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3D ANALYSIS OF TOMOGRAPHIC IMAGES

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ABSTRACT

In order to analyze increasingly common 3D image data, new techniques are required. Some of these techniques can be derived from traditional 2D image processing, while others must be created for a particular problem. Using various 3D techniques, we are analyzing high resolution tomographic data of concrete in order to study its fracture energy and permeability. The techniques we are using include: thresholding, boundary finding, connected component analysis and a newly developed technique based on relative motion analysis.

Keywords: Microtomography, fracture-mechanics, image processing and analysis, pore structure

3D IMAGE PROCESSING

3D image data is produced from a wide range of sources. Everything from surveying and weather studies down to radiography and nuclear magnetic resonance creates volumetric data, all of which is readily thought of as 3D images. The data that we are examining are 3D images of concrete created with high-resolution tomography (Landis 99). We are using several tools to extract information from 3D images. Some of these tools are traditional image processing techniques, while others have been developed specifically for this project.

The areas that we have been investigating include fracture energy, pore structure and permeability of concrete. Fracture energy has been studied extensively using many 2- and 3D techniques. None of these have been able to produce the level of resolution in three dimensions that x-ray microtomography is capable of. They did demonstrate that a two-dimensional model cannot be used effectively to investigate concrete, a highly anisotropic material that exhibits complex 3D fracture surfaces. There have also been many previous studies of permeability using such techniques as mercury intrusion porosimetry penetration and nitrogen absorption. By using 3D imaging techniques, we hope to relate these older studies to the actual microstructure of concrete.

Internal Crack Measurements

In order to accurately measure fracture energy in concrete, it is essential to be able to analyze the fracture surfaces in a true 3D fashion. We have developed two techniques to relate the change

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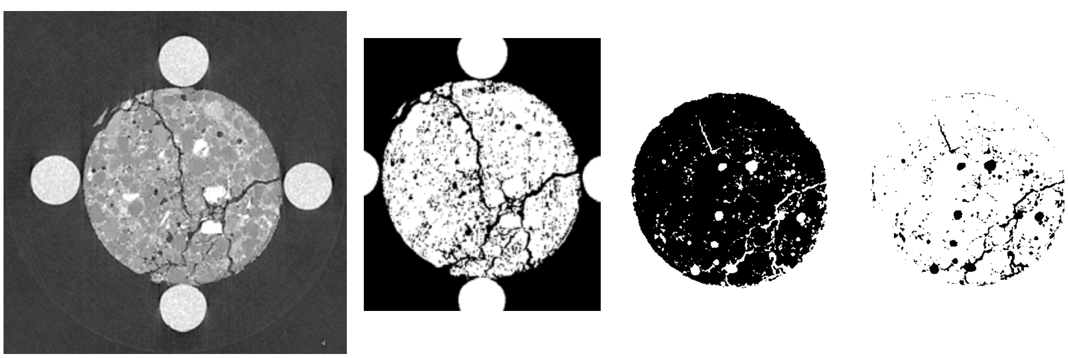
in fracture surface to the amount of external work performed on the specimen. The first method extracts the void surfaces at each load independently by applying thresholding and connected component analysis – a threshold-based procedure. The second method processes pairs of images at different loads by identifying the relative motions of a fractured specimen, and recovering the changes in crack surfaces – a vector-based procedure. Having two image analysis procedures allows us to lessen the uncertainties that are inherent to each individual procedure. The uncertainties stem from thresholding and resolution levels that are manually chosen in the methods, as well as from a slight potential rotational anisotropy introduced by one of the methods.

Threshold Based Procedure

This was our first attempt at measuring the change in crack surface area with increasing load steps. Not only is each measurement based only on the current load, but most of the image processing steps are performed on 2D "slices" of the volumetric data. While relatively fast and easy to implement, there is a danger of introducing some directional dependence with 2D processing. The initial steps were cropping and thresholding the data. We use the threshold to separate void space from solid space. Although a simple procedure, the effects of the choice of threshold value can be critical – too far one way and everything appears to be void and vice versa. Fortunately, it appeared that for our data, within a certain fairly obvious range, changing the threshold level did not drastically affect the *change* in measured fracture area between successive loads. These first steps may be seen in figures 1a and b.



a. b. c. d.

FIG. 1. Threshold-Based Procedure

The next step in the analysis is to separate the interior void space (cracks and air bubbles) from the exterior void space (surrounding air). The results of this are shown in figures 1c and d. For this, we developed a six-step "painting" program. The procedure has been detailed in (Nagy 98) but in short, involves finding and marking the projected surface of the solid section of the image, filling in the voids space that is enclosed within the marked boundary and then changing all the unmarked void space to be the same color as the solid. In this way, only the interior void space is left. This process was performed two-dimensionally. That is, the volume data are divided into slices and the operations are performed on each slice independently. Due to the nature of the data set, and the orientation of the slices, it does not appear that the two-dimensional nature of this procedure brings about significant anisotropy. Within the two-dimensional image, however, the procedure is not completely rotationally invariant.

Following the extraction of the important elements of the data (the interior void space), we implement a 3D connected components routine (Franklin 02). This routine simultaneously finds and measures each individual component. The product is a list of 3D components, and their respective volumes and surface voxel count (area). Due to the large size of the data set (~500 MB), the connected components algorithm needed to be specially tailored. The original version required over 2 weeks to run on a high-powered work station. The combination of a better algorithm, tight coding, and a faster computer has brought the computational time down to the minute range.

The final step in the process is sorting out the cracks from the air voids. This is accomplished through the use of a shape measure. The surface to volume ratio for an object is minimal for a sphere, and increases as the object gets less sphere-like. Using this measure, we are able to distinguish the cracks from the bubbles.

Vector Based Procedure

This procedure involves an entirely different, and we believe novel, approach to finding crack surfaces by identifying the interior surfaces of multiple concrete segments which have been separated and moved apart due to cracking. The process starts by a level-set based shrink-wrapping procedure to find the concrete region. Using a 3D registration method the motion of a grid of points is tracked from one load step to the next (figure 2). The registration algorithm works on full gray scale images. Neighboring blocks having similar motions are joined together in a statistical framework. A multi-resolution approach is designed to cope with the large concrete data size. Starting with a block size of 64^3, a coarser representation is first identified with refined versions obtained as the block size gets smaller. The refinement is able to catch smaller objects initially missed in the coarse step. The current limit of block size is 16^3 and is due primarily to computational requirements. Finally the interior surface of each object (the surface which is distinct from the original shrink-wrap surface) is measured. Each such surface has been created by the separation of the concrete specimen – in other words it is a crack surface.

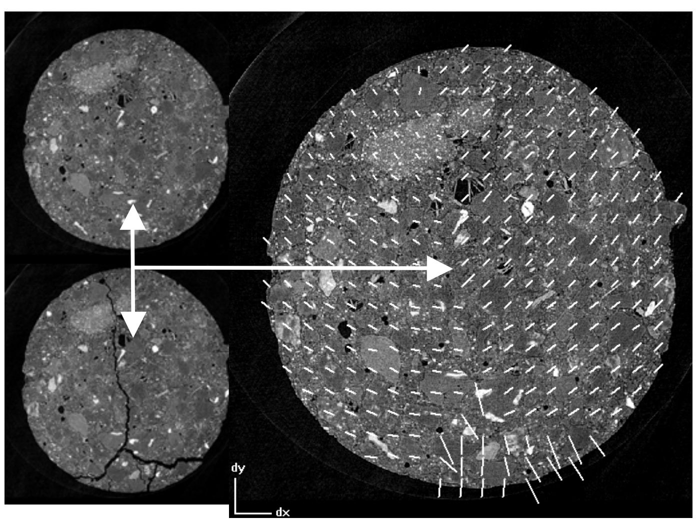


FIG. 2. Motion Vectors

The entire process, minus the shrink-wrapping, is repeated for each load step, and the growth in crack surface area can be calculated for each pair of load steps. One nice aspect of this procedure is that we can measure the growth in crack surface directly from the unloaded specimen to the nth load step, or proceed stepwise through the n steps, calculating the change at each step. We believe that this will allow us to increase our confidence in the process.

Pore Structure and Porosity

Many of the image processing techniques used for these studies are similar to the threshold-based procedure. The main distinction is that we are not only interested in finding the void space, but in discovering which voids are connected to the surface and how close the solid material is to a free path to the surface. Using the quasi-static method, we produce an image of the voids. Combining this with our painted boundary surface, we are able to determine which connected components intersect the boundary. From here, a simple distance measure (using a sphere of increasing radius) allows us to measure the shortest distance between any point within the solid material and a surface connected void. Figure 3 presents the change in minimum distance for a two-dimensional slice as the specimen undergoes damage. Using the same technique, we are also examining the difference in the amount of surface-connected pore space for different mix designs in an undamaged state.

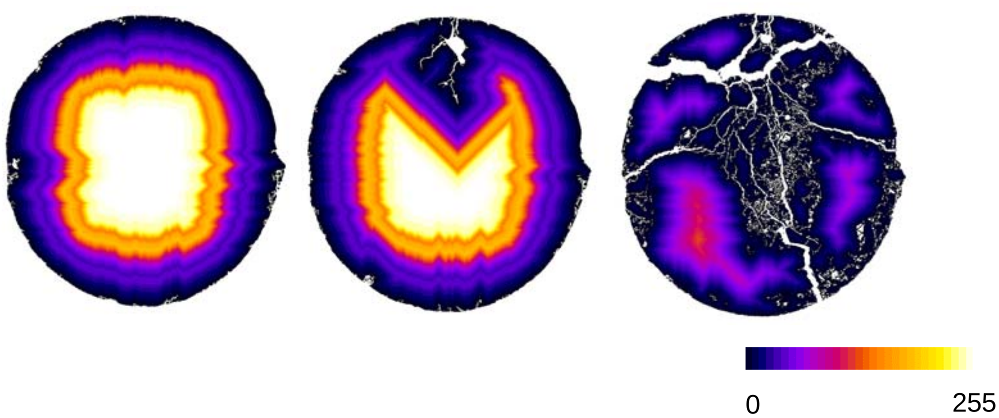


FIG. 3. Minimum Distance From Surface

CONCLUSIONS

Three dimensional data are becoming more and more common. As the data get more complex, new tools need to be developed in order to extract useful information from the data. We have developed a combination of simple and complicated 2- and 3D image processing techniques to analyze 3D microtomographic data of concrete. Using these tools, we are beginning to gain a new understanding of some truly 3D phenomena such as fracture and pore structure.

We expect that not only can this work be continued to develop a further understanding of these issues, but that the tools developed can be useful in investigating other 3D phenomena in concrete, and indeed in many other arenas.

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