ENHANCING COMPOSITE MICROGRAPH ANALYSIS WITH SEMANTIC SEGMENTATION

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Christoph Brauer, Institute of Lightweight Systems, May 19, 2025

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INVESTIGATION OF FIBER VOLUME FRACTION AS KEY PARAMETER IN CRYOGENIC HYDROGEN TANK DEVELOPMENT

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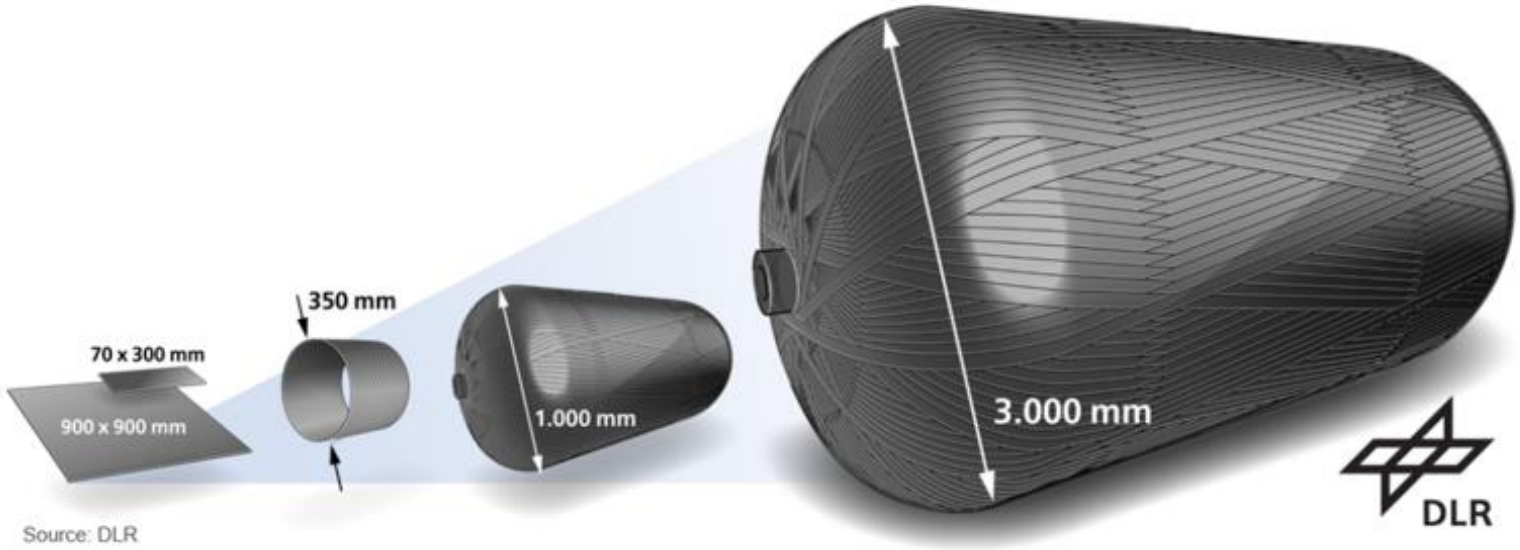
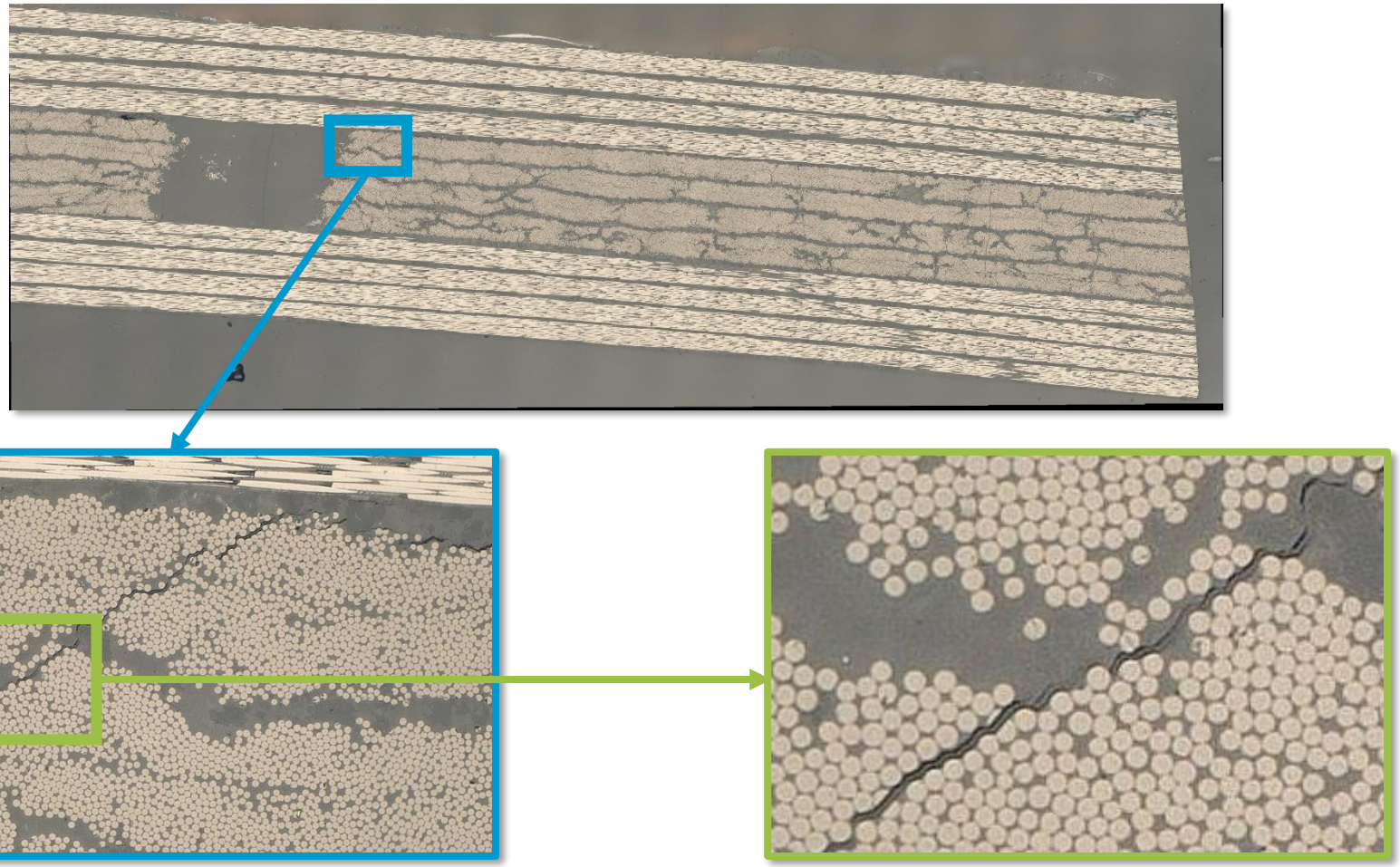
Motivation: CFRP LH2 Storage Tanks



Why manual analysis is not efficient

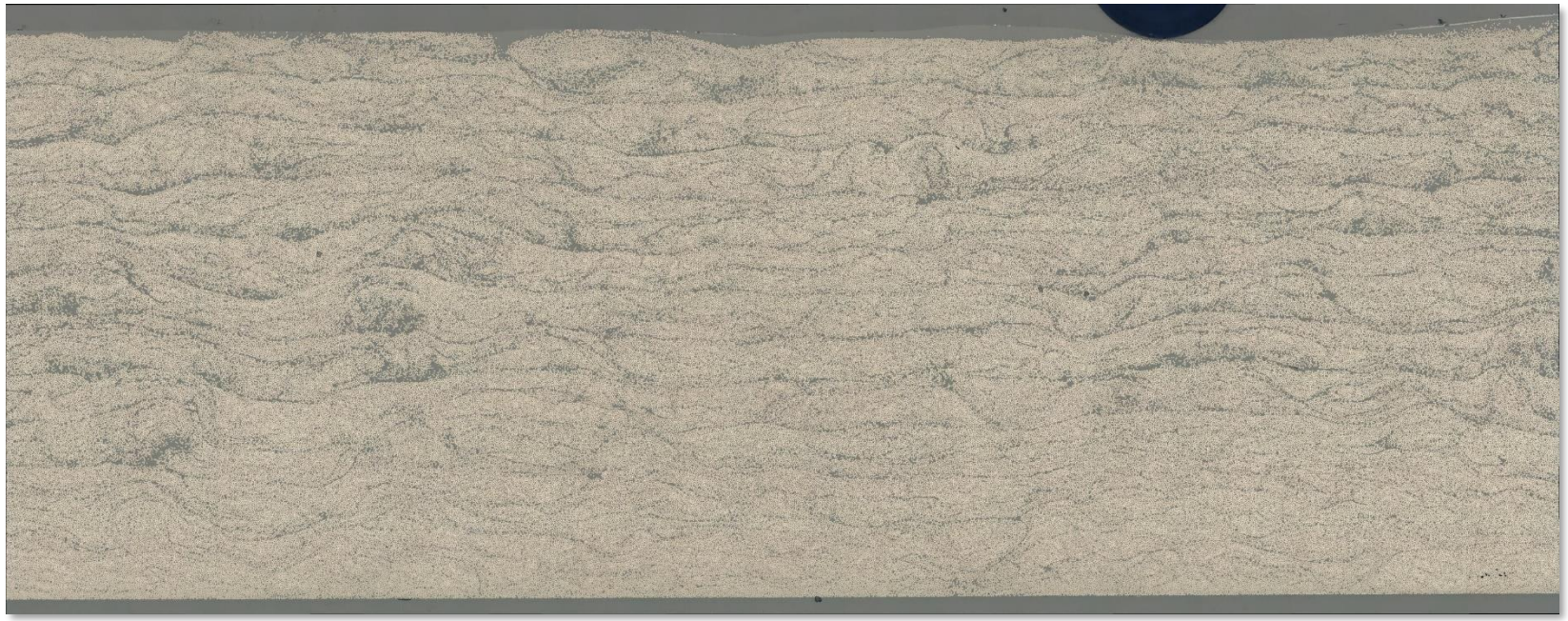
- Manual inspection is arduous due to the large image and small feature size



Why manual analysis is not sufficient

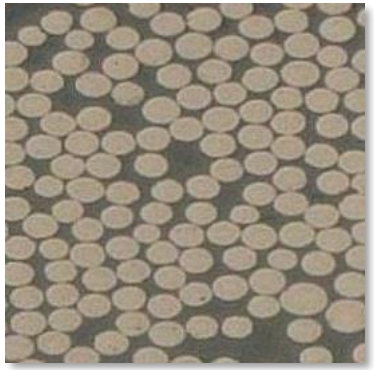
- Material characteristics can hardly be quantified by a manual inspection

Increasing fiber volume ratio?



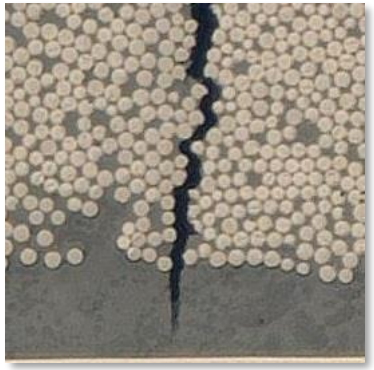
Semantic Classes

0° fibers



45° fibers

90° fibers



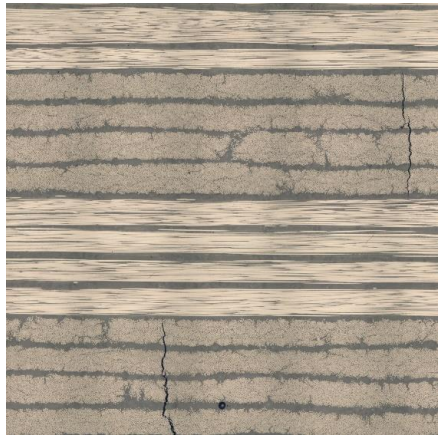
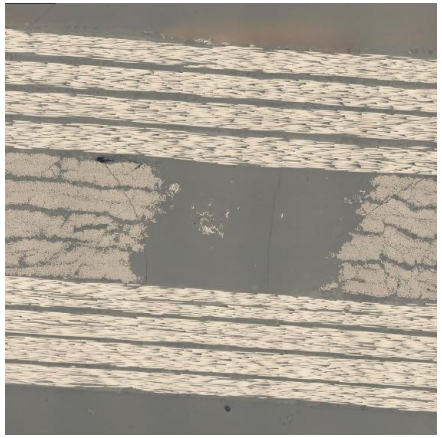
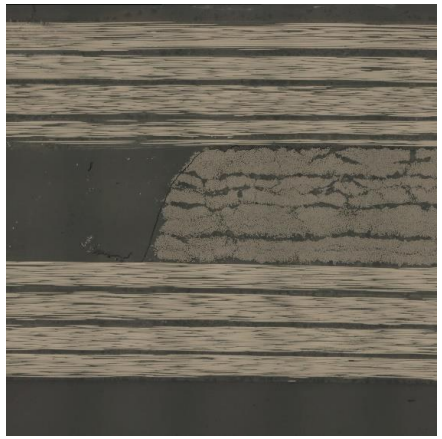
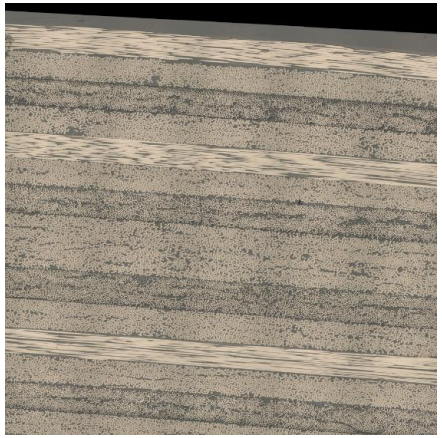
Crack

Epoxy

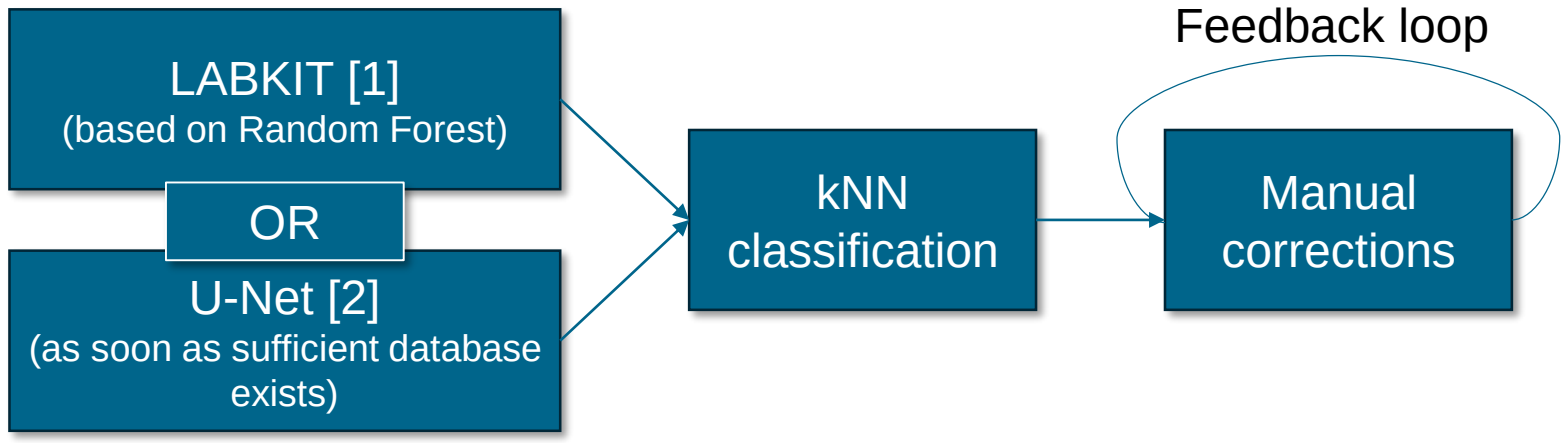
Other

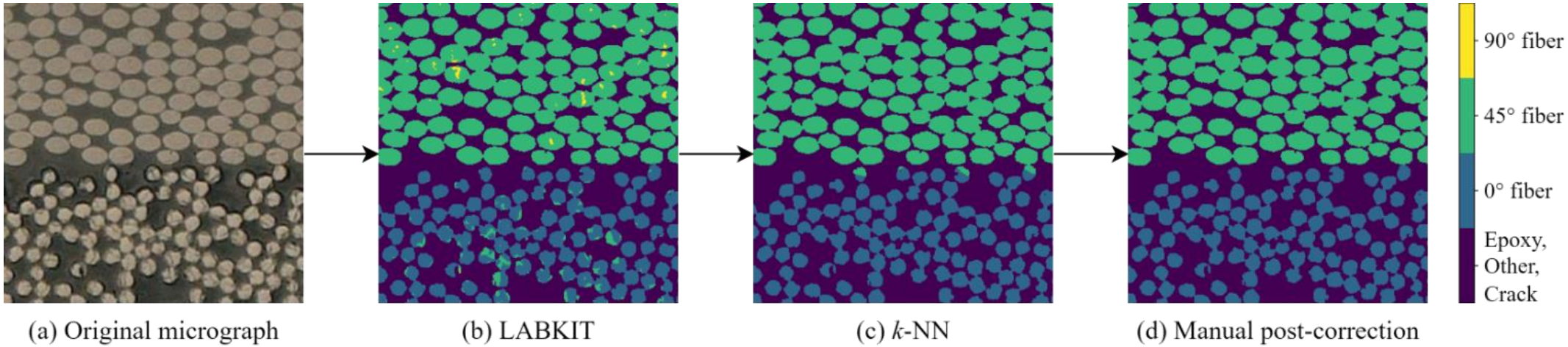
Image Database

- 7 CFRP samples covering a wide range of characteristics
- All micrographs are split into training, validation and test set
- 3,357 patches of size 512×512 px for training

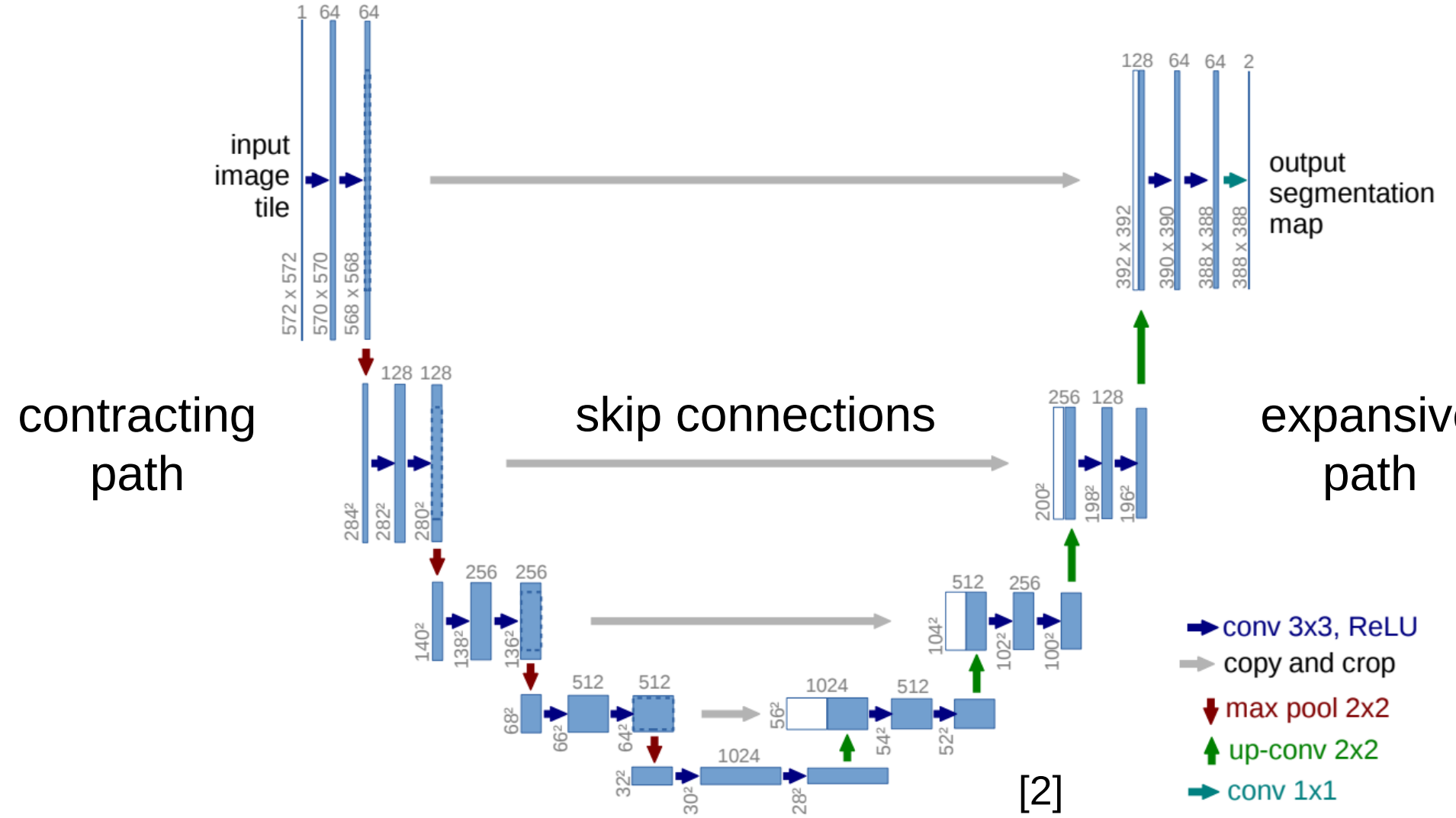
Data Labelling





(a) Original micrograph (b) LABKIT (c) *k*-NN (d) Manual post-correction

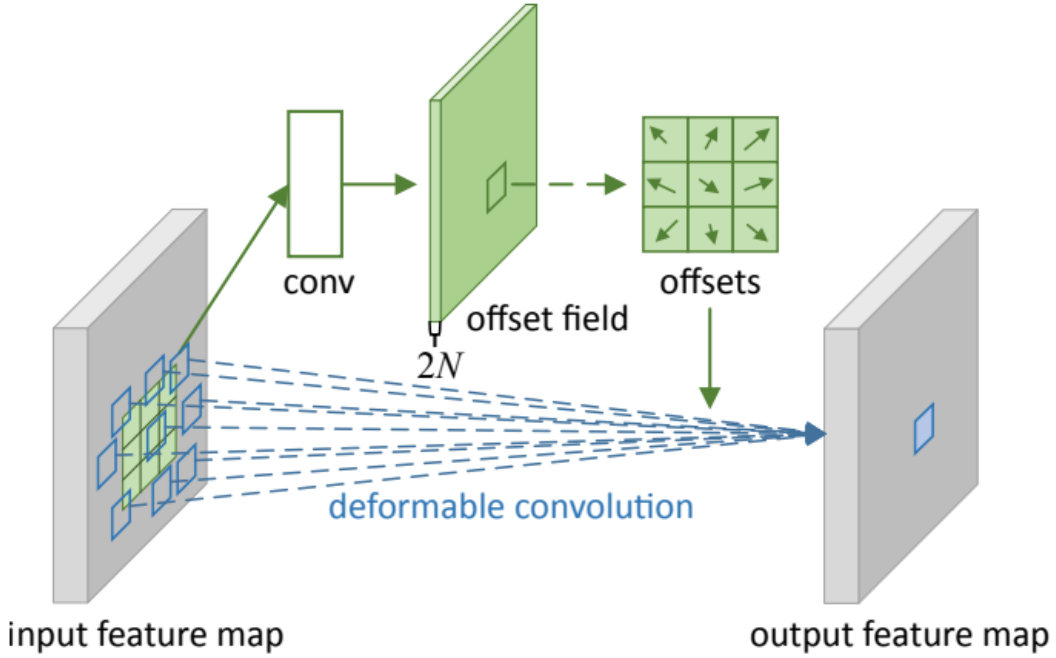
U-Net


input image tile
output segmentation map
contracting path
skip connections
expansive path
conv 3x3, ReLU
copy and crop
max pool 2x2
up-conv 2x2
conv 1x1
[2]

InternImage

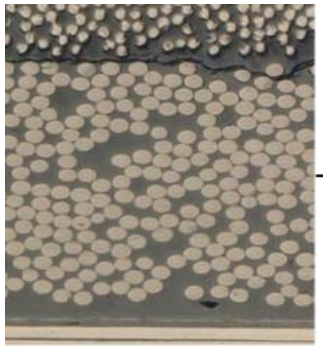
- Large-scale foundation model based on deformable convolutions [3]

+ Large receptive field
+ Adaptive spatial aggregation



[4]

InternImage U-Net



Stem

InternImage Block (x4)
H/4 × W/4 × 32

InternImage Block (x4)
H/8 × W/8 × 64

InternImage Block (x18)
H/16 × W/16 × 128

InternImage Block (x4)
H/32 × W/32 × 256

Convolutional Decoder Stage
H/4 × W/4 × 32

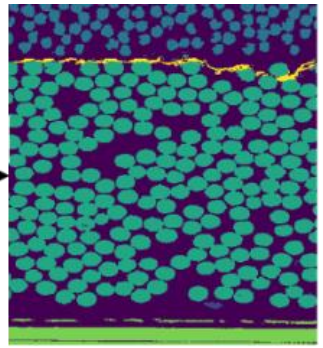
Convolutional Decoder Stage
H/8 × W/8 × 64

Convolutional Decoder Stage
H/16 × W/16 × 128

(x2)

1x1 Convolution

torch.argmax()

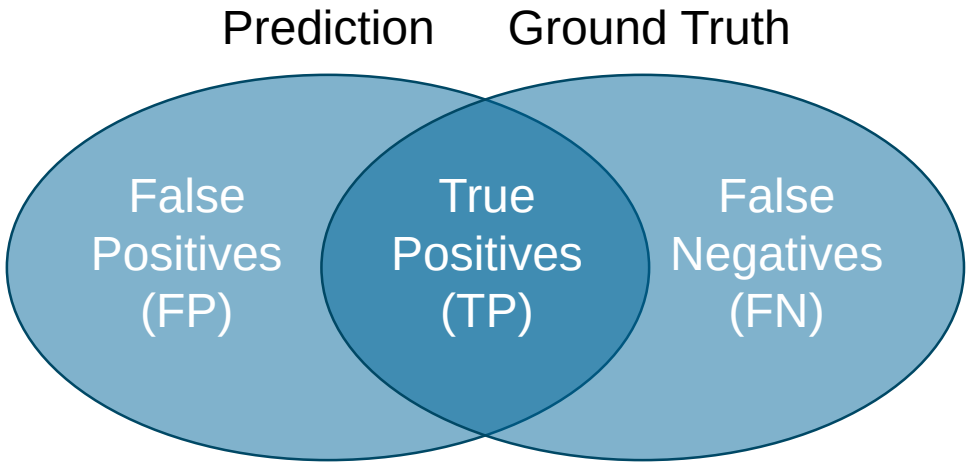


2×2 transp. conv, s2, p0

3×3 conv, s2, p1
LN

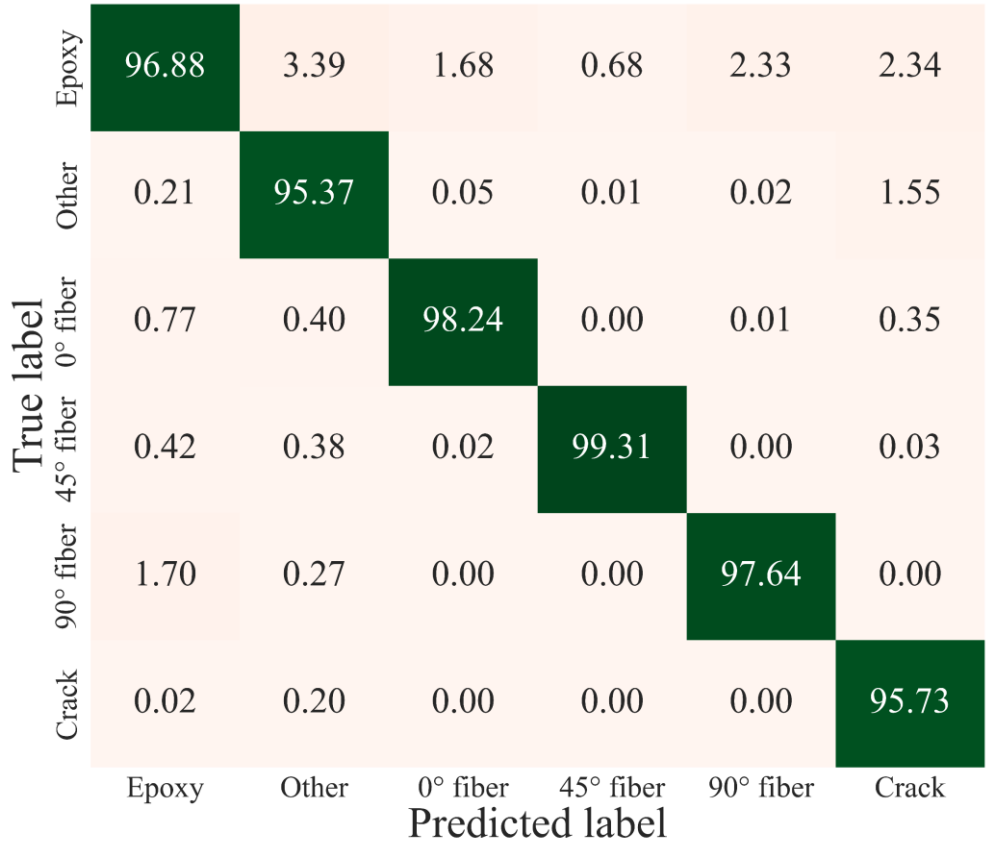
Evaluation Metrics

- Pixel Accuracy: $\frac{TP+TN}{TP+TN+FP+FN}$
- Recall: $\frac{TP}{TP+FN}$
- Precision: $\frac{TP}{TP+FP}$
- Intersection over Union (IoU): $\frac{TP}{TP+FP+FN}$

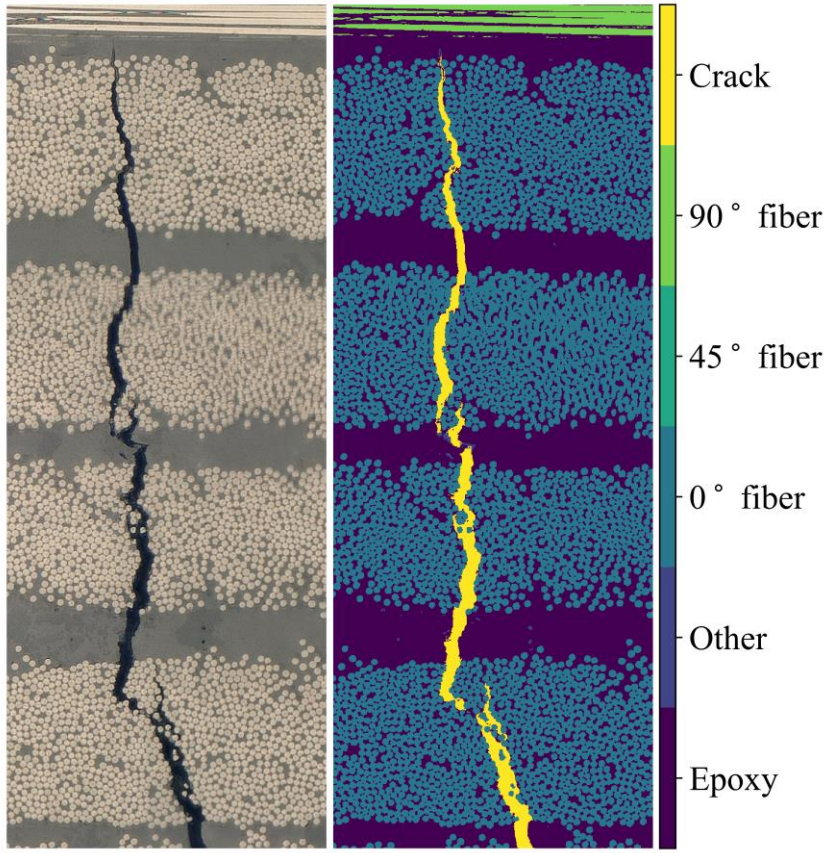


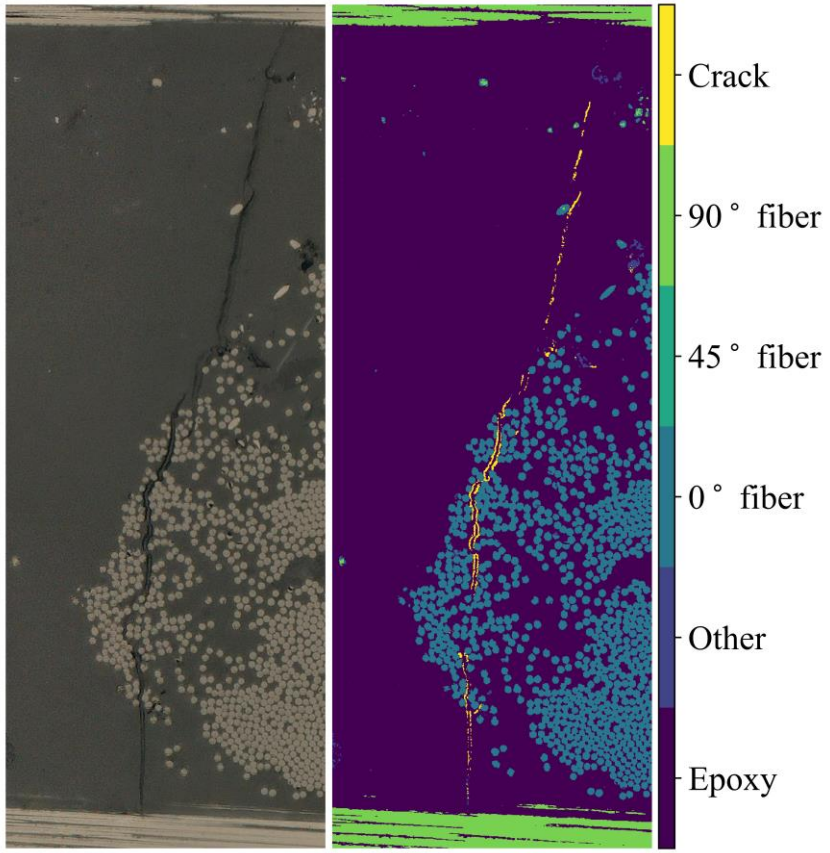
Evaluation

- Pixel Accuracy: 97.7 %
- Mean IoU: 0.9071
- Precision values > 95 %
- Crack Recall of 78.16 %
- *Crack* and *Other* class are the most difficult ones and mainly mixed up with *Epoxy*



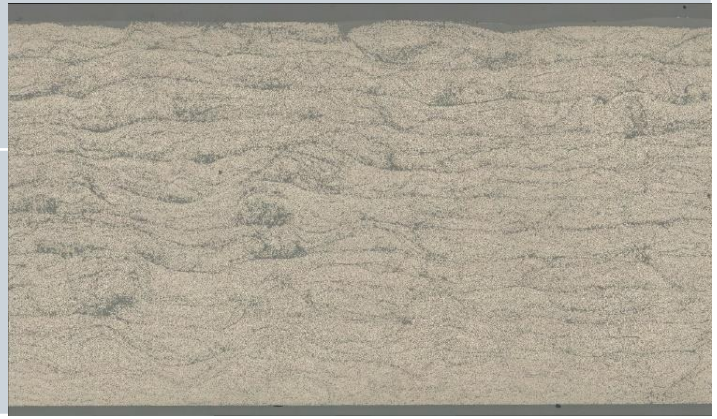
Crack Examples





Fiber Volume Ratio (FVR) Heatmaps

Use case	Investigation of the effects of manufacturing process parameters on the FVR gradient of cylindrical CFRP tank structures
Challenge	How to quantify the local FVR?



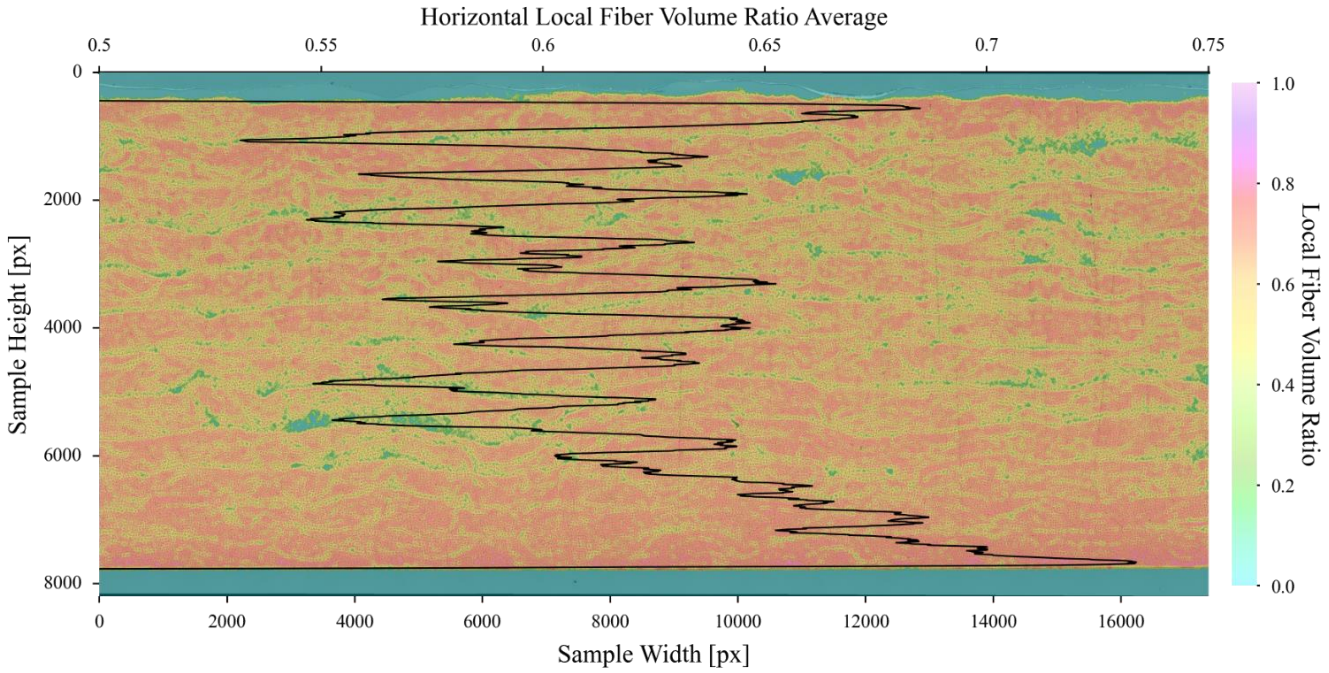
Fiber Volume Ratio (FVR) Heatmaps

- Estimate FVR by ratio of *0° fiber* and *epoxy* pixels
- Color pixels based on the local FVR in their neighborhood

Jonas Appels et al.:

Investigation of Fiber Volume Fraction as Key Parameter in Cryogenic Hydrogen Tank Development

(SAMPE 2025)

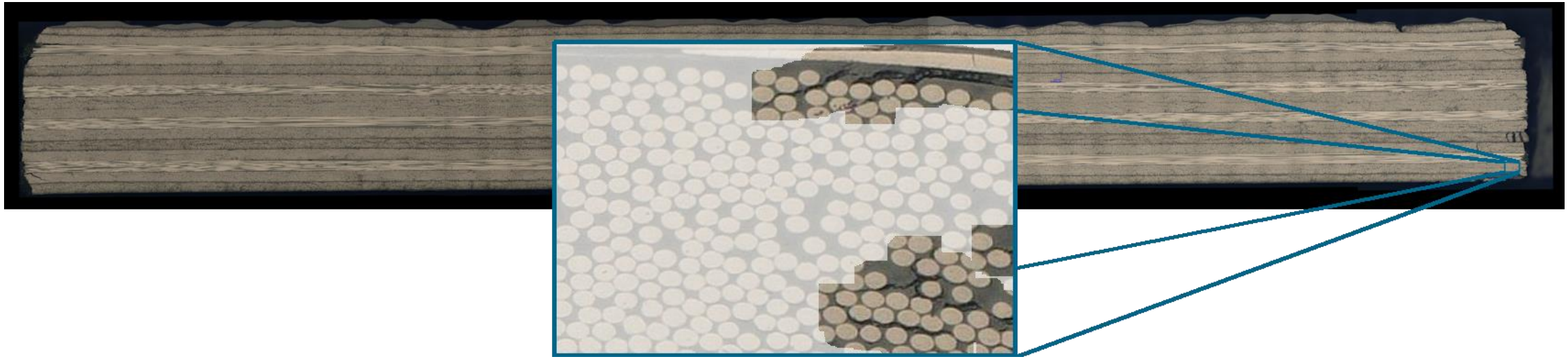


Crack Search Tool

Use case	Investigation of crack formation in cylindrical CFRP tank structures during thermal cycling
Challenge	How to detect cracks efficiently?

Crack Search Tool

- MaxPooling and thresholding on crack probability masks
- Outcome: Coarse highlighting of potential crack areas
- Increases **crack recall** up to **97 %** with a threshold of 20 %



Conclusion & Outlook

- Our segmentation model
  - + **accelerates** and **automates** the micrograph analysis,
  - + enables us to **quantify** laminate characteristics and
  - + opens up many more possibilities for further analysis…

- Future research:
  - void quantification
  - detect instances of fibers and plies

References

[1] Arzt, M., et al.: *LABKIT: Labeling and Segmentation Toolkit for Big Image Data.* (2022)

[2] Ronneberger, O., Fischer, P. & Brox, T.: *U-Net: Convolutional Networks for Biomedical Image Segmentation.* (2015)

[3] Wang, W., et al.: *InternImage: Exploring Large-Scale Vision Foundation Models with Deformable Convolutions.* (2023)

[4] Dai, J., et al.: *Deformable Convolutional Networks.* (2017)

Impressum

Thema:	Enhancing Composite Micrograph Analysis with Semantic Segmentation
Date:	2025-05-19
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Institute:	Institute of Lightweight Systems
Images:	All images “DLR (CC BY-NC-ND 3.0)”, unless otherwise noted