

# Effect of Induced Delamination Defects on the Mechanical Performance of Composite Laminates

Aristea Giannakopoulou<sup>1</sup>, Mohamed S. Loukil<sup>1</sup>, Marie Jonsson<sup>1</sup>, Sibin Saseendran<sup>2</sup>

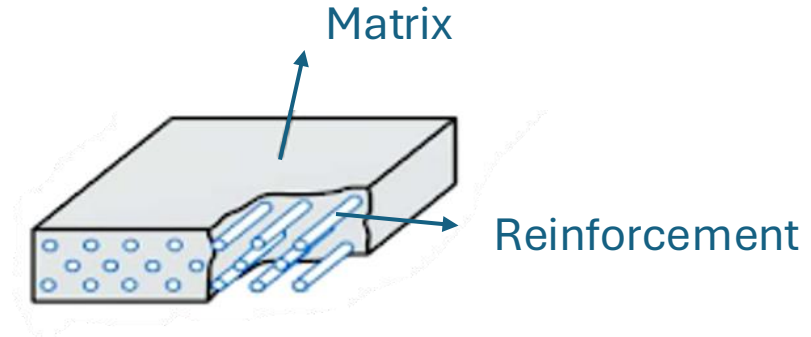
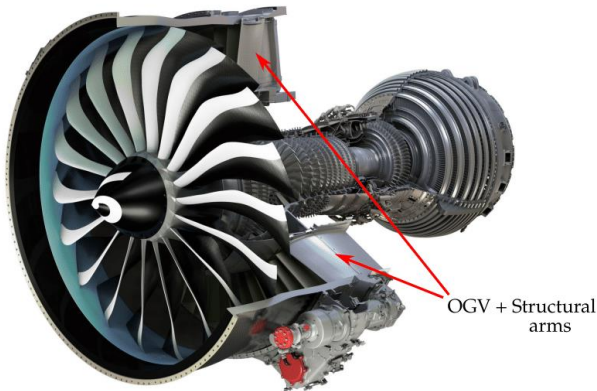
<sup>1</sup> *Division of Engineering Materials (KMAT), Linköping University, Linköping, Sweden*

<sup>2</sup> *GKN Aerospace Sweden AB, Trollhättan, Sweden*

# Why Composites ?

## Boeing 787 Dreamliner skin structure

### COMPOSITES



### What:

- Hybrid materials (e.g., CFRP: matrix + reinforcement)
- Lightweight, strong, and tailorable

### Why (Aerospace):

- Efficiency: Unmatched strength-to-weight ratio
- Durability: High fatigue & corrosion resistance
- Performance: Design flexibility & fuel savings

# The MADEiMPACT project



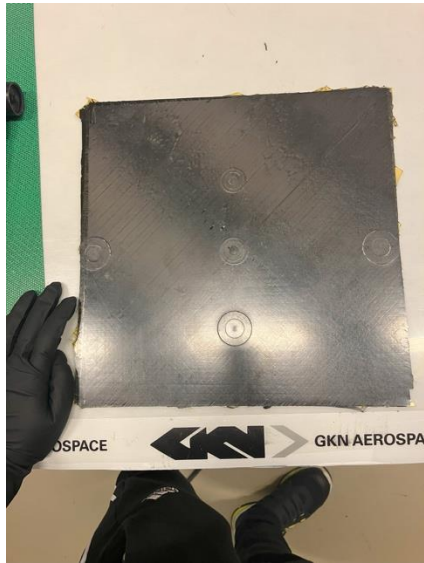
**Collaboration:** GKN Aerospace & Linköping University

**Goal:** Enhance CFRP performance for aero-engine parts

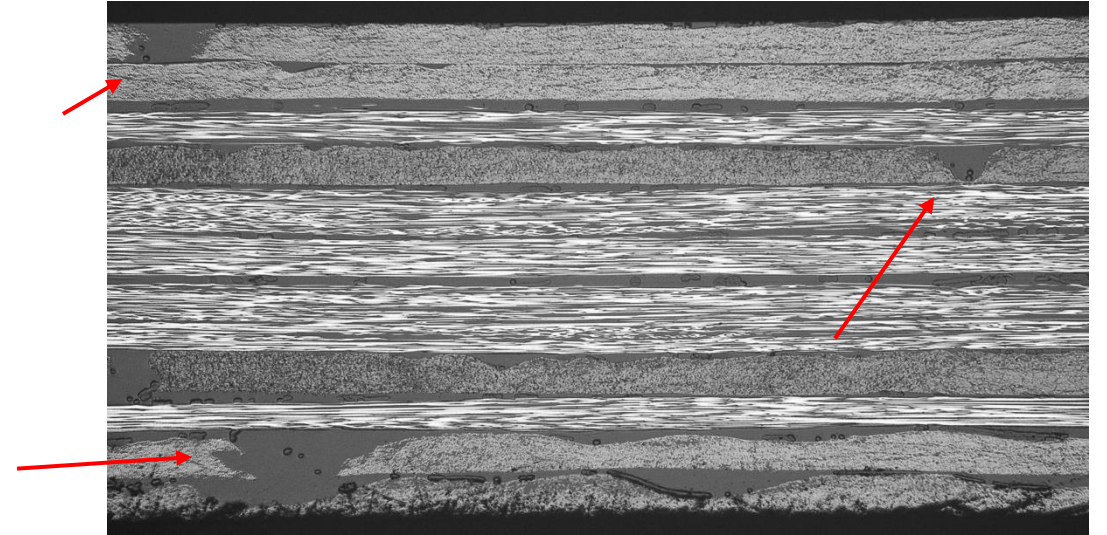
**Focus:** Effect of manufacturing defects on mechanical behavior

TeXtreme® Gapped UD

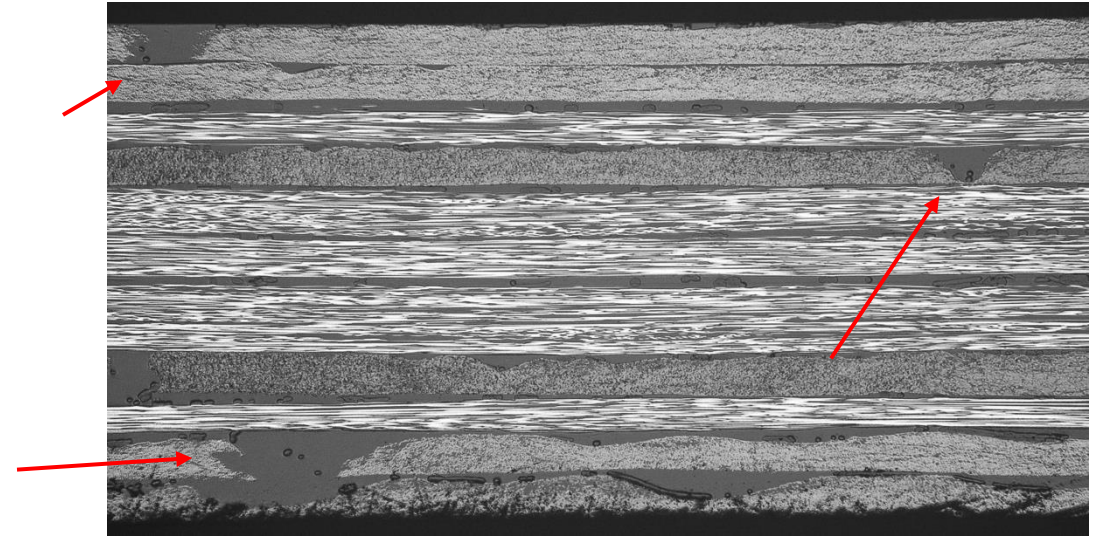
Our lay-up  $[\pm 45, 0, 90, 0_4]_s$



- Waviness of the non 0° layers

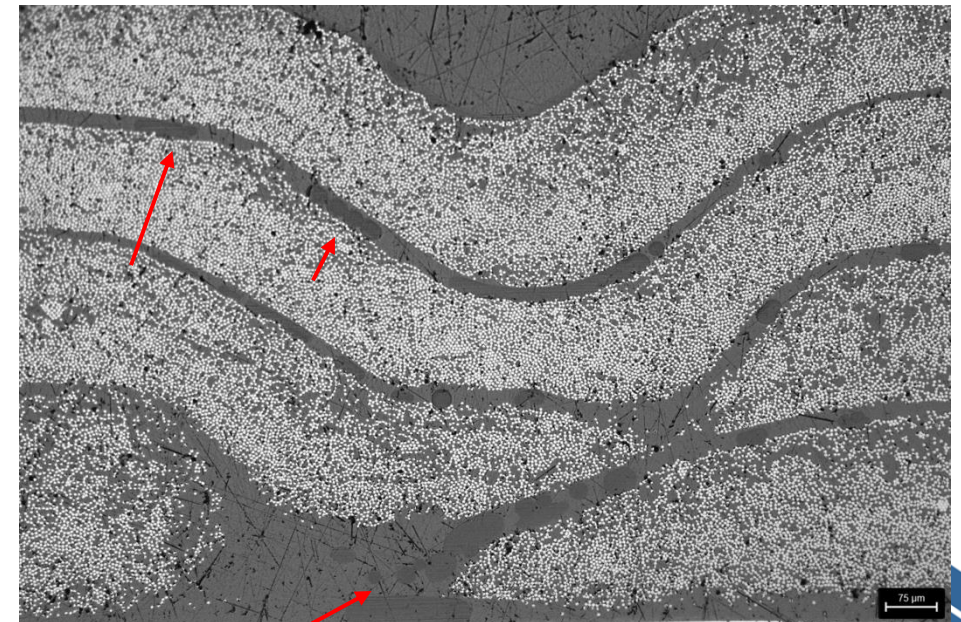


➤ Waviness of the non 0° layers



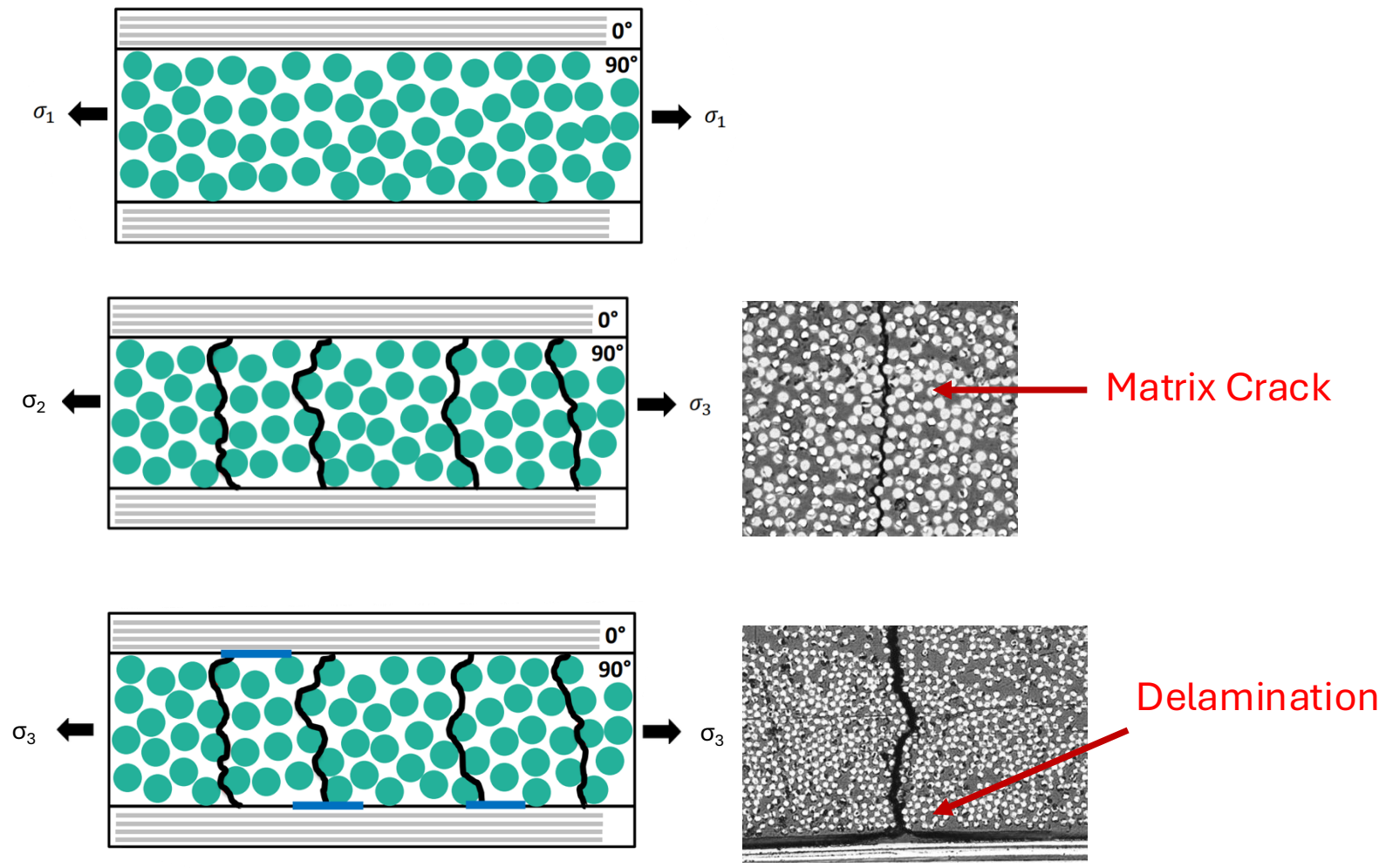
➤ Defects

- Waviness
- Unmelted Particles
- Voids



Unmelted particles

# Damage in Composite Materials

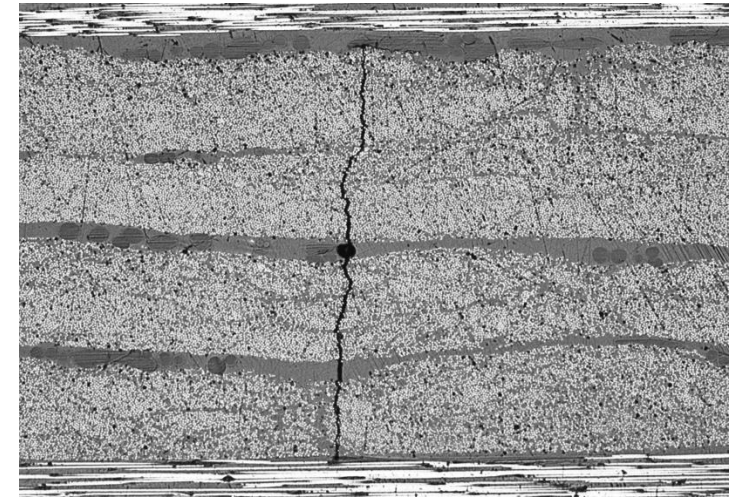
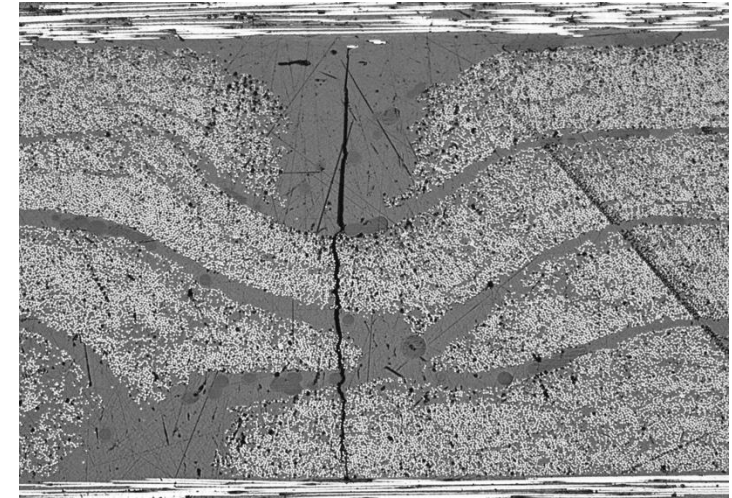
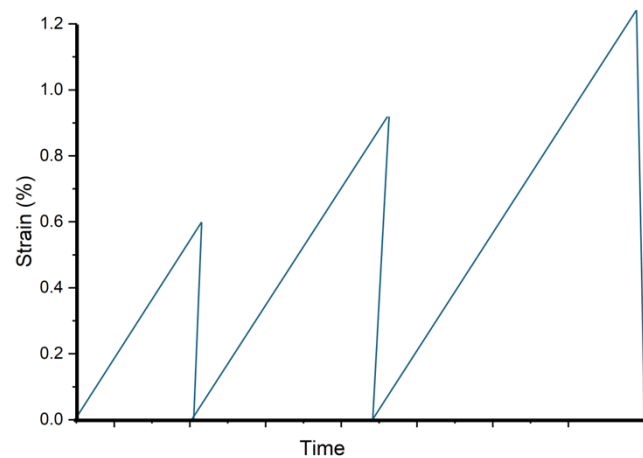


## Method

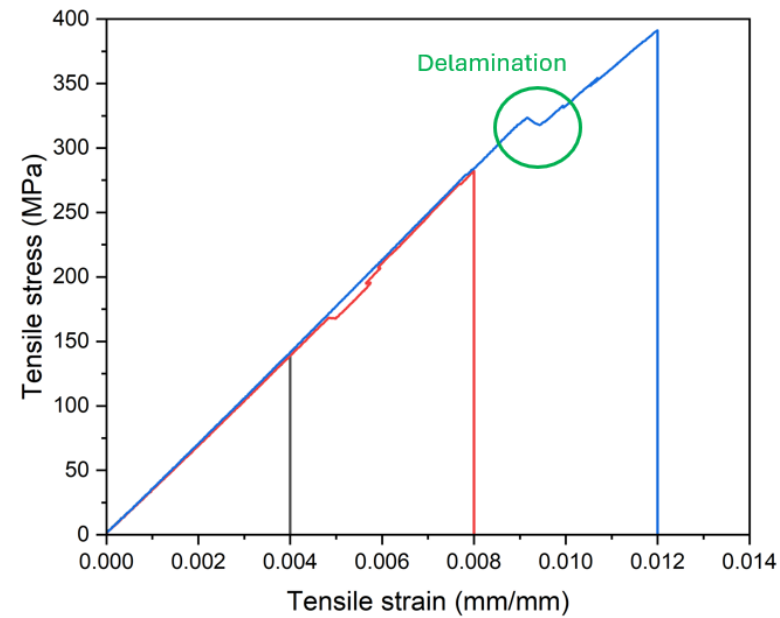
- Incremental loading: 1 mm/min
- Tracked cracks & delamination
- Focus: waviness, voids, resin-rich zones

## Results

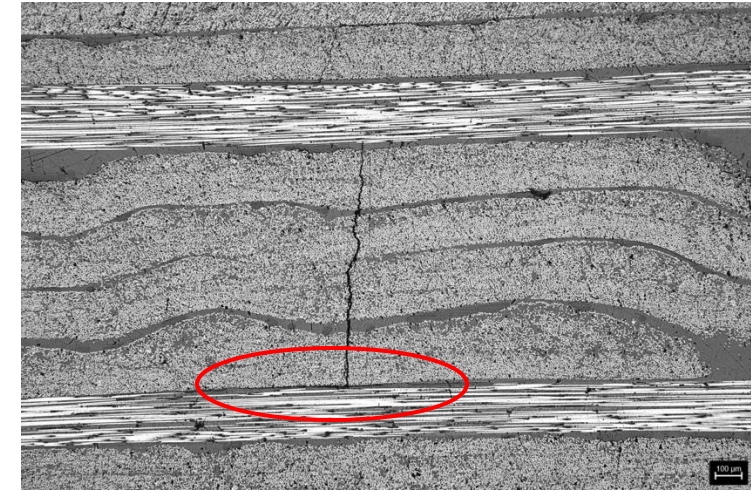
- **0.6% strain** → crack initiation
- **0.9% strain** → crack growth
- **1.2% strain** → delamination



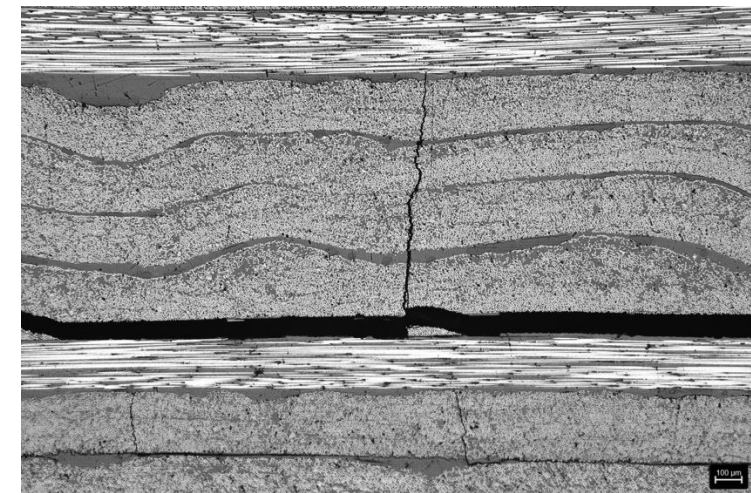
# Tensile Testing



- Early onset, gradual progression of damage
- Stress-strain "step" confirms interlaminar failure

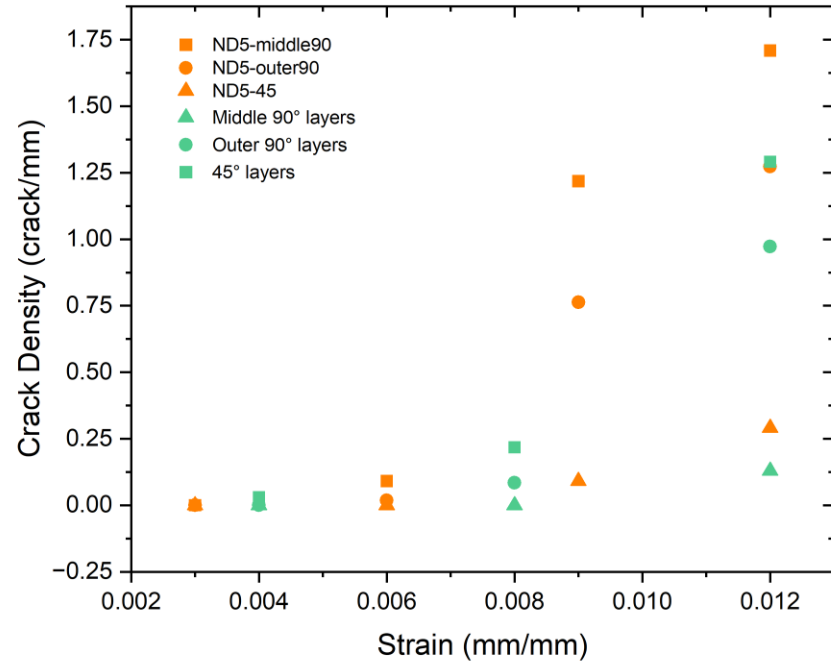


0.8% strain

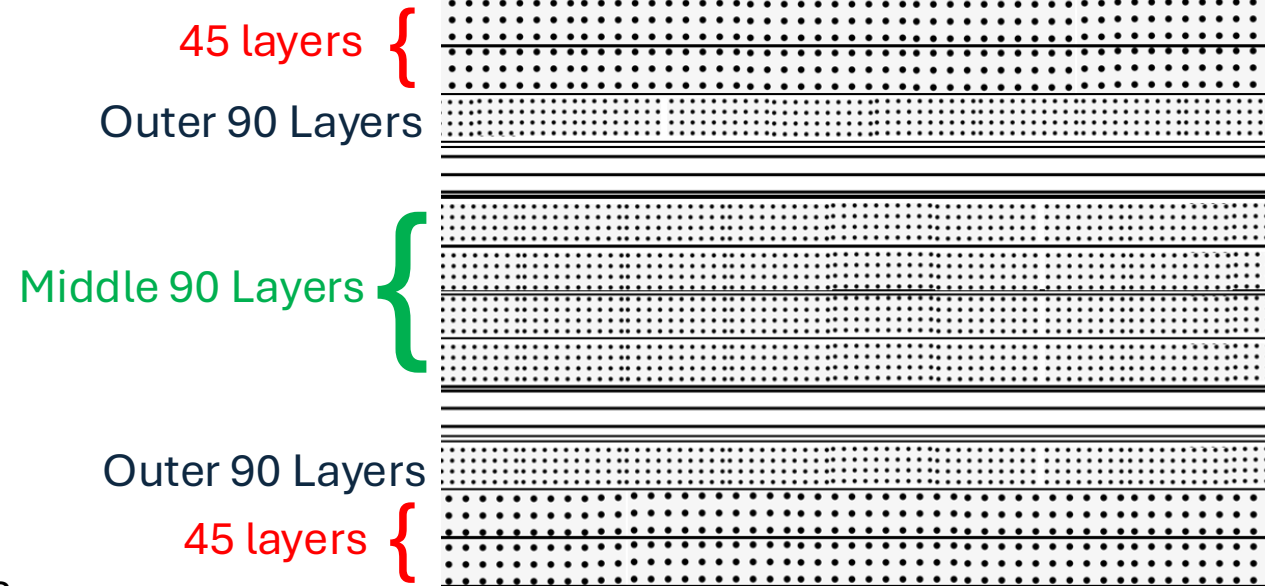


1.2% strain

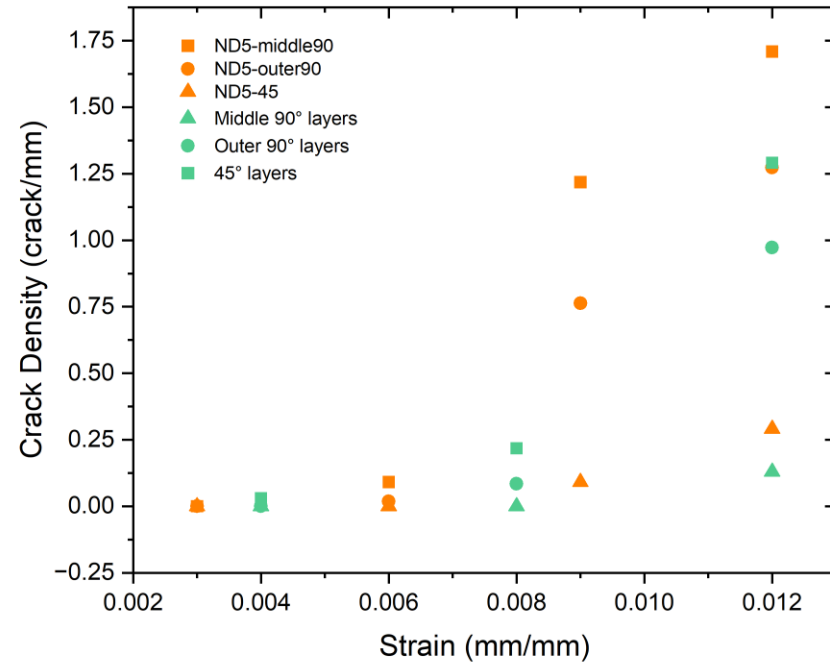
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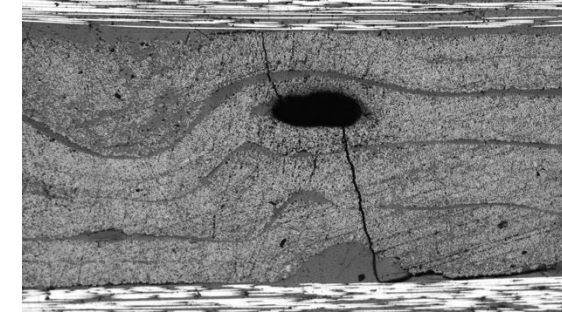
- **N5 (with voids):** Highest crack count across all orientations
- **Voids amplify damage** and crack behavior varies by ply orientation



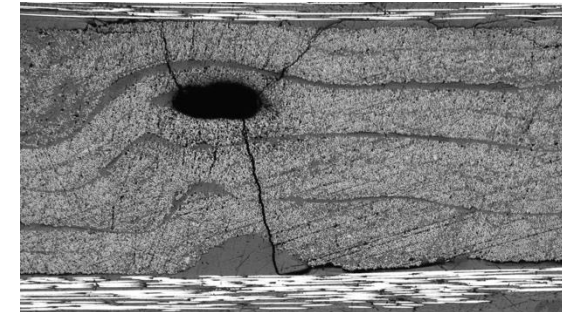
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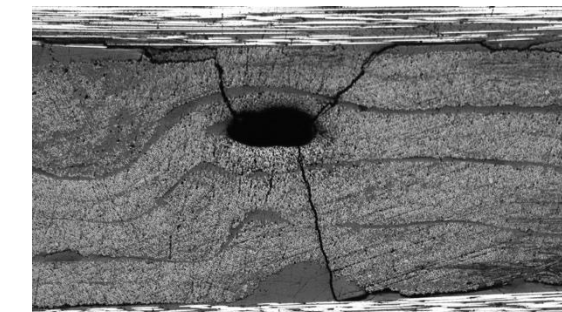
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0.6%



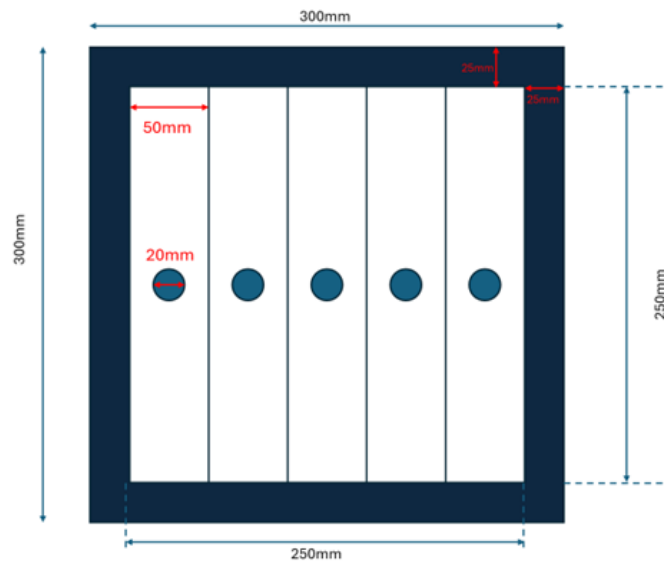
0.9%



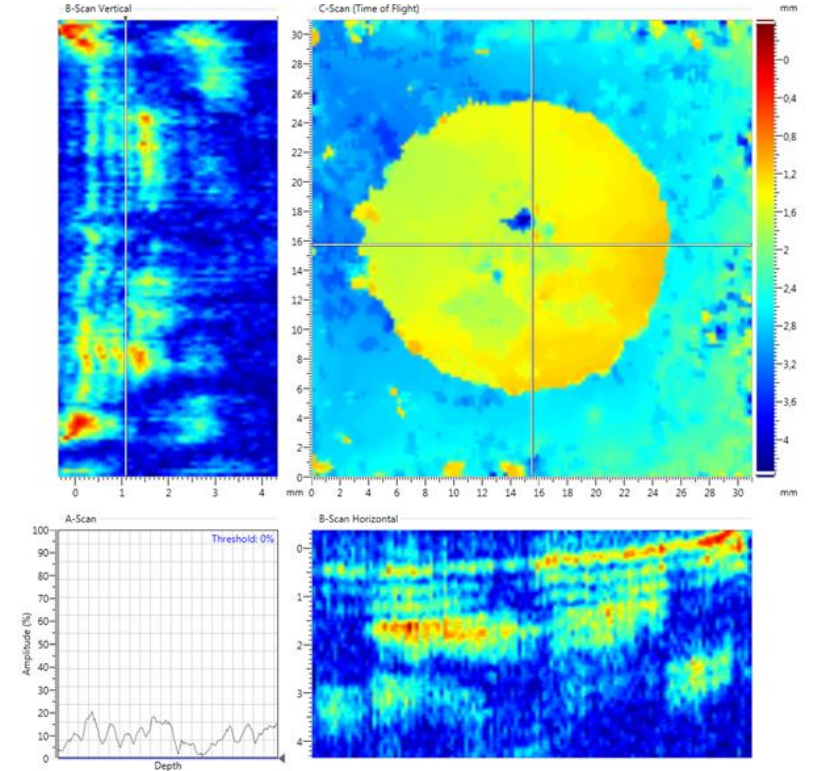
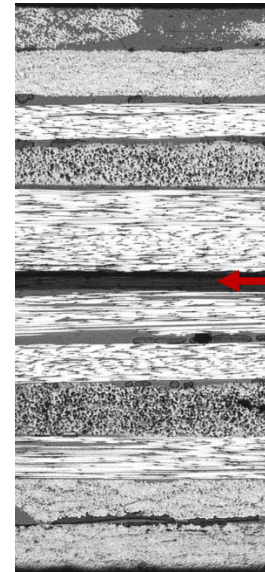
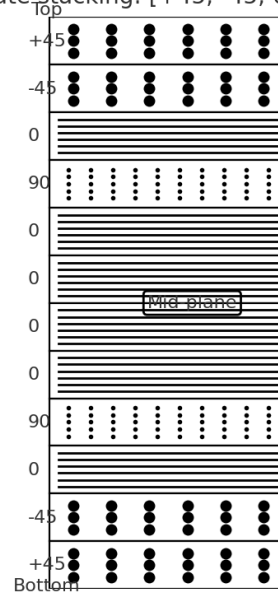
1.2%

# Induced Delamination

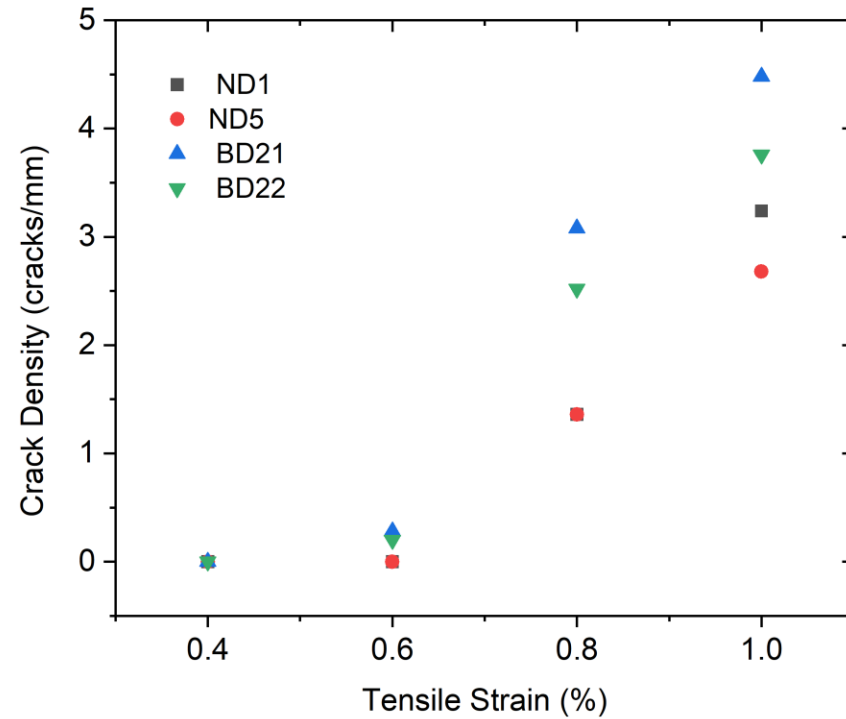
- Introduced circular delaminations with Teflon film
- Ultrasound clearly confirmed defects
- Test to isolate the effect of delamination



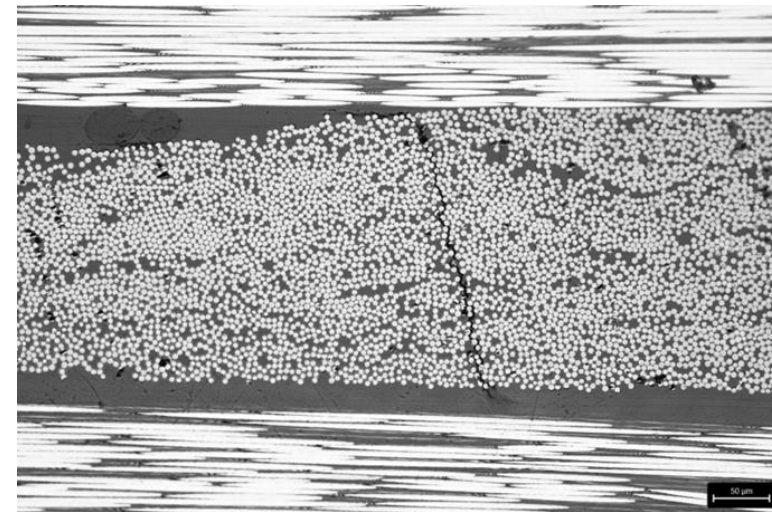
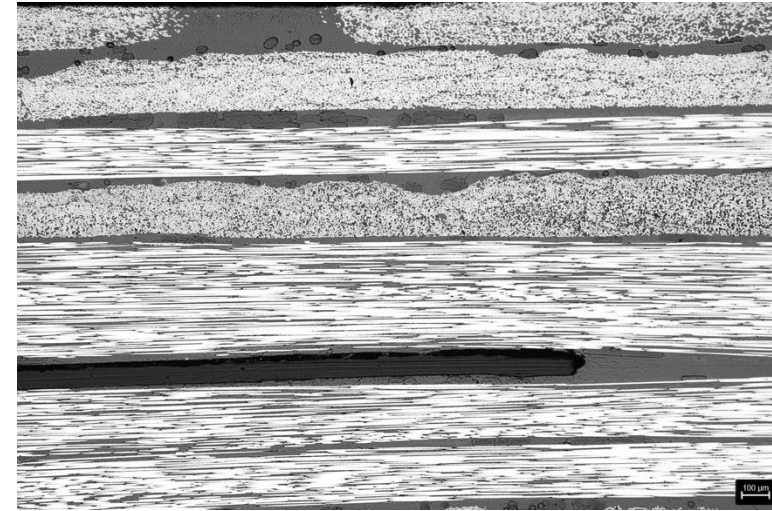
Laminate stacking: [+45, -45, 0, 90, 0(2)]s



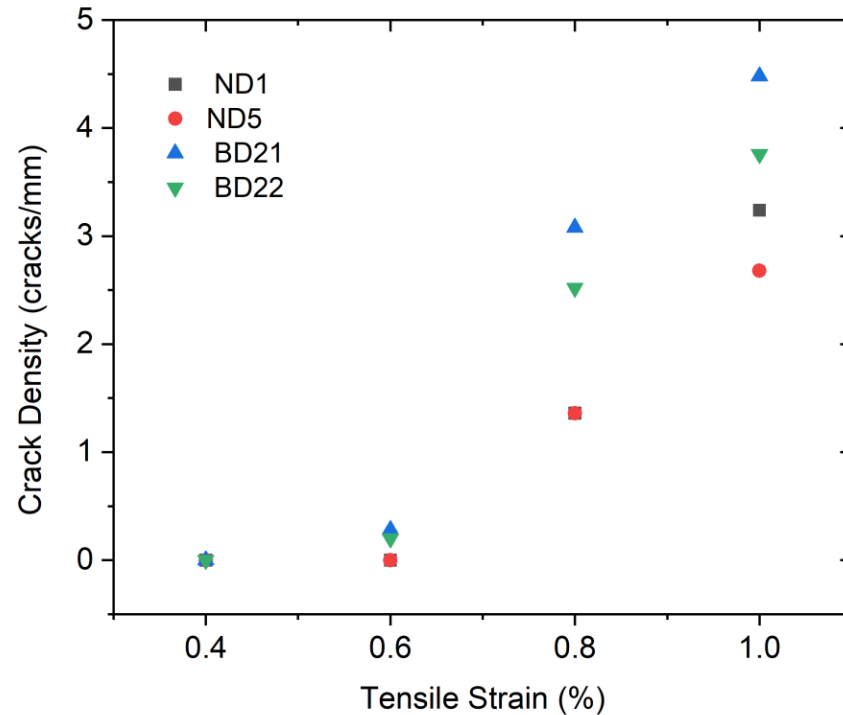
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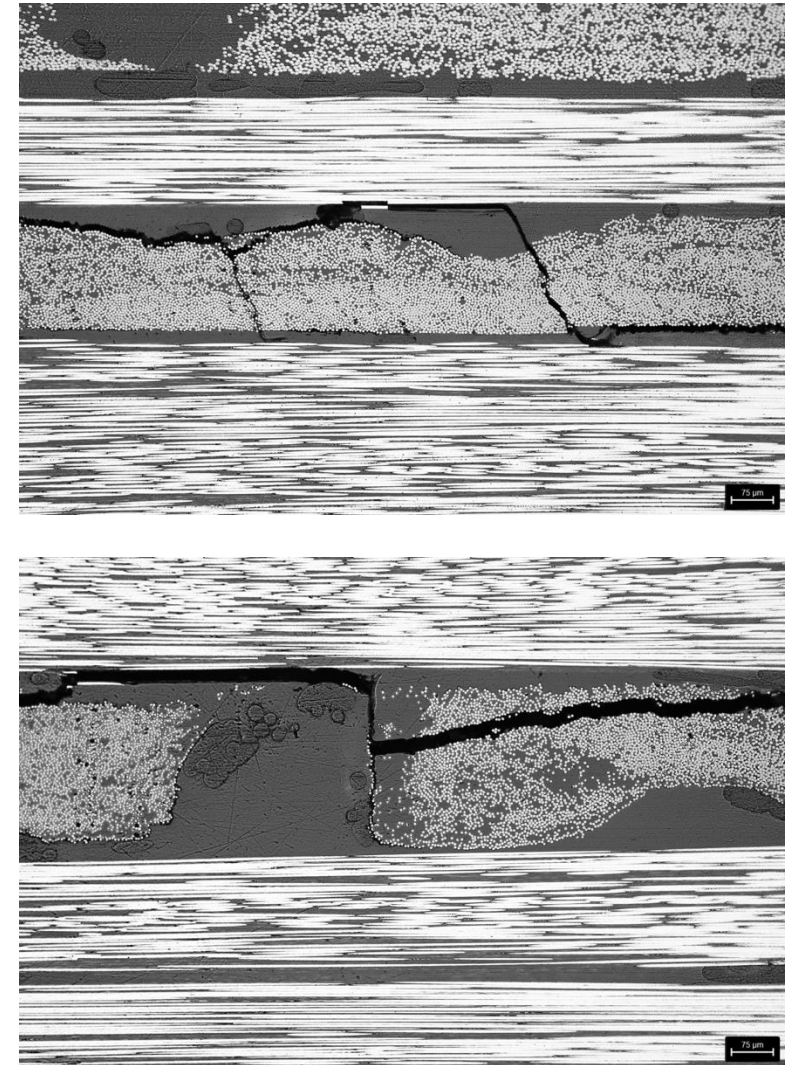
- No cracks at 0.4% strain
- First cracks at 0.6% for BD samples



# Tensile Testing

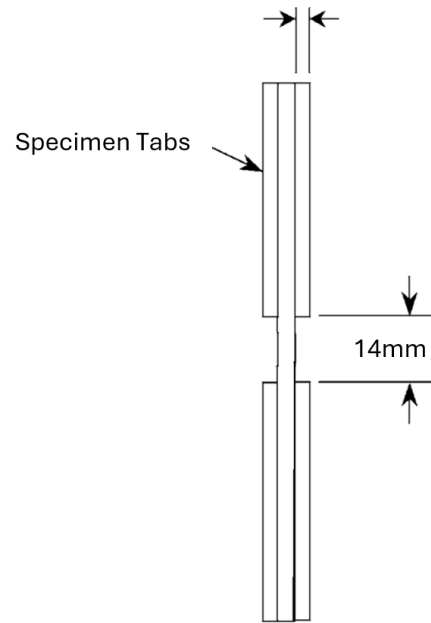


- Cracks localized in 90° layers
- Induced Teflon :
  - Earlier cracking at lower strain
  - Higher crack density

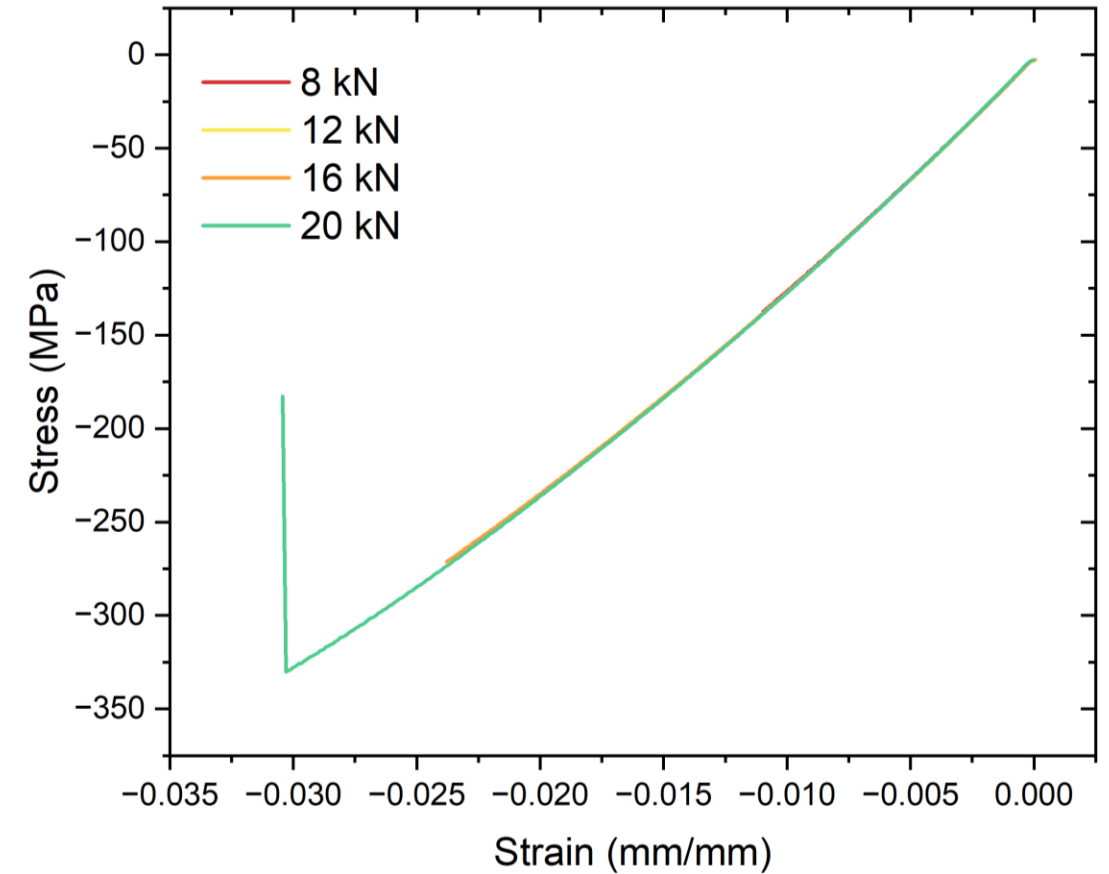


No effect of the resin rich areas or unmelted particles was observed

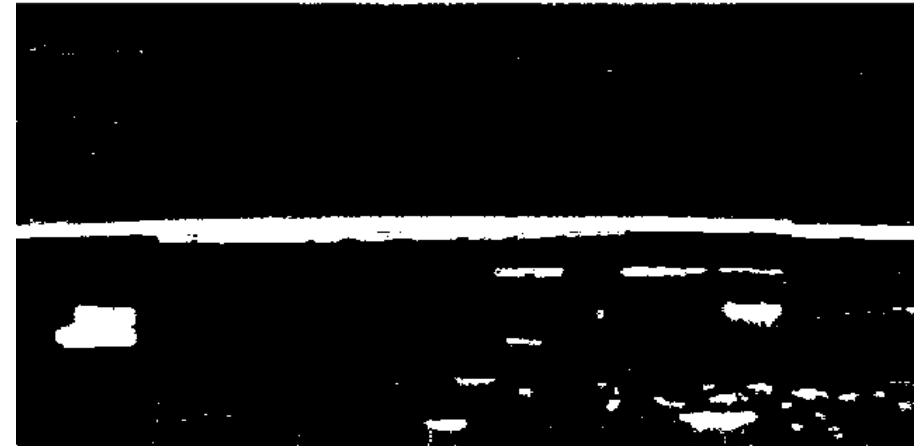
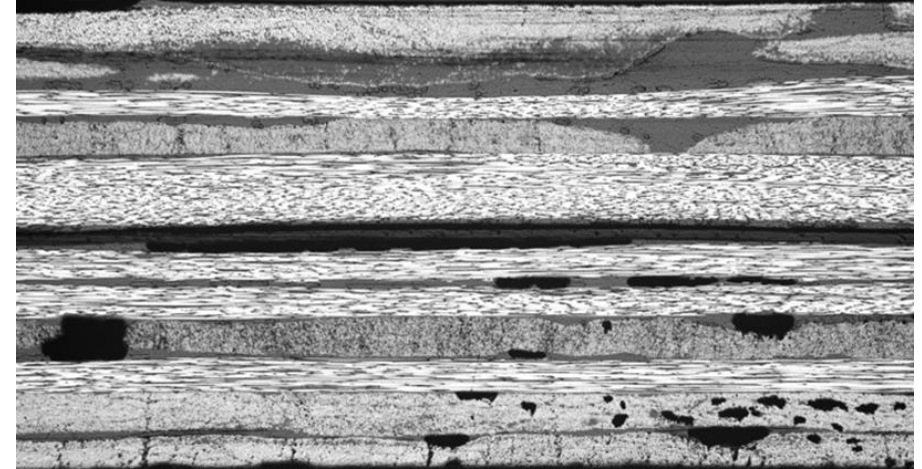
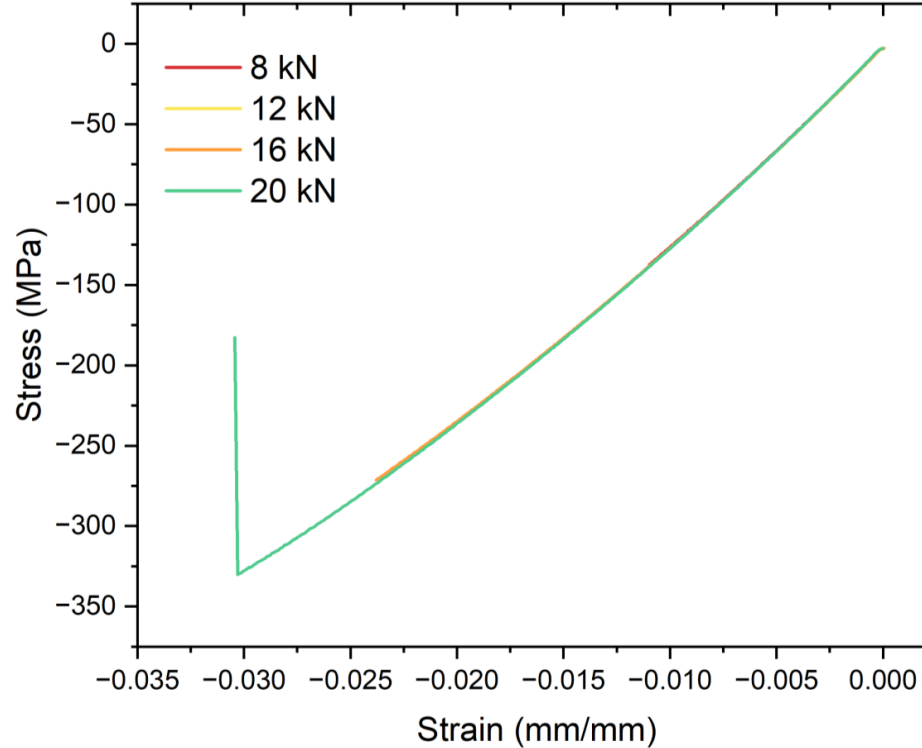
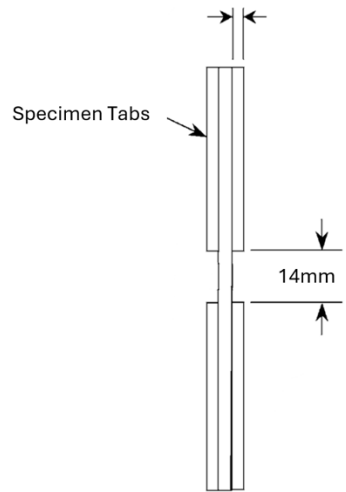
# Compression Testing



- Stepwise compression loading
- Brittle failure prevented POM inspection
- MATLAB image analysis
- Void fraction vs. maximum compressive load

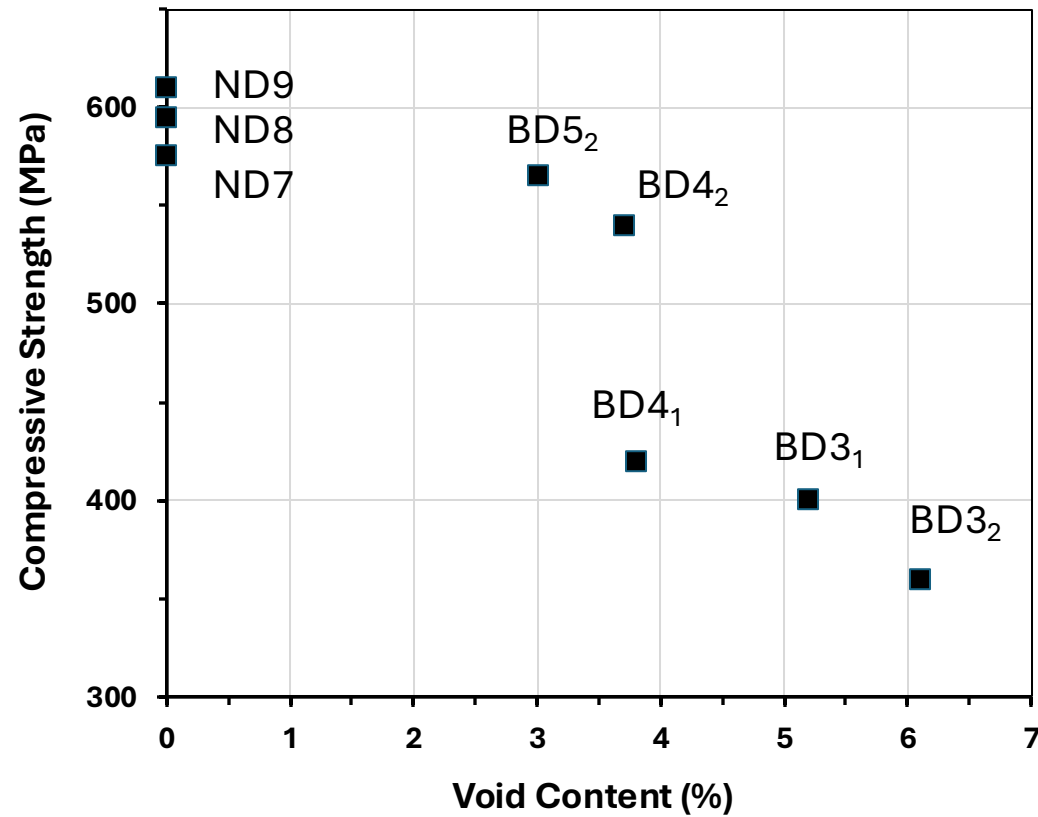


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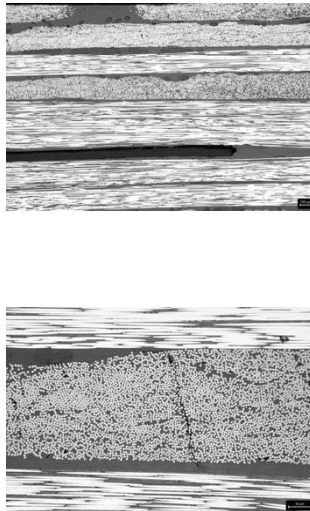
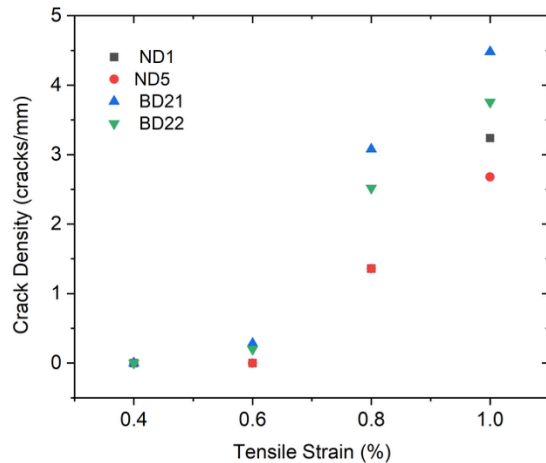


- Higher void fraction reduces compressive strength
- Voids directly degrade structural performance
- Minimizing voids is essential for maximum strength

# Conclusions

## Tensile Tests

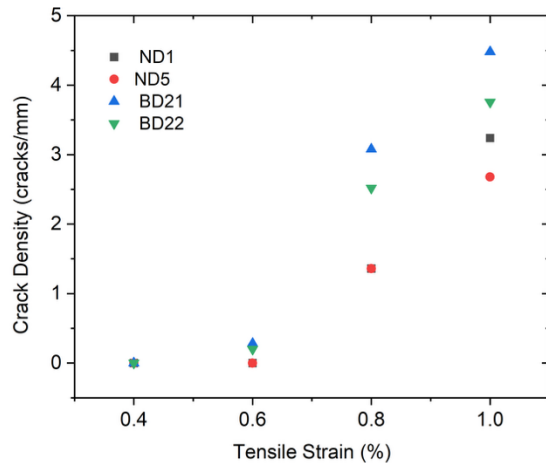
- Delaminated samples showed **earlier crack initiation** (~0.6% strain).
- **Cracks localized in 90° layers** and increased with strain.
- **Higher crack density** in delaminated vs. non-defective samples.
- **Unmelted particles/resin-rich zones** had **no effect**.
- **Teflon insert** reduced stiffness but didn't trigger cracks.



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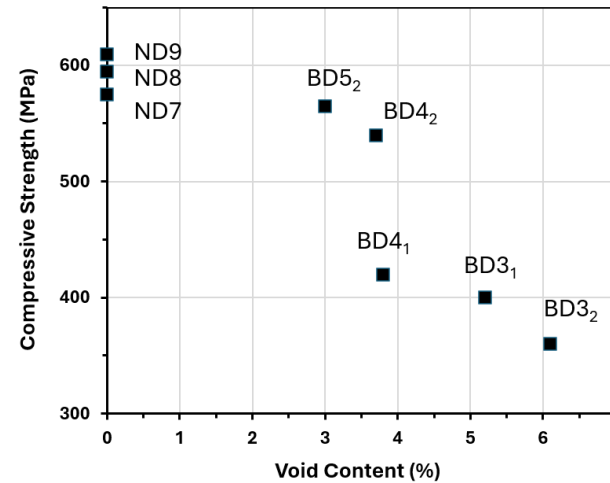
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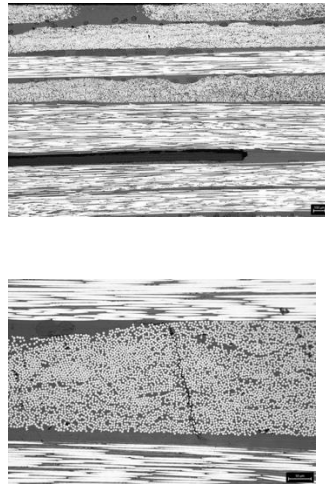
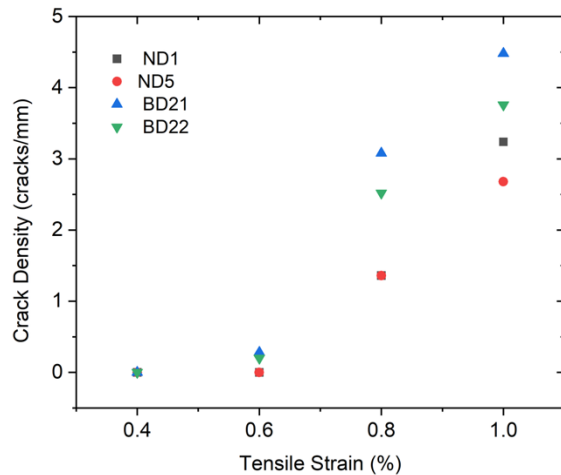
- **Brittle failure** prevented damage progression observation.
- **Void content**  $\uparrow$   $\rightarrow$  **compressive strength**  $\downarrow$  (clear correlation).
- **Voids weaken load transfer** and lower structural performance.
- Highlights the importance of **minimizing porosity** in manufacturing.



# Conclusions & Acknowledgements

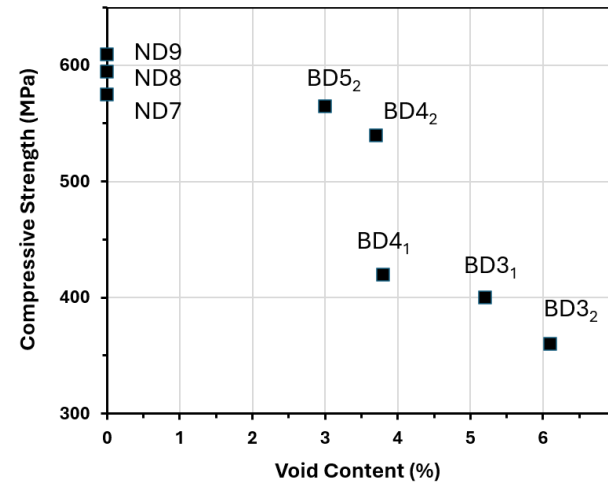
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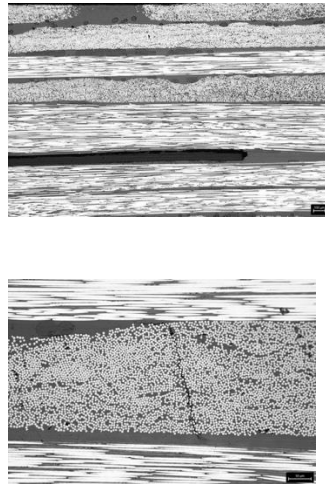
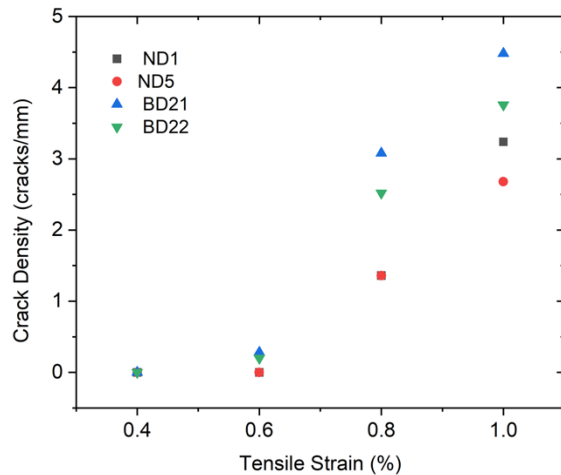
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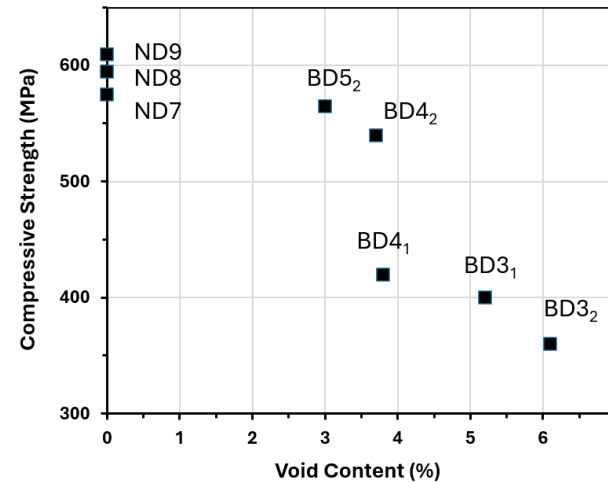
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Thank you for your attention 😊

