Automated Three-Dimensional Blob Analysis on Bone Cement Micro-computed Tomography

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Introduction: Micro-computed Tomography (μ-CT) is an increasing common technique used to reveal minute details and micro-architecture of bio-materials. With the vast dataset involved, manual analysis of images is time-consuming and impractical. The aim of this study is to develop a fully automated approach to perform three-dimensional blob analysis of μ-CT data to assist further study on the distribution of pores in bone cement block cured under various environmental conditions.

Materials and Methods: Three cements (CMW1, CMW3, Endurance) were prepared and mixed at room temperature and each cured in preheated cylindrical moulds at room temperature, 37°C, 40°C and 50°C. The cement cylinders were μ-CT scanned with a SkyScan 1172 high-resolution system (SkyScan, Belgium), 40x magnification. Each scan resulted in 488 grayscale-inverted image slices with x-y and z pixel spacing of 6.83μm and 13.66μm respectively following reconstruction.

The blob analysis was programmed using Matlab (Mathworks, Massachusetts) and can be summarized into three major steps; 1) segmentation of the cement area from each μ-CT slice, 2) application of watershed transform to segment blob regions, and 3) extraction of individual blob properties.

To segment the cement dowel, each image was first binarized using a threshold based on the Ostu method [1]. The binary mask was inverted and converted to polar coordinates (Fig 1A). Morphological closing was applied with a horizontal structuring element, followed by selection of the largest connected region (Fig 1B). The perimeter of the resulting binary mask was converted back to Cartesian coordinates and a best-fit circle was then computed minimizing absolute error (Fig 1C). For performance reasons, 20 out of 488 slices were processed and interpolated to obtain all the circle centers and all images are masked with a circle of 420 pixel radius and its corresponding center points. Based on the resolution this represents the entire radius of the cement dowel.

Watershed transformation [2] was used in the segmentation of the blob and an extended H-maxima [3] transform located the marker. Morphological reconstruction was applied to the inverted image stack to enforce regional minima only in the markers and the background region. Watershed transform was applied and resulting blobs labeled (Fig 1D).

Due to the vast amount of memory required to process the abovementioned three-dimensional watershed transformation, the image stack was divided into groups, each with 10 images. The transformation was applied to each group and results combined thereafter.

Properties of each individual blob were measured, namely the centroid, volume, and distance from the center axis. Distribution of the pore volume from the center axis is also recorded. The overall pore volume for each cement dowel along the radius was normalized and plotted.

Results: All 12 image stacks were accurately processed, with the dowel region identified and individual blobs segmented and labeled. Figure 2 shows that pores are distributed more towards the center axis for higher cure temperature.

Discussion: Streaking artifacts due to photon starvation were observed due to the presence of Barium Sulphate and Zirconium Dioxide as radio-opacity agents. Normal edge detection routines are often not robust enough to handle this amount of noise. The proposed segmentation approach makes use of the fact that the cement was molded into cylindrical shape where the polar coordinates of the cylindrical edge are relatively horizontal, while the polar coordinates of the outward-radiating streaking artifacts are relatively vertical (Fig 1B). Morphological operations comprising a horizontal structure element could then be performed to eliminate the majority of the streaking artifacts radiating outwards from the center, with minor effect to the cement block edge. A best-fit circle chosen to minimize absolute error also minimizes the effect of possible outliers, resulting in an accurate segmentation of bone cement out of its noisy background corrupted with streaking artifacts.


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