Application of X-ray Micro-computed Tomography for Evaluations of 3D Printed Concrete

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Abstract. Despite significant development of the 3D printed concrete (3DPC) technology in recent years, performance evaluation techniques have yet to be standardized. There is a widespread agreement that printed specimens should be evaluated in relation to mold-cast samples. The microstructural characteristics of mold-cast specimens differ from that of 3D printed ones. The printing process consists of pressure-pumping and deposition, while cast specimens are placed into formwork and compacted to remove entrained air, resulting in discrepancies in the microstructural characteristics.

Various microstructural evaluating techniques are typically used to assess mechanisms related to the mechanical and durability performances of 3D printed elements. These include scanning electron microscopy (SEM), optical microscopy, mercury intrusion porosimetry (MIP) and 2D image evaluation techniques. Unfortunately, microscopic evaluations are limited only to flat surface evaluations, while volumetric ones are rarely performed. The MIP technique is very effective in evaluating pore characteristics, but has limited size determination, making it impossible to determine larger air voids.

The 3D imagining techniques such as X-ray micro-computed tomography (micro-CT) can be utilized for qualitative and quantitative evaluation of printed elements including aggregate distribution, shape stability and fiber orientation without damaging the specimens.

This study presents the possibility of applying the micro-CT for investigation of the 3D printed elements. The volumetric pore images allow to examine the general features of each specimen type (printed or cast) as well as to characterize the interlayer connection and pore distribution, as shown in Figure 1. Probability functions, such as two-point correlation and lineal-path functions, can be used to examine pore characteristics, particularly the anisotropy of the pores. With these functions, probabilistic characteristics such as relative pore clustering, can be examined using two random points (two-point correlation function, P_2) or a test line (lineal path function, L_2). For a more detailed investigation of the pore structures of the specimens, several aspects of the pore characteristics, such as pore shape and pore size distribution, can be examined quantitatively. Wadell's sphericity index was used to characterize the equiaxed shape degree, so as to evaluate pore shape. Wadell's sphericity is defined as the ratio between the surface area of a target pore and the surface area of a sphere, with the same

pore volume. Sphericity can have a value between 0 and 1, where 1 designates a completely spherical pore. With this index incorporating pore sizes, quantitative analysis of the pore structures of the 3DPC can be available, and more detailed characteristics of the material can be examined in both macro- and microstructure level. The quality of the 3DPC can be also confirmed from micro-CT data by evaluating its solid characteristics and the pore structure according to height. In the micro-CT image, the mean pixel value in relation to the height of each specimen can be evaluated, which indicates the relative solid density at the position. Comparison of the specimens' relative density can be used to demonstrate the solid structures of the 3DPC.

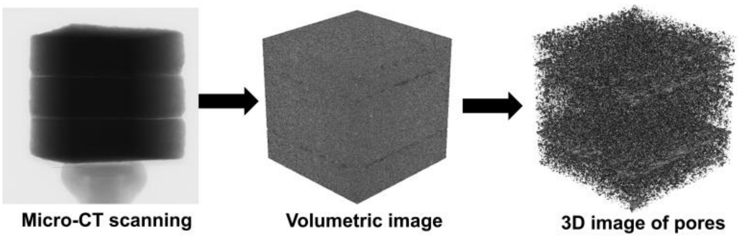

Figure 1. Micro-CT imaging to visualize the pore structure of a target specimen

As an outcome the comparison between cast and printed specimen is presented which allows to correlate the micro-CT data with mechanical and durability-related properties of 3DPC, and finally confirm the usability and effectiveness of the 3DPC suggested in this study.

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