A study of concrete deterioration using X-ray microCT

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Aims
The processes of degradation of concrete have been an important issue for many years. Better understanding of concrete deterioration gives the possibilities to design a more durable and resistant to damage material, capable of withstanding different surrounding conditions. Concrete destruction due to non-mechanical loading is usually caused by chemical or physical processes. The most dangerous chemical problems include: leaching of the paste components, carbonation of calcium hydroxide and C-S-H, paste deterioration due to exposure to aggressive chemicals such as acids, agricultural, sulfates, corrosion of the steel reinforcement, alkali – aggregate reaction. Usually they are combined with physical phenomena such as abrasion, erosion, cavitation, freezing and thawing cycles. This paper presents an application of X-ray microtomography to identification of the carbonation zone in concrete material.

Method
A cylindrical concrete sample of the diameter of 5 cm and height 10 cm has been examined. The sample was extracted as a core from the wall of the city sewage system canal. The analyzed concrete has been subjected to the diverse aggressive environmental conditions including carbonation and sulfate attack. The mineral composition of the concrete is not known. However, it can be notified that it was made of Portland cement. In order to visualize the concrete microstructure, the sample was scanned with X-ray microtomography. The high resolution Skyscan 1172 system has been used with 11 Mp X-ray camera. Image processing and 3D reconstruction as well as data analysis have been performed with the use of software (NRecon, DataViewer, CTAn and CTVox), provided by the producer of the equipment. The scanning parameters are listed in Table 1.

Table 1: Scanning parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scanning no.1</th>
<th>Scanning no.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source voltage</td>
<td>100 kV</td>
<td>100 kV</td>
</tr>
<tr>
<td>Source current</td>
<td>100 µA</td>
<td>78 µA</td>
</tr>
<tr>
<td>Filter</td>
<td>Al + Cu</td>
<td>Al + Cu</td>
</tr>
<tr>
<td>Resolution</td>
<td>13.5 µm per 1 pixel</td>
<td>6.8 µm per 1 pixel</td>
</tr>
<tr>
<td>Rotation angle</td>
<td>0.12°</td>
<td>0.15°</td>
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</table>

Results
The results of the experiments were initially confusing and inconsistent. After first scanning, the images of the carbonated and uncarbonated layer did not present any major differences (Fig. 1). It was hard to distinguish the area where the corrosion of concrete occurred. Furthermore, the parameters of the sample were measured in the software and compared for the upper (known to be carbonated) layer and the lower one. The porosity for the upper layer was found to be 0.55% and for the lower layer – 0.84%. The results showed that there was no significant difference in porosity for each layer which was surprising.
Figure 1: The images of the cross-sections of the concrete after first scanning
a) upper layer, b) lower layer

The preliminary conclusion based on observations and analysis of the results was that the resolution of the scanning was too low and this led to the false output. Nonetheless, in order to check the details of the microstructure, the images were zoomed in and just a piece of the sample has been selected as a volume of interest (VOI) for further investigation.

As can be seen in Fig. 2 and 3, such presentation enables to get more detailed images. The grey values on the 2D cross-sections of the sample correspond to the attenuation coefficient which is proportional to the density of the material. The lighter pixels resemble the areas of higher density whereas dark pixels indicate low density areas. It can be clearly seen in Fig. 2, that the density of the concrete is greater near the surface. The upper regions of the sample are almost white, while deeper layers are distinctly darker. The carbonated concrete tends to have higher density than the uncarbonated one. Therefore, obtained results support this thesis. Additionally, one may easily notice clear changes in microstructure on the upper and lower cross-sectional images of the sample. The matrix (hydrated cement) has changed and it forms irregularly shaped clusters with discontinuities which indicates that its chemical composition is different than before corrosion processes.

Figure 2: Cross-sections of the sample on different heights and 3D reconstruction
The diversity of microstructure as well as the attenuation coefficient changes are clearly visible on the absorption curves shown in Fig. 5. Density is proportional to the absorption curve thus one can see the rise of the absorption in the direction of the carbonated layer. After analysis of preliminary results, the second scanning has been made at higher resolution in order to obtain details of the microstructure and to achieve more precise results.

Figure 3: a) upper (corroded) layer of the sample, b) lower layer of the sample

As a result of an experiment, the similar images were achieved to those presented before. However, the carbonation profile looks differently. There is no attenuation curve increase with the height of the sample. However, one can notice evidently distinguishable micro cracking on the top of sample (corroded layer). As Han et al. observed in their experiment [1], the progressing carbonation process results in the final loss of density of the structure due to the occurring of the cracking.

Figure 4: Results of the final scanning: a) coronal cross-sections, b) trans-axial cross-section

The cracking is also the main reason of the problematic nature of the carbonation. In the situation investigated in this paper, the sample was subjected to the harsh environmental conditions for decades and not only to carbon dioxide but also to other chemical compounds. The microcracks presumably appeared after leaching. The carbonated material subjected to other chemical processes was carried downward (eluviated) and probably was redeposited (illuviated) in the lower layer. This resulted in a porous upper layer with lots of microcracks and dense, compact lower layer. The images obtained with the high resolution test prove this theory. It is also visible on the attenuation curve (Fig. 5). Due to the lower density, one can see a decrease of absorption in the direction of the corroded layer.
Figure 5: attenuation curves: a) on the height of the sample after first scanning, b) for upper and lower layer after first scanning, c) on the height of the sample after final scanning, d) for upper and lower layer after final scanning

Conclusion
The paper presented an application of X-ray microtomography to identification of the carbonation zone in concrete material. A concrete specimen subjected earlier to harsh environmental conditions was investigated. The microstructural analysis of the material was performed with the use of X-ray microtomography. Two different settings of scanning parameters were applied implying the image resolutions of approximately 14 µm per 1 pixel and of about 7 µm per 1 pixel, respectively. The obtained results were compared and analyzed. The most significant findings to emerge from this study are:

- microCT can be a useful tool to investigate the microstructural changes of concrete due deterioration processes,
- attenuation curves are helpful to determine the depth of carbonation zone in concrete,
- the resolution of the scanning has a major influence on the results.

References: