Journal of KONES Powertrain and Transport, Vol. 24, No. 4 2017

ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.3354

APPLICATION OF SIMILARITY METHOD OF DISTANCE COURSES DESCRIBING THE ELEMENTS CONTENT IN CONCRETE INTENDED FOR AIRFIELD PAVEMENTS

Małgorzata Linek

Kielce University of Technology
Faculty of Civil Engineering and Architecture, Department of Transportation Engineering
Tysiąclecia Państwa Polskiego Street 7, 25-314 Kielce, Poland
tel.: +48 41 3424844
e-mail: linekm@tu.kielce.pl

Abstract

The work presents the applied similarity methods of distance courses in case of cement concrete intended for airfield pavements. Composition of concrete mixes was designed and their parameters were defined. Compressive strength of hardened concrete and components thereof and the occurrence of crystal phases were determined. 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. Similarity indexes between input and target sequence were defined. Diagrams presenting the similarity of the analysed concretes were prepared. It was proved that the suggested method could be used to assess the elements content and define the similarity of concrete intended for airfield pavements. The scope of works consisted of two stages. During the first one, two series of cement concrete were prepared. The analysis included cement concretes intended for airfield pavements, in compliance with requirements. The influence of variable environmental conditions with respect to standard ones on the selected features of hardened concretes was assessed.

Keywords: *cement concrete, airfield pavement, 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. During the first stage, being the introduction to the publication, two series of cement concrete were prepared. The analysis included cement concretes intended for airfield pavements, in compliance with [3] requirements. BW symbol refers to cement concrete of standard composition – Tab. 1. Ceramic additive as the substitute for the part of fine aggregate was used in BM concrete composition. This modifier was distinguished by different properties from fine aggregate (absorbability, physical and chemical characteristics, resistance to high temperature). The influence of variable environmental conditions with respect to standard ones on the selected features of hardened concretes was assessed.

In the course of laboratory tests, the parameters of concrete mixes and hardened mixes were determined, after 28 days of concrete curing [8, 9]. Consistency class (V) [according to 6] and air content (p) [according to 7] were defined for the designed concrete mixes. Compression strength (f_{ck}) [10] in case of hardened concrete was determined. 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 concretes. Preliminary assumptions within the scope of second stage analysis (Fig. 1.)

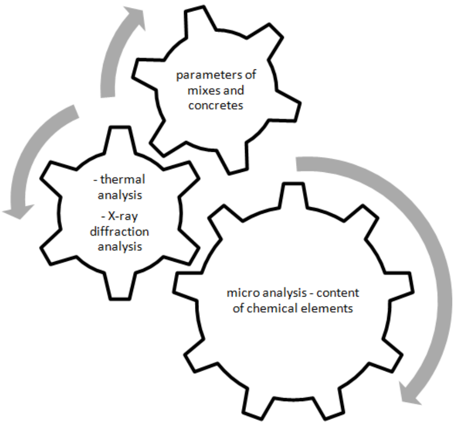

Fig. 1. Preliminary assumptions of the analysis of similarity of distance courses

2. Tests results and their analysis

The obtained parameters of mixes and concretes after 28-day-curing period were listed in Tab. 1. According to the obtained results, it was proved that concrete of BM series has average compressive strength 59.4 MPa.

Tab. 1. Parameters of mixes and concretes – first stage

concrete	Composition [kg/m^3]				parameters		
					mixes		concretes
	Cement (according to 4)	aggregate	admixtures	Water (according to 5)	V	p [%]	f_{ck} [MPa]
BW	370.00	1382.00	2.37	148	16	4.5	57.0
BM	370.00	1340.00	2.37	148	14	4.6	59.4

Thermal analysis conducted in case of BW and BM concrete series proved diversification of features – Tab. 2. Differences between characteristics of BW and BM concretes can apparently be observed in case of calcium hydroxide. In case of BW concrete, the content of calcium hydroxide is much higher than in case of BM concrete. The content of all analysed components in case of BW concrete is higher than in case of BM concrete.

Tab. 2. Content of selected components in tested concrete based on the results of thermal analysis (DTG, DTA and TG) [2]

sample	content, [% m/m]					
	water bound			calcium hydroxide	calcium carbonate	loss of roasting to 1000°C
	HI	HCH	sum			
BW	3.40	1.10	4.50	4.50	1.80	5.30
BM	3.15	0.89	4.04	3.66	1.66	4.78

Determination of qualitative phase composition of BW and BM concrete slurry (Tab. 3) proved diversification. During the analysis of BW aggregate components were distinguished (in the form of quartz, feldspars and biotite), products of hydration and cement carbonatation (portlandite and calcite) and cement remnants. Additionally, in case of BM concrete, mullite and carboaluminate occurrence was proved.

According to the results of X-ray diffraction analysis in BW concrete, the following crystal components were distinguished:

- Aggregate components – quartz, calcite,
- products of hydration and cement carbonatation – portlandite and ettringite,
- cement remnants.

Tab. 3. Qualitative phase composition according to X-ray diffraction analysis results [2]

sample	Intensity of selected reflexes of distinguished components						
	alite	portlandite	ettringite	carboaluminate	calcite	mullite	quartz
BW	433	1159	690	-	322	-	2173
BM	399	1429	643	220	298	268	1594

According to the results of X-ray diffraction analysis in BM concrete, the following crystal components were distinguished:

- Aggregate components – quartz, calcite, feldspars, biotite,
- products of hydration and cement carbonatation – portlandite and ettringite,
- cement remnants.

Pursuant to observations of fracture of BW and BM concrete series, it was proved that, internal structure changed. In case of crystallization, there is diversification within the area of cement matrix, contact area between cement matrix and aggregate grains and in case of porosity characteristics of both concretes. In case of BW concrete, bigger air voids than in case of BM concrete were found. Moreover, these voids in BW concrete were located in greater distances than in case of BM concrete (on average by 0.12 mm). Crystallization of cement matrix was also different. In case of BW concrete, numerous and long ettringite crystals (up to 100 μm) predominated, while in case of BM concrete, crystals of this type were rare. In case of BM concrete, numerous hydrated calcium silicates type C-S-H crystallized. Moreover, in case of BM concrete, there were fewer cracks both in cement matrix itself, as well as within contact areas with aggregate grains.

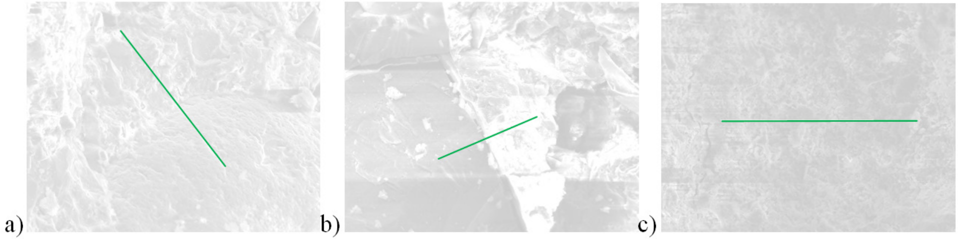

Fig. 2. Exemplary microanalysis of BW concrete: a) contact area between fine aggregate grains and cement matrix, b) contact area between coarse aggregate grains and cement matrix, c) cement matrix

Fig. 3. Exemplary microanalysis of BM 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, BM28 characteristics values obtained as w result of microanalysis of BM concrete series were assumed. The data, which reflect the percentage of selected elements in one of BW28 reference concrete sections, play the role of target sequence, which input sequence is compared with. Basic input sequence characteristics were presented in Tab. 4, while Fig. 4 presents the original form of input and target sequence.

Tab. 4. Input sequence characteristics in case of the selected element (oxygen) within cement matrix section

variable	a number of observations	minimum	maximum	mean	standard deviation
BM28	64	19.91	46.39	35.03	6.134

In general case, the analysed courses were represented as (x_1, x_2, …, x_{nx}) for input sequence and (y_1, y_2, …, 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, the element d_{ij} of which, 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 average distance along the path. Fig. 5 presents the route of such path in case of the considered sequences. Relocation along the diagonal means direct influence between the target and input sequence. Motion along vertical path refers to the compression of target sequence with respect to input sequence, while the motion along the horizontal path – expansion of the target sequence with respect to input sequence. Expansion of a single value of target sequence takes place when it refers to more than one value of input sequence. Expansion of a single value of input sequence takes place when it refers to more than one value of target sequence. Statistics concerning the path present the amount of compression and expansion of target sequence with respect to input sequence.

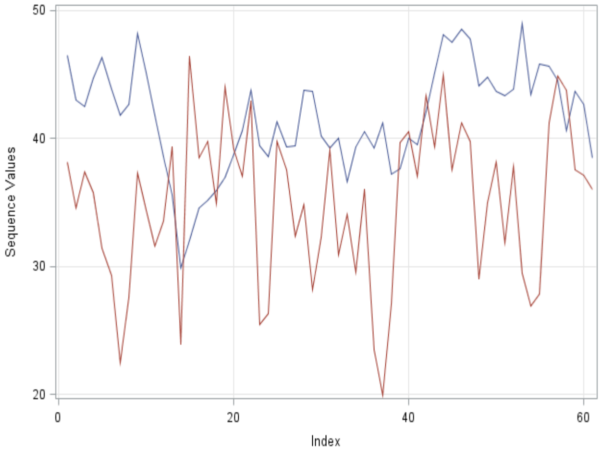

Fig. 4. Distance courses of original input sequence (red) and target sequence (blue)

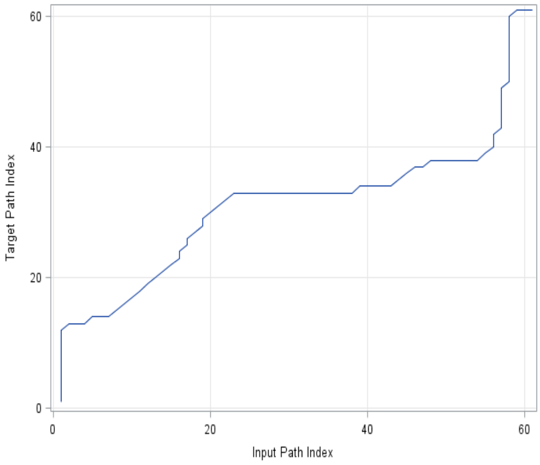

Fig. 5. Path leading to the smallest distance between the input and target sequences

Distances were determined (Fig. 6) between the values of input and target sequences along the optimal path. Path indexes are placed on the axis of abscissa. Vertical sections refer to the distance between sequences along the path. Bold horizontal line refers to the average distance; the two remaining horizontal lines refer to distances, which differ from the average one by one or two standard deviations. Fig. 7 presents distance histogram between input and target sequences along optimal path with the indicated Gauss's curve and nuclear density curve.

According to the conducted analysis, similarity index was obtained between the input and target sequences along the optimal path, which is 4.551.

In order to compare the analysed distance courses, both sequences: input and target ones, were subject to normalization. For this purpose, standardization of values of both sequences was used. Average values were deducted from each element and the difference result was divided by standard deviation. Fig. 8 presents distance courses of standardized input sequence and standardized target sequence.

Figure 9 presents the chart of path from the smallest distance between the standardized input sequence and standardized target sequence.

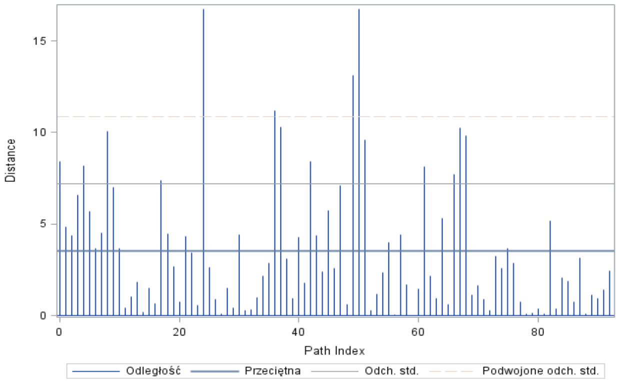

Fig. 6. Distance between the input and target sequences along optimal path

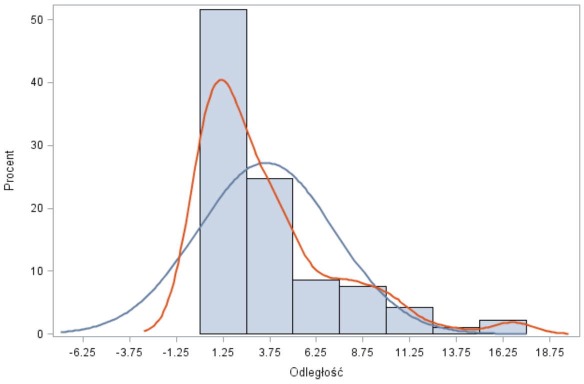

Fig. 7. Histogram of distance between input and target sequences along optimal path with indicated Gauss's curve (blue) and nuclear density curve (red)

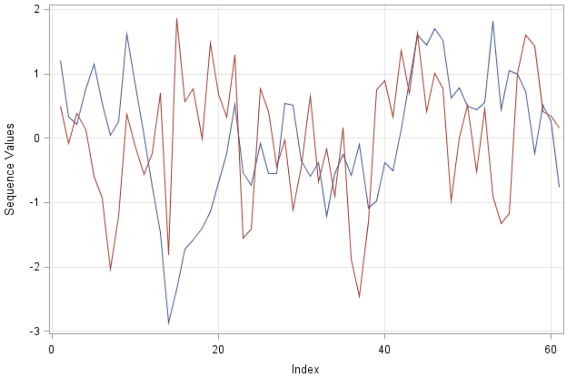

Fig. 8. Distance courses of the standardized input sequence (red) and standardized target sequence (blue)

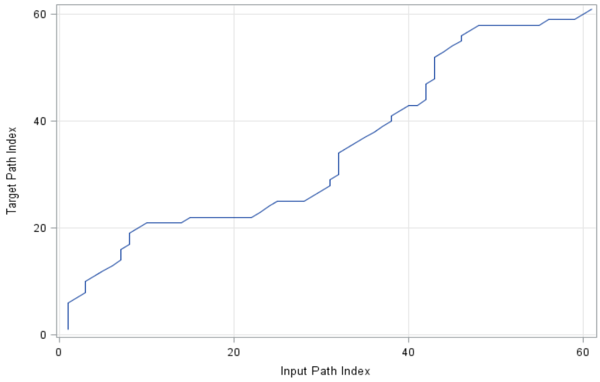

Fig. 9. Chart of path from the smallest distance between the standardized input sequence and standardized target sequence

Figure 10 presents the distance between values of input and target sequences along the optimal path. Path indexes are located on the axis of abscissa. Vertical sections refer to the distance between sequences along optimal path. Bold horizontal line refers to the average distance; the two remaining horizontal lines refer to the distance, which differs from the average one by one or two standard deviations. Fig. 11 presents histogram of distance between standardized input and target sequences along optimal path with the indicated Gauss's curve and nuclear density curve.

The final effect of the conducted analysis was to define similarity index between input and target sequences along the optimal path, which is 0.438.

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). So far, such wide range of chemical microanalysis with the use of formal similarity analysis of the obtained data has not been conducted. Similarity indexes included in Tab. 5 were obtained analogically, as described above. These indexes allow assessing independently the similarity of each concrete with respect to contents of individual elements in the considered areas.

According to the obtained similarity indexes, diagrams presenting „proximity" of distance courses of the analysed concretes were prepared, with respect to reference concrete in terms of contents of elements in matrix and contact areas with quartz, and granite grains and air voids.

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.

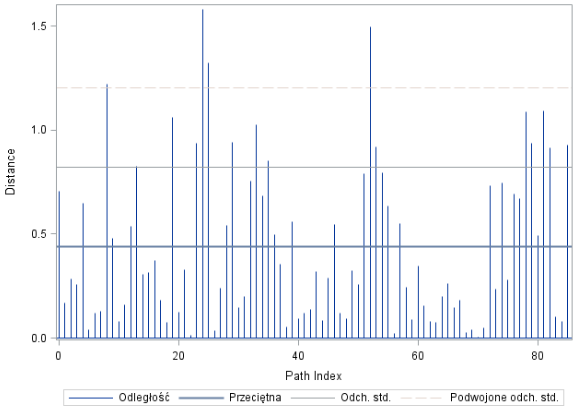

Fig. 10. Diagram of distance between standardized input sequence and standardized target sequence along optimal path

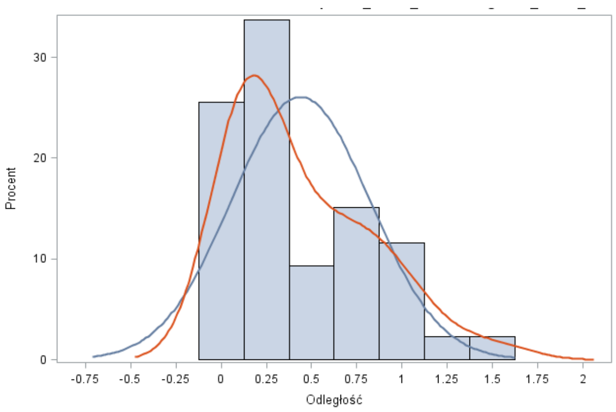

Fig. 11. Histogram of distance between standardized input sequence and standardized target sequence along optimal path with the indicated Gauss's curve (blue) and nuclear density curve (red)

Tab. 5. The list of similarity indexes w_p for selected areas

element									
C	O	Al	Si	S	K	Ca	Fe	Na	Mg
matrix (data prior to standardization)									
1.850	3.550	0.360	1.780	1.700	0.350	2.860	0.750	1.050	1.340
matrix (data after standardization)									
0.513	0.438	0.366	0.449	0.803	0.496	0.451	0.346	0.812	0.766
matrix-void (data prior to standardization)									
4.200	3.300	0.600	2.400	0.200	0.200	3.500	1.500	0.200	0.200
matrix-void (data after standardization)									
0.371	0.386	0.552	0.383	0.427	0.560	0.414	0.623	0.525	0.524
matrix-quartz (data prior to standardization)									
1.900	3.000	1.800	4.100	1.000	0.800	6.300	0.900	1.300	1.100
matrix-quartz (data after standardization)									
0.394	0.386	0.457	0.557	0.760	0.583	0.377	0.444	0.677	0.814
matrix-granite (data prior to standardization)									
0.519	0.392	0.452	0.428	0.740	0.496	0.544	0.420	0.517	0.619

In order to create polygons, values of each attribute were arranged and then the length of radii indicating vertices of individual polygons was calculated. 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. 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. 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. Attributes are similarity indexes of distance courses of concrete and reference concrete for subsequent elements in the defined area. Smaller polygon proves higher similarity of concrete to the reference concrete.

Based on the obtained distance courses (Fig. 12), it was proved that the influence of results standardization is a significant factor. In case of data without standardization, the contact area between the air void and cement matrix has the most similar distance courses to the reference concrete. The highest diversification was proved in case of cement matrix. 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 fine aggregate grains. The remaining contact areas prove higher similarity of distance course with respect to BW concrete; however, they clearly differ from thereof. The observed phenomena of high diversity can be explained by mix composition, due to dust additive and diversification with respect to the occurred hydration products.

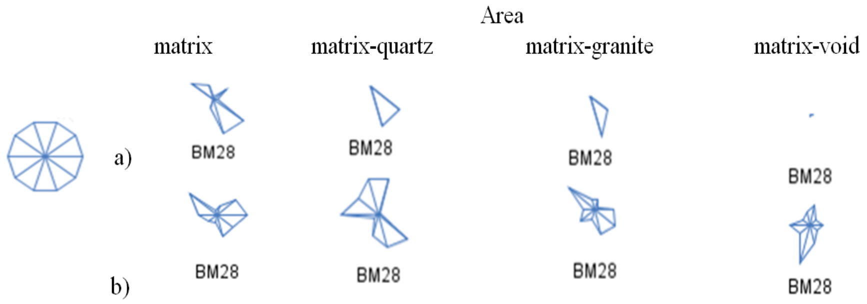

Fig. 12. The polygon method: a) data prior to standardization, b) data after standardization

3. Conclusions

According to the thermal analysis results, it was proved that concrete of BW series is distinguished by higher contents of the selected components (water combined as a result of hydration and hydrolysis processes, hydroxide and calcium carbonate).

Comparative analysis of phase composition of BM concrete with reference to BW concrete proved higher portlandite contents and mullite and calcium carbo aluminate occurrence. Alite, ettringite, calcite and quartz predominated in the composition of BW concrete.

Pursuant to the observations conducted by means of SEM, it was proved internal microstructure of BM concrete significantly differs from the structure of BW concrete. BM concrete is distinguished by more-favourable internal structure.

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 of all research methods, it was proved that the suggested method of similarity of distance courses could be applied to assess the elements content in concrete intended for airfield pavements.

References

[1] Krzywobłocka-Laurow, R., Siemaszko-Lotkowska, D., *Determination of the phase composition of common cements*, Instruction of Building Research Institute, No. 419, Warsaw 2006.
[2] Linek, M., *Surface concrete with improved parameters of physical and mechanical on the loads caused by forced temperature*, PhD Thesis, Kielce 2013.
[3] NO 17-A204:2015 *Airfield concrete pavements – Requirements and test methods for cement concrete pavements* – Polish standard, 2015.
[4] PN-EN 197-1:2012 *Cement, part 1: Composition, specifications and conformity criteria for common cements* – Polish standard 2012.
[5] PN-EN 1008:2004 *Mixing water for concrete – Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete* – Polish standard 2004.
[6] PN-EN 12350-2:2011 *Testing fresh concrete, Part 2: test* – Polish standard 2011.
[7] PN-EN 12350-7:2011 *Testing fresh concrete, Part 7: Air content – Pressure methods* – Polish standard 2011.
[8] PN-EN 12390-1:2013 *Testing hardened concrete – Part 1: Shape, dimensions and other requirements for specimens and moulds* – Polish standard 2013.

[9] PN-EN 12390-2:2011 *Testing hardened concrete – Part 2: Making and curing specimens for strength tests* – Polish standard 2011.
[10] PN-EN 12390-3:2011 *Testing hardened concrete – Part 3: Compressive strength of test specimens* – Polish standard 2011.