INFLUENCE OF COMPOSITION FACTORS AND STRENGTH AND DURABILITY CHARACTERISTICS OF CONCRETES ON RADON EMISSION*

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This paper presents the research program which consisted in the determination of concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ radionuclides in concretes prepared with some cement types with additions. The results achieved in the determination of concentrations of the main radioactive elements ($^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$) and of the radioactivity index are presented for various additions used in cements, blended cements and concretes prepared therewith.

The contribution of tested additions was assessed by adding them in the manufacturing process of different cement types. Thus, tests were performed on no-addition cements and cements with additions of slag, fly-ash, limestone, slag + limestone, puzzolana + limestone, fly-ash + slag.

The research program consisted in the determination of certain strength and durability characteristics (compressive strength, porosity, water and air permeability, etc.) of concretes prepared with cements with various additions and admixtures, in order to cross-reference results achieved with the radon exhalation rates and respectively the values acquired for the indoor radon concentration. During the research program, the strength characteristics, the air and water permeability were determined on concretes having various compositions, in order to enable cross-reference with radon exhalation rates.

Key words: radon emission, concrete characteristics, exhalation, radioactivity index.

1. INFLUENCE OF ADDITIONS IN CEMENTS AND OF ROMANIAN CEMENTS ON CONCRETE’S RADIOACTIVITY

The research program consisted of tests on additions included in the composition of cements present on Romanian market, of various blended cements and respectively the preparation of concretes using such cements to assess the influence of additions, implicitly cements, on concrete’s radioactivity.


The results achieved in the determination of concentrations of the main radioactive elements (Ra-226, Th-232, K-40) and of the radioactivity index are presented below for various additions used in cements, blended cements and concretes prepared therewith. In the assessment of the radioactivity of additions used in cements, measurements were taken through gamma spectroscopy. Thus, measurements were taken for the main radioactive elements in various compounds used in cements.

![Flow chart of the research program](image)

**Fig. 1 – Flow chart of the research program on the determination of influence of cement additions, cements and aggregates on concrete’s radioactivity.**

For the same type of component, results achieved vary based on the different generating sources. Moreover, we obtained high values of radionuclides for slag and fly-ash compared to those obtained for limestone. The contribution of tested additions was assessed by adding them in the manufacturing process of different cement types. Thus, tests were performed on no-addition cements and cements with additions of slag, fly-ash, limestone, slag + limestone, puzzolana + limestone, fly-ash + slag. Tested cements are manufactured in Romania, by different manufacturing plants, and the addition rate used for the same cement type vary from one plant to another.

Cements with fly-ash additions display radium concentration values closed to the maximum value permitted in Romania. In case of slag cement, values achieved...
are observed to be dependent on the slag source and respectively on the percentage
used in cement manufacturing processes (6-20%). In case of $^{232}$Th and $^{40}$K
radionuclides, all tested cement types display values far inferior to the maximum
value permitted in Romania [1].

Cement with fly-ash additions, presents a radioactivity index 10% higher
than the maximum value permitted in Romania. Fly-ash cements present values
(0.5 and respectively 0.49) that are close to the maximum value permitted for the
radioactivity index. The other tested cement types displayed radioactivity index
values below the maximum permitted value.

In the preparation of concretes were used aggregates with sorts of 0–4 mm,
4–8 mm, 8–16 mm and 16–32 mm. Values achieved for the 4 sorts, for $^{226}$Ra, $^{232}$Th
and $^{40}$K radionuclides are observed to be far inferior to the maximum values
permitted in Romania.

The research program consisted in determining the concentrations of $^{226}$Ra,
$^{232}$Th and $^{40}$K radionuclides in concretes prepared with some cement types with
additions.

Among the cement types surveyed, those having the highest values for
radium activity concentration and respectively for radioactivity index were selected
in order to enable the assessment of concretes prepared therewith. Thus, the
following cement types were used: cement with various fly-ash percentages and
sources, cement with slag additions, cement with various slag and limestone
concentrations and with puzzolana and limestone additions.

Therefore, concretes were prepared with blended cements (Portland cements
with additions that vary between 21–35%: slag + limestone, puzzolana + limestone
and Portland cements with additions between 6–20%: fly-ash, slag), in various
cement dosages, using different types and concentrations of admixtures
(superplasticizing / plasticizing, air entrainment) and aggregates with maximum
granulation of 16 mm and respectively 32 mm. The cement types, cement dosages
and admixtures used in concrete preparation, the overall quantity of aggregates
used as well as the water / cement ratio are presented in extenso in [2].

Concrete samples with sizes of 150x150x150 mm were executed in
compliance with the norms in force upon the execution date [3]. They were
emerged in water for 2 or 7 days, and then cured until the test age (28 days, 180 days
and one year) in air with 20°C temperature and 65% humidity.

The activity concentration of $^{226}$Ra varies between 15–25 Bq/kg. The values
achieved for $^{232}$Th range between 10–22 Bq/kg, and between 250–770 Bq/kg for
$^{40}$K. Concretes prepared with the same cement type, submerged in water for 2 days
display values of the radioactivity index 30% higher compared to concretes cured
for 7 days.

For concretes prepared with the same cement type in class 32.5 cured in
similar conditions, the radioactivity index values raise with the increase of cement
dosage. In case of concretes prepared with cement in class 42.5 small differences
may be noted between the radioactivity index values for different cement dosages.
2. INFLUENCE OF STRENGTH AND DURABILITY CHARACTERISTICS OF CONCRETE ON ITS RADIOACTIVITY

The research program consisted in the determination of certain strength and durability features (compressive strength, porosity, water and air permeability, etc.) of concretes prepared with cements with various additions and admixtures, in order to cross-reference results achieved with the radon exhalation rates.

During the experimental program, concrete samples were prepared with cements having various additions of slag, slag + limestone, limestone + fly-ash, no admixtures and respectively concretes with cements having various additions of slag, slag + limestone, limestone + fly-ash, slag + fly-ash, fly-ash and various dosages of admixture.

3. CONCLUSIONS

The main ideas that may be issued based on experimental research carried out on several types of additions used in cement preparation, on cements with/without additions and respectively on concretes prepared with various concrete types are shown below.

Additions: For the same type of addition, results achieved vary based on the different sources of such addition. Also, high values are noted for radionuclides in fly-ash and slag, compared to those measured for limestone.

Cements: Cement with fly-ash addition has a radium activity concentration equal with or higher than the maximum permitted value, based on the source and
respectively on the fly-ash percentages used. As for the cement with slag addition it
has radium concentrations between 45 and 66 Bq/kg, differences being due to
sources and slag percentages used in cement manufacturing. All cement types
tested have lower values of thorium and respectively potassium concentrations
compared to the maximum permitted limits in Romania [1].

**Aggregates:** The values achieved for the 4 sorts used in concrete preparation
for radionuclides $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ are much lower than maximum permitted
limits in Romania.

**Concretes:**

- **Radioactivity indexes:** Values of radioactivity indexes achieved for
  concretes submerged in water for 7 days after unmolding and then maintained in
  air until the test age range between 0.25 and 0.38, while concretes submerged in
  water for 2 days achieved a radioactivity index 30% higher, all data were obtained
  for concretes prepared with the same cement type. The increase of water
  submerging period determines an improvement in concrete’s microstructure. An
  increase of the cement dosage used in the preparation of concretes causes an
  increase of the radioactivity index. For the same cement dosage and for various
  cement types we can note that concretes submerged in water for 7 days and then
  cured in air have a radioactivity index that ranges between 0.25 (cement dosage of
  320 kg/m$^3$) and 0.38 (cement dosage of 400 kg/m$^3$). The results acquired during
  this research program may be synthesized in the chart displayed in Figure 3.

![Fig. 3 – Flow chart of results acquired for cement additions, cements, aggregates and concretes.](image)

- **Compressive strength:** For the same concrete class, we can note that
  concretes prepared with cement with slag addition have higher compressive
  strength than other concretes, disregarding the presence / absence of admixtures.
  Lower compressive strengths were achieved in case of concretes prepared with
cement with limestone and fly-ash additions. Of course, the compressive strength of cements is very important.

- **Porosity:** Porosity decreases in time, more significantly in case of concretes prepared with cement with slag and respectively fly-ash additions comparative with concretes prepared with cement with slag and limestone.

- **Air and water permeability:** Of all concretes assessed, those prepared with cement with slag have the denser structure, are less permeable and therefore less porous than other concrete types, fact that results from the outcomes achieved for water infiltration depth, air flow depth and respectively for the air permeability coefficient. Comparing the concretes prepared with the same cement dosage, those prepared with cement with slag addition present air flow depths lower than other types of concretes surveyed, disregarding the presence / absence of admixtures. Water infiltration depth and respectively the air flow depth decrease with the reduction of W/C ratio.

- **Permeability coefficient:** For concretes prepared with admixtures, values achieved for the permeability coefficient are several level orders lower than those achieved for admixture-free concretes. The reduction of permeability coefficient is faster as the Water /Cement ratio is lower. At the age of 1 year, values achieved for the permeability coefficient of concretes prepared with admixtures are 15-20 times lower than values achieved for admixture-free concretes, at the same W/C ratio. The air permeability coefficient decreases with the increase of concrete density and respectively with the increase of compressive strength, higher coefficient values being achieved for admixture-free concretes, at the same W/C ratio. The increase of the water submerging period reduces permeability and porosity of concrete improving its microstructure.

The findings of this research program are synthesized in charts displayed in Figures 4 and 5.

![Chart showing the influence of Water/Cement ratio, cement dosage and additions on the characteristics of concretes prepared with various cement types.](image-url)
Fig. 5 – Chart of results achieved for correlation of concrete characteristics with radon exhalation rate and indoor concentration.

- **Exhalation rate**: As for the radon exhalation rate from concretes, several conclusions may be drawn, synthesized as follows:
  - The radon exhalation rate decrease with the increase of concrete density, disregarding concrete’s age. The exhalation rate increase with concrete porosity.
  - The radon exhalation rate per mass unit vary linearly with the permeability coefficient, achieving higher radon exhalation rate values for high values of the permeability coefficient, i.e. concretes with low density and high porosity.
  - Exhalation rates achieved for concretes prepared with cement with limestone and fly-ash additions are approximately 20–60% higher than the values achieved for concretes prepared with cement with slag addition.
  - The radon exhalation rate from concrete vary based on the type and percentage of addition in cement, on the cement dosage, on the presence type and dosage of admixture, on the water / cement ratio, on concrete’s porosity, density and age.
  - The air flow depth and radon exhalation rate vary based on the cement type, on the admixture type and on the concrete age.
  - The radon exhalation rate, water infiltration depth and respectively the gas flow depth decrease with the reduction of the W/C ratio.
  - The radon exhalation rate from admixture-free concretes is higher than in case of concretes prepared with superplasticizing admixture or air entrainer, at the same W/C ratio.
In case of concretes prepared with cements with slag, lower values were achieved for the radon exhalation rate than in case of other types of concretes. Highest values were achieved for concretes prepared with concretes with limestone and fly-ash additions.

We may note that radon exhalation rate is dependent on the concrete features (Water/ Cement ratio, concrete age and humidity, air and water permeability, density and porosity), on environmental factors (temperature and humidity) and on concrete ingredients (cement type and dosage, percentage and type of additions, use of admixtures).

REFERENCES