C, the effect patterns of the W/C ratio – and therefore of porosity – will be the same as when water is lost from the pores after 150 °C and 350 °C

The same effects of the W/C ratio and porosity with a similar mechanism for heating up to 550 °C were observed with shrinkage of cement stone and concretes as they hardened [33].

Meanwhile, quoting from the thermal tests described in [16–18] (Table 3 and 4), loss of cement stone weight after heating is not unambiguously caused by shrinkage and loss of volume. As the superplasticizer is added with a constant W/C ratio, the degree of weight loss due to dehydration increases, but loss of volume hardly progresses. As superplasticizers are added and the W/C ratio gets lower, shrinkage will be the less, the less is the extent of weight loss. Therefore, adding the superplasticizers changes the ratio of weight loss to shrinkage compared to that in cement stone without additives in the mix.

Notably, research failed to observe any significant unambiguous effect on thermal and radiation changes in the cement stone, from lateral chain length or by the extent of steric effect of polycarboxylate superplasticizer discussed in [18], or the amount of portlandite and tiff formed in cement stone, as shown in [18].

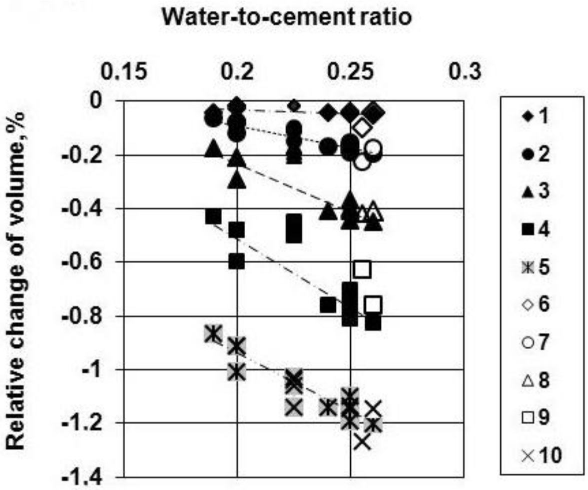

Figure 6. Water-to-cement ratio dependence of radiation-change of volume of Portland cement stones with and without various superplasticizers additives – after radiation treatment with different fluency of fast neutrons charged above 0.8 MeV

1–5 – with additives; 6–10 – without additives; 1 and 6 – fluency 0.03×10^{24} neutron/m^2; 2 and 7 – fluency 0.09×10^{24} neutron/m^2; 3 and 8 – fluency 0.18×10^{24} neutron/m^2; 4 and 9 – fluency 0.3×10^{24} neutron/m^2; 5 and 10 – fluency 0.42×10^{24} neutron/m^2.

For W/C ratio = 0.19, 0.20, 0.24, 0.25 and 0.26, we quote calculated radiation-induced changes in volume of Portland cement stones with and without various modern superplasticizers, examined in [16–18] after 5 hours of heating.

For W/C ratio 0.225 and 0.255, we quote radiation-induced (less thermal-induce) changes in volume of Portland cement stones with and without superplasticizers S-3 and S-4, examined in [14, 15] after treatment in reactor IBR-2.

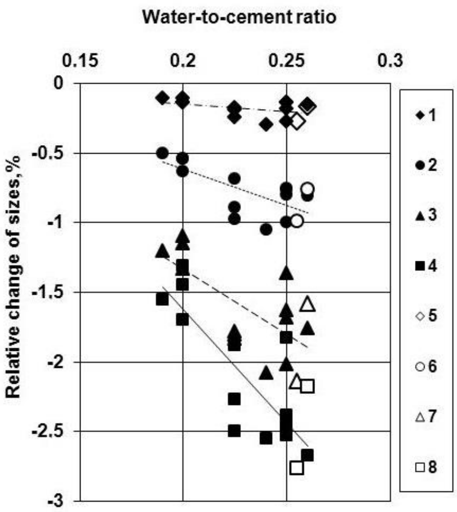

Figure 7. Water-to-cement ratio dependence of radiation-change of volume of Portland cement stones with and without various superplasticizers additives – after brief (5 hours) heat treatment at various temperatures

1–4 – with additives; 5–8 – without additives;

1 and 5 – after 150^{o} C; 2 and 6 – after 350 °C;

3 and 7 – after 600^{o} C; 4 and 8 – after 900 °C.

For W/C ratio = 0.19, 0.20, 0.24, 0.25 and 0.26 we quote data with various modern superplasticizers as presented in [16–18].

For W/C ratio= 0.225 and 0.255, we quote data with and without superplasticizers S-3 and S-4, as presented in [12].

Results of calculations with use of formulas (5) – (8) of radiation changes in concretes with various superplasticizers due to radiation changes in volume and strength of Portland cement stone are represented in Table 7–10. Considered, that the true W/C ratio Portland cement stone in concrete, taking into account the water demand of aggregates is approximately the same as the samples of Portland cement stones. Although in the manufacture of concrete W/C ratio by number is typically greater than in the manufacture of cement stones. In this connection in calculations of radiation changes in concretes used the data of tables 5 and 6.

Table 7. Calculated radiation-induced changes in volume of concrete and relative micro-cracking ratio due to radiation changes in Portland cement stone, listed in Table 5

Mix No. in Table 1 in concrete	Relative volume changes $\Delta V_{CR}/V_{C0}$ and relative cracking ratio V_{CRRC} for concretes with various Portland cement stone radiation-treated with various fluency of fast neutrons with charge above 0.8 MeV									
	F_{FN} = 0.03×10^24 neutron/m^2		F_{FN} = 0.09×10^24 neutron/m^2		F_{FN} = 0.18×10^24 neutron/m^2		F_{FN} = 0.3×10^24 neutron/m^2		F_{FN} = 0.42×10^24 neutron/m^2	
	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %
0	-0.003	0.011	-0.012	0.041	-0.027	0.095	-0.051	0.177	-0.076	0.268
1	-0.003	0.012	-0.013	0.046	-0.030	0.106	-0.055	0.192	-0.080	0.280
2	-0.003	0.010	-0.010	0.037	-0.025	0.086	-0.047	0.165	-0.073	0.257
3	-0.003	0.011	-0.012	0.041	-0.027	0.095	-0.051	0.177	-0.076	0.268
4	-0.002	0.009	-0.010	0.034	-0.023	0.080	-0.044	0.156	-0.071	0.249
5	-0.003	0.011	-0.012	0.041	-0.027	0.095	-0.051	0.177	-0.076	0.268

Table 8. Calculated radiation-induced changes in strength and deformation modulus due to radiation changes in Portland cement stone, listed in Table 5

Mix No. in Table 1 in concrete	Relative residual strength R_{CR}/R_{C0} and relative residual deformation modulus E_{CR}/E_{C0} of concretes with various Portland cement stone radiation-treated with various fluency of fast neutrons with charge above 0.8 MeV									
	F_{FN} = 0.03×10^24 neutron/m^2		F_{FN} = 0.09×10^24 neutron/m^2		F_{FN} = 0.18×10^24 neutron/m^2		F_{FN} = 0.3×10^24 neutron/m^2		F_{FN} = 0.42×10^24 neutron/m^2	
	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units
0	0.990	0.984	0.961	0.941	0.913	0.872	0.848	0.782	0.785	0.700
1	0.988	0.982	0.957	0.935	0.905	0.860	0.837	0.767	0.777	0.690
2	0.991	0.986	0.965	0.947	0.921	0.883	0.858	0.795	0.792	0.709
3	0.990	0.984	0.961	0.941	0.913	0.872	0.848	0.782	0.785	0.700
4	0.991	0.987	0.968	0.951	0.926	0.890	0.864	0.804	0.797	0.715
5	0.990	0.984	0.961	0.941	0.913	0.872	0.848	0.782	0.785	0.700

Table 9. Calculated radiation-induced changes in volume of concrete and relative micro-cracking ratio due to radiation changes in Portland cement stone, listed in Table 6

Mix No. in Table 1 in concrete	Relative changes in volume $\Delta V_{CR}/V_{C0}$ and relative cracking ratio V_{CRRC} for concretes with various Portland cement stone, radiation-treated with various fluency of fast neutrons with charge above 0.8 MeV									
	F_{FN} = 0.03×10²⁴ neutron/m²		F_{FN} = 0.09×10²⁴ neutron/m²		F_{FN} = 0.18×10²⁴ neutron/m²		F_{FN} = 0.3×10²⁴ neutron/m²		F_{FN} = 0.42×10²⁴ neutron/m²	
	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %	$\frac{\Delta V_{CR}}{V_{C0}}$, %	V_{CRRC}, %
0	-0.003	0.011	-0.012	0.041	-0.027	0.095	-0.051	0.177	-0.076	0.268
1.1	-0.003	0.010	-0.011	0.040	-0.026	0.093	-0.050	0.175	-0.075	0.265
1.2	-0.001	0.005	-0.005	0.019	-0.014	0.049	-0.032	0.112	-0.060	0.212
2.1	-0.003	0.011	-0.012	0.041	-0.027	0.095	-0.051	0.177	-0.076	0.268
2.2	-0.001	0.005	-0.005	0.019	-0.014	0.049	-0.032	0.112	-0.060	0.212
3.1	-0.003	0.012	-0.013	0.046	-0.030	0.106	-0.055	0.192	-0.080	0.280
3.2	-0.002	0.007	-0.008	0.028	-0.019	0.068	-0.040	0.139	-0.067	0.235
4.1	-0.003	0.012	-0.013	0.045	-0.029	0.103	-0.054	0.189	-0.079	0.278
4.2	-0.001	0.004	-0.004	0.015	-0.012	0.041	-0.029	0.100	-0.058	0.202

Table 10.Calculated radiation-induced changes in strength and deformation modulus due to radiation changes in Portland cement stone, listed in Table 6

Mix No. in Table 2 in concrete	Relative residual strength R_{CR}/R_{C0} and relative residual deformation modulus E_{CR}/E_{C0} of concretes with various Portland cement stone, radiation-treated with various fluency of fast neutrons with charge above 0.8 MeV									
	F_{FN} = 0.03×10²⁴ neutron/m²		F_{FN} = 0.09×10²⁴ neutron/m²		F_{FN} = 0.18×10²⁴ neutron/m²		F_{FN} = 0.3×10²⁴ neutron/m²		F_{FN} = 0.42×10²⁴ neutron/m²	
	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units	$\frac{R_{CR}}{R_{C0}}$, rel. units	$\frac{E_{CR}}{E_{C0}}$, rel. units
0	0.990	0.984	0.961	0.941	0.913	0.872	0.848	0.782	0.785	0.700
1.1	0.990	0.984	0.962	0.943	0.915	0.874	0.850	0.785	0.787	0.702
1.2	0.995	0.993	0.981	0.972	0.953	0.930	0.899	0.852	0.823	0.749
2.1	0.990	0.984	0.961	0.941	0.913	0.872	0.848	0.782	0.785	0.700
2.2	0.995	0.993	0.981	0.972	0.953	0.930	0.899	0.852	0.823	0.749
3.1	0.988	0.982	0.957	0.935	0.905	0.860	0.837	0.767	0.777	0.690
3.2	0.993	0.989	0.973	0.959	0.937	0.905	0.878	0.822	0.807	0.728
4.1	0.989	0.982	0.957	0.936	0.906	0.862	0.839	0.770	0.779	0.692
4.2	0.996	0.994	0.985	0.977	0.961	0.941	0.909	0.866	0.830	0.758

Tables 7–10 show that in the fast neutron fluency range between 0.03×10^{24} and 0.42×10^{24} neutron/m², radiation-induced changes in concretes due to radiation-caused changes in volume and strength of Portland cement stone will grow along with the fluency of fast neutrons and will be:

- relative decrease in volume between 0.001 %–0.003 % and 0.058–0.076 %;
- relative micro-crack ratio between 0.004 %–0.012 % and 0.202–0.280 %;
- relative residual strength between 0.984–0.996 and 0.777–0.830.
- relative residual modulus of deformation between 0.984–0.994 and 0.690–0.758.

Change of volume of concretes is about 15 times less than that for Portland cement stones; micro-crack ratio is about 0.25 of change in volume of Portland cement stone by modulus; its residual strength is not much lower than that of Portland cement stones, and residual deformation modulus is a bit lower than the residual strength, by up to 7 %. Effect of superplasticizer type, quantity and W/C ratio are the same as for Portland cement stone.

Depending on radiation-induced change of aggregate, not considered for our calculations due to the vast range of their type-specific values, real-life radiation-induced changes of concretes will differ from the data that only considers changes of cement stone. However, absolute differences in radiation changes due to the effect of superplasticizers will be the same as if aggregate changes are considered; therefore, the conclusion about the superplasticizer effect on radiation-induced changes in concretes is true for any aggregate.

Conclusion

1. To estimate the effect of modern superplasticizers on radiation-induced changes in Portland cement stone, based on experimental data on the effect of modern superplasticizers on thermal changes in Portland cement stone available in published literature, we propose the use of coefficient K_{RT} that describes the ratio of superplasticizer additive effect on radiation and thermal change of volumes of Portland cement stone.

2. It has been established that the value of coefficient K_{RT} describing the relation between the effect of additives on thermal change of volume (after 5 hours of heating) and radiation change of volume (after exposure to neutrons) of Portland cement stone with and without superplasticizers, varies between 2.5 and 06, and depends on the temperature that underlies the relation, and on fluency of fast neutrons. Now we have analytical expressions to describe the dependence of coefficients K_{RT} on fast neutron fluency under various heating temperatures during thermal tests. Relation between the superplasticizer type and K_{RT} has not been found.

3. Based on received values of coefficient K_{RT} it has been established that superplasticizers used tend to decrease relative radiation shrinkage of Portland cement stone compared to stone without additives by some 1.0–2.8 times, while weakening is much lower, mainly up to 6 %. At water-cement ratio W/C = 0.25 – 0.26 radiation-induced changes in Portland cement stones with superplasticizers of group I (MF) and group II (NF) tend to be somewhat above the radiation changes in Portland cement stone without additives, but in the case of superplasticizers of group IV (P) are either commensurable or weaker than the changes in Portland cement stone without additives.

4. The reducing effect on radiation change of volume of Portland cement stone is increased by superplasticizers, if higher content of superplasticizer in the mix lowers the water-to-cement ratio of manufactured Portland cement stone in the range between 0.25–0.26 and 0.19–0.20. Such W/C ratio dependency was also observed with the heating test results.

5. From compositions of Portland cement stones investigated at low W/C = 0.19–0.20 the greatest drop in radiation change was observed with superplasticizers Melflux 1641f, Melflux 4930f, and Melflux 6681f. Researchers have not observed any significant and unambiguous influence on thermal and radiation changes of cement stone by such factors as lateral link length, steric effect of polycarboxylate superplasticizers, and the amount of portlandite and tiff formed in cement stone.

6. Based on available tried and trusted analytical methods of measuring radiation changes in concrete using data about changes in their components (aggregate and Portland cement stone), we have calculated radiation-induced changes in concretes with different added superplasticizers due to radiation and thermal changes in the volume and strength of Portland cement stone.

7. It has been established that radiation change of volume of concretes is approximately 15 times less than change of volume of Portland cement stones, the micro-cracking ratio is about 0.23 of change of volume of Portland cement stone by modulus, and the residual strength is just a bit lower that that of Portland cement stones, while the residual deformation modulus is by up to 8 % less than the residual strength. Relative effect of the superplasticizer type, quantity and W/C ratio is the same as with Portland cement stone.

8. The results of calculations suggest that the use of modern superplasticizers, particularly ones that are polycarboxylate-based, tend to reduce radiation-induced changes (especially change of volume)

of Portland cement stone and concrete. The effect of radiation change reduction is in inverse proportion with the water-to-cement ratio.

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