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Using Scanning Electron Microscope and Computed Tomography for Concrete Diagnostics of Airfield Pavements

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***Abstract*—**This article presents the comparison of selected evaluation methods regarding microstructure modification of hardened cement concrete intended for airfield pavements. Basic test results were presented for two pavement quality concrete lots. Analysis included standard concrete used for airfield pavements and modern material solutions based on concrete composite modification. In case of basic grain size distribution of concrete cement CEM I 42,5HSR NA, fine aggregate and coarse aggregate fractions in the form of granite chippings, water and admixtures were considered. In case of grain size distribution of modified concrete, the use of modern modifier as substitute of fine aggregate was suggested. Modification influence on internal concrete structure parameters using scanning electron microscope was defined. Obtained images were compared to the results obtained using computed tomography. Opportunity to use this type of equipment for internal concrete structure diagnostics and an attempt of its parameters evaluation was presented. Obtained test results enabled to reach a conclusion that both methods can be applied for pavement quality concrete diagnostics, with particular purpose of airfield pavements.

***Keywords*—**Scanning electron microscope, computed tomography, cement concrete, airfield pavements.

I. Introduction

AIRFIELD pavement concrete diagnostics requires application of up-to-date research and analytical methods, which allow for sufficiently accurate assessment of structure condition. It is particularly significant to implement methods which efficiently and quickly allow to assess quality and forecast service life of cement concrete structures. As far as airfield pavements are concerned, particularly important aspect is an opportunity to assess changes of concrete condition and predict future defects development. Any pavement defects in macrostructure, even those evaluated visually, occurred much earlier, in microstructure. In order to obtain comprehensive information regarding concrete pavement condition, it is necessary to refer to internal structure of cement composite being analysed. Detailed evaluation of microstructure parameters of such concrete allows also to forecast the future composite changes. Properly planned maintenance, the scope of repairs scheduled in advance and counteracting further defects of concrete structure, has significant influence on extending safe operation period of the whole structure which, due to constant development of aircraft industry and increase of aircraft transport, is the significant aspect of extending operation period and service life of airfield pavements.

Parameters and quality of concrete incorporated into structure are determinants of pavement service life. Cement composite structure refers usually to internal structure image, including components distribution typical for this structure [2], [9]. Hardened cement component contains the following elements: Hardened cement slurry (referred also to as cement matrix), coarse and fine aggregate grains (mainly of diversified mineral composition and diversified shapes and dimensions), pores and air gaps, scratches and cracks (occurred, for example in the course of hydration process, and later, in the course of hardening process and operation or as a result of variable surrounding temperature and humidity, high temperature during thermal shock or fire, etc.) [1], [9]. Contact zones, also referred to as contact layers, are separate components of cement composite. These zones occur between aggregate grains and cement slurry and they are usually distinguished by increased porosity. Cement slurry is concrete component, which is the most susceptible to variable ambient conditions, especially variable humidity and temperature conditions. The changes of concrete composition and his structure determine mechanical properties of hardened concrete [9]. With reference to thereof, it is necessary to learn the internal concrete composite structure and relations between individual concrete components. Intentionally modifying concrete mixture composition, hardened concrete parameters can be changed, which, with suitable material selection, can influence the extension of service life of concrete and the whole structure.

The aim of the study was the possibility of using SEM (scanning electron microscope) and TC (computer tomography) to evaluate changes in the microstructure of hardened cement concrete in the result of modifications of the composition of the mixture.

II. Applied Research Methods

The article presents selected diagnostic methods which allow to evaluate parameters of internal cement composite structure. Application of scanning electron microscope and X-ray computed tomography in diagnostics of cement concrete intended for airfield pavements has been discussed.

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A. Scanning Electron Microscopy

The analysis has been conducted using scanning electron microscope of Zeiss-SUPRA, type, manufactured by German company Zeiss. Recent fractures were obtained from CC-1 and CC-2 concrete samples, after 28-day-curing period. In order to increase conduction and obtain better secondary electron emission from a sample, and, as consequence, obtain better quality images, 10 nm, gold coat was applied on analysed concrete samples using Baltec SCD 005 equipment with CEA 035 attachment. Preparation surface, monitored by means of scanning electron microscope, each time was greater than 1,0 cm^2. Applied magnification range was assumed from 200x to 100000x [4].

Using scanning electron microscope allowed to assess changes occurring in hardened concrete structure as a result of modification of concrete mixture composition. According to single observations, there were changes of crystals quantity and morphology, dimensions and orientation of components and additionally chemical composition.

B. X-Ray Computed Tomography

Using X-ray computed tomography method, among others, the following were analysed: porosity geometry of permeable cement concrete [3] and pavement concrete [5] and phenomena occurring within concrete with reference to their influence on service life [11]. Moreover, the author [6] proved that the type of applied software or research accuracy do not play significant role in respect of obtained results quality, with reference to which X-ray computed tomography can be considered useful diagnostic instrument.

Using computed tomography allowed obtaining layered images of the tested cement concrete sample. Creating of such an image is strictly related to the measurement of radiation beam absorption, which penetrates the analysed structure. This radiation is attenuated (radiation energy, type and thickness of the tested material). Such edited image creates quantity map of linear radiation absorption coefficient in scanned layer cells. [10] By means of tomography method, we can measure precisely individual elements of internal concrete structure in all directions and identify spatially possible defects or discontinuities.

On the analysed concrete, samples were conducted by means of CT scan V/Tome by GE. Analysed structures were placed on a rotating table, while lamps (of 300 kV and 180 kV) and the detector remained still. The image of analysed samples was obtained after full rotation.

III. Testing Materials

The analysis was included two sets of concrete (CC-1 and CC-2). Material compositions of concrete mixtures were analyzed in each case pure Portland cement clinker - CEM I 42.5 N HSR. Used coarse aggregate in the form of granite grit with a grain size to 31.5 mm. The composition of the mixture CC-2 considered part of the ceramic additive in an amount of 10.5% as a replacement for a fine aggregate.

The chemical composition of the additive distinguished significantly from the composition of aggregate replaced. The composition of concrete series CC-1 was coarse aggregate in the form of granite grit with a maximum grain size to 31.5 mm, aggregate fine a grain size of 0/2 mm, CEM I 42.5 N - HSR, water and additives to ensure obtaining the desired consistency of the concrete mix and the content of air pores.

The composition of SB concrete part of fine aggregate (10.5%) was replaced by the ceramic additive. The ratio w / c is assumed to be 0.37. Concrete have matured over a period of 28 days under the conditions of standards by [7], [8] (temperature 20°C and relative humidity > 95%), and then were used for laboratory tests.

TABLE I
MATERIAL COMPOSITION OF CONCRETE MIXES

Materials		Concrete CC-1	Concrete CC-2
Cement CEM I 42,5R	[kg/m^3]	377	
Granite grit	[kg/m^3]	1400	
Flushed sand	[kg/m^3]	415	370
Plasticizer	[kg/m^3]	0.7	
Aerating agent	[kg/m^3]	1.7	
Modifier	[kg/m^3]	-	45
Average air content PN-EN 12350-7:2001	[%]	4.5	4.6
Consistency rate (Ve-Be) PN-EN 12350-3:2001	[s]	16	14
w/c coefficient	-	0.368 ≈ 0.37	

Samples intended for comparative observation using scanning electron microscope and computed tomography each time included the series of three samples of concrete CC-1 and CC-2. Preparing samples, subject to observation, included cutting test samples out of 150 x 150 x 150 mm samples and sanding them several times. Uses a fine powder in order to obtain polished sections of suitable quality.

Samples intended for observation using scanned tomography method did not have to be prepared in advance.

IV. Results

Fig. 1 presents exemplary micro pictures of concrete CC-1 and CC-2 samples observed by means of the scanning electron microscope with diverse magnification.

According to observations of polished sections of CC-1 and CC-2 concretes by means of scanning electron microscope, it was proven that distribution of individual internal components is diversified. In case of CC-1 concrete, numerous micro cracks (Figs. 1 A-b and c) were observed. 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 whole grains area and their maximum aperture was up to 5 μm. In case of CC-2 concrete polished sections, micro cracks of cement matrix occurred very rarely and their aperture did not exceed 3μm. Interface between aggregate grains and matrix of CC-2 concrete remained continuous. Only in case of interface of coarse fraction aggregate, very rarely discontinuity sections of these areas occurred. The most extensive micro crack aperture was 2 μm. Interfaces identified with the weakest element of internal concrete microstructure play an important role and influence greater mechanical parameters of hardened concrete. Observed diversification within these zones proves the most advantageous response of CC-2 concrete. Rare micro cracks prove better affinity of modified CC-2 cement concrete matrix with aggregate grains and, consequently less local stress occurrences, which do not result in exceeding of limit values.

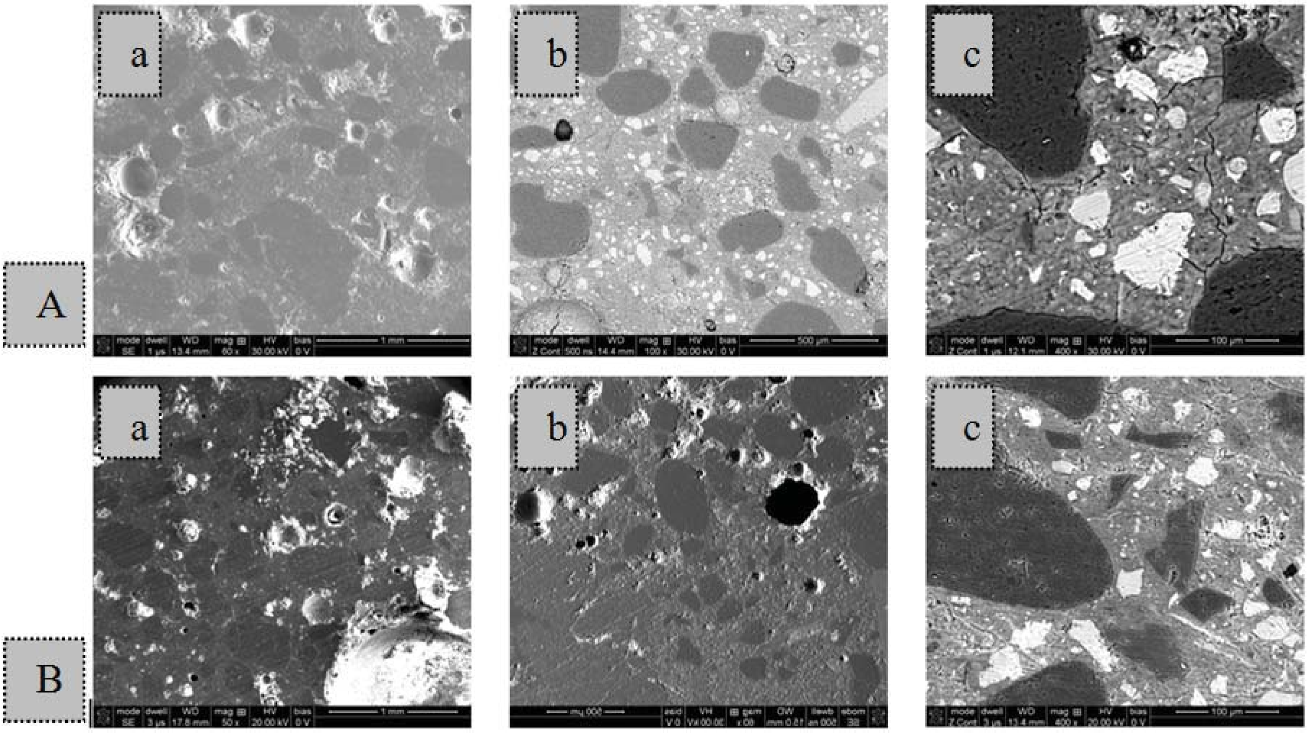

Fig. 1 Micro pictures of polished sections of concrete CC-1 (A) and concrete CC-2 (B) with magnification of 60x (a), 100x (b) and 400x (c)

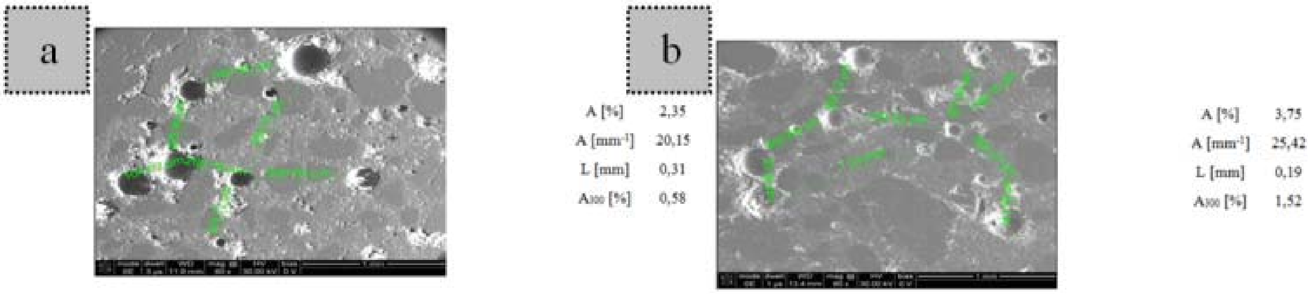

Fig. 2 Micro pictures of concrete CC-1 (a) and CC-2 (b) porosity together with determined porosity characteristics parameters

Diversity of CC-1 and CC-2 concrete porosity has also been observed. It was manifested by fewer number of air pores in CC-1 concrete. Additionally, air pores diameters in case of this concrete were much bigger than diameters of air pores of CC-2 concrete. One of the most significant elements of internal structure of cement composite, which is considered as structure concrete service life determinant, is porosity characteristics. Fig. 2 presents exemplary micro pictures of analysed concretes, considering pores characteristics, according to PN-EN 480-11 requirements. Porosity characteristics is one of the most significant elements of internal cement composite structure, which is considered as determinant of concrete structure service life. Fig. 2 presents exemplary micro pictures of analysed concrete taking into consideration pores characteristics, according to PN-EN 480-11.

Using scanning electron microscope in case of airfield concrete diagnostics requires representative selection of samples intended for observation. Since only the properly selected sample provides for suitable assessment of concrete occurrences and reaching a conclusion regarding concrete structure condition and its possible service life.

Observations of selected cross-sections of CC-1 and CC-2 concrete samples using computed tomography method, proved diversified internal microstructure. CC-1 concrete microstructure is distinguished by numerous micro cracks, which are visible using various magnifications. These cracks occur clearly in the same cement matrix (Fig. 3 (b)) and go deep inside the sample, even several dozen μm. Interface is also covered with cracks between aggregate grains and cement matrix. In case of this section, delamination of concrete from aggregate grains can be observed and cracks width reaches a dozen or so μm. In case of CC-2 concrete samples, rare surface matrix micro cracks have been observed (usually, width and depth did not exceed a couple of μm). Cracks within the area of interface between cement matrix and CC-2 concrete aggregate grains have not been observed. Also, diversity of porosity in case of both concretes have been identified. In case of CC-1 concrete, clearly fewer air pores than in CC-2 concrete occurred, regarding this selected cross section, which has been presented in Fig. 3. Air pores in case of CC-1 concrete were distinguished by significant gap sizes. According to cross-sectional assessment, CC-1 concrete pores went deep inside the sample, whereas in case of CC-2 concrete, their depth was significantly smaller. Observed porosity characteristics proves less favourable microstructure of hardened concrete.

General porosity contents, in case of CC-1 concrete, in spite of the fact that air pores of this concrete have significantly bigger diameters, is lower than in CC-2 concrete. This differentiation is very evident during the observations using tomography method. It is confirmed by nominated content of air in relation to the remaining volume of the sample.

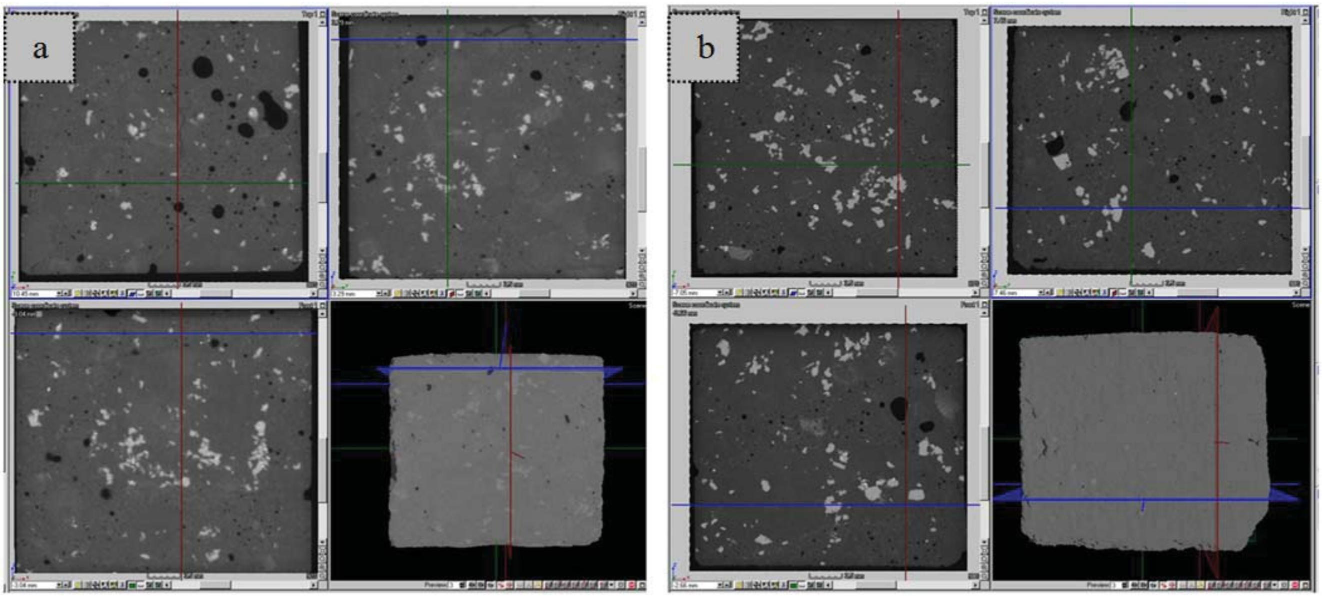

Fig. 3 Exemplary images of concrete CC-1 (a) and CC-2 (b) samples together with analysed cross-sections - using computed tomography method

V. Conclusions

Based on the study and analysis of concrete, we stated that:

1. An application of SEM and TC method allows analysis of changes in the microstructure of hardened concrete. Both methods prove more micro cracks occurrences in case of CC-1 concrete. Tomography method allowed also to define the nature and depth range of occurred discontinuities, which, due to the nature of this microstructure element influencing concrete mechanical parameters, is very valuable. Complete information regarding the analysed sample can be obtained and it is possible to define concrete condition precisely in relatively short time, without the necessity of additional sample preparation, which reduces the time required to diagnose the structure and possible composite damages. In case of CC-1 concrete, significantly fewer air pores have been observed but also their diameters have been bigger than in CC-2 concrete (Table II). Additionally, tomography method allowed (apart from defining pores diameter and quantity) to specify exact shapes of air gaps.
2. The SEM observations enable local analysis of the cross-section, while the use of TC refers to the entire volume of the material. Therefore, the computed tomography appears to be more precise concrete composite diagnostics method. The analyses using TC method included the cross-section of the whole sample, not only its selected specimen, as in scanning electron microscope. Observed phenomena using tomography method, more accurately present actual internal structure of cement composite. Polished sections prepared for observation by means of scanning electron microscope are only part of the sample, and performed analyses refer directly to the selected surface. Both the choice of location from which a specimen of the sample was taken, method and quality of polished section preparation will be of high importance while drawing conclusions. Computed tomography method allows to assess internal distribution of individual concrete components, with reference which it is also possible to diagnose defects occurring inside of the sample.
3. The use of modifier in composition of the CC-2 concrete had a positive impact on the parameters of its internal structure and porosity characteristics.

TABLE II
POROSITY CHARACTERISTICS PARAMETERS

	Concrete CC-1		Concrete CC-2	
	SEM	TC	SEM	TC
Total air contents in hardened concrete [%]	2,35	2,49	3,75	3,77
Pores distribution indicator [mm]	0,31	0,30	0,19	0,18

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