Computer Vision for the Characterization of Fibers in Material Design

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Abstract

To study the structure of materials acquired using Micro-CT, we resort to computer vision and machine learning techniques such as filtering, enhancement, and pattern classification to analyze a ceramic matrix composite (CMC) sample, reinforced by fibers. Our image workflow starts by transforming crops of image cross-sections (1200 "curated images") using normalization of pixel intensities to minimize spurious photometric variations. We tested two classification approaches: a supervised (LeNet) and an unsupervised (hierarchical clustering) one. With the LeNet neural network, we perform classification of curated images into fibers and non-fibers. Next, we cluster the curated images with hierarchical clustering for the characterization of fibers, which provide insights with regards to taxonomy. Our results show that we can classify fibers with an accuracy for the samples for training and 27% for testing. The clustering analysis points out to two main types of fibers: thin-coated at the center of the specimen and thick-coated fibers at the outer parts. The merging of these computational processes helped to understand the false positives and false negatives, which are mostly due to the agglutination of fibers or very thin-coating. Future work includes exploring advanced feature extraction methods, and tracking of 3D fiber structures in the entire image sequence.

Background

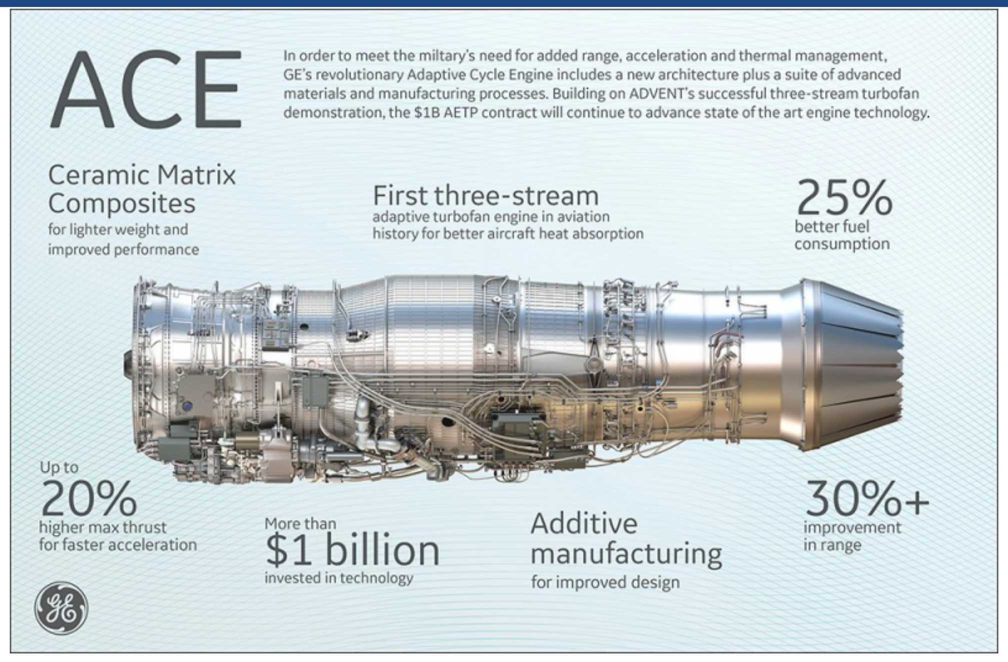


Fig I. Ceramic Matrix Composites in Jet Turbines [1].

Research Question

What are some computer vision techniques and machine learning algorithms to study the characterization of fibers in ceramic matrix composites?

Materials

To examine the characteristics of a CMC sample, we resort to Micro-CT data "Real-Time Quantitative Imaging of Failure Events in Materials under Load at Temperatures above 1,600 ° C" by Bale, Hrishikesh A, et al in *Nature Materials,* displayed and labeled in the middle column.

1. "GE Aviation Hits Farnborough at Full Throttle; $7.5B in R&D Investments since 2010; Ceramic Matrix Composites and 3D Printing." *Green Car Congress*

Ceramic Matrix Composite

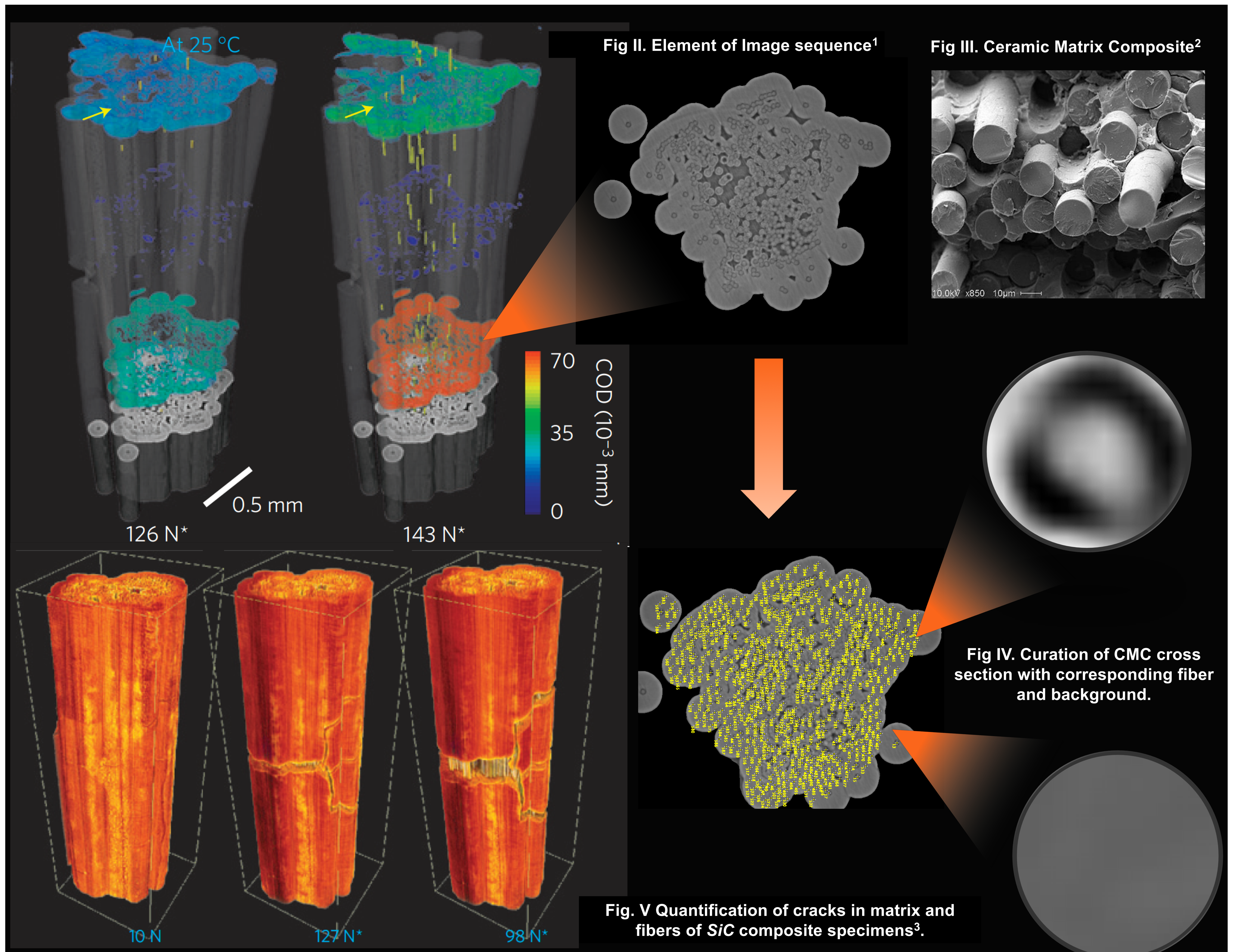


Fig II. Element of Image sequence[1]

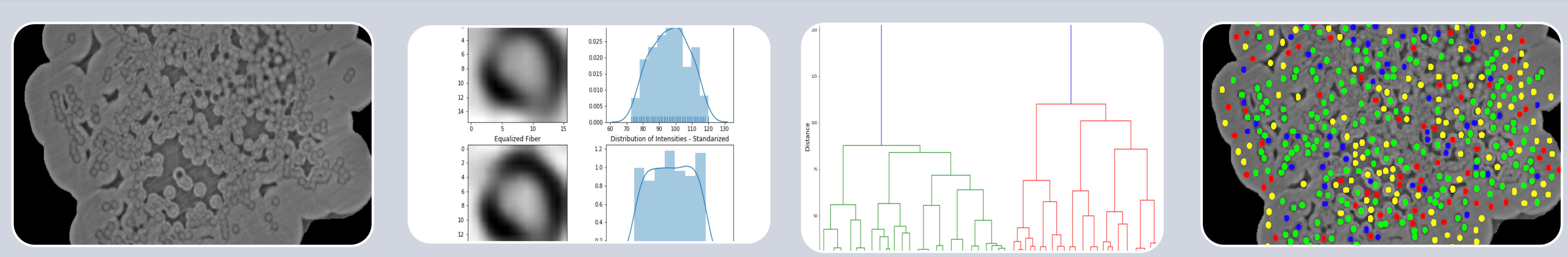
Fig III. Ceramic Matrix Composite[2]

Fig IV. Curation of CMC cross section with corresponding fiber and background.

Fig. V Quantification of cracks in matrix and fibers of *SiC* composite specimens[3].

1. Ushizima et al, J. " Structure recognition from high resolution images of ceramic composites", IEEE Int. Conf on Big Data, Washington, D.C., Oct 2014.
2. Research Allied Market. "Ceramic Matrix Composites Market Expected to Reach $7,707 Million by 2023." *OpenPR*, OpenPR, 25 Sept. 2018
3. Bale, Hrishikesh A et all J. "Real-Time Quantitative Imaging of Failure Events in Materials under Load at Temperatures above 1600 C", Nature Materials, vol. 12, no. 1, 2012, pp. 40–46.

Methodology



Micro-CT Volume
- 2D cross section of CMC sample
- Grayscale Image
- Curation for single fiber extraction

Preprocessing Techniques
- Applied to 1200 images
- Histogram Equalizer
- Standardization

Pattern Classification
- Hierarchical Clustering
- LeNet Architecture

Categorization
- Spatial Distribution from dendrogram's sub-clusters
- Difference in Coating

Fig VI. Image workflow and methodology outline.

Classification Analysis

LeNet Training

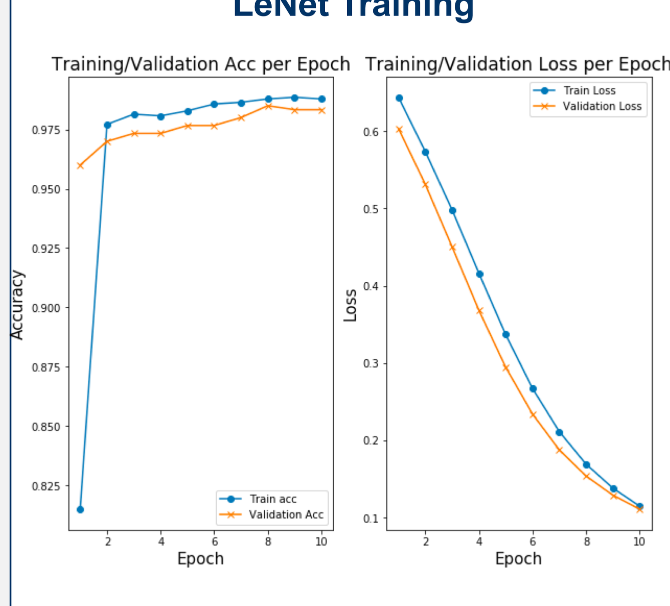


Fig VII. Loss and Accuracy per epoch in LeNet

The model consists of a total of seven layers: an input layer, three convolutional, two pooling layer, and one fully connected layer. The activation functions utilized include *tanh* and *relu.* The choice of architecture results in a classification accuracy of 0.98 and performance of < 1m.

Clustering Analysis

Spatial Distribution

Sub-clusters dictated by spatial distribution of fiber in sample	Direct correlation with composition of fibers.

Fiber Coating Thickness

Fibers of thicker coating appeared in the edges, correctly classified.	Thinner coatings located at center in close contact with other fibers.

Results & Future Work

With the curation of the images we developed a new method to categorize fibers according to their composition and location in CMCs. Additionally, with the fast results of the LeNet architecture, we successfully distinguished voids and backgrounds from fibers with an accuracy of 98%. We hope to combine these categorizing and classification methods with other CAMERA software to further analyze the design and structure of materials.

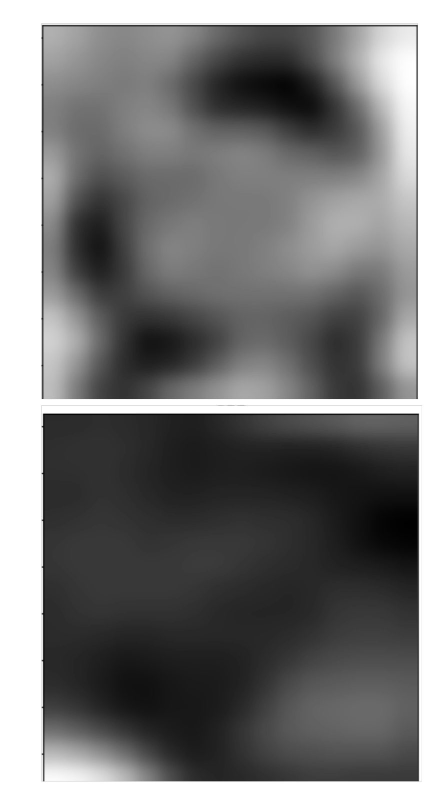


Fig VIII. Fiber vs Void in CMC

Acknowledgements

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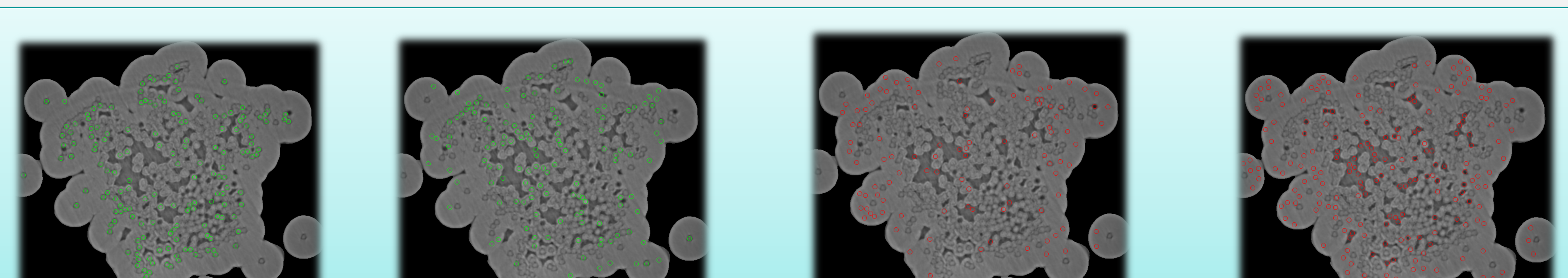

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