Automatic Segmentation of Micro CT Images

ME EN 6035 Final Project

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Abstract

In this study, the accuracy of a novel automatic segmentation method was statistically compared to a manual segmentation method. Segmentation was performed on fiber-reinforced ceramic matrix composites in order to extract porosity from the surrounding microscturcture. Four different automatic segmentation methods were investigated. Statistical analysis was performed to determine how the methods compared. It was found that using a combination of pre-segmentation filtering, 3D machine learning segmentation, and post-process edge erosion had the best agreement with manual segmentation of the methods evaluated.

1 Introduction and Background

Fiber-reinforced ceramic matrix composites (CMCs) are widely used in the aerospace industry due to their high specific strength, high stiffness, and their ability to withstand prolonged exposure to extreme high-temperature and oxidative environments. Despite their increased use, the physics governing their manufacturing, stochastic microstructure, and long-term structural performance remains an active area of research. Understanding the complete life-cycle of CMCs is critical towards improving existing and future applications of CMCs. In recent years, the emerging practice of in situ X-ray micro-computed tomography (X-ray μCT) experiments has proven useful for providing a holistic understanding of the behavior of CMCs on multiple length scales [1–6].

Unique to X-ray μCT is the ability to take through-thickness images of specimens in 3-D. This provides much more information compared to other 2-D surface based techniques. However, processing these images to extract information comes at high computational costs. One of the most common imaging processing operations is segmentation, in which pixels are categorized into two more groups that correspond to some characteristic of the material being imaged. For example, CMC images are often segmented to distinguish between fibers and the surrounding epoxy matrix. There exist active areas of research in improving best practices for the segmenta-

tion of X-ray μCT reconstructions. Segmentation techniques vary widely depending on image properties such as noise characteristics, contrast between segments, and edge sharpness. X-ray μCT of large specimens results in image with significant noise and edge softness, making automatic segmentation challenging. Researchers have largely relied on manual segmentation, in which a user classifies each pixel by hand. While accurate, this method is very time consuming and impractical for processing of large data sets. For this reason the development of an automated method of segmentation is desired.

In this study, several automatic segmentation strategies were constructed and tested against a manually segmented data set to determine accuracy. Slices of a 3-D X-ray μCT image data set were segmented to calculate the porosity of each slice. A statistical validation was performed to compare the differences in segmentation ability between the automatic methods and the manual segmentation method.

2   Materials and Methods

2.1   Composite CMC and X-ray μCT

This study is an extension of current research being performed in the Utah Composites lab where X-ray μCT is being utilized to image the entire multi-step manufacturing process of CMCs combined with *in situ* testing during extreme environments. The end goal is to fully quantify the changes of the CMC microstructure throughout their entire life-cycle via methods of segmentation. The composite system used consisted of a 8HS satin weave CG Nicalon-fiber fabric infiltrated with SMP-10 resin. Imaging was performed using a Zeiss Versa-520 X-ray CT 3D microscope at the Air Force Research Laboratory (Dayton, OH). In this study, images were analyzed from the pyrolysis step of the manufacturing process after which the resin was cured at $1000°$C.

2.2   Data

Image were collected with a scan time of 37.3 hours. A small region of interest (ROI) from the entire CMC specimen was selcted for analysis. There were 1980 8-bit images collected with a spatial resolution of 1.21 μm/voxel. In total, the entire image stack consisted of 22.1GB of information. For this study, a small sub-volume of $500\times500\times500$ pixels analyzed. Within this sub-volume, both manual and automatic segmentation were performed in order to extract porosity (e.g. cracks or voids) from the surrounding microstructure. It is assumed that the manual segmentation based method of porosity is considered ground truth to compare the accuracy of the automatic segmentation.

2.3   Statistical Analysis

Several different statistical techniques were used to evaluate segmentation algorithms. First a one-way ANOVA was conducted on the porosity measurements for each technique to determine whether or not automatic calculations of porosity were significantly different from manual calculations. Here the null hypothesis is that all

methods result in the same mean porosity measurement for the image set. They alternative hypothesis is that some means are not equal. A multiple comparisons analysis (Tukey's HSD) was then conducted to test multiple alternative hypothesis and determine which methods, if any, were significantly different.
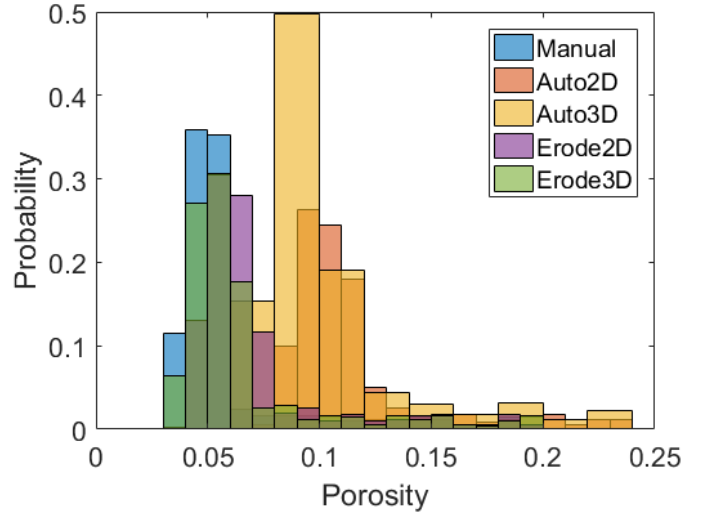
3   Results and Discussion

Figure 1: Histogram of porosity distribution for each segmentation method

An additional data set was constructed by calculating the percent error between each of the automatically segmented results and the manually segmented results. This data was no longer dependent on the underlying image and could be treated as a random variable. Normality of data was checked by plotting the histograms for each automatic method. Finally, the four automatic methods segmentations were broken into two categories based on algorithm features with "high" and "low" treatments for each category. A 2 by 2 factorial and 2-way ANOVA were performed to determine which algorithm features (Analysis Dimensions and Edge Erosion), most effected the results.
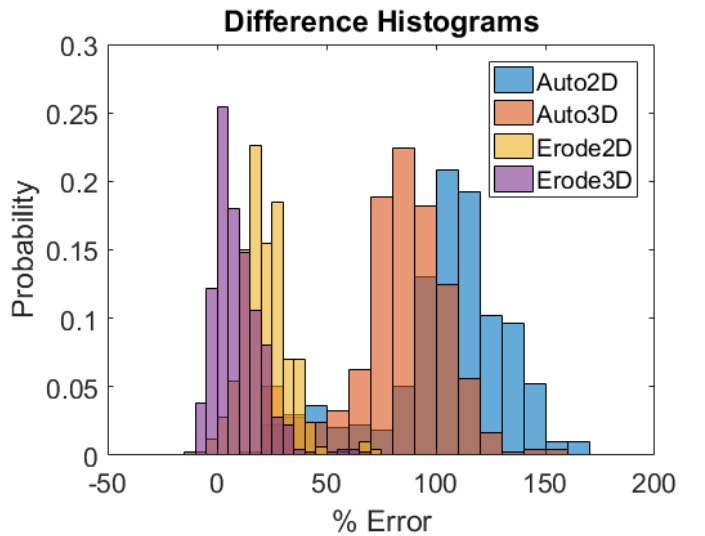

Figure 2: Histogram of percent error for each of the automatic segmentation methods
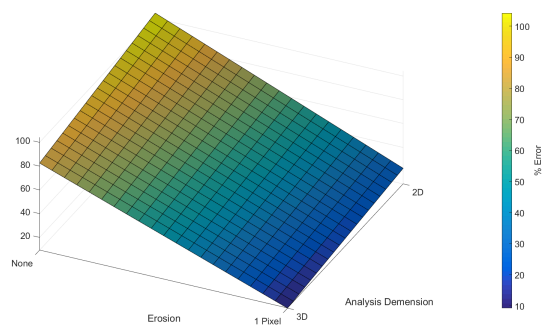
Figure 3: Response surface model for two different algorithm features

Table 1: One Way ANOVA Results

Source	SS	DF	MS	F	P
Group	1.8878	4	0.29719	281.14	0
Error	2.63218	2490	0.00106		
Total	3.82096	2494			

Table 2: Two Way ANOVA for factorial analysis

Factor	SS	DF	MS	F	P
Dimensionality	15.075	1	15.08	370.4	0
Edge Erosion	300.577	1	300.58	7386.0	0
Interaction	0.911	1	0.911	22.39	0
Error	81.066	1992	0.041		
Total	397.629	1995			

3.1   Error and Uncertainties

4   Conclusion and Future Directions

References

[1] N. Larson and F. Zok, "In-situ 3d visualization of composite microstructure during polymer-to-ceramic conversion," *Acta Materialia*, vol. 144, pp. 579–589, 2018.

[2] H. Bale, A. Haboub, and et al., "Real-time quantitative imaging of failure events in ultrahigh-temperature materials under load at temperatures above 1600c," *Nature Materials*, vol. 12(1), pp. 40–46, 2013.

[3] H. Bale, M. Blacklock, and et al., "Characterizing three-dimensional textile ceramic composites using synchrotron x-ray computed micro-tomography," *Journal of the American Ceramic Society*, vol. 95, pp. 392–402, 2012.

[4] B. Cox, H. Bale, and et al., "Stochastic virtual tests for high-temperature ceramic matrix composites," *Annual Review of Materials Research*, vol. 44, pp. 479–529, 2018.

[5] A. Haboub, H. Bale, and et al., "Tensile testing of materials at high temperatures above 1700 c with in situ synchrotron xray micro-tomography," *Review of Scientific Instruments*, vol. 85.8, p. p.083702, 2014.

[6] D. Marshall and B. Cox, "Integral textile ceramic structures," *Annual Review of Materials Research*, vol. 38, pp. 435–443, 2008.