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Gamma irradiation sensitivity of early hardening concrete

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Purpose of research

Revealing the influence of gamma irradiation on cement setting, the early age strength and microstructure of cement mortar.

The range of investigation comprises the effects selected micro- and nano-additions to cement mortar used to control the kinetic of setting and early hardening of Portland cement.

Materials and specimens

MORTARS:
- Cement to sand 1:2
- Water to cement 0.45
- Mineral additions in small quantities – retardation or acceleration
- CEM I 52,5 R

- ulexite (U) addition of 0.5%, 0.75%,
- colemanite (C) addition of 3%, 6%
- irradiated mortar (γ)
- reference mortar (52)

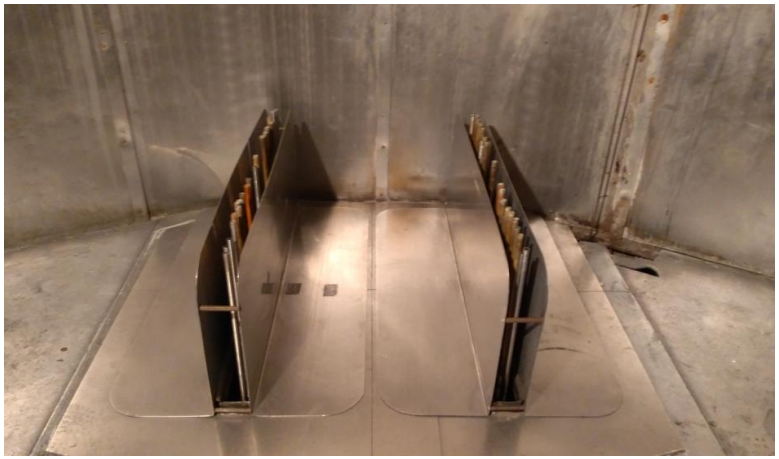
The mould with mortar wrapped against moisture lost

- mortar mixes were prepared in the laboratory adjacent to the gamma radiation facility
- consolidated using vibrations induced by attached small-size vibrator
- the air temperature was 10°C to 13°C
- mortar in moulds was protected against moisture loss by foil wrapping
- fresh mortars were exposed to irradiation after 60 minutes from mixing

Irradiation and testing methods

- Irradiation exposure:8 h
- Dose rate about 4.6 kGy/h.

- demoulding after gamma irradiation
- immersing in pure acetone for up to 48 hours (cement hydration arrest for air-transport time needed)
- drying at 50°C until a constant mass was achieved.

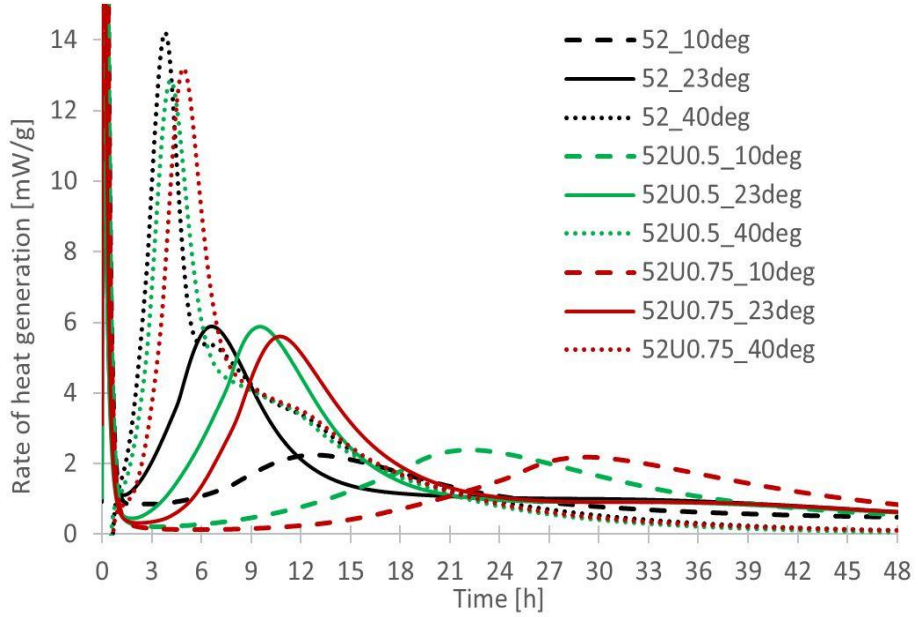


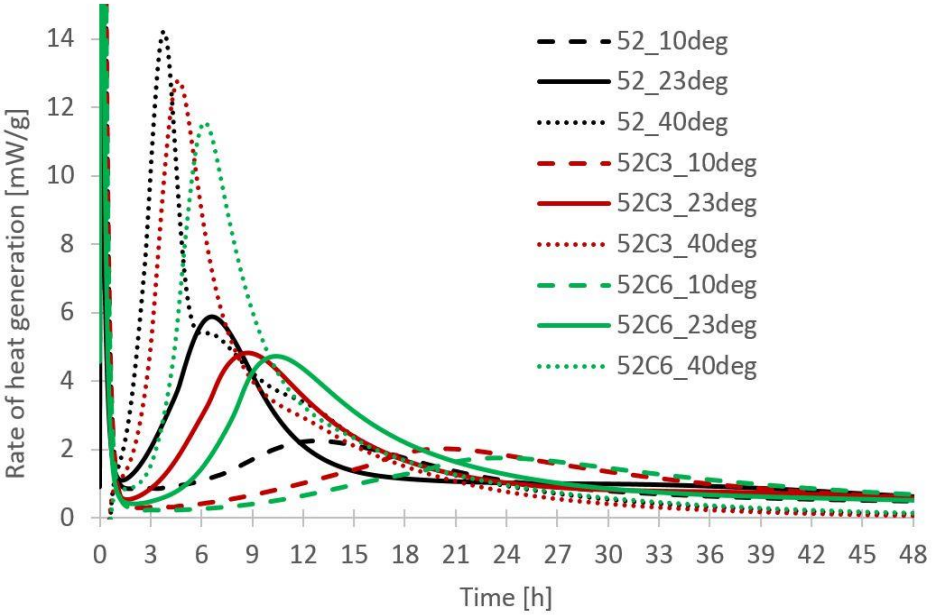
radiative fuel rods protruding from the gaps in the floor - the specimens are placed along the line of rods

Testing methods:

- Isothermal calorimetry (without irradiation)
- Flexural and compressive strength
- Mercury intrusion porosity (MIP)
- X-ray diffraction

Isothermal calorimetry





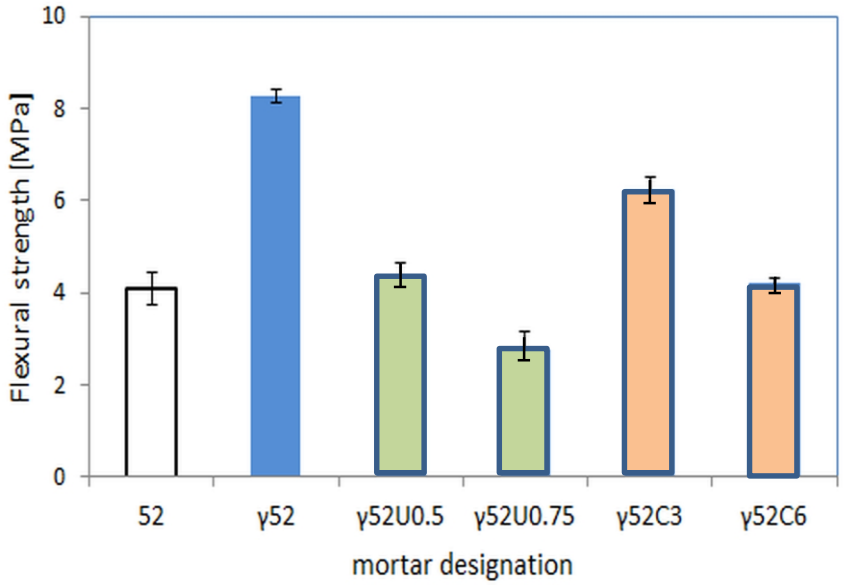
The influence of temperature and content of ulexite and colemanite on the rate of heat generation during hardening of cement mortar with CEM I 52.5R

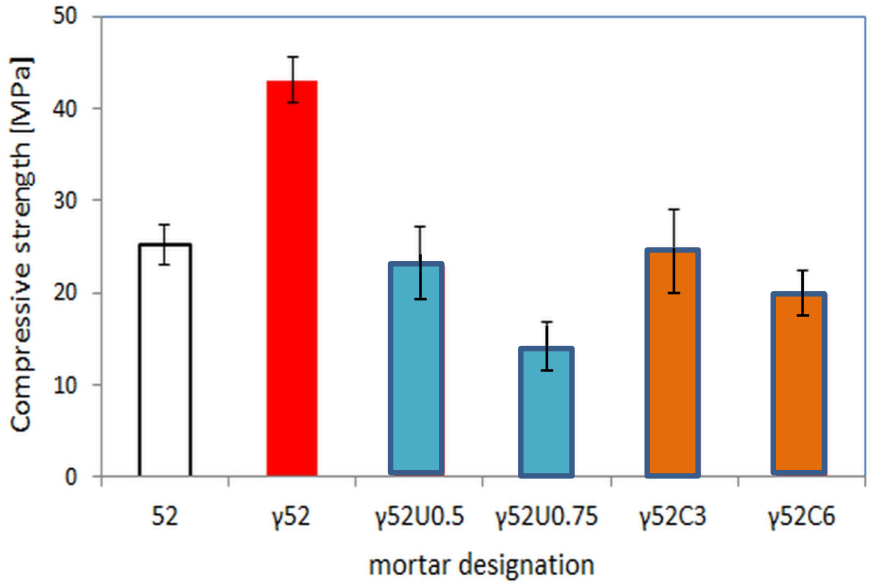
The setting time determined on cement paste using a modified Vicat method at 23°C

Setting time	Cement paste composition				
	52	52U0.5	52U0.75	52C3	52C6
initial [min]	202	423	451	317	350
final [min]	337	768	781	467	570

By design, the irradiation period lasting for 8 hours was intended to cover a possible wide range of cement hydration kinetics

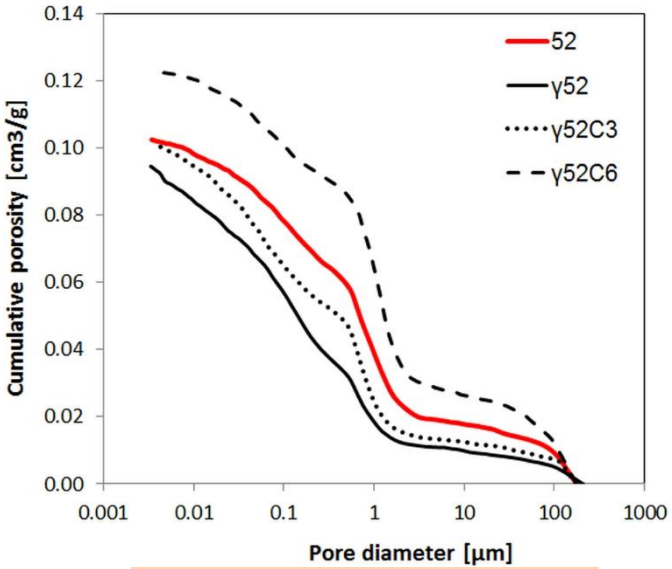
Flexural and compressive strength



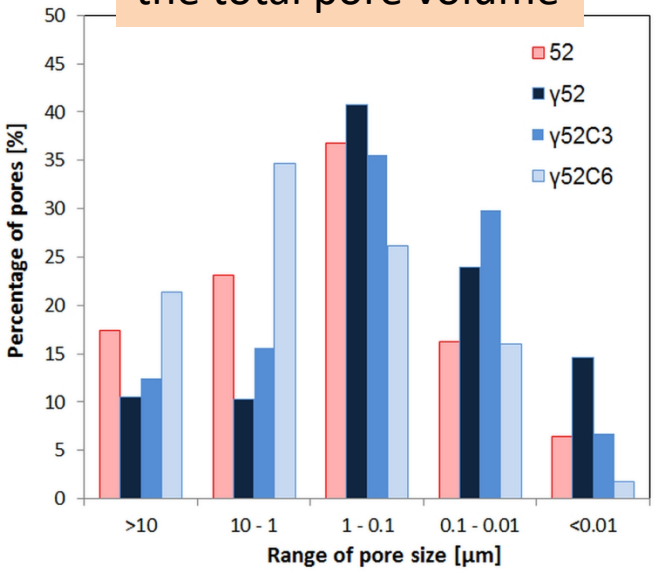


- Due to gamma irradiation the flexural strength increased twice
- Strong effect of gamma irradiation on the compressive strength of reference mortar: increase from 25.2 MPa to 43.1 MPa
- Presence of boron additives (strong retarders), was revealed by a reduced strength of mortar after irradiation
- Strength reduction was proportional to the increasing content of boron compounds with a different coefficient of proportionality for ulexite and colemanite

Pore size distribution



the total pore volume



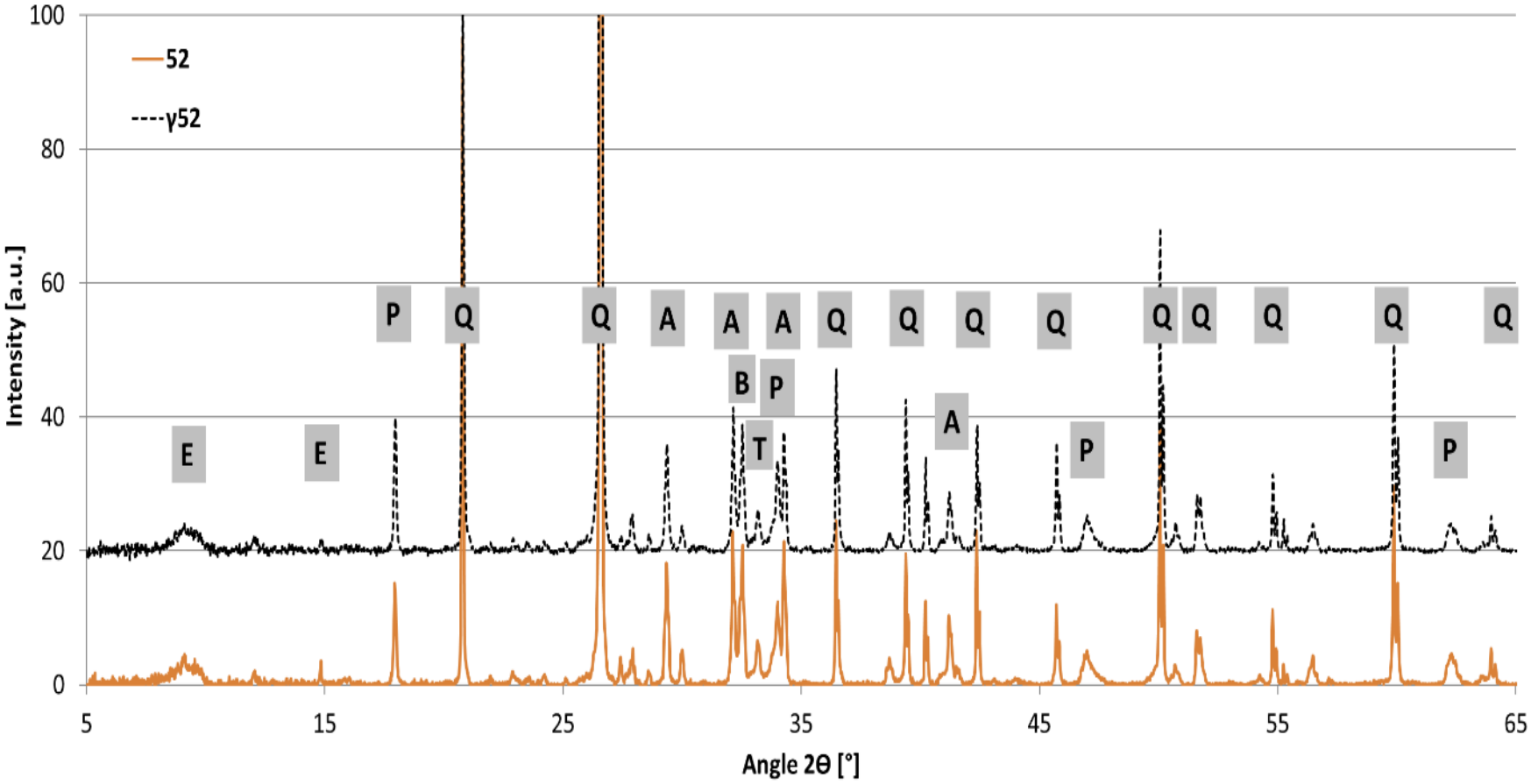
the percentage of pores in selected size range

Due to irradiation the total content of pores was increased and the changes in the relative content of large capillary pores and small pores < 100 nm, were observed

Effects of ulexite and colemanite additions in mortar with CEM I 52.5R were similar but more pronounced for increased boron content in mortar

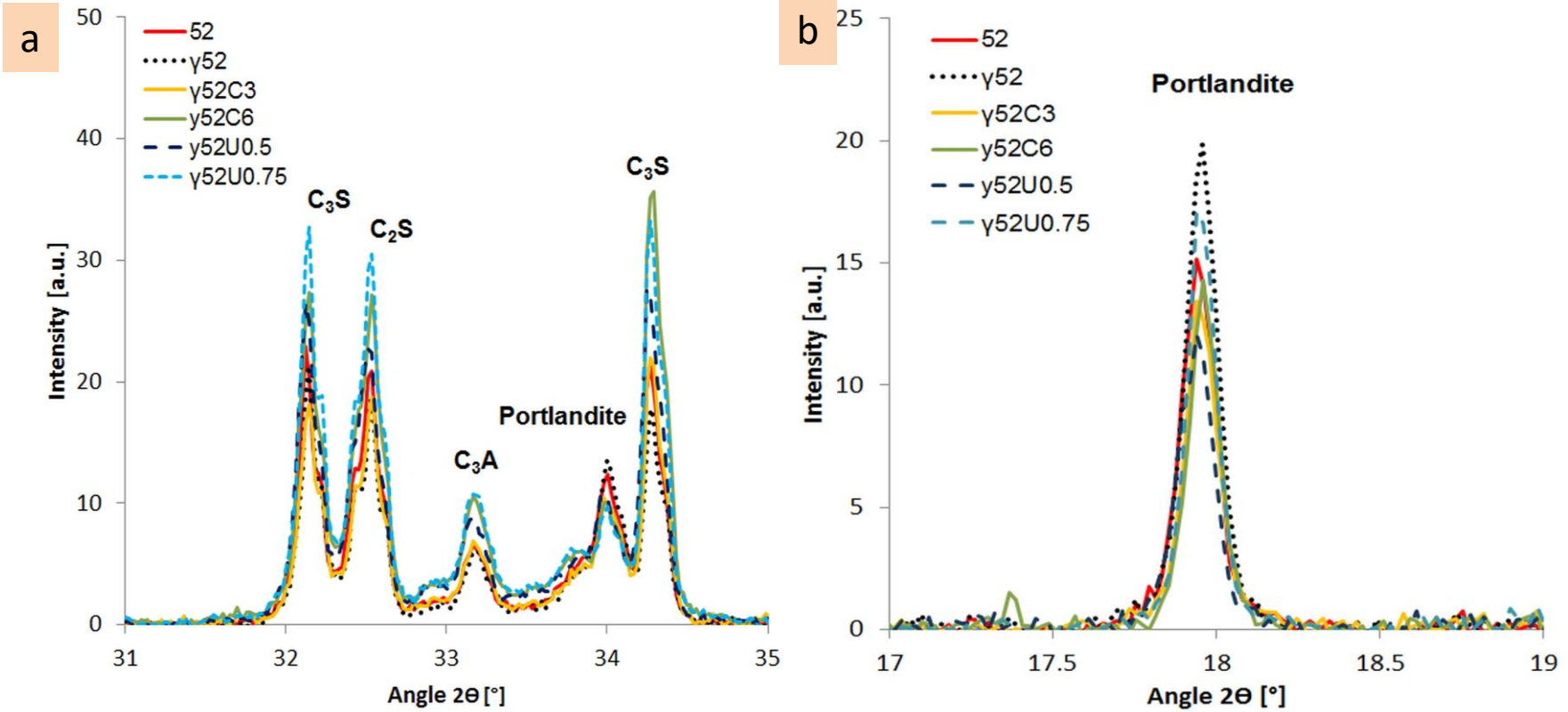
The reduction of cumulative porosity and the degree of pore refinement was smaller than in the case of reference mortar without additions

Phase composition



X-ray powder diffraction patterns for mortar specimens without additions
Q – quartz, A – C_3S , B – C_2S, E – ettringite, T – C_3A, P – portlandite

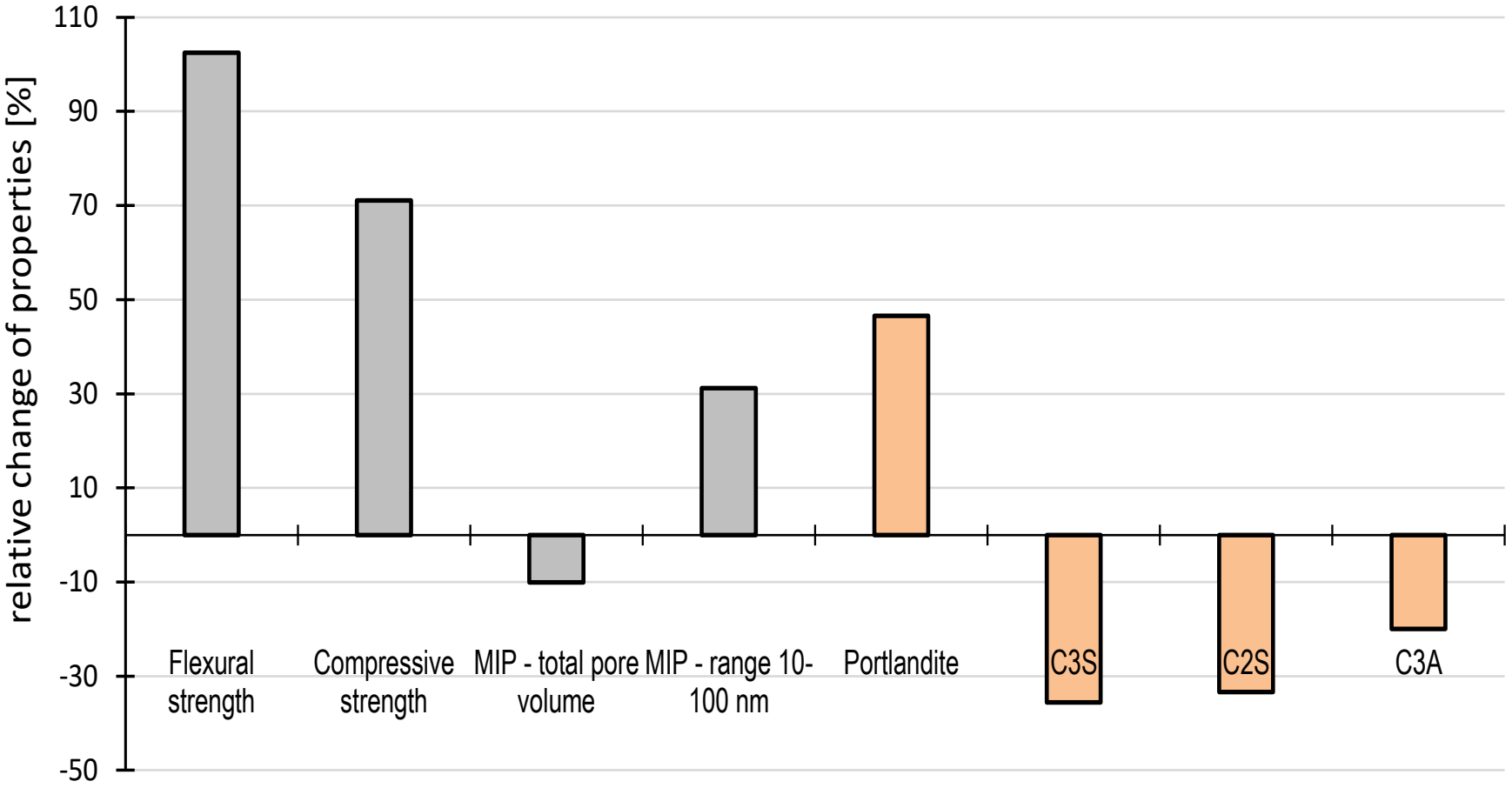
Phase composition



The influence of gamma irradiation on the selected diagnostic peaks of XRD pattern for mortar with CEM I 52.5R and boron minerals: a) relics of clinker minerals and portlandite, b) portlandite

The highest intensity of portlandite reflection was observed for irradiated reference mortar, the lowest - for the retarded systems with colemanite or ulexite

Influence of gamma irradiation on mortar properties



Relative increase or decrease of strength and porosity of early age mortar with CEM I 52.5R induced by gamma dose close to 40 kGy (including qualitative indication of intensity change of selected XRD reflections: portlandite d=4.902 Å, C3S d=2.776 Å, C2S d=2.744 Å, C3A d=2.700 Å)

Conclusions

- Gamma irradiation of hardening cement mortar, starting before initial setting time, resulted in an increase of the flexural and compressive strength by 102 or 71%, respectively.

- A 10% reduction of capillary porosity and pore size refinement (a decrease of pores > 10 mm and increase of pores < 100 nm) is found as a result of early gamma irradiation of hardening cement mortar.

- Early gamma irradiation with the dose up to 40 kGy results in increased presence of portlandite and reduced presence of unhydrated clinker minerals C_3S, C_2S, C_3A, thus exhibiting increased rate of hydration.

Conclusions

- Gamma irradiation sensitivity of early strength of Portland cement mortar is found equivalent to elevated temperature curing, representative for the relative temperature increase by about 27.2 °C and 27.5 °C for the flexural and compressive strength, respectively.

- Effects of boron minerals in irradiated mortar on capillary porosity and qualitative phase composition are representative for delayed hydration of cement:
  - ulexite - an increase in capillary porosity up to 20%;
  - colemanite – an increase in capillary porosity by 10% and 30% for colemanite content of 3% and 6%, respectively,
  - significant reduction of intensity of portlandite reflection and an increase of reflections intensity of unhydrated main clinker minerals as C_3S, C_2S and C_3A.

Thank you for your attention!

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