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APPLICATION OF SIMILARITY METHOD OF DISTANCE COURSES DESCRIBING THE ELEMENTS CONTENT IN TYPICAL CEMENT CONCRETE

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Abstract

The article concerns the use of similarity analysis of distance course in the internal area of cement concrete intended for airfield pavements. Research procedure was presented and the obtained laboratory tests results were discussed. The contents of diversified elements in four zones (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) were specified by using scanning electron microscope. Based on the results obtained diagrams similarity of the analysed of areas in the concretes were prepared. The purpose of this article has been the assessment of an opportunity to apply the analysis of similarity of distance courses with respect to cement concrete intended for airfield pavements. The scope of article consisted of two stages. The analysis included cement concretes intended for airfield pavements, in compliance with requirements. The thermal analysis method was used; the selected concrete components were determined by means of quantitative method. The occurrence of crystalline stages was determined using X-ray diffraction method. Internal structure of concrete composite was assessed with the scanning electron microscope.

Keywords: *transport, airfield pavements, cement concrete, concrete microstructure, analysis of similarity*

1. Purpose and scope

The purpose of this publication has been the assessment of an opportunity to apply the analysis of similarity of distance courses with respect to cement concrete intended for airfield pavements. The scope of works consisted of two stages. The series of the cement concrete were prepared. The analysis included cement concretes intended for airfield pavements, in compliance with [2 and 6] requirements.

Airfield pavement concrete should be resistant to environmental impact, such as frost corrosion (XF 4), corrosion caused by carbonatation (XC 4), corrosion caused by chlorides (XD 3) and abrasion impact (XM 3) [6]. Cement concrete intended for the construction of airfield pavements should contain:

– Portland cement – which minimum class is CEM I 32.5 and moreover should contain below 0.6% Na_2O. Restrictions regarding the cement content intended for airfield pavements, depending on the environmental exposure classes, presented in Tab. 1,

- water in the amount dependent on the assumed w/c ratio, which the maximum value according to standard requirements [2] is 0.4. The used water pH value should be ≥4, H_2S content ≤20 mg/dm^3, sulphates content ≤600 mg/dm^3, and carbohydrate content ≤500 mg/dm^3,
- aggregate, which content in mix is 70-75% and total fine aggregate and cement content in the mix should not exceed 450 kg/m^3. Grain-size distribution curves of the designed aggregate mixes (fine + coarse) should be in between limit curves (lower and upper) which indicate the range of good grain size distribution, in accordance with [2]. The aggregate used in case of airfield pavements should meet the following requirements:
  - for coarse aggregate: mineral fines content ≤1.0%, evenness index ≤15, fragmentation resistance ≤40, abrasion resistance ≤20%, polishing resistance ≥50, grain absorbability ≤1.0%, foreign impurities ≤0.1% m,
  - for fine aggregate: mineral fines content ≤1.0%, foreign impurities ≤0.25%,
- additives and admixtures.

Tab. 1. Restrictions regarding the cement content depending on the environmental exposure classes

parameter	XF 4	XC 4	XD 3	XM 3
Minimum cement content CEM I 32.5, kg/m^3	340	280	300	300
Minimum cement content CEM I 42.5, kg/m^3	340	270	270	280

In the course of laboratory tests, the consistency class and air content were defined for the designed concrete mixes. In order to assess the suitability of the designed concretes to incorporate into airfield pavements, according to [2], it is required to determine their physical and mechanical properties during the assumed curing period (acc. to the standard after 28 days). Within the scope of concrete assessment, the following was determined:

- Volume density (ρ_o) according to [5],
- Compression strength (f_c) in accordance with the guidelines of [3], which should not be lower than 30/37 MPa for class C30/37, 35/45 MPa for class C35/45, 40/50 MPa for class C40/50 and 45/55 MPa for class C45/55,
- Tensile strength during splitting (f_{ct}) according to [4], which should not be lower than 3.3 MPa for class C30/37, 3.6 MPa for class C35/45, 3.7 MPa for class C40/50 and 3.8 MPa for class C45/55.

Using thermal analysis method, the selected concrete components were determined by means of quantitative method. The occurrence of crystalline stages was also determined using X-ray diffraction method. 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[1]. 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 the first stage served as the basis for the analysis of similarity of distance courses of analysed area of the concretes.

2. Tests results and their analysis

Class of concrete mixture consistency determined by means of Vebe method is S1. The air content in the mixture, which is 4.5%, meets the requirements of the NO standard (the recommended air content should be in the range of 4.5-5.5%). The volume density of hardened concrete is 2460 kg/m^3, and the mechanical parameters of the concrete meet the requirements for the assumed class of concrete. The obtained parameters of mixes and concretes after 28-day-curing period were listed in Tab. 2.

Tab. 2. Parameters of mixes and concretes (average of 6 measurements)

Composition [kg/m^3]				parameters			
				mixes		concretes	
Cement (according to 4)	aggregate	admixtures	Water (according to 5)	V [mm]	p [%]	f_c [MPa]	f_{ct} [MPa]
370.00	1382.00	2.37	148	16	4.5	57.0	4.29

Thermal analysis conducted in case of concrete series was the content of calcium hydroxide is 4.50% m/m determined. The content of calcium carbonate at the level of 1.80% m/m was determined, and the loss of roasting is 1000°C equal to 5.3% m/m – Fig. 1.

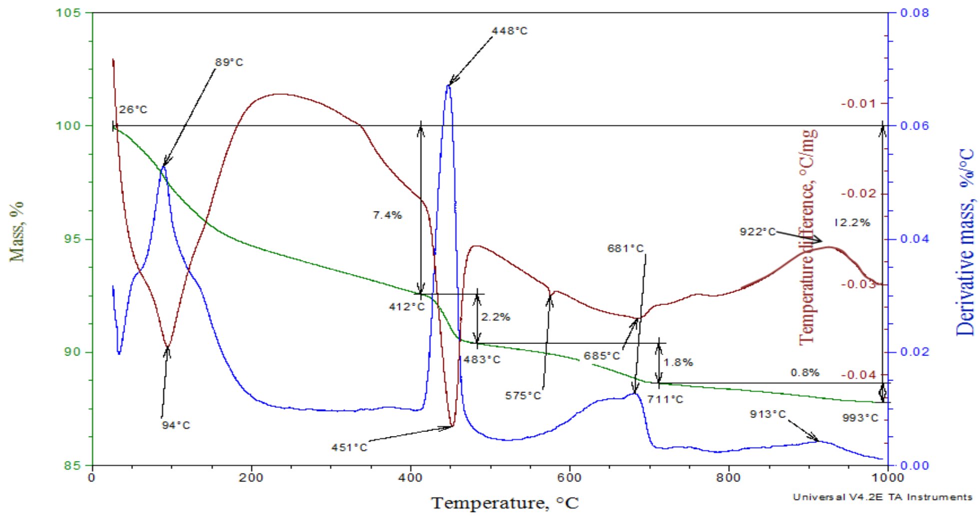

Fig. 1. Thermogram of the analysed concrete

Determination of qualitative phase composition of BW concrete slurry aggregate components were distinguished (in the form of quartz, feldspars and biotite), products of hydration and cement carbonatation (portlandite and calcite) and cement remnants – Tab. 3.

Tab. 3. Qualitative phase composition according to X-ray diffraction analysis results[1]

sample	intensity of selected reflexes of distinguished components				
	alite	calcite	ettringite	quartz	portlandite
BW	433	322	690	2173	1159

In this concrete, according to the results of X-ray diffraction analysis, were distinguished components aggregate components (quartz and calcite), products of hydration and cement carbonatation (portlandite and ettringite) and cement remnants – Fig. 2.

According to observations of polished sections of concrete by means of scanning electron microscope, it was proven that distribution of individual internal components is diversified. In case of this concrete, numerous micro cracks (Fig. 3b and 3c) were observed, which in case of cement matrix, these cracks were distinguished by average aperture of 8 μm. Cracks of interface between aggregate grains and cement matrix occurred mostly within the coarse grains area and their maximum aperture was up to 5 μm. In case of cement matrix of this concrete numerous and long ettringite crystals (up to 100 μm) predominated.

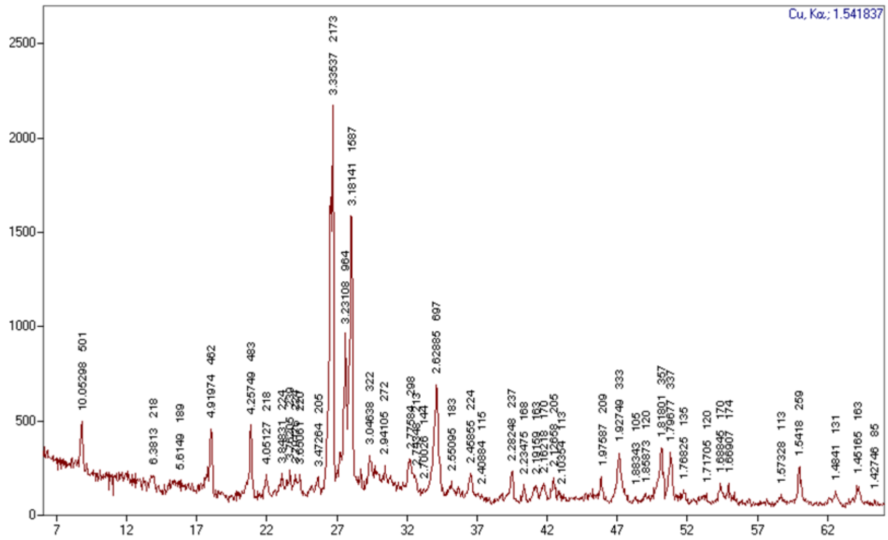

Fig. 2. Phase composition of cement concrete

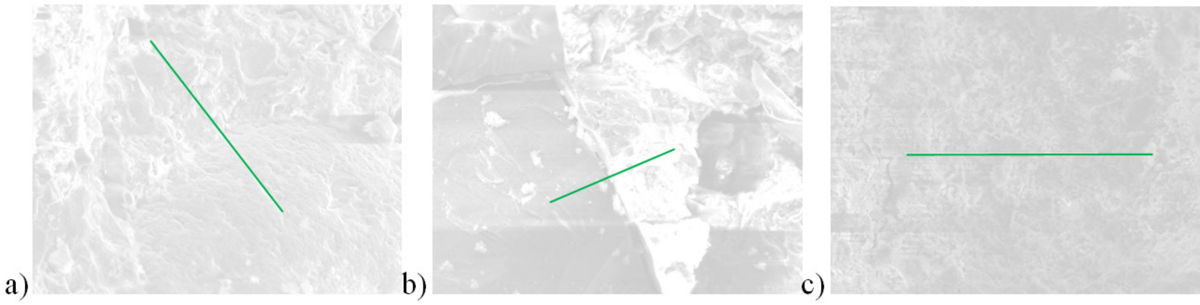

Fig. 3. Exemplary microanalysis of BW concrete: a) contact area between fine aggregate grains and cement matrix b) contact area between coarse aggregate grains and cement matrix, c) cement matrix

Data obtained as a result of chemical microanalysis (average values of 6 analyses) of concretes was subject to similarity analysis. As an input sequence in similarity analysis of BW, concrete series were assumed.

The data, which reflect the percentage of selected elements in one of BW reference concrete sections, play the role of target sequence, which input sequence is compared with. The original form of input and target sequence was presented on Fig. 4.

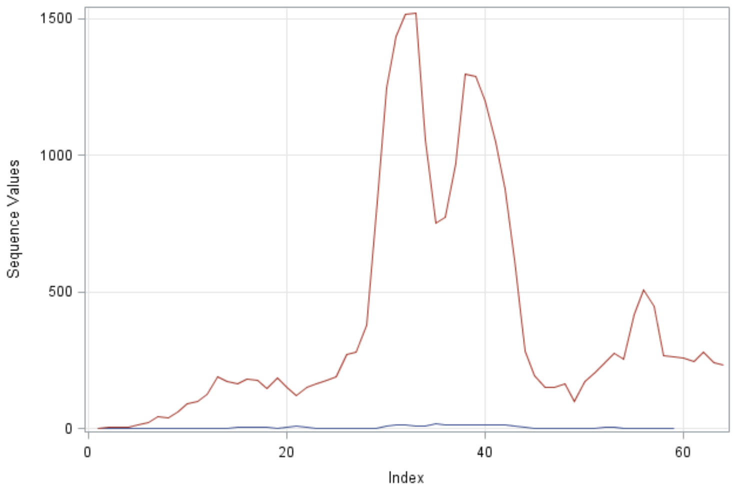

Fig. 4. Distance courses of original input sequence (red) and target sequence (blue) – contact area between cement matrix and fine aggregate for aluminium elements

In general case, the analysed courses were represented as $(x_1, x_2, \dots, x_{nx})$ for input sequence and $(y_1, y_2, \dots, y_{ny})$ for target sequence. As a record intended for comparison of input value x_i and target value y_j, the absolute value of difference $x_i - y_j$ was assumed. In case of input and target sequences n_x x n_y of the distance between all possible pairs of elements of these sequences were calculated. These distances were presented in the form of matrix D – Fig. 5.

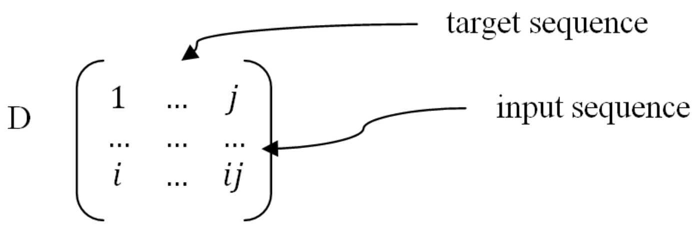

Fig. 5. Designed D matrix

Average value of all D matrix elements was defined as similarity measurement of both sequences. The path was determined, which leads from the least average distance along the path – Fig. 6. Relocation along the diagonal means direct influence between the target and input sequence. Statistics concerning the path present the amount of compression and expansion of target sequence with respect to input sequence.

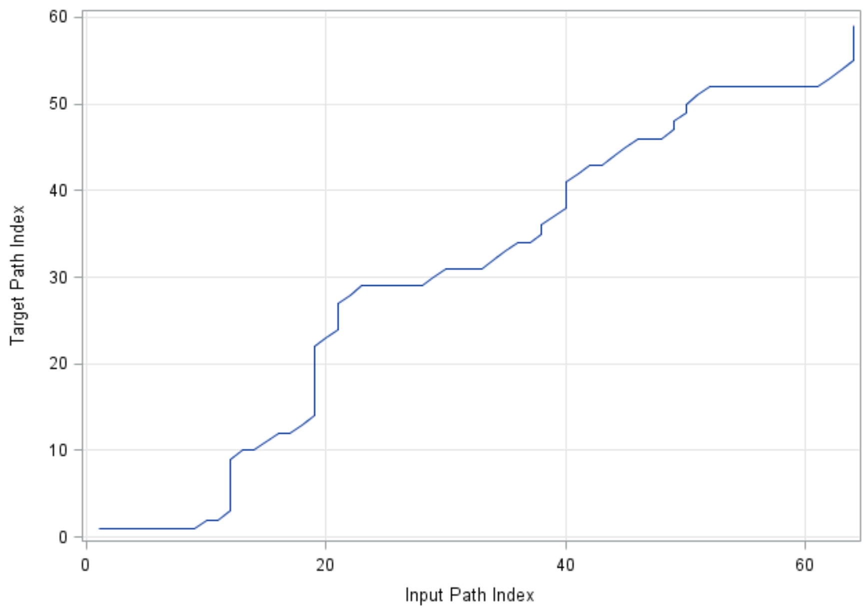

Fig. 6. Path leading to the smallest distance between the input and target sequences – contact area between cement matrix and fine aggregate for aluminium elements

Distances were determined (Fig. 7) between the values of input and target sequences along the optimal path and the Fig. 8 presents distance histogram between input and target sequences along optimal path.

According to the conducted analysis, similarity index was obtained between the input and target sequences along the optimal path, which is 5.246. In order to compare the analysed distance courses standardization of values of both sequences (input and target) was used. Average values were deducted from each element and the difference result was divided by standard deviation. Fig. 9 presents distance courses of standardized input and target sequence.

Figure 10 presents the distance between values of input and target sequences along the optimal path and Fig. 11 presents histogram of distance between standardized input and target sequences along optimal path.

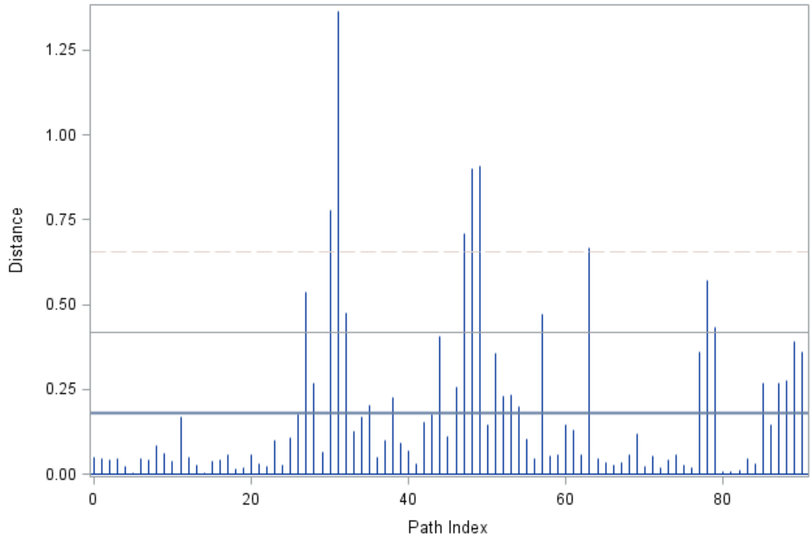

Fig. 7. Distance between the input and target sequences along optimal path – contact area between cement matrix and fine aggregate for aluminium elements

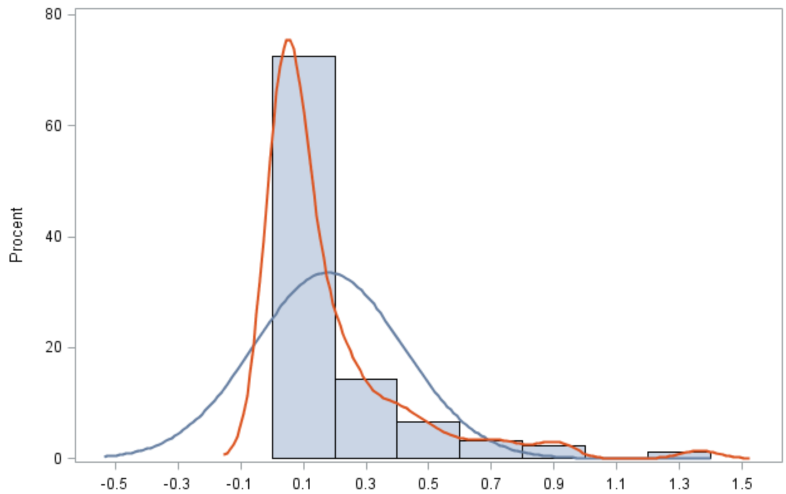

Fig. 8. Histogram of distance between input and target sequences along optimal path with indicated Gauss's curve (blue) and nuclear density curve (red) – contact area between cement matrix and fine aggregate for aluminium elements

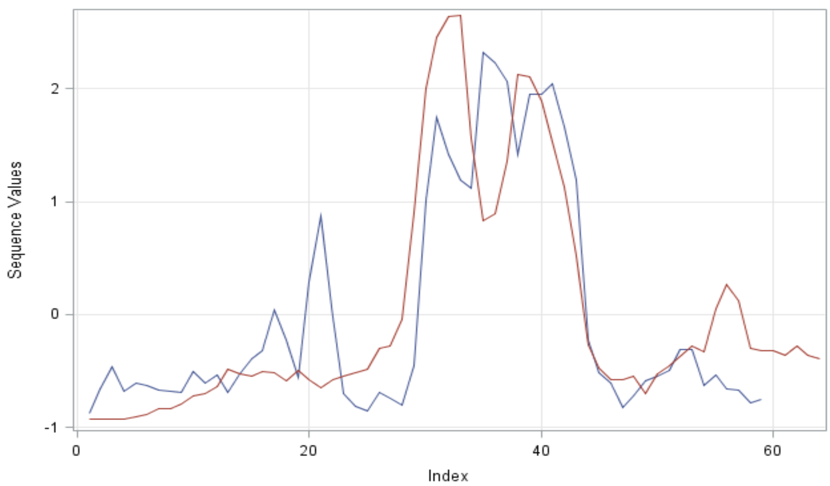

Fig. 9. Distance courses of the standardized input sequence (red) and standardized target sequence (blue) – contact area between cement matrix and fine aggregate for aluminium elements

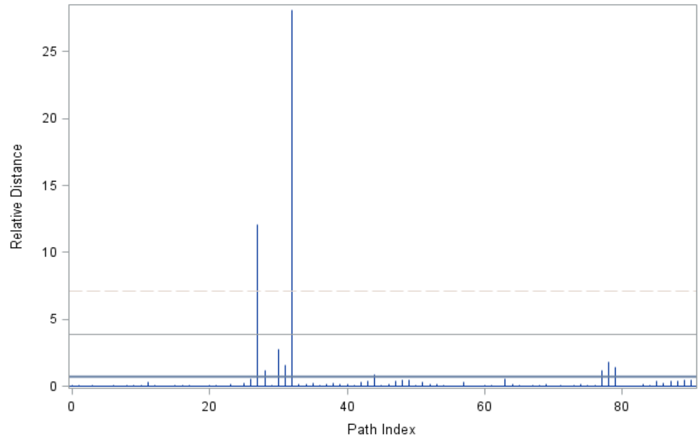

Fig. 10. Diagram of distance between standardized input sequence and standardized target sequence along optimal path – contact area between cement matrix and fine aggregate for aluminium elements

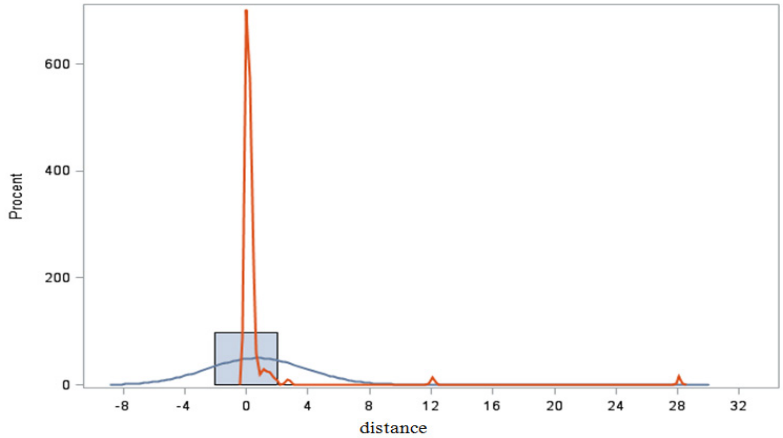

Fig. 11. Histogram of distance between standardized input sequence and standardized target sequence along optimal path with the indicated Gauss's curve (blue) and nuclear density curve (red)

The final effect of the conducted analysis was to define similarity index between input and target sequences along the optimal path, which is 0.378. The scope of the conducted analyses included diversification in terms of content of 10 chemical elements (carbon – C, oxygen – O, aluminum – Al, silicon – Si, sulphur – S, potassium – K, calcium – Ca, iron – Fe, sodium – Na, magnesium – Mg) in four various areas (matrix, matrix-granite, matrix-quartz, matrix-void) – Fig. 12.

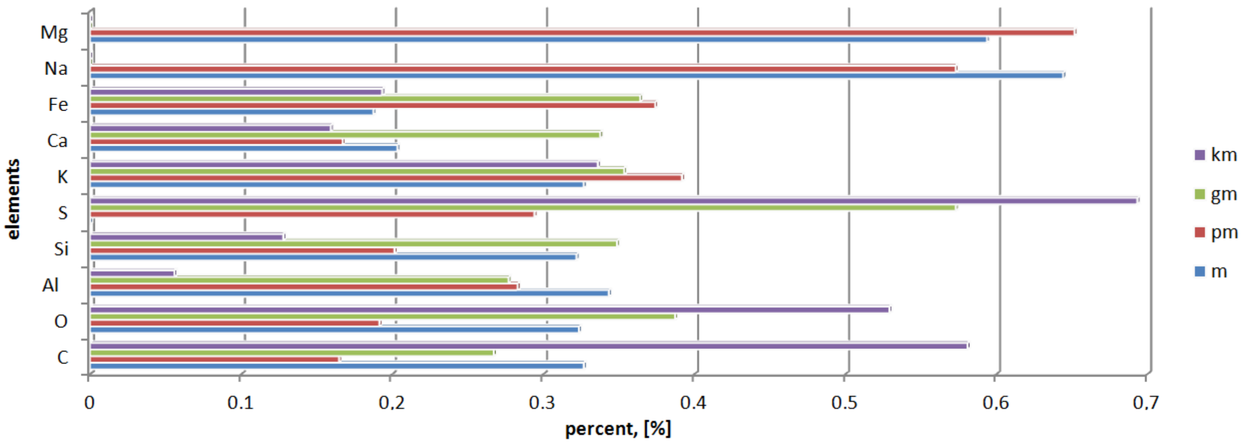

Fig. 12. The similarity indexes w_p for areas of cement matrix (a), contact area between granite grit and cement matrix (b), contact area between quartz aggregate and cement matrix (c) and contact area between air voids and cement matrix(d)

For this purpose, the polygon method was used, where the shape and size of the result polygons, in minor extent, depend on the order of attributes. The number of sides of individual polygons equals the number of attributes used to specify objects.

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. Values of the first attribute were presented on the radius of Ox axis direction. Values of the next attributes are located on the subsequent radii, counted from the first one counter-clockwise. Over the radius corresponding with the first attribute, there is the radius referred to the second attribute and under thereof – to the last attribute. Smaller polygon proves higher similarity of area of concrete to the reference area of concrete.

In the event of data subject to standardization, the most significant differences were found within the matrix area and contact area between the matrix and aggregate grains (quartz and granite).

3. Conclusions

According to the analysis of the obtained distance courses, it was proved that the most significant differences occur within the area of cement matrix and contact areas between cement matrix and aggregate grains.

Pursuant to the analysis of the obtained results, it was proved that the suggested method of similarity of distance courses could be applied to assess the elements content in different areas of concrete intended for airfield pavements.

References

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