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AFP Defects: Insertion & Post-cure Assessment

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AFP Defects: Insertion and Post-Cure Assessment

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Biography

Roudy Wehbe

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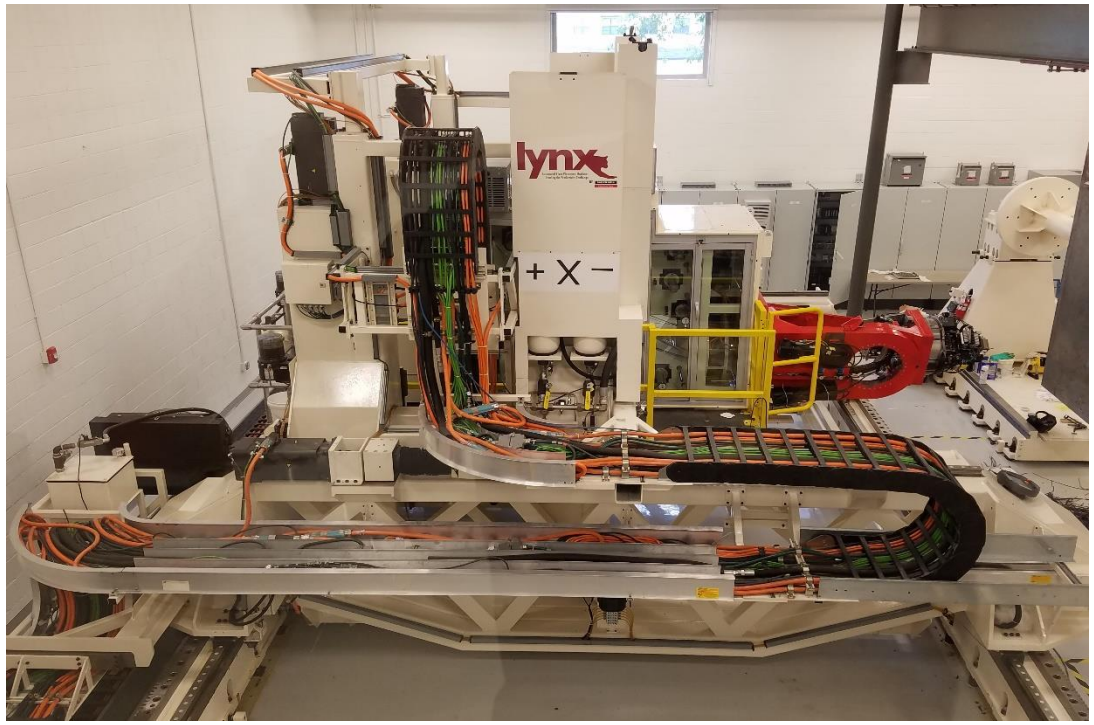
Roudy has obtained his Masters in Aerospace Engineering in 2017, his PhD in Mechanical Engineering in 2020 from the University of South Carolina and is currently a post doctoral fellow at the McNair center. His research interest is related to the Automated Fiber Placement process, specifically experimental, analytical and data driven modeling of AFP defects.

Outline

- Introduction
- Defect Insertion
  - Gap/Overlap
  - Twist
  - Wrinkle
- Post-Cure Assessment
  - Gap
  - Overlap
  - Twist
  - Wrinkle
- Conclusion & Future Work

Introduction

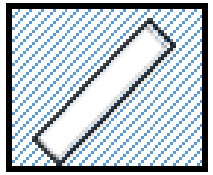
- Automated Fiber Placement (AFP) is an **additive process** used to manufacture large composites aerospace structures
- During the process, several slit-tapes (**tows**) are deposited along a prescribed path
- Layup **speed**, **temperature** and roller **compaction** can be varied to obtain a good layup **quality**
- However, several **defects** can still occur during the process, and repairs may be needed



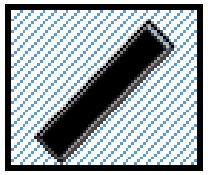
AFP machine at the McNair Center, University of South Carolina

Introduction

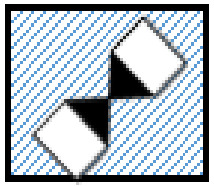
- The **objective** of this work is:
  - To propose best practices on how to intentionally insert AFP defects in laminates:
    - Automatically
    - Manually
  - Quantify their post-cure persistence
- The focus will be on 4 main AFP defects:
  - Gap, overlap, twist, wrinkle



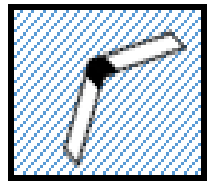
Gap



Overlap



Twist

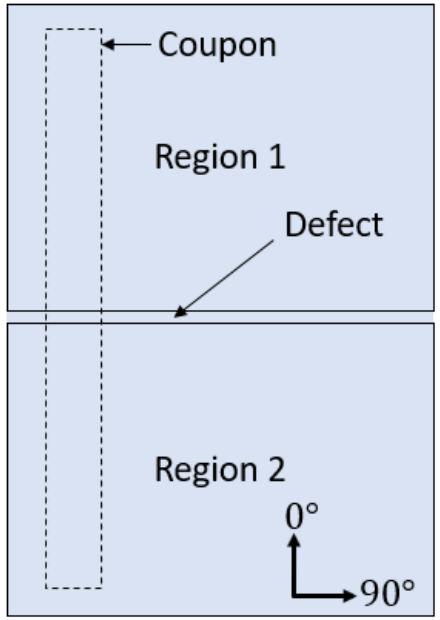


Wrinkle

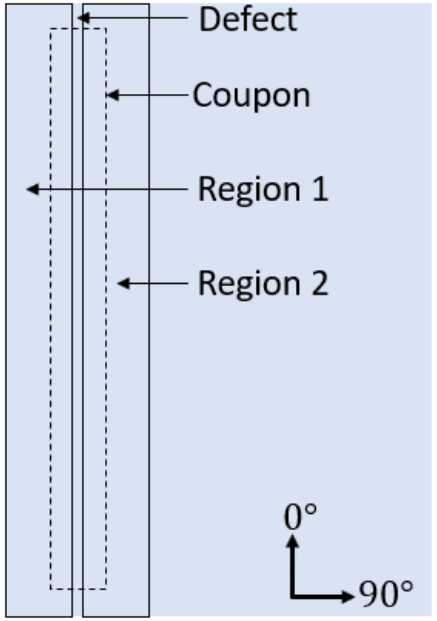
AFP Defects: Insertion

Defect Insertion: Gap/Overlap

- Definition:
  - **Gap**: it occurs when 2 adjacent tows are not placed perfectly next to each other leaving an empty spacing between them
  - **Overlap**: it occurs when two adjacent tows are overlaid
- Automatic insertion:
  - 90° layer: split the lamina into 2 regions and space them apart
  - 0° layer: split the lamina into n+1 regions and space them apart (n = number of coupons)



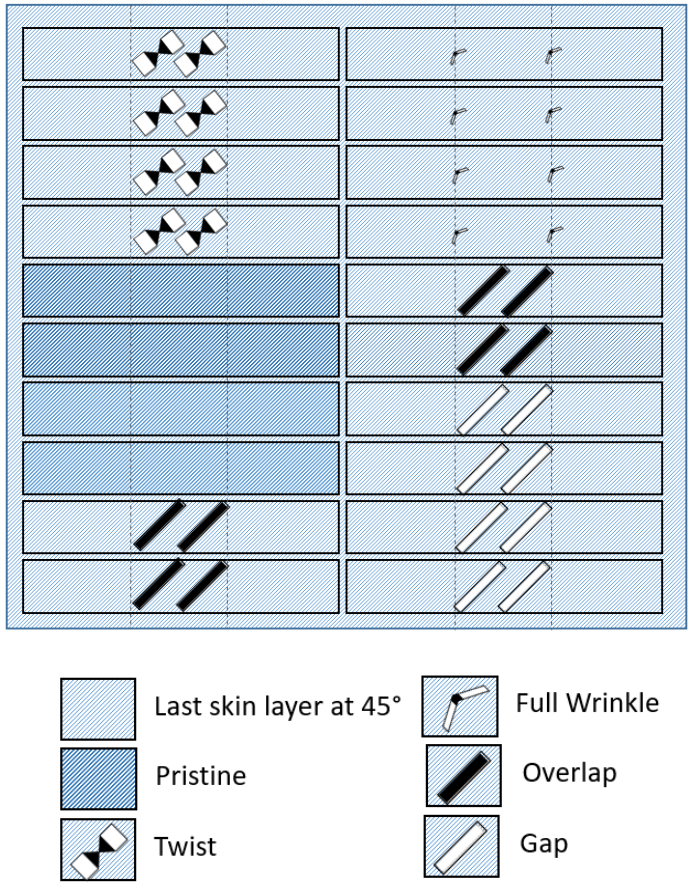
Gap/Overlap across 90° layer



Gap/Overlap across 0° layer

Defect Insertion: Gap/Overlap

- Manual insertion:
  - Gap:
    1. Cut the tow at the boundaries of the coupon
    2. Peel the tow from the substrate
    3. Slit the tow at the required gap width (if necessary)
    4. Place the remaining of the tow (if any) in its original location
  - Overlap:
    1. Slit a tow with the required overlap width & length
    2. Place the slit tow at the defect location



Defect Insertion: Twist

- Definition:
  - A **twist** occurs when the tow rolls axially 180° onto itself and then gets flattened by the AFP roller usually resulting in a bowtie shape

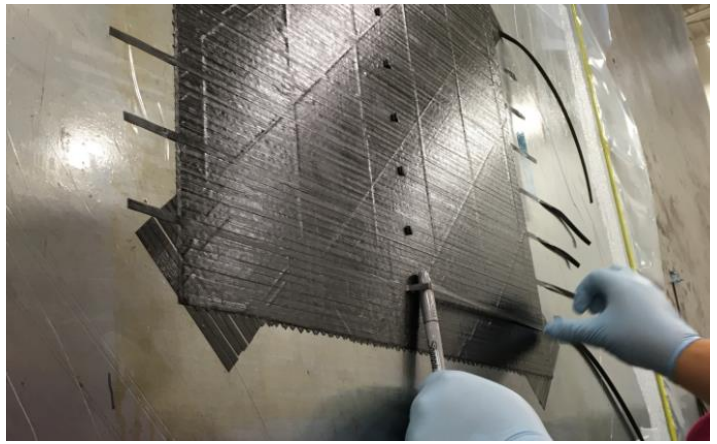
Twist schematic

- Manual insertion:
  1. Partially peel the tow from the substrate
  2. Twist the tow 180° at the required length
  3. Place the tow in its location using a roller

Twisted tow before autoclave cure

Defect Insertion: Wrinkle

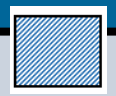
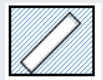
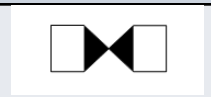
- Definition:
  - A **wrinkle** is an out-of-plane deformation of the tow due to excess in length in the material fed compared to the actual length of the path
- Manual insertion:
  1. Peel the tow from the substrate
  2. Insert a pen at the defect location and perpendicular to the tow
  3. Place the tow on top of the pen using a roller
  4. Remove the pen, and flatten the wrinkle using a roller



Manual insertion of a wrinkle

Pre-cured shape of a full wrinkle

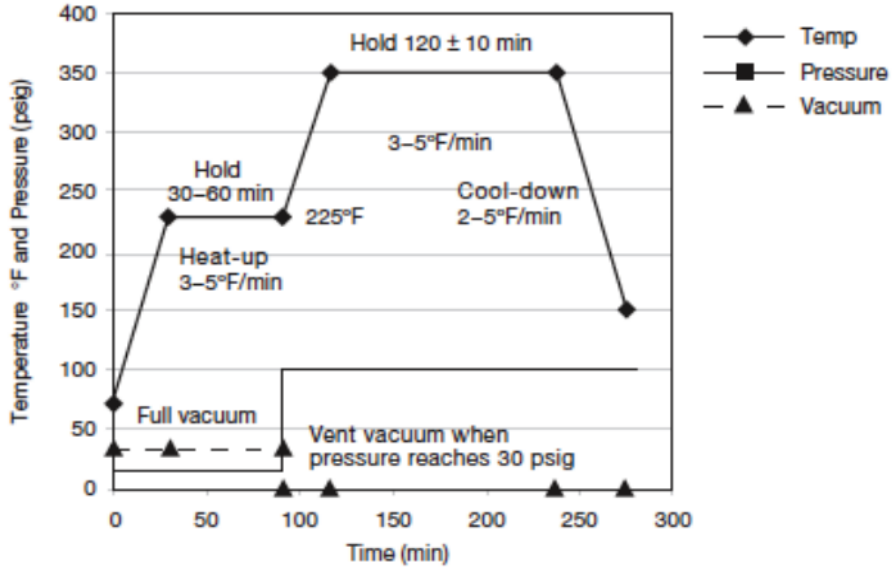
Summary of Manual Defect Insertion

Defect	Identity Card	Tows Schematics	Manufacturing notes
Pristine			
Gap			1. Cut the tow at the boundaries of the coupon 2. Peel the tow from the substrate 3. Slit the tow at the required gap width 4. Place the remaining of the tow in its original location
Overlap			1. Slit a tow with the required overlap width 2. Place the slit tow at the defect location
Twist			1. Partially peel the tow from the substrate 2. Twist the tow 180° at the required length 3. Place the tow in its location using a roller
Wrinkle			1. Peel the tow from the substrate 2. Insert a pen at the defect location and perpendicular to the tow 3. Place the tow on top of the pen using a roller 4. Remove the pen, and flatten the wrinkle using a roller

AFP Defects: Post-cure Assessment

Specimen Preparation

- The laminates consist of 7 layers with the following stacking sequence: $[45\ /\ 90/-45/\bar{0}]_s$
- The gaps and overlaps defects are inserted automatically using the AFP machine
- The twists and wrinkles are manually inserted
- All defects were placed in the 0° orientation.
- The layup is bagged with a caul plate on top of the panel then cured in the autoclave
- A diamond saw is used to cut the coupons
- The edges of the coupons are polished using sandpaper (180, 240, 400, 600, 800, and 1200 grits)
- Additional cutting planes are made to observe the post-cure shape of the twists and wrinkles

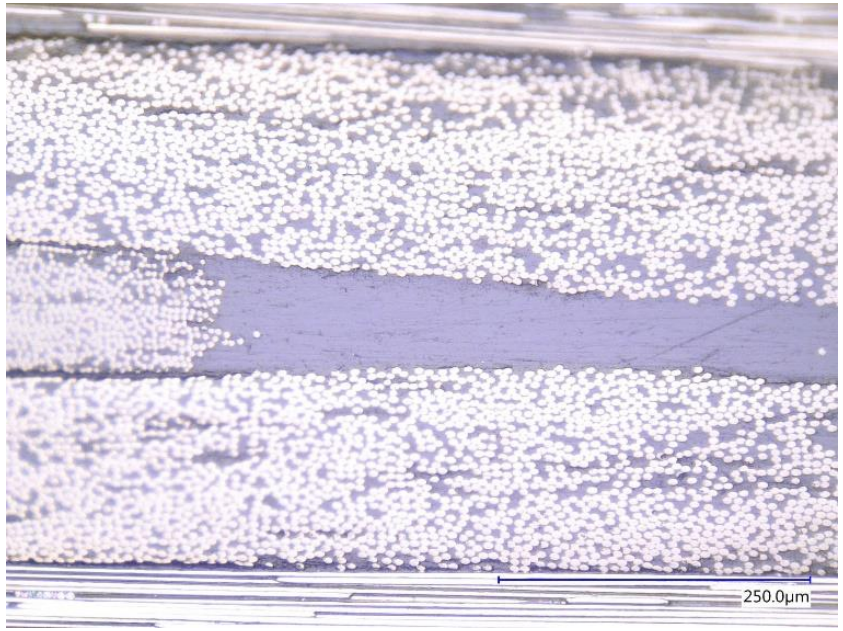


Recommended autoclave cure cycle for 8552 resin

Microscopic Images: Gap

Stitched microscopic images of a gap

- Observations:
  - The gap is filled with resin during the cure cycle and no visible voids are formed
  - The thickness of the resin rich area is smaller than the typical cured lamina thickness
  - The fibers from neighboring layers are shifting/moving to fill the gap during the cure cycle

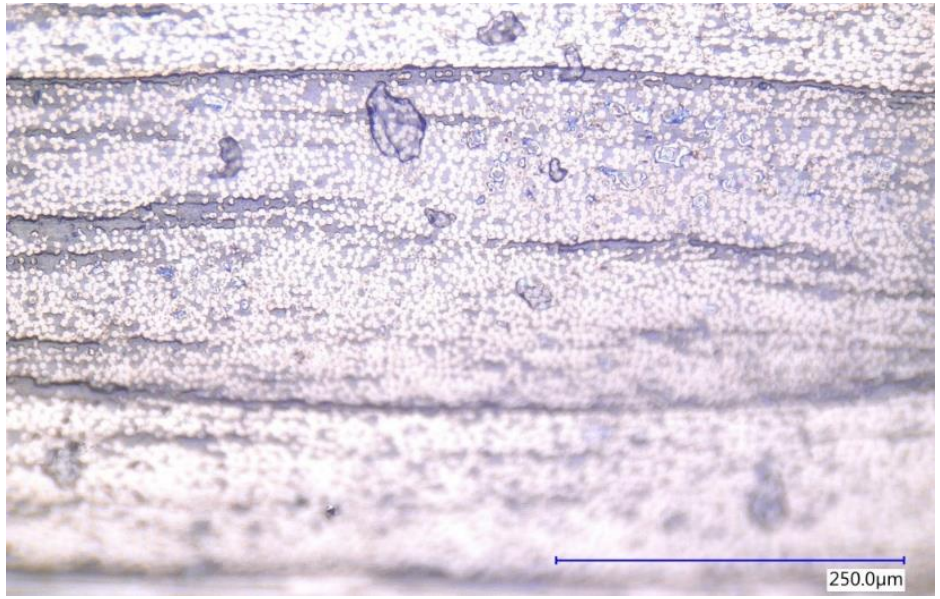


Microscopic image of a gap at 500X magnification

Microscopic Images: Overlap

Stitched microscopic images of an overlap

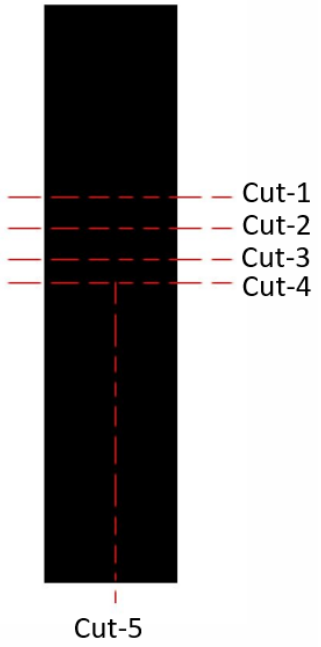
- Observations:
  - At the overlap location, an in increase in the layer's thickness can be observed
  - The interface between the overlap and the original 0° layer appear to mostly vanish compared to the interface between the other layers where a resin rich area is easily identified



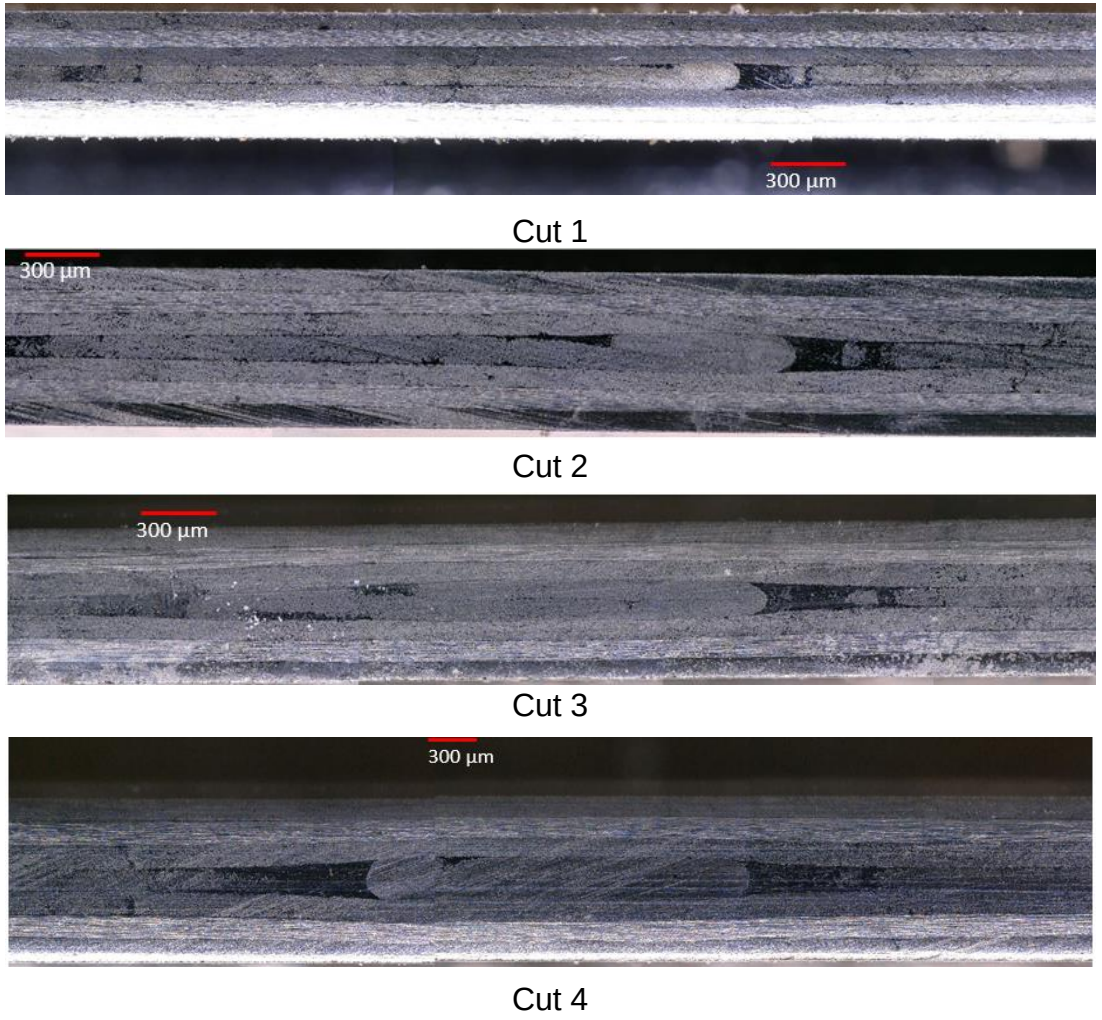
Microscopic image of an overlap at 500X magnification

Microscopic Images: Twist

- The progression of the twist is depicted in with cut 1 where a small resin rich area is observed next to a fold (~200 µm)
- The size of tow folded over itself and the size of the resin rich area increase from cuts 1 - 4
- Cut 4 (mid-section) is characterized by an increase in the thickness of the layer since the tow is fully folded over itself and two resin rich areas from each side



Cutting planes for the twist defect



Microscopic images of a twist at different cross-section at 50X magnification

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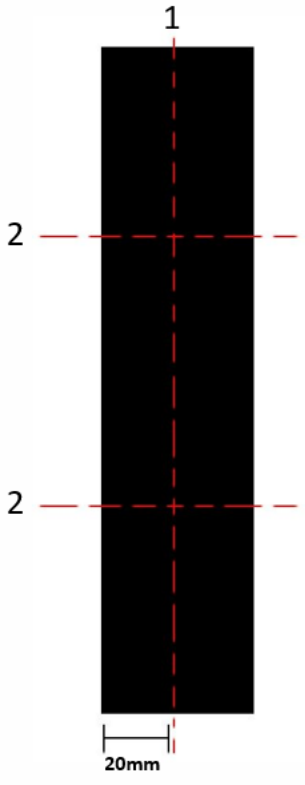
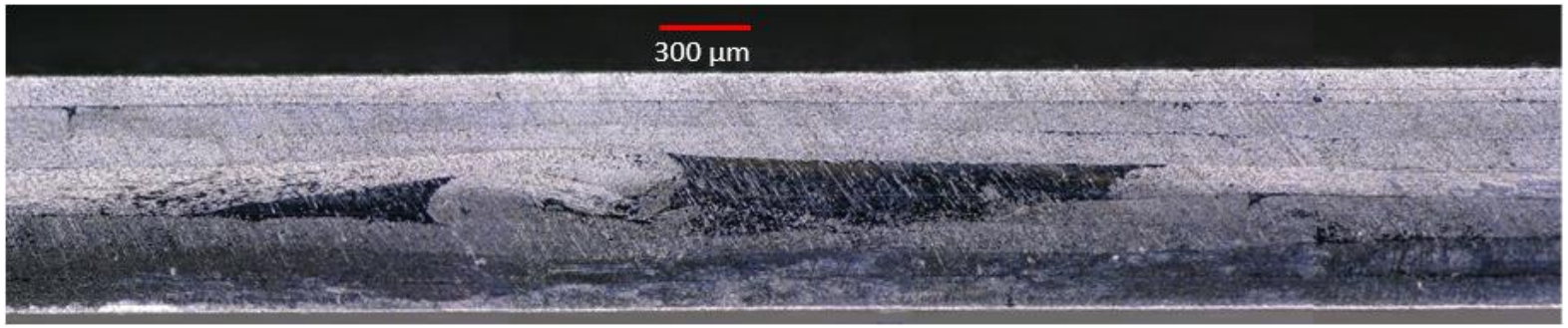
Microscopic Images: Wrinkle

Pre-cured shape of a full wrinkle



Cutting planes for the wrinkle defect



Microscopic image of a wrinkle at 50X magnification at cutting plane 1

- Observations:
  - The out-of-plane full wrinkle is folded over itself after the roller has passed over it while placing the consecutive layer
  - This resulted in a local increase of the lamina thickness, and resin rich pockets has formed on both sides of the wrinkle during the autoclave curing process

Conclusion & Future Work

- **Best practices** on how to intentionally insert AFP defects in laminates are proposed for: gap – overlap – twist – wrinkle
- Several composite panels are produced using the proposed techniques and the **post-cure persistence** of the defects is quantified using microscopic images
- It is concluded that the obtained **post-cure shape** of the defects **is not** necessarily **the same** as the pre-cure one due to the resin flow in the composite part during the autoclave curing cycle
- These images will be used for accurate modeling of the **post-cure shape** of defects, which is necessary for future **numerical simulation** studies
- The produced coupons are used in several **experimental testing** programs

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