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APPLICATION OF SIMILARITY METHOD OF DISTANCE COURSES DESCRIBING THE ELEMENTS CONTENT IN CEMENT CONCRETE AFTER FROST RESISTANCE TEST

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Abstract

The work concerns test results of cement concrete and the use of similarity analysis of distance course. Research procedure was presented and the obtained laboratory tests results were discussed. Composition of concrete mixes was designed. The cement concrete composition includes cement, coarse aggregate, fine aggregate, water, admixtures and a ceramic addition. The addition of ceramic was used as a replacement for part of the fine aggregate Fresh concrete mixture parameters were tested and basic parameters of hardened concrete were defined (density, compression strength and tensile strength). The scope of works included concretes intended for airfield pavements and this concretes after frost resistance test. The test has been conducted in diversified media generally used in the course of winter maintenance. Subject to observations of internal structure of concretes and conducted chemical microanalyses using scanning electron microscope, the contents of diversified elements in four zones were specified. The following zones were subject to analysis: cement matrix, contact area between air pores and cement matrix, contact area between fine aggregate and cement matrix and contact area between coarse aggregate and cement matrix. Based on the results obtained diagrams similarity of the analysed concretes were prepared.

Keywords: *airfield pavements, cement concrete, ceramic additive, frost resistance, analysis of similarity*

1. Purpose and scope of the research

The purpose of the laboratory tests was to application of similarity analysis of distance courses. Due to operating conditions of airfield pavements [4, 6] the significant element with respect to its durability is frost resistance of concrete composite. During the first stage of tests, the composition was developed and cement concrete intended for airfield pavements was prepared. Concretes of class C40/50 intended for airfield pavements were subject to laboratory tests.

In the course of laboratory tests, the parameters of concrete mixes and hardened mixes were determined. Air content (p), according to [9], were defined for the designed concrete mixes.

During scientific research, the amount of the required samples was determined using student's T-distribution assuming the significance level of 0.05. The minimum essential number of samples ranged between 4 and 5, depending on the type of the conducted test. In case of such assumptions, 6 samples were selected, which, each time, were intended for the laboratory tests.

Compression strength (f_c) [11] in case of hardened concrete was determined. The size of the test samples was 150x150x150 mm. Samples size and the loading method were consistent with the requirements of [8]. The samples were positioned centrically in the durometer, which complied with the requirements of [12]. Load speed applied to the sample during the test was 0.05 MPa/s. In the course of the test, maximum load value was determined. The concrete sample is capable to transfer the load before it is damaged.

Concrete compressive strength (f_c) was determined according to formula (1) in which F refers to maximum load applied to the sample [N], A_c – cross-sectional area of the sample [mm].

$$f_c = \frac{F}{A_c}. \qquad (1)$$

Frost resistance cycles were conducted in two media. The first series of samples was exposed to the destructive influence of carbamide (symbol BM_{Mt}). The second series was stored in potassium formate (symbol BM_{Mr}).

Samples of the following dimensions 150x150x150 mm were intended to determine frost resistance. So-called usual analysis method was used in this type of test. It was based on freezing and defrosting of series of 12 concrete samples, which cured for 28 days in water of 20ºC. Research goals included 200 freezing-defrosting cycles. Samples were frozen in the air for 4 hours in temperature -18ºC and defrosted for 3 hours in water of temperature +18ºC. Evaluation of frost resistance refers to the determination of two parameters. The first parameter is the change of compressive strength of samples subject to freezing and defrosting cycles, according to formula (2) in which ΔR – change of compressive strength, f_{c1} – compressive strength of comparative samples, f_{c2} – compressive strength of samples subject to 200 frost resistance cycles. This test was conducted in compliance with guidelines [7] and determined the maximum load applied to the sample.

$$\Delta R = \frac{f_{c1} - f_{c2}}{f_{c1}} \cdot 100. \qquad (2)$$

The second parameter is the change of sample weight after frost resistance test determined according to formula (3) in which ΔG – change of samples weight after frost resistance test, G_1 – sample weight before the first freezing during water saturation, G_2 – sample weight before the last defrosting during water saturation.

$$\Delta G = \frac{G_1 - G_2}{G_1} \cdot 100. \qquad (3)$$

Internal structure of concrete composite was also assessed. Scanning electron microscope was used for this purpose. Fresh fractures were performed taking concrete samples; the preparation surface subject to SEM observations was not less than 1.0 cm^2. The extent of magnification was from 200x to 100000x. Chemical microanalyses of selected sections in concrete composite were performed, as well. The results obtained during this stage served as the basis for the analysis of similarity of distance courses of analysed concretes.

2. Research materials

The designed aggregate mixes of series BM complied with the requirements of [7]. The aggregate compositions of the designed mixes were considered as good grain size distribution of airfield pavements. Composition of BM concrete included: cement [14] in the quantity of 370 kg/m^3, sand in the quantity of 390 kg/m^3, granite grit fraction 2/8 mm in the quantity of 510 kg/m^3, granite grit fraction 8/16 mm in the quantity of 430 kg/m^3, granite grit fraction 16/32 mm in the quantity of 442 kg/m^3, water [8] in the quantity of 148 kg/m^3, air entraining agent – 1.74 kg/m^3 and plasticizing admixture – 0.63 kg/m^3. Ceramic dust was used as the modifier of concrete mix. The dust was dozed, as the substitute of part of fine aggregate. The modifier of grain size distribution 0/2 mm in the amount of 45 kg/m^3 were used This modifier is distinguished by high durability and resistance to variable temperature conditions. Using of dust influences lower susceptibility of hardened concrete to basic operation factors related to the air traffic.

The obtained concrete test results after 28 days of curing and subject to 200 frost resistance cycles were presented in Tab. 1.

Tab. 1. Parameters of concretes

Parameter	Unit	Concrete				
		BM	$^{św}BM_{Mt}$	$^{200}BM_{Mt}$	$^{św}BM_{Mr}$	$^{200}BM_{Mr}$
f_c	[MPa]	61.1	83.0	78.6	68.6	70.4
ΔR	[%]	–	3.6	4.8	2.9	4.2
ΔG	[%]	–	< 0.1	< 0.1	< 0.1	< 0.1

Based on observations of fractures of BM concretes stored in liquids (witnessing – ^{św}BM) and exposed to the influence of freezing cycles (^{200}BM) it was proved that the internal structure has changed. Observations of internal microstructure of concretes subject to frost resistance cycles (Fig. 1 and 2) proved significant diversification. In CC-II, concrete rare micro cracks were found of the width up to 4 µm in case of freezing in water and 5-6 µm in case of freezing in carbamide. Hydration products of both concretes also changed. Within contact area between quartz grains and CC-II concrete matrix, there is no portlandite crystallization in the form of tiles, while locally, ettringite concentration occurs. Internal crystallization in voids changed in comparison to concretes, which were not subject to frost resistance cycles, instead of ettringite crystals, sharp-edged portlandite tiles occurred. Within the contact area with the grain of the modifier, the extended zone with portlandite occurred. Additionally, concentration of silicates and hydrated calcium silicates type C-S-H in the form of fibres were present.

Fig. 1. Internal microstructure of selected sections (cement matrix) in concrete
a) BM_{Mt}, b) $^{św}BM_{Mt}$ and c) $^{200}BM_{Mt}$

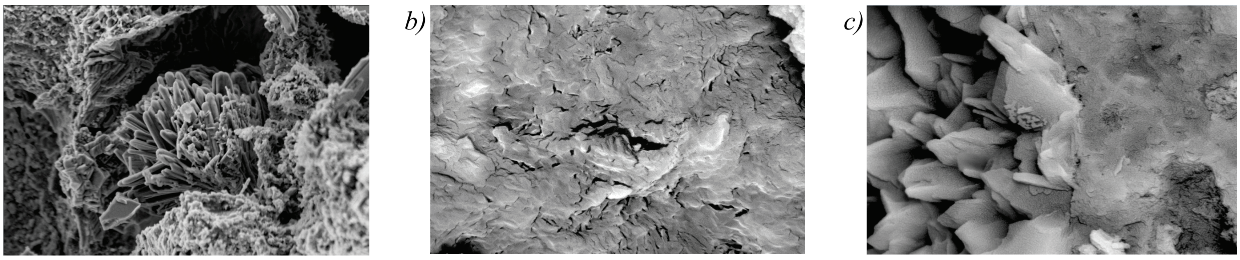

Fig. 2. Internal microstructure of selected sections (cement matrix) in concrete
a) BM_{Mr}, b) $^{św}BM_{Mr}$ and c) $^{200}BM_{Mr}$

3. Research methods

Data obtained as a result of chemical microanalysis (average values of 6 analyses) of concretes was subject to similarity analysis [1-3].

Chemical microanalyses (Fig. 3-6) of selected sections in concrete composite were performed, as well. The results obtained during the first stage served as the basis for the analysis of similarity of distance courses of analysed concretes.

As an input sequence in similarity analysis, BM characteristics values obtained were assumed. The data, which reflect the percentage of selected elements in one of świBM and 200BM reference concrete sections, play the role of target sequence, which input sequence is compared. Average

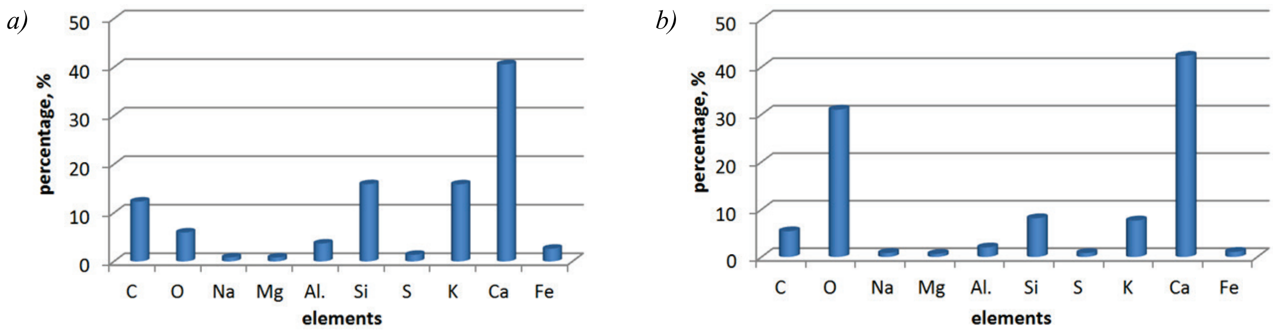

Fig. 3. Chemical microanalyses of selected sections (cement matrix) in concrete: a) $^{św}BM_{Mr}$ and b) $^{200}BM_{Mr}$

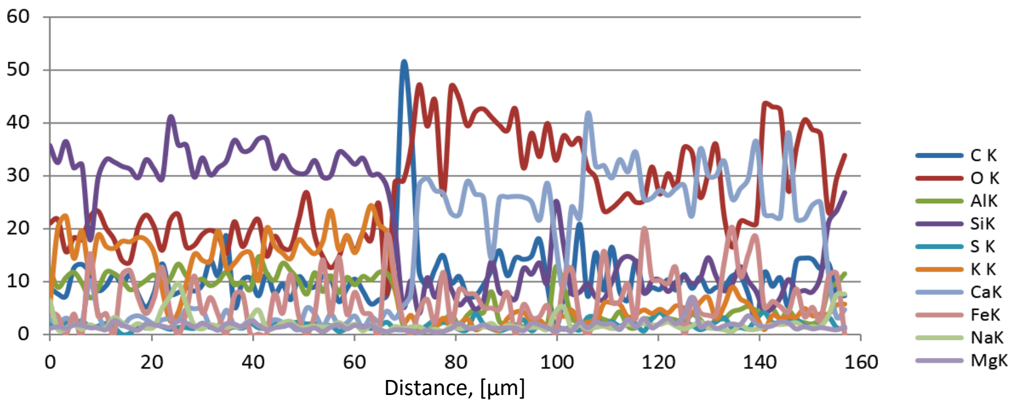

Fig. 4. Chemical microanalyses in contact area between granite aggregate and cement matrix in concrete BM_{Mr}

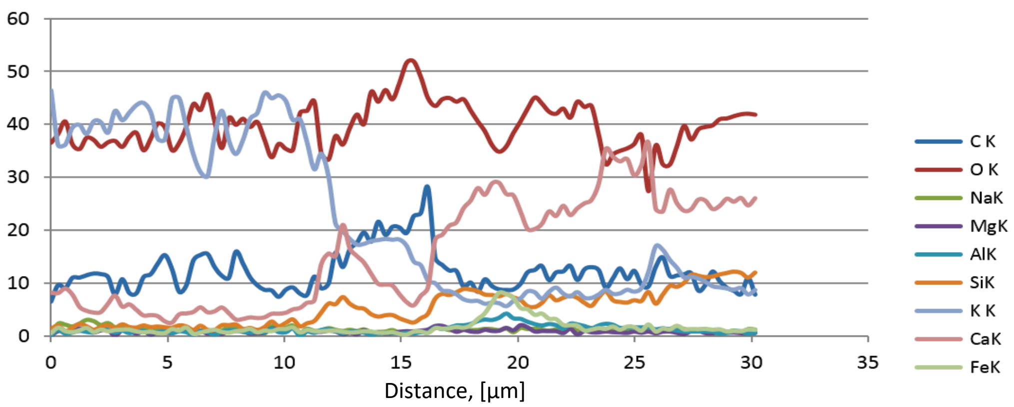

Fig. 5. Chemical microanalyses in contact area between granite aggregate and cement matrix in concrete $^{św}BM_{Mr}$

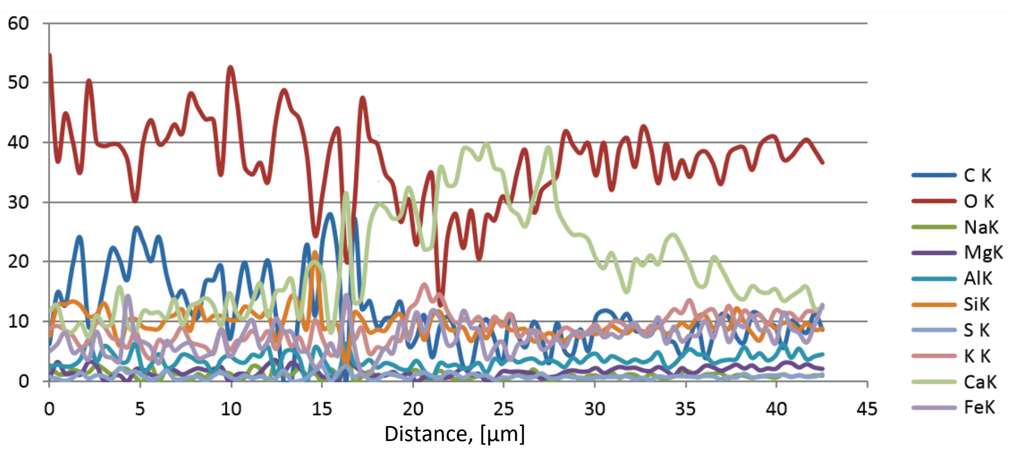

Fig. 6. Chemical micro analyses in contact area between granite aggregate and cement matrix in concrete $^{200}BM_{Mr}$

value of all D matrix elements was defined as similarity measurement of both sequences. The matrix D represents the distance between input and output values. The element d_{ij} of matrix D, located within the intersection *i*-of this line and *j*-of this column D. Refers to the distance i-of this value of input sequence and *j*-of this value of target sequence. Average value of all D matrix elements was defined as similarity measurement of both sequences. Due to the failure to take into consideration the arrangement of sequence values, similarity measurement was performed in the next stage. According to this measurement, various paths leading through the matrix from element (1, 1) to element (n_x, n_y) were compared. The path was determined, which leads from the least average distance along the path. Distances were determined between the values of input and target sequences along the optimal path. Determined distance histogram between input and target sequences along optimal path with the indicated Gauss's curve and nuclear density curve.

4. Results and discussions

According to the conducted analysis, similarity index was obtained between the input and target sequences along the optimal path. Determined similarity indexes were included in Tab. 2.

Tab. 2. Determined similarity indexes w_p in case of data before standardization and in case of data after the standardization for area of cement matrix.

Concrete	$^{św}BM_{Mr}$	$^{200}BM_{Mr}$	$^{św}BM_{Mt}$	$^{200}BM_{Mt}$
Data before standardization	2.02	1.57	2.02	1.94
Data after standardization	0.587	0.564	0.587	0.494

Analyses included the diversification in terms of contents of carbon (C), oxygen (O), aluminium (Al), silicon (Si), sulphur (S), potassium (K), calcium (Ca), iron (Fe), sodium (Na) and magnesium (Mg). The data for four various section were analysed. As the first section, cement matrix was taken into consideration. The three remaining sections included contact areas between cement matrix and grains of granite aggregate, grains of quartz aggregate and air voids. These indexes allow assessing similarity of each concrete in terms of contents of individual elements in the analysed sections.

Obtained similarity indexes were used as the basis to prepare diagrams of „proximity" of distance courses [3, 5]. The polygon method was applied, in which the number of sides corresponds to the number of attributes used in case of structure description.

The first stage was to arrange values of each attribute then the length of radii was calculated. These radii indicate vertices of individual polygons. It was assumed that attributes are similarity indexes of distance courses of concrete and BM concrete for the subsequent elements in the defined section. The object of the minimum attribute value corresponds with the shortest radius towards this attribute. The object of the greatest attribute value had the longest radius. The remaining values of attributes were converted linearly within the length of radii coming from the centre of polygon towards relevant attributes. It was assumed that values of the first attribute correspond to the radius of Ox axis direction. Next attributes are located on the subsequent radii, counted from the first one counter-clockwise, counted from the first one counter-clockwise. Shape and size of a single polygon reflects how a given object is presented in comparison with other objects described by means of the same attributes. Higher polygon proves smaller similarity of concrete to the reference concrete.

Based on the obtained distance courses, it was proved that the standardization of results has significant influence on the obtained results.

Analysing the data after the standardization it was proved that the contact area between air pores and cement matrix of $^{200}BM_{Mt}$ concrete is distinguished by the most similar nature of distance courses to the reference concrete. In case of concrete $^{św}BM_{Mt}$, contact areas between granite aggregate and cement matrix are distinguished by the most similar nature of distance courses to the reference concrete. In case of $^{200}BW_{Mt}$ concrete, the contact areas between air voids and matrix are distinguished by the most similar nature of distance courses to the reference concrete. In case of concrete $^{św}BM_{Mr}$, cement matrix are distinguished by the most similar nature of distance courses to the reference concrete. In case of $^{200}BW_{Mr}$ concrete, the contact areas between fine aggregate and matrix are distinguished by the most similar nature of distance courses to the reference concrete.

Changes of internal structure of concrete composite determined on the basis of the observation conducted by means of scanning electron microscope were proved.

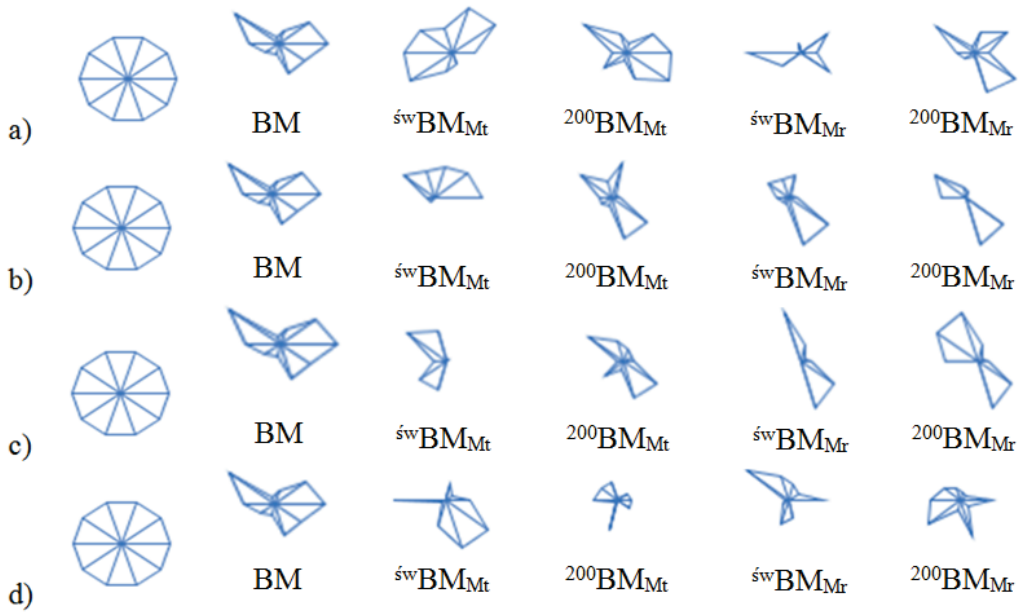

Fig. 7. The polygon method for data after standardization: a) concrete cement matrix, b) contact area between fine aggregate and cement matrix, c) contact area between granite aggregate and cement matrix, d) contact area between air pores and cement matrix

5. Conclusions

According to the conducted laboratory tests, the following conclusions have been reached:

1) Application of ceramic additive to the cement mix influences the changes of BM concrete ultimate compressive strength (decrease of resistance $^{200}BM_{Mt}$ concrete by 4.4 MPa in comparison of concrete of concrete $^{św}BM_{Mt}$ and increase of resistance $^{200}BM_{Mr}$ concrete by 2.2 MPa in comparison of concrete of concrete $^{św}BM_{Mr}$).
2) Characteristics of internal microstructure of BM concrete stored in carbamide and potassium formate with respect to the comparative concrete was changed.
3) Characteristics of internal microstructure of BM concrete after 200 frost resistance cycles in carbamide and potassium formate with respect to the comparative concrete was changed.
4) The determined wp similarities in the case of data after standardization for the cement matrix differ after 200 cycles by approximately 7%.
5) According to the analysis of the obtained distance courses for the concrete $^{św}BM_{Mt}$ it was proved that the most significant differences occur within the area of cement matrix.
6) According to the analysis of the obtained distance courses for the concrete $^{200}BM_{Mt}$ it was proved that the most significant differences occur within the area of cement matrix.
7) According to the analysis of the obtained distance courses for the concrete $^{św}BM_{Mr}$ it was proved that the most significant differences occur within the contact areas between cement matrix and fine aggregate grains.

8) According to the analysis of the obtained distance courses for the concrete $^{200}BM_{Mr}$ it was proved that the most significant differences occur within the contact areas between cement matrix and granite aggregate grains.
9) Concrete $^{św}BM_{Mt}$ within the contact area between air voids and cement matrix is the most similar to the reference BM concrete, in terms of distance courses.

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