CEMENT MORTAR CREEP UNDER EXPOSURE TO GAMMA-RAY IRRADIATION

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Abstract

The effect of gamma-ray irradiation on the cement mortar creep is investigated in this study. The creep investigation is accompanied by the shrinkage measurements and the compressive strength test. The measured creep and shrinkage strains are compared with the values calculated according to the existing models which showed that the creep and the shrinkage of both the control and the irradiated samples lie within the interval predicted by the models. However, creep of the irradiated samples is slightly higher. The gamma-ray irradiation also leads to the significant decrease in compressive strength (20% on average). The physics behind this process is still unclear and demands supplementary porosity and mineral composition investigation.

Keywords: *Cement mortar, Compressive strength, Creep, Gamma-ray, Shrinkage*

Introduction

The creep of concrete is one of the basic and fundamental concrete properties. Creep not only redistributes stresses in the structure and consequently alters the damage pattern [1] and delays the damage onset [2] but it may also cause a significant displacement and deviations from the designed position of the structure [3]. These statements are extremely important for the pressurized water reactors since the low creep level may restrict the stress relaxation and may result in damage of the biological shield, while a higher creep level may cause the biological shield movement and thus may lead to deviation in the pressure vessel position, which may damage the cooling system or complicate the normal nuclear power plant operation in any other way.

The creep depends, besides others, on the amount and the state of water in the cement paste. Since the gamma-ray causes the water radiolysis with the subsequent free radicals, hydrogen peroxide and gas formation [4-6], it may alter the creep performance of the cement paste. The products of radiation-induced radiolysis may react with the products of cement hydration and may result in carbonation which may vary cement paste properties [7-9]. Also, the gamma-ray irradiation provokes the gamma-heating, which may speed up the water evaporation and thus may affect the cement paste creep. Since the mechanism of cement creep is not fully understood [10-12], it is difficult to predict the particular effect of gamma-ray irradiation. According to the only one available research of the effect of gamma-ray irradiation on the creep of cement paste [13], the gamma-ray reduces creep and increases autogenous shrinkage.

According to [14], a significant reduction of the cement paste properties appears beyond the threshold of 200 MGy of the absorbed gamma-ray dose. Also, [15] found the hydrates decomposition within the absorbed gamma-ray dose range of 130 to 836 MGy. According to [16] and [17], on the other hand, the reduction in compressive strength was observed at much lower absorbed gamma-ray dose (15% reduction with the absorbed dose of 22 MGy and 10% reduction with the absorbed dose of 0.3-0.5 MGy, respectively). The mechanism of this strength reduction is still unclear.

Experiment

The mortar which consists of CEM I 42.5R cement paste with the water-cement ratio of 0.38, siliceous aggregates with the fraction of 0-4 mm and a polycarboxylate-based superplasticizer was used to produce small-scale 10x10x40 mm samples. The small-scale samples were selected in order to allow for the gamma-induced heat dissipation and uniform distribution of gamma-rays. The mortar and the cement compositions are given in Table 1 and Table 2, respectively. According to the Certification of Natural Aggregate Quarries of the Czech Republic (for Dobříň-jih 1-Předonín), the aggregates consist predominantly of quartz with small fragments of feldspar and mica. The mixture composition corresponds to the structural concrete mixture without coarse aggregate.

All samples were cured in water during 10 days and 62 more days in a sealed condition till the beginning of the experiment. The insulation was provided by a polyethylene foil. The samples were loaded and irradiated just after insulation removal.

Table 1. Composition of mortar

Component	Weight
Cement (CEM I 42.5R)	2625 g
Water	1000 g
Siliceous aggregates with fraction of 0-4 mm	4200 g
Superplasticizer (Glenium ACE 442)	25g

Table 2. Chemical composition of CEM I 42.5R Mokrá according to X-ray fluorescence elemental analysis

CaO	65.00 %
SiO_2	19.00 %
Al_2O_3	4.00 %
Fe_2O_3	3.00 %
MgO	1.00 %
SO_3	3.00 %
S	0.04 %
Cl	0.05 %
K_2O	0.75 %
Na_2O	0.15 %
Ig. Loss	3.10 %
Insoluble residue	0.70 %

Six loading frames were designed and constructed (see Fig. 1) in order to provide the sustained loading for the creep measurement. The load was controlled by the loading spring compression so that 1 cm of spring contraction is equal to the load of 0.5 kN. Two load levels of 1 kN and 1.5 kN (10 MPa and 15 MPa, respectively) were considered, which is approximately equal to 13.5 % and 20 % of sample strength. In order to separate shrinkage from the creep, not loaded samples were also investigated. Three loading frames with three samples in each (9 samples in total, of which 4 samples were under the sustained load of 1 kN and 5 samples were under the sustained load of 1.5 kN) and 5 not loaded samples were irradiated. An identical set of control samples was placed in the same laboratory conditions (with the average temperature of 16.2 °C and the average relative humidity of 50%) but away from gamma radiation, so as the presence/absence of gamma-ray irradiation is the only influence parameter. The experimental set-up is presented in Fig. 2.

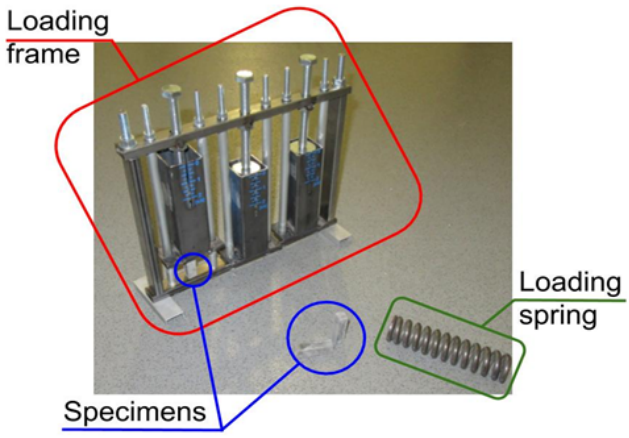


Fig. 1. Loading frame

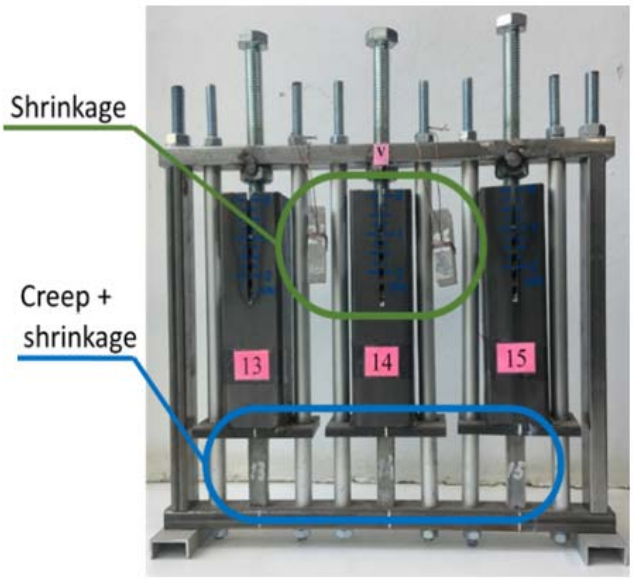


Fig. 2. Experimental set-up

^{60}Co Irradiation Facility UGU-420 of The Joint Institute for Power and Nuclear Research - Sosny of the National Academy of Sciences of Belarus, Minsk with the following irradiator characteristics (the height of the active part is 50 cm; the generating dose rate is 0.1-10 Gy/s and the total number of sources is 768 with the total activity of $4.4 \cdot 10^{15}$ Bq (120 kCi)) was used in order to carry out the presented experimental investigation. The radiation dose rate was in the range from 3.90 kGy/h to 4.71 kGy/h. The average irradiation period was 8.6 hours per day (the irradiation facility was operated during the day period only).

The total absorbed dose after 369 days of irradiation varies from $12.0 \cdot 10^3$ kGy to $15.0 \cdot 10^3$ kGy for different samples. The length of samples was measured during the irradiation period using the high accuracy digital calipers in four different points of a sample and then averaged.

Results and discussion

The measured sample strains are shown in Figs. 3 ÷ 5. It should be noted that the measurements of strain of the loaded samples were taken without significant difficulties due to the relatively high strain, while the shrinkage strain of the not loaded samples are on the threshold of measurability of the above prescribed method which complicated the processing of results.

In order to evaluate the average strain of the samples, the following logarithmic function was fitted to the measured data

$$\varepsilon(t, t_0) = \alpha \ln(t - t_0) \qquad (1)$$

where $\varepsilon(t, t_0)$ is the sample strain, t is the age of the sample in days, t_0 is the age of a sample at loading/drying and α is the fitted parameter.

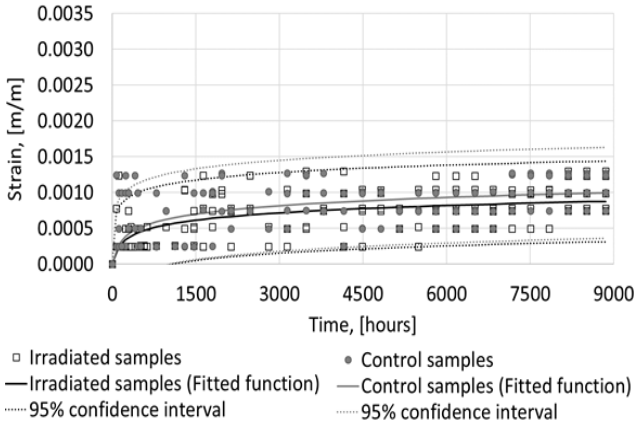


Fig. 3. Shrinkage strain of not loaded samples

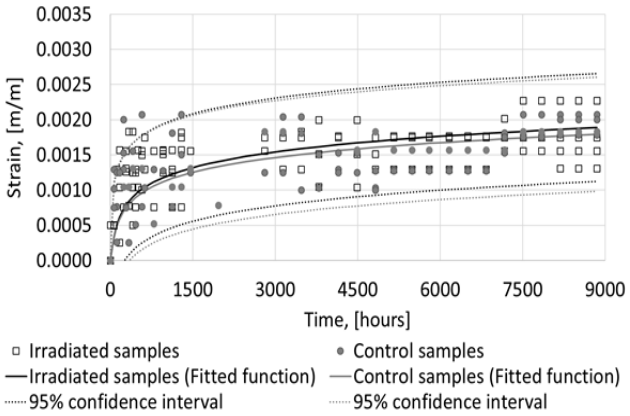


Fig. 4. Strain of 1 kN loaded samples

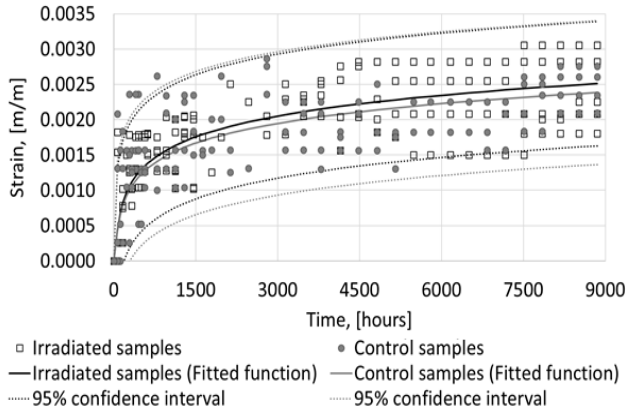


Fig. 5. Strain of 1.5 kN loaded samples

The fitted average curve as well as the 95 % confidence interval is also shown in Figs. 3 ÷ 5. It can be seen that the shrinkage strain of the not loaded control samples is insignificantly higher while the strain of the loaded control samples (the sum of the creep and the shrinkage) is slightly lower in comparison with the irradiated samples, but the difference is negligibly small and located within the 95% confidence interval. Moreover, the 95% confidence intervals of the control and the irradiated samples are very similar despite the large scatter of data.

The shrinkage and the creep strain were also calculated using the common models, namely B3 model [18], CEB model according to [19], FIB model according to [20], ACI model according to [21] and GL2000 model as presented in [21-22]. The comparison of the measured strain of the not loaded samples and the shrinkage strain calculated according to the standards is shown in Fig. 6. While the comparison of measured strain of the loaded samples (1 kN and 1.5 kN) and the sum of the calculated creep and shrinkage strains are is shown in Figs. 7 and 8.

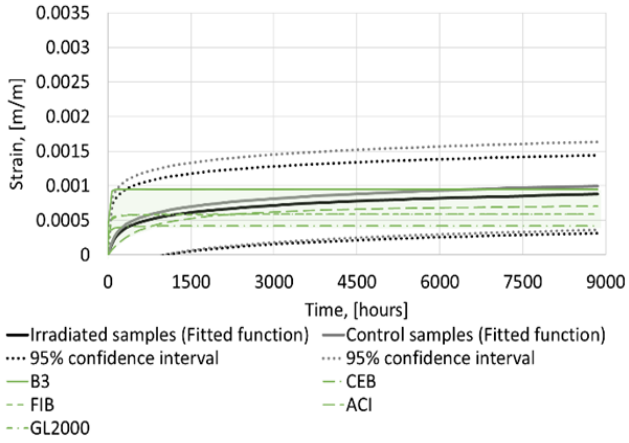


Fig. 6. Comparison of measured and calculated shrinkage strain of not loaded samples

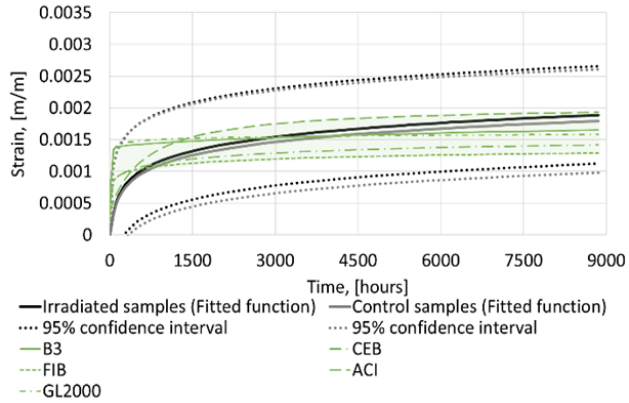


Fig. 7. Comparison of measured and calculated strain of 1 kN loaded samples

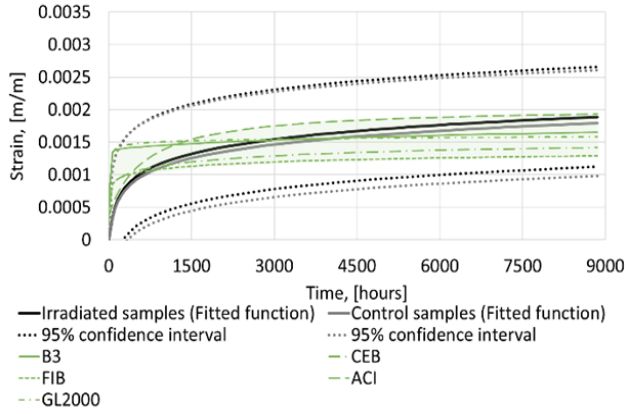


Fig. 8. Comparison of measured and calculated strain of 1.5 kN loaded samples

The comparison of the calculated and the measured creep compliance is shown in Fig. 9 and it can be seen that the creep compliance of the irradiated and the control samples is within the calculated limits. The creep compliance of the irradiated samples is slightly higher in comparison with the corresponding control samples.

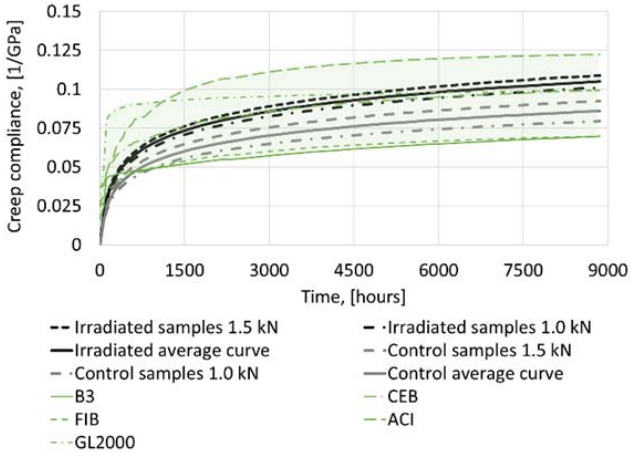


Fig. 9. Comparison of measured and calculated creep compliance of loaded samples

From the above, we can conclude that the difference in the shrinkage of the irradiated and the control samples is insignificant, but a slight effect of irradiation on the creep is observed, nevertheless, the creep is still within the interval predicted by the standards for both the irradiated and the control samples.

Since there was no trend in the strength difference of the not loaded and the loaded samples, as the load was too low to cause any damage to the samples, the results were combined and the strength of the irradiated and the control samples with the depiction of the mean strength value is shown in Fig. 10.

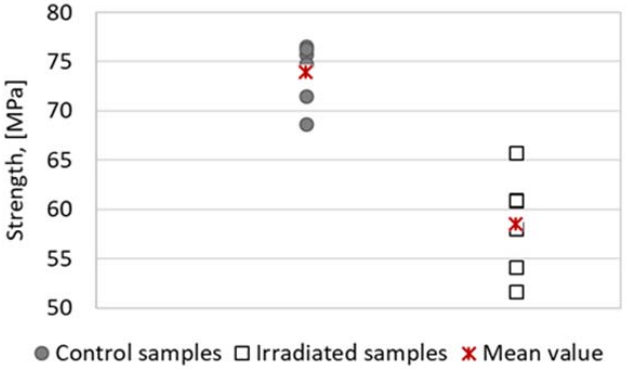


Fig. 10. Compressive strength

It can be seen that the gamma ray cases significant strength reduction (20% in average). The average strength reduction is higher than that presented in [16] and [17] (15% and 10%, respectively).

The relative compressive strength in dependence to the absorbed irradiation dose is shown in Fig. 11, where the trend is obvious despite the scatter of the data of the samples with different total absorbed dose.

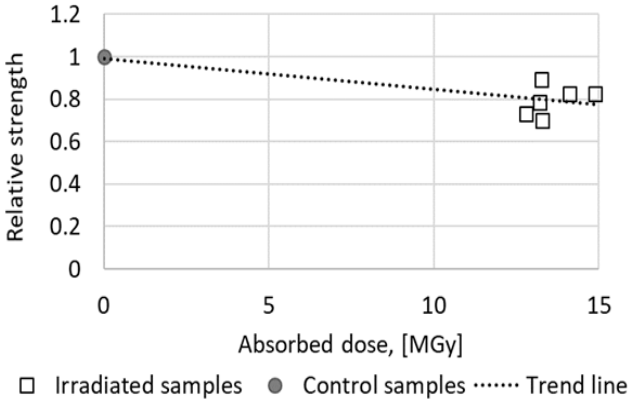


Fig. 11. Compressive strength in dependence with absorbed irradiation dose

Conclusions

Based on the obtained results, the following conclusions can be drawn.

No significant effect of gamma-ray irradiation on the cement mortar shrinkage is observed, the shrinkage of the irradiated and the control samples corresponds to the predictions given by the existing models.

The slight increase in the creep compliance due to the gamma-ray irradiation that is caused by increase of porosity lies in the interval predicted by the existed models.

The gamma-ray irradiation decreases the cement mortar compressive strength significantly (20% in average).

The physics behind these processes is still unclear and demands further investigation.

Acknowledgment

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