

Multi-criteria Analysis of Factors for Application of Concrete Composites Considering Their Environmental Harmfulness

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Abstract. The analysis of factors is important in insight of the selection of proper building material with environmental added value. A comprehensive solution is possible if at the beginning there are all the relevant factors in detail characterized predominately that have got a major impact on the area in terms of environmental harmfulness prevention. There are many groups of environmental factors. In this article only four factors are considered, i.e. contain of Cr^{VI} (mg/kg) and index of mass activity for radionuclides (Ra, Th, K) which are the most harmful. These factors can be evaluated by means of a supplementary tool, e.g. multi-criteria analysis, which improves and supports decision processes in the framework of construction by building management, etc.

1. Introduction

In general, it is difficult to select criteria for evaluation of building material harmfulness because of a wide range of human health-linked indicators and methods. There are many various approaches to evaluate the negative or dangerous even toxic impacts of building materials from the simple lists or calculation to the sophisticated software [1,2,3,4]. However, the evaluating methods are usually based on the inputs data from the commonly used databases which give often only the average values.

Therefore, the calculations based on the real experimental data are still of great importance.

The current trend in the use of secondary fuels in cement production and the use of secondary raw materials in the production of concrete and cement composite materials has drawn attention to the environmental safety of building materials. Special attention is paid to leaching of environmentally hazardous substances, in particular toxic heavy metals, from water-borne structures [5,6] and the radioactivity of building materials. The aforementioned factors are involved in the negative effects of building materials on human health.

This paper presents a part of a proposal of methodology enabling to obtain data for the relevant selection of application material, where environmental safety and protection measures should be applied at first. The harmfulness evaluation, in the presented paper, aims at comparison of the radioactivity and leachability of hexavalent chromium from selected cement composites using multi-criterial approach.



2. Methodology of complex assessment

The paper aims at the calculation of order for priorities concerning environmental harmfulness of concrete composites based on ordinary Portland cement as well as composites containing secondary materials such as silica fume and zeolite. The evaluation of environmental harmfulness was performed on four concrete types whereas all mixtures contained the same amount of CEM I 42.5 N cement (360 kg). The K1 and K4 samples were of almost the same compositions, based on ordinary Portland cement, differing only in water and plasticizer amounts. K4a and K4b samples differ from the point of treatment after the hardening. The K4a sample was cured in water while K4b sample was cured in the laboratory atmosphere. K2 concrete sample has been enriched by silica fume (20 kg) while K3 sample by mix of silica fume and zeolite (20 + 20 kg). The recipes of the concretes investigated were designed in our previous research regarding the durability of concretes testing [7,8].

The proposed methodology of complex environmental harmfulness for human health was based on the quantification of qualitative parameters using multi-dimensional harmfulness assessment indicators in recommended composition according to the evaluation purpose.

The recommended number of quantifiable indicators defined and monitored by experts is $20 \div 25$. As an input to the problem solution serves a matrix of data values for individual j -indicators with determination of the permissible standard for their values u_j , evaluated from i -th number of sites. The calculation includes a triangular matrix of correlation indexes r_{ij} , as well as the values of the arithmetic mean y_j , a standard deviation s_j from a set of individual indicators and the Student's t -test values for these indicator values.

The indicators are further processed using an original mathematical and statistical method, based on vector, factor and discriminant analysis, correlation calculus and tests of significance so that a complex of environmental harmfulness value for human health or building material (concrete) application is determined by a dimensionless criterion Q_i .

The value behaviour of Q_i can be well-arranged demonstrated graphically on a map of the evaluated building application or it follows its course in the dynamic of environmental protection.

This methodology can be applied as a supplementary tool for the building developers' management, state government offices, the Ministry of Environment, Ministry of Transport and Construction and Ministry of Health. It allows a complex view of multi-criteria environmental issues. Significance tests also allow a partial or detailed detection of critical environmental harmfulness with regard to the human health and building application.

The selection of descriptors, i.e. selected evaluating factors as well as their arrangement in a matrix (an order of columns in a data sheet) depends on evaluator's professional orientation. This choice influences the final level of the actual environmental harmfulness. In our evaluation, the radioactivity and the heavy metals toxicity have been considered as the most dangerous to human health. Isotopes of potassium (^{40}K), uranium (^{238}U) and thorium (^{232}Th) are the most important radionuclides when assessing the radioactivity of building materials due to their primary origin in raw materials [9]. Heavy metals present in the cement composites can be released to the surrounding aqueous medium which acts on the material by direct leaching or dissolution and diffusion in the porous liquid. These processes are influenced by the structure of the pores and the porosity of the building material. The solubility of heavy metals depends on their binding to the hydration products, the oxidation number in which they occur as well as their ability to form complex compounds and precipitates. The negative effects of heavy metals on human health are widely known. Chromium, commonly present in cement raw materials, belongs to the most dangerous metals. A very special toxicity is connected with the hexavalent form of chromium. Therefore, the following individual factors have been selected for the multi-criterial evaluation of concretes:

- mass activities of radionuclide ^{226}Ra [Bq/kg],
- mass activities of radionuclide ^{232}Th [Bq/kg],
- mass activities of radionuclide ^{40}K [Bq/kg],
- leachability of Cr(VI) [mg/kg].

3. Results

Table 1 presents input data for the concrete composites: K1, K2, K3, K4a and K4b (for their characteristics see Section 2 “Methodology of complex assessment”) with the selected monitored and measured characteristic factors which have got various level of environmental harmfulness. The values of the selected indicators, chosen for the calculation, were achieved in our previous research focused on the durability of cement-based materials [10,11]. The order of columns with selected factors is arranged according to environmental significance, which was determined by an environmental specialists (three independent evaluators with various universities). These evaluators are strongly environmental oriented to support of environmental protection for the new application of concrete composites. The individual factors A, B, C and D have got an amplifying effect on environmental harmfulness and they have got a positive polarization of criteria.

Table 1. Input data - individual factors for a multi-Criteria analysis.

individual criteria of environmental harmfulness for concrete composite "j"		A	B	C	D
		^{226}Ra	^{232}Th	^{40}K	Cr(VI)
units		[Bq/kg]	[Bq/kg]	[Bq/kg]	[mg/kg]
maximum value of criteria "a _{ij} " for individual concrete composites					
labelling of concrete composite "i"	K1	13.98	83.00	32.50	0.84
	K2	9.55	508.70	14.10	1.44
	K3	7.84	388.60	21.80	0.39
	K4a	14.70	347.20	27.60	1.24
	K4b	10.74	759.40	23.10	0.98

Legend:

i – labelling of concrete composite, j – factors (criteria), A – mass activities of radionuclide ^{226}Ra , B – mass activities of radionuclide ^{232}Th , C – mass activities of radionuclide ^{40}K , D – amount of Cr(VI).

The results of multi-criteria prioritization for level of environmental harmfulness of the selected concrete composites are presented in figure 1 and table 2. The figure 1 shows a comparison of the calculated level of environmental harmfulness (Q_i) of evaluated concrete composites according to the above-mentioned methodology and using the calculation performed by a computer algorithm.

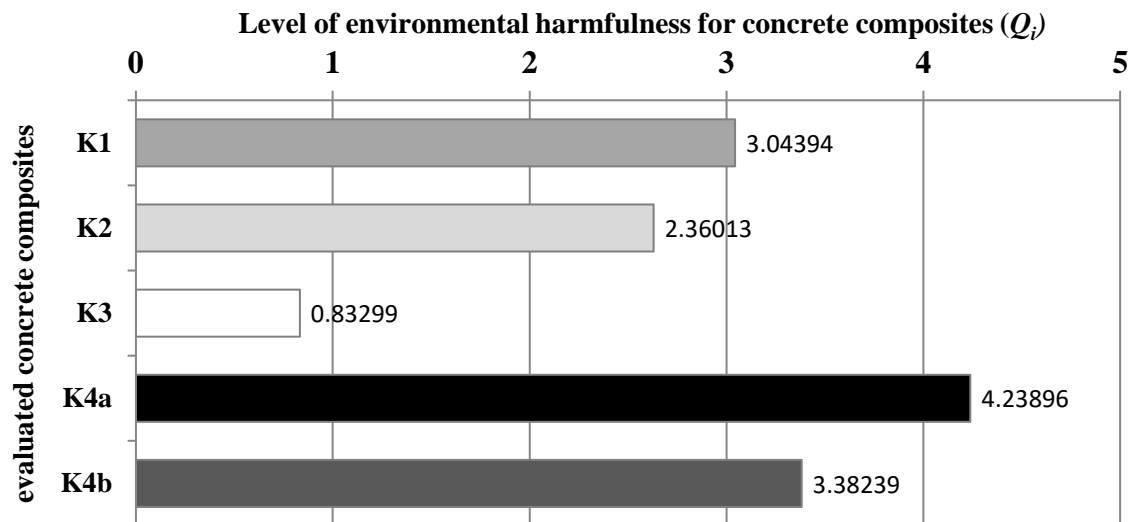


Figure 1. Environmental harmfulness of concrete composites.

Based on the calculated level of environmental harmfulness (Q_i), i.e. dimensionless variable which considers with harmful influences of concrete composites in their application sphere, table 2 determines the order of the concrete composites regarding their harmfulness. The multi-criteria calculation taking into consideration environmental harmfulness of concrete composite can help to determine the priority for their application in new buildings.

Table 2. Multi-criterial analysis of the concretes harmfulness.

Individual concrete composite	Level of environmental harmfulness Q_i [dmnl]	Application priority for construction/buildings
K1	3.04394	III.
K2	2.63013	II.
K3	0.83299	I.
K4a	4.23896	V.
K4b	3.38239	IV.

The concrete composite K3 with mix of silica fume and zeolite has been identified to have the lowest human health impact in terms of evaluated parameters. The calculated level of environmental harmfulness ($Q_3 = 0.83$) was significantly lower than those of calculated for the other composites. As seen in table 2, the most negative human health impact ($Q_{4a} = 4.24$) has been calculated for the K4a composite based on ordinary Portland cement (OPC). When comparing the Q_3 to Q_{4a} , the found harmfulness parameter of K3 was even 5 times lower. The other composites based on ordinary Portland cement reached the close values of 3.04 and 3.38 for K1 and K4b, respectively. The cement composite with only silica fume addition was found to be more dangerous than K3 but less dangerous than OPCs.

As presented in table 2, the order of cement composites regarding their harmfulness, according to the used methodology, can be as follows: $K3 < K2 < K1 < K4b < K4a$.

4. Conclusions

The paper presents the results of the multi-criterial analysis of the harmfulness of the selected cement composites. To evaluate the suitability of cement composites to practical application, a more complex approach is needed considering another mechanical, chemical or technological indicators. The extended multi-criterial evaluation of the cement composites is of our interest at present. These complex evaluation could be used in real decision-making processes within a building developers' management.

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