Using AI and Image Processing to Improve Fatigue Failure Analysis in 3D-Printed Materials

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Introduction

3D PRINTING (ADDITIVE MANUFACTURING) IS USED TO CREATE COMPLEX PARTS IN INDUSTRIES LIKE AEROSPACE AND AUTOMATIVE.

THESE MATERIALES CAN EXPERIENCE FATIGUE FAILURE DUE TO REPEATED STRESS OVER TIME.

TRADITIONAL ANALYSIS METHODS ARE SLOW, MANUAL, AND PRONE TO ERRORS.

OUR SOLUTION: USING AI AND IMAGE PROCESSING TO AUTOMATE AND IMPROVE THIS ANALYSIS.

BENEFITS: FASTER, AUTOMATE VS MANUAL, MORE ACCURATE, BETTER FAILURE PREDICTION.

Additive Manufacturing & Fatigue Failure

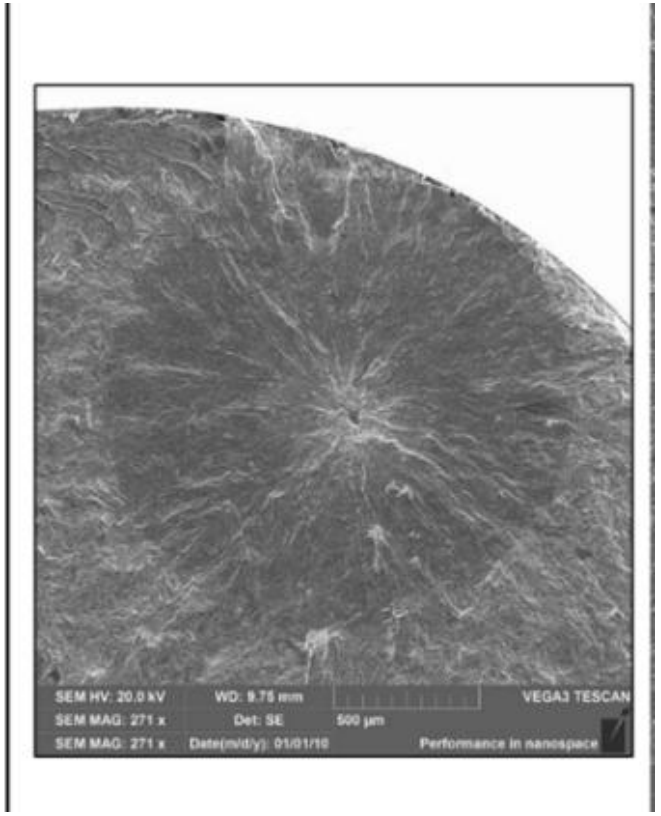
- **What is Additive Manufacturing (AM) ?**
  - 3D printing technique used to create parts layer by layer.
  - Popular in aerospace and automotive for lightweight and complex designs.

- **Fatigue Failure in Materials:**
  - Repeated stress leads to material failure (cracks, fractures).

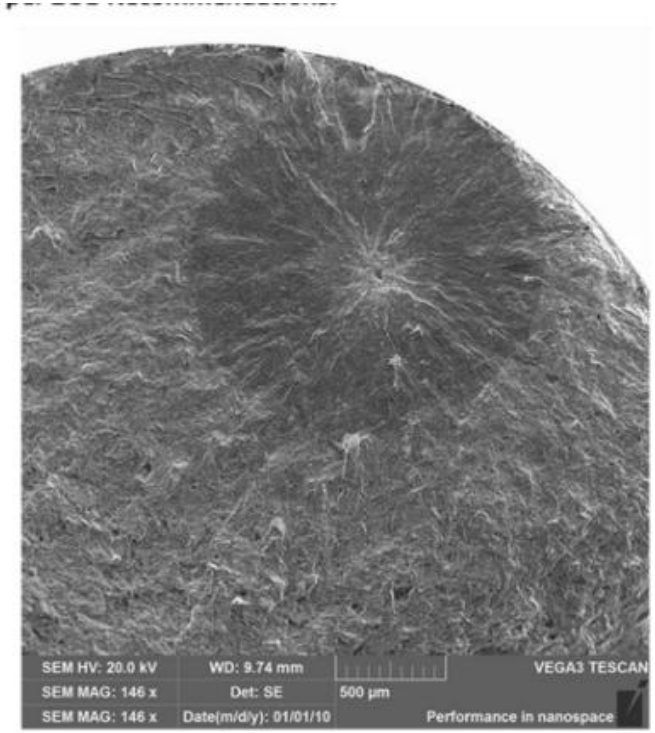
- **Challenges with Traditional Analysis:**
  - Involves **manual fractography**, where experts visually examine fracture surfaces.
  - Time-consuming, prone to human error, and lacks scalability.
  - Difficult to predict when and where cracks will occur.

Failure Propagation Phases

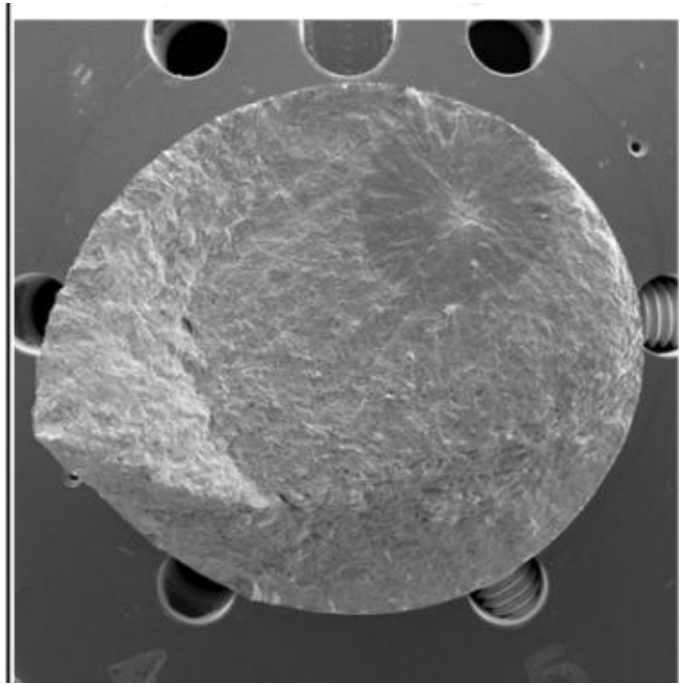
Initiation Source



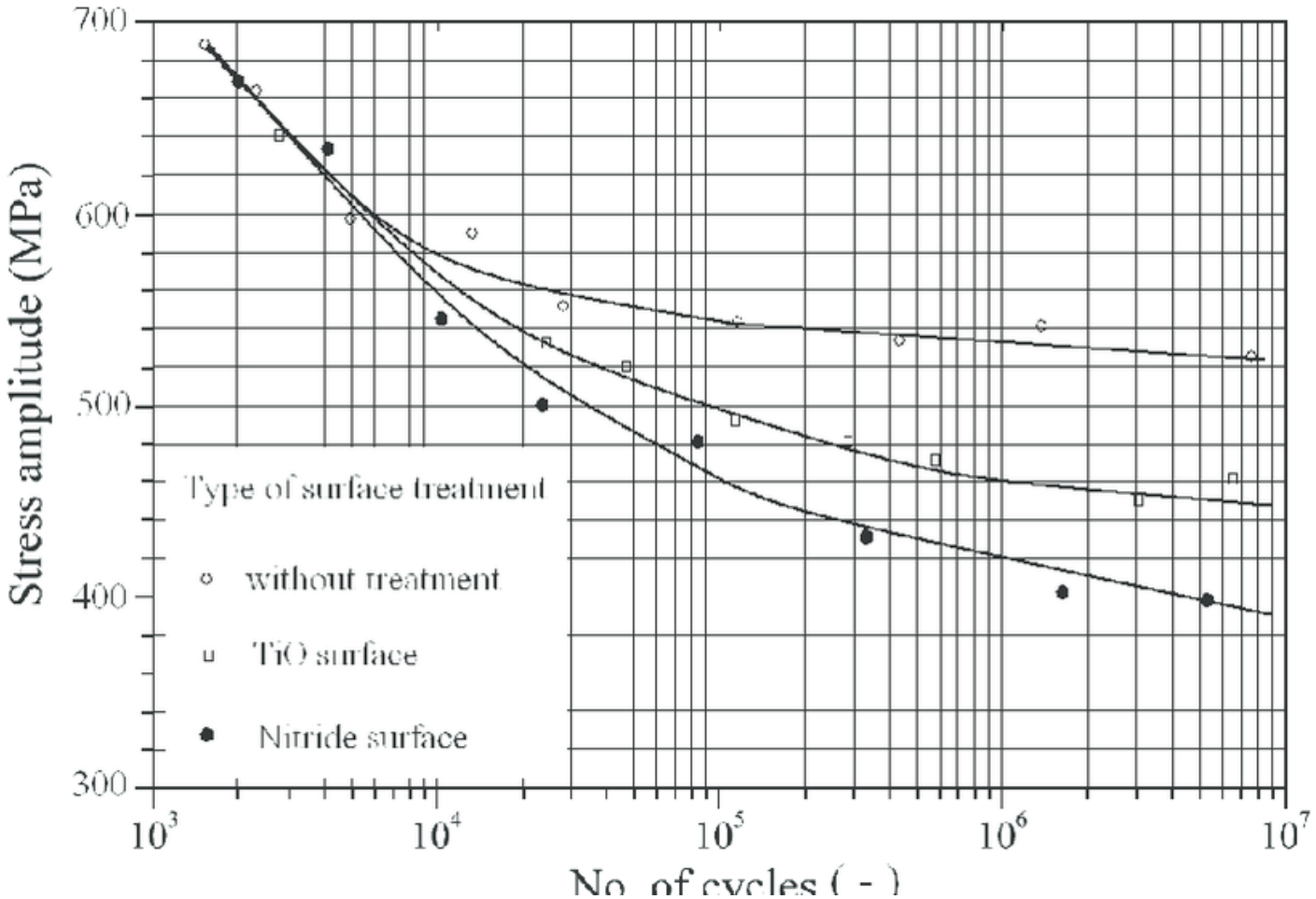
Crack propagation



Final Failure



Fatigue Failure



Dataset

- The dataset utilized in this research comprises 63 Scanning Electron Microscope (SEM) images of Ti-6Al-4V alloy fatigue specimens.
- The dataset is organized into three categories based on the print quality recommended by the manufacturer: P1, P2, P3 ...
- Included of duplicated images for certain specimens from lower and upper surfaces

Figure 3: Fatigue (crack initiation) & Crack Growth Test Specimens and the Tensile Machines used

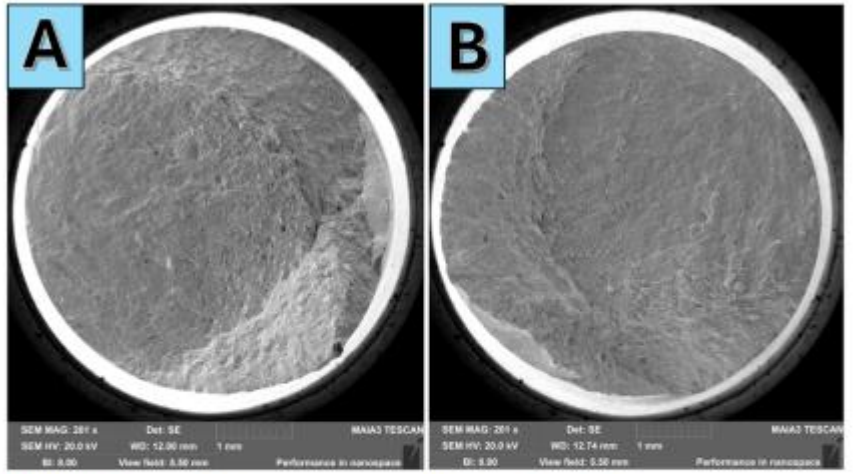


FIGURE 3: SEM images of a Ti-6Al-4V fatigue specimen from two opposing viewpoints (A and B), showcasing the fracture surfaces from the lower and upper surfaces at different angles.

AI and Image Processing Approach

Our solution:

- Combine image processing techniques and AI to analyze fatigue failure in 3D printed materials.

Key steps:

Image Proccesing:

- Use sobel operator to detect edges for generate heatmaps for identifying critical features (crack ares).

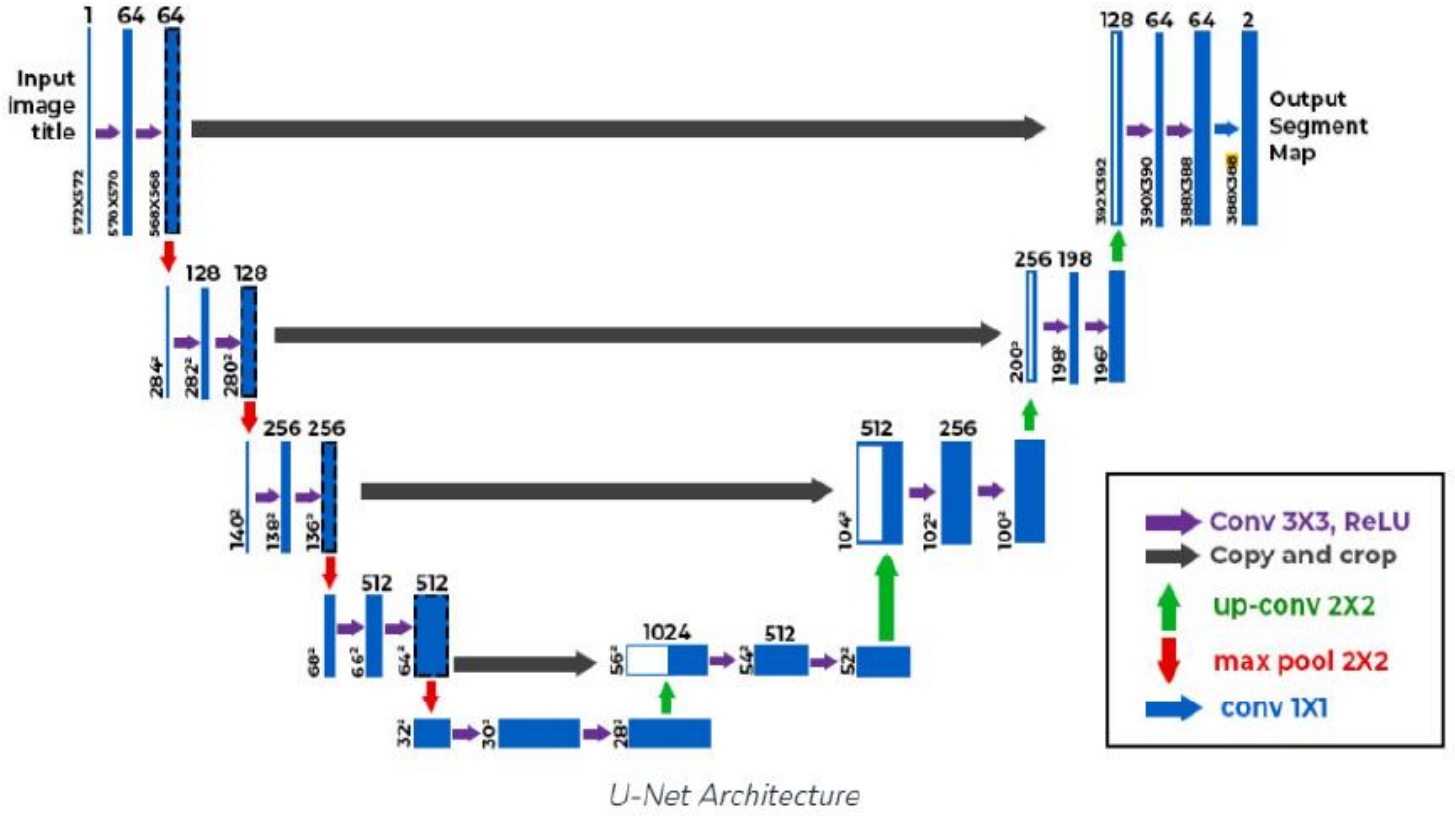
Preproccesing:

- resize and clean Scanning Electron Microscope (SEM) images for uniforn analysis.

AI (Unet model):

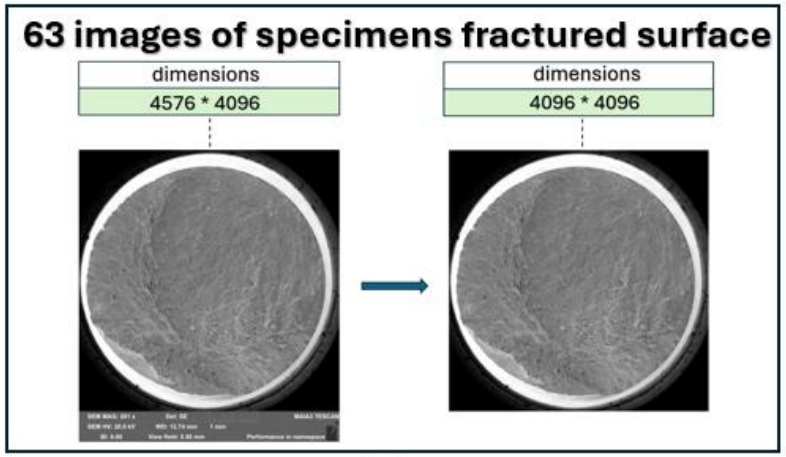
- Apply **UNet architecture** for image segmentation.
- Detect external contours (whole surface) and internal contours (crack propagation) in fracture surfaces.

Proposed approach - U-Net

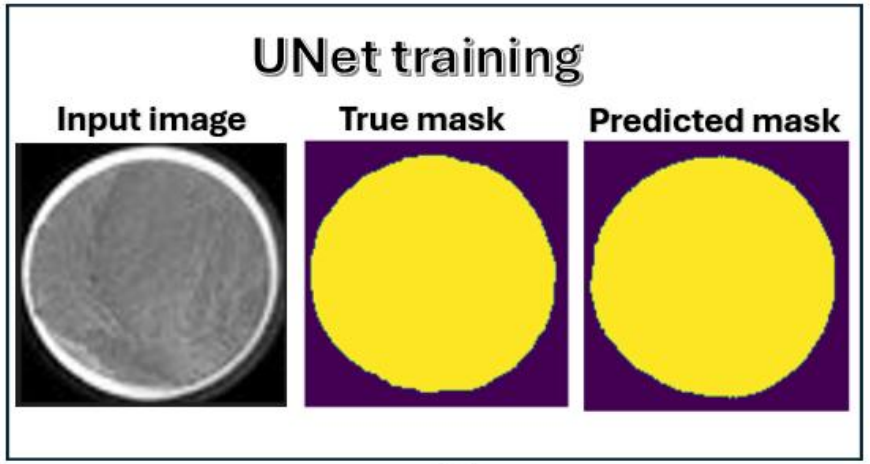


U-Net Architecture

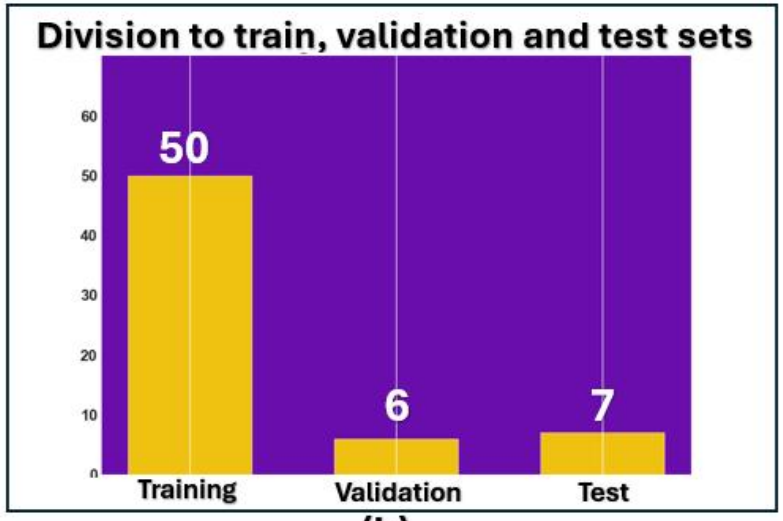
Visualization of the Process



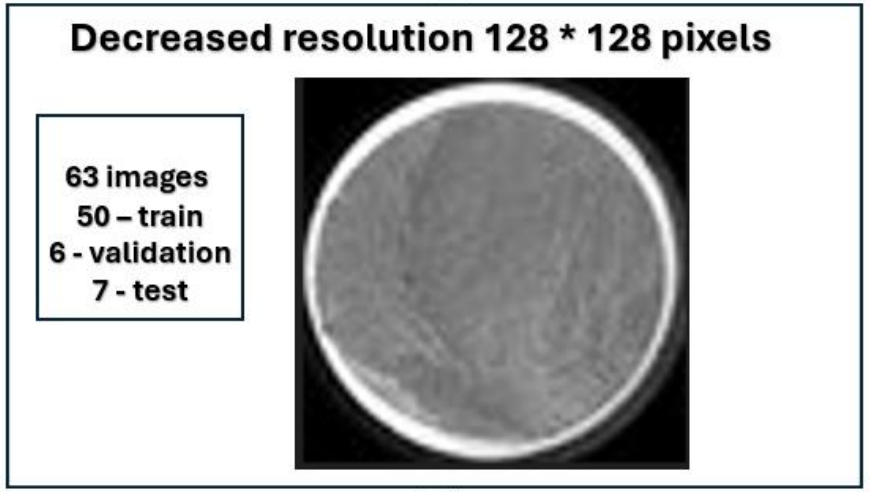
(a)



(d)

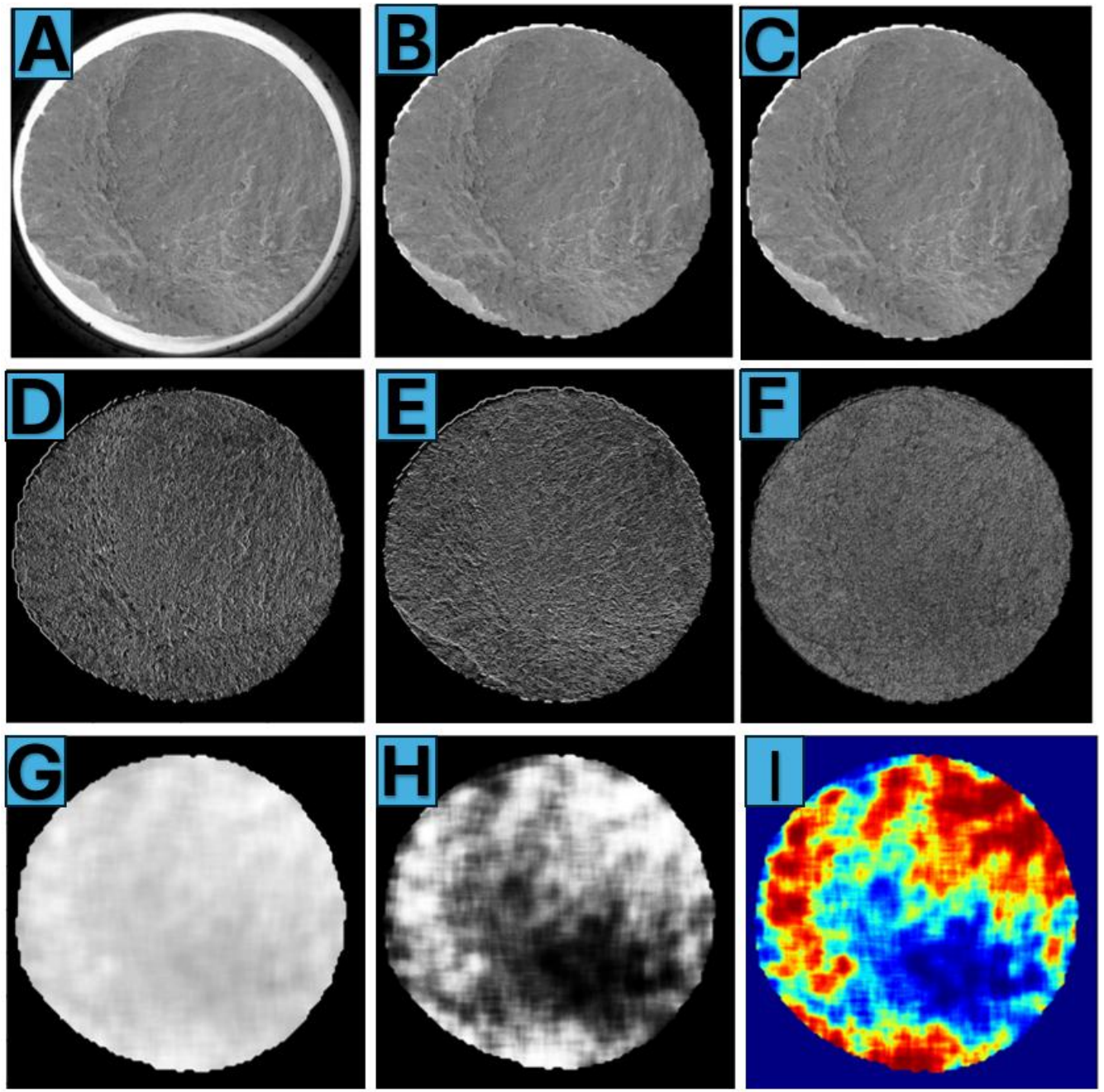


(b)

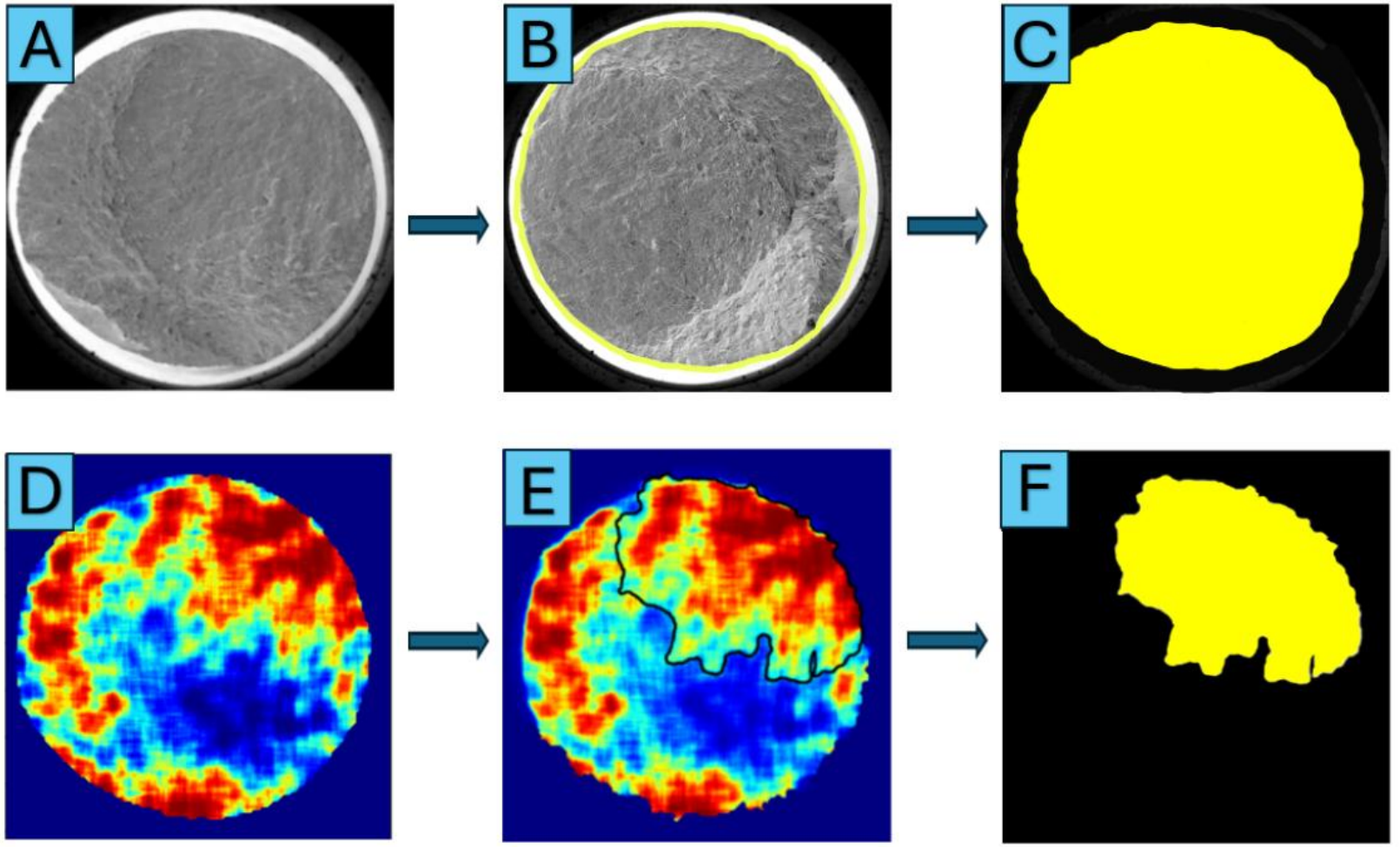


(c)

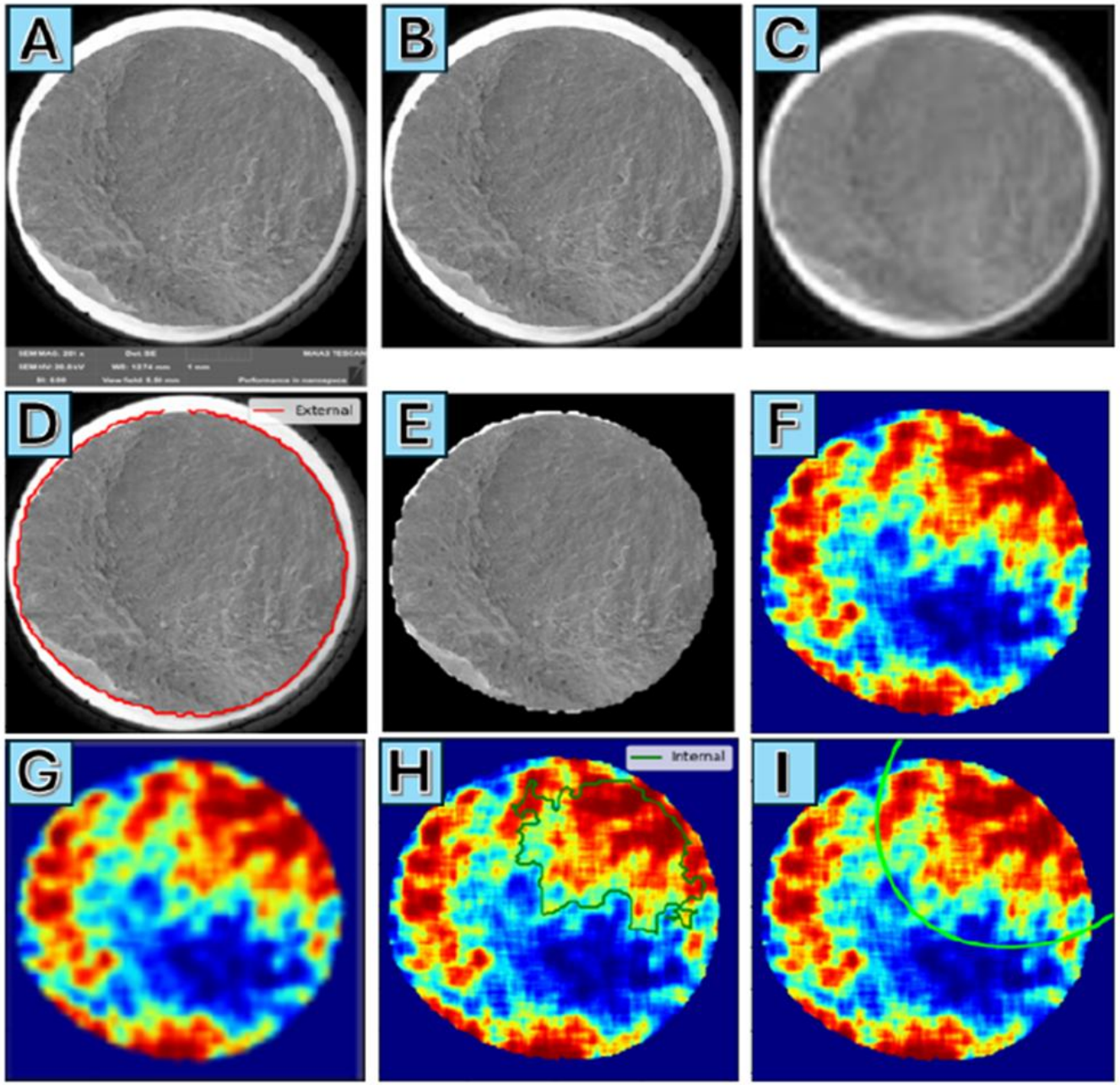
Visualization of the Process-Heatmap using sobel operator



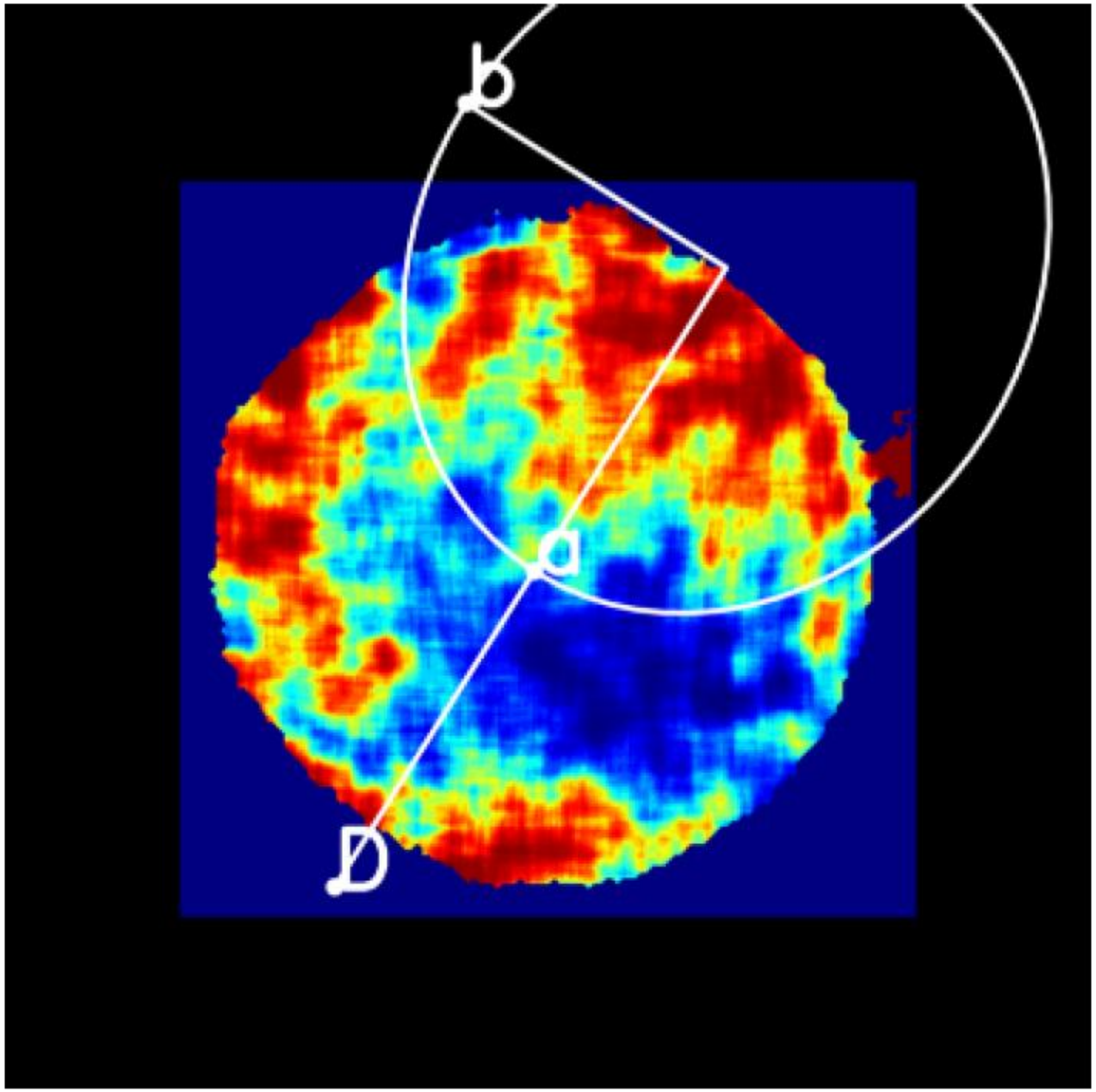
Visulaization of the Process – Labeling



Visualization of the Process – Get ellipse



Visualization of the Process – Get ellipse



Results

Training and Validation accuracy and loss

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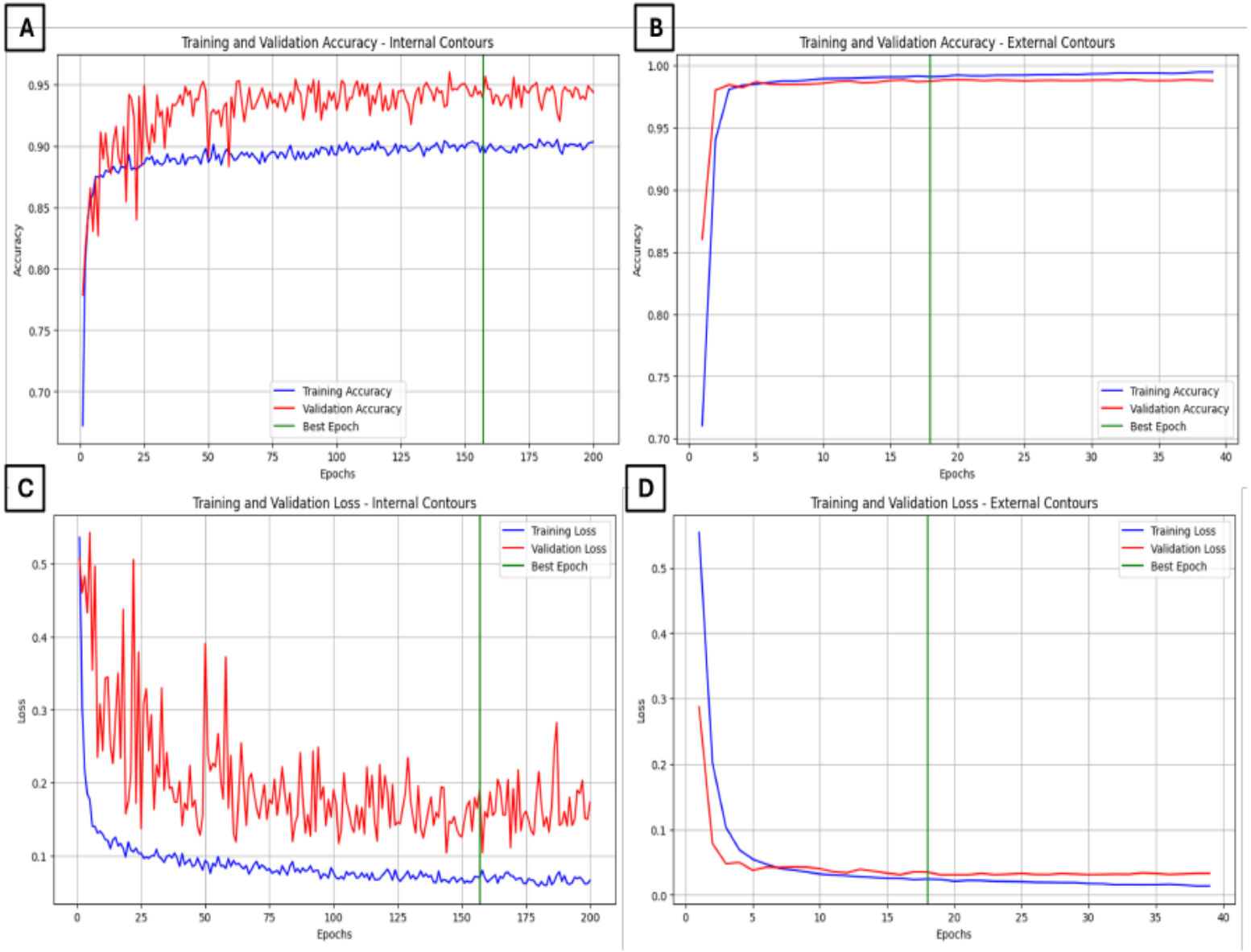
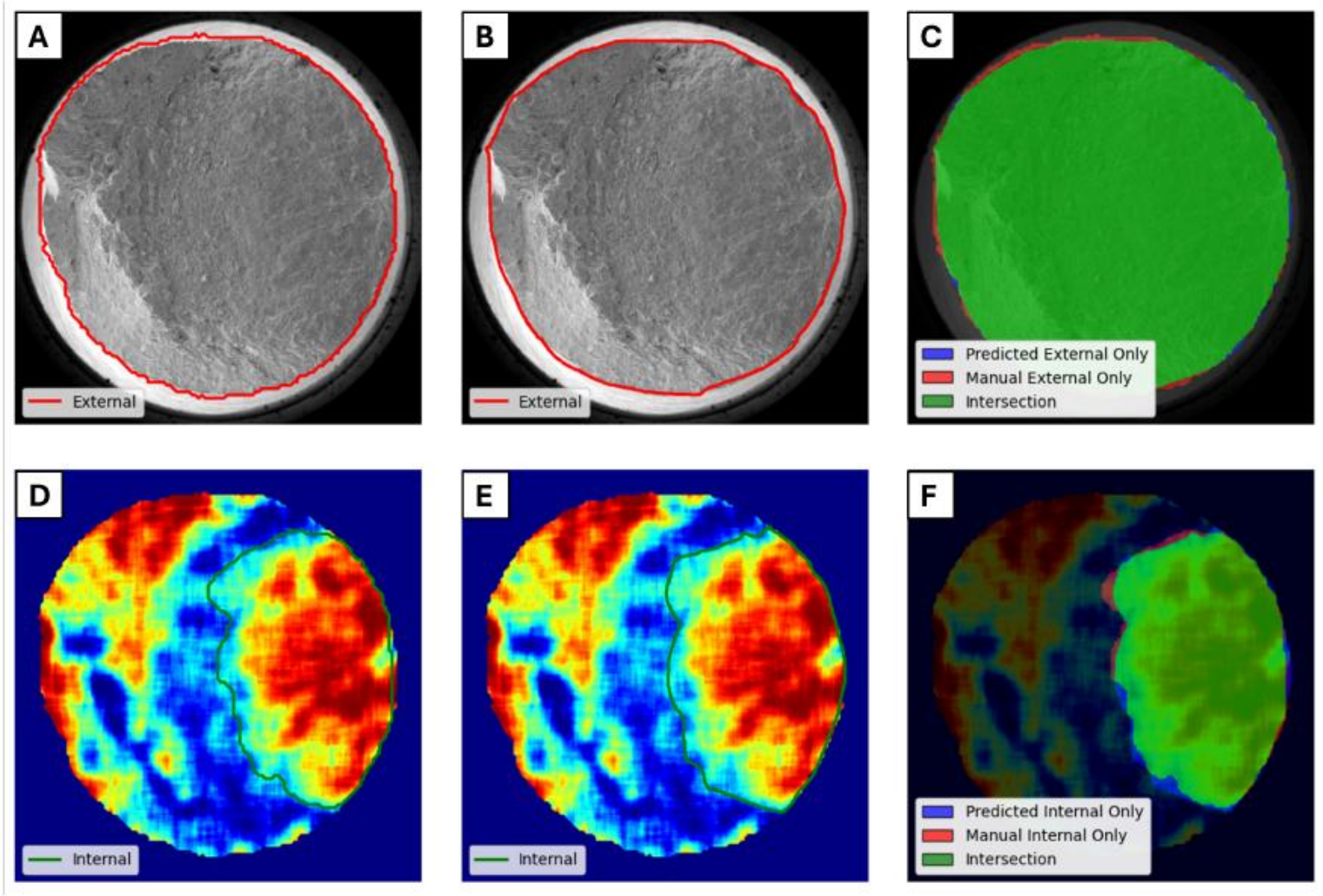
External and internal contours



Results

IOU - (Intersection Over Union)



External contour detection achived 0.97 in the IOU.
Internal contour detection achived 0.93 in the IOU.

Conclusion and Future Work

Conclusion:

- Developed an AI-driven solution for fatigue failure analysis in 3D printed materials.
- Achived high accuracy: IoU of 0.97 for external contour and 0.93 for internal.
- Faster and more reliable than traditional manual methods.

Future Work:

- Extend the model to analyze other materials and failure types.
- Explore real-time monitoring during 3D printing processes.
- Investigate additional AI models for even better accuracy and speed.