STRETCH-STEERING OF ALIGNED DISCONTINUOUS FIBER TAPES ON HIGHLY CURVED PATHS USING AUTOMATED FIBER PLACEMENT

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Introduction

TuFF is a novel material with highly-aligned short fibers. The discontinuous microstructure allows deformation in all directions allowing forming of complex geometries and elongation of up to 40%. During tape placement, *TuFF* tapes can be stretched to mitigate buckling improving steering radii by a factor of ~10 compared to continuous fiber tape material.

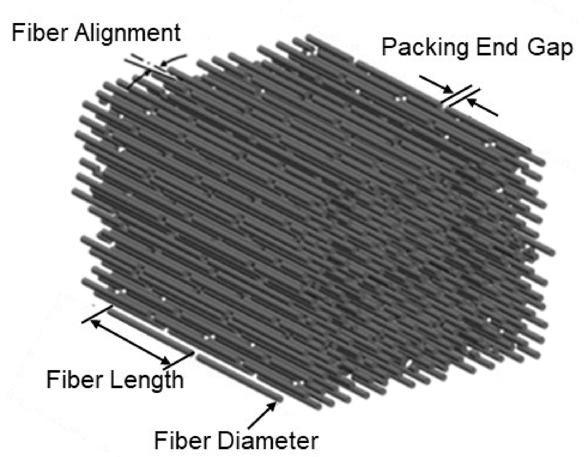

Fig. 1: Idealized TuFF microstructure

Motivation

- *TuFF* tape steering enables:
  - Variable angle tow laminate designs optimizing weight vs. performance
  - Use of wider tapes for complex geometries increasing throughput
- The material deformation during *TuFF* steering is unknown and has to be understood to optimize process conditions

Objective

Evaluate the material deformation by developing a methodology to measure strain during tape steering of *TuFF*/PEI tapes using Photogrammetry and minimize the path deviation

- Deformation occurs continuously in the heating and placement zone
- Induced strains offset the compression strains resulting in buckling free steering of the tape

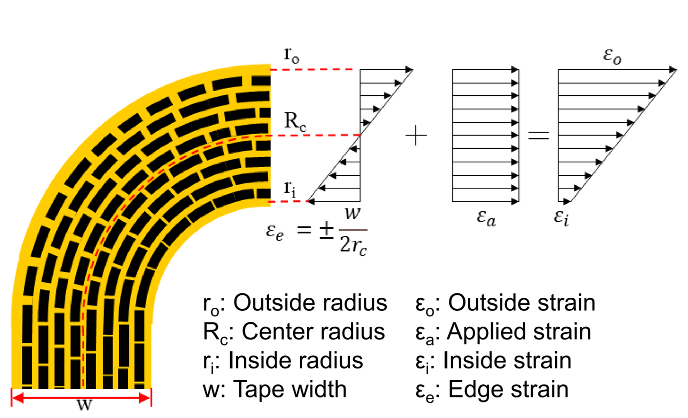

Fig. 2: Offsetting of the inside radius compressive strain with tensile strain

Fig. 3: 100 mm steering; wrinkles in continuous tape (top), wrinkle-free TuFF (bottom)

Methodology

Automated Tape Placement:

- Tapes are cut from *TuFF*/PEI blanks and fed into the ATP head alignment channels
- All tapes are placed at 450°C laser set-point temperature, 15 mm/s lay-up speed, 400 N consolidation force using a 1 in consolidation roller
- Kinematic strain is applied due to a difference in the speed of the feed roller and the compaction roller
- The tape is stretched in the heated zone and placed onto the substrate in a straight line or a curved path with different radii

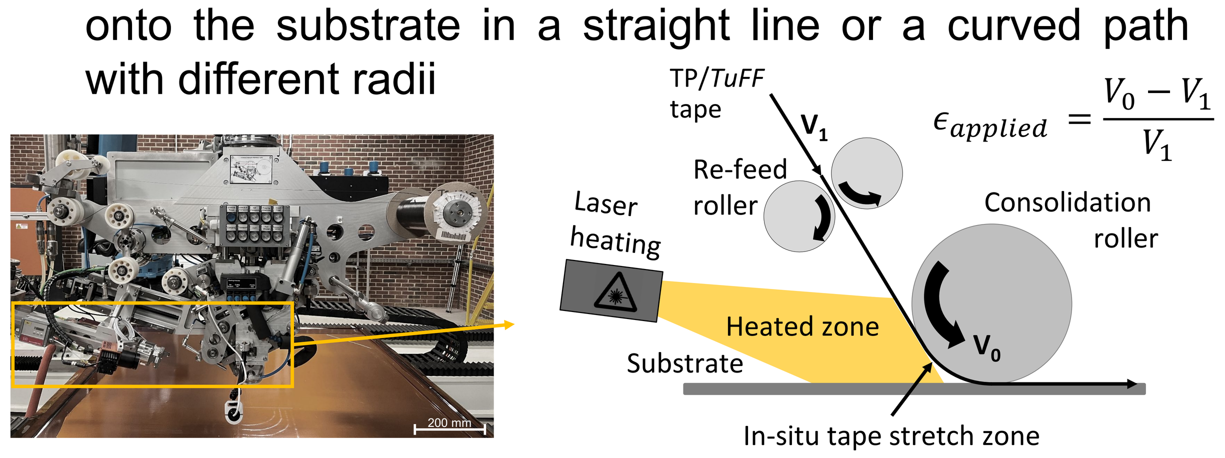

Fig. 4: ATP head (left), Schematic of velocity difference for stretch steering (right)

Photogrammetry and Path Deviation:

Photogrammetry measures the location of dots on the measuring surface by taking multiple images of the measuring object from different positions. Based on the initial distance between the dots a strain field can be generated

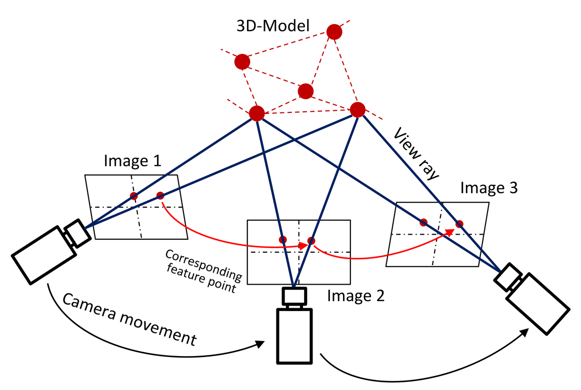

Fig. 5: Schematic of photogrammetry measurement

- Patterns are applied to the tape with high temperature paint and pressed in at 330°C with 300 psi to embed the pattern into the blanks
- Tapes are placed on a substrate, and pictures are acquired. Photogrammetry method is applied to measure final strain in the coupons
- The path deviation can be minimized by offsetting the Tool Center Point (TCP) to the nip-point of the consolidation roller

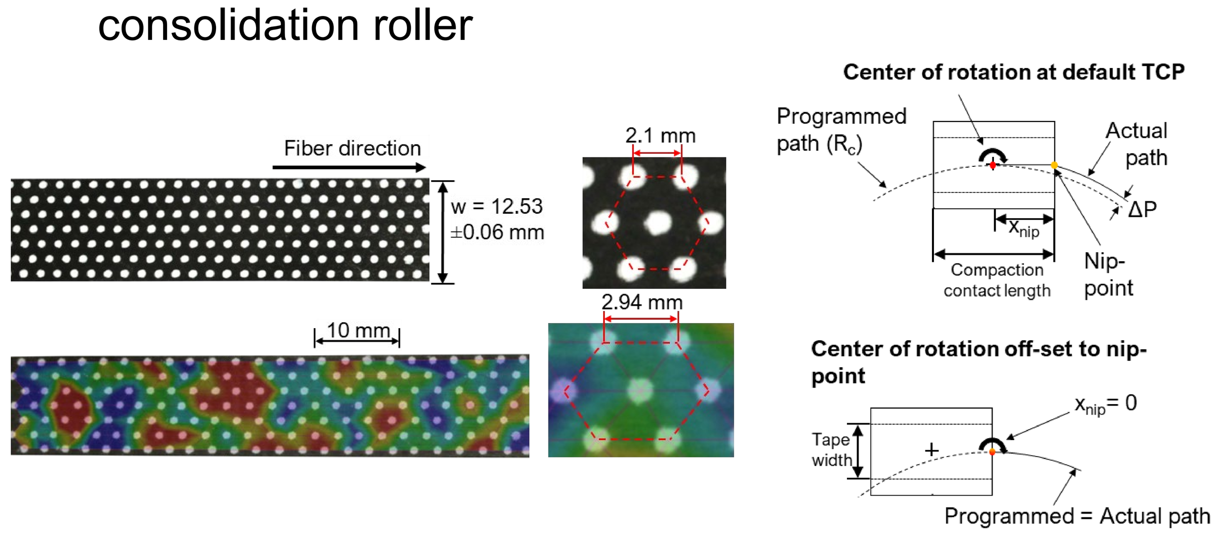

Fig. 6: Point grid on TuFF/PEI with strain map and mesh before and after stretching at ε_a= 40% (left), Default TCP position (right, top) and TCP off-set to the nip-point (right, bottom)

Results

Path Deviation

- The default TCP position results in path deviations of up to 2.5 mm
- TCP positions in front of the nip-point result in understeering (smaller than the desired steering radii)
- The optimal TCP off-set can be found at the intersection of a linear fit through the average path deviations at different off-sets with ΔP = 0

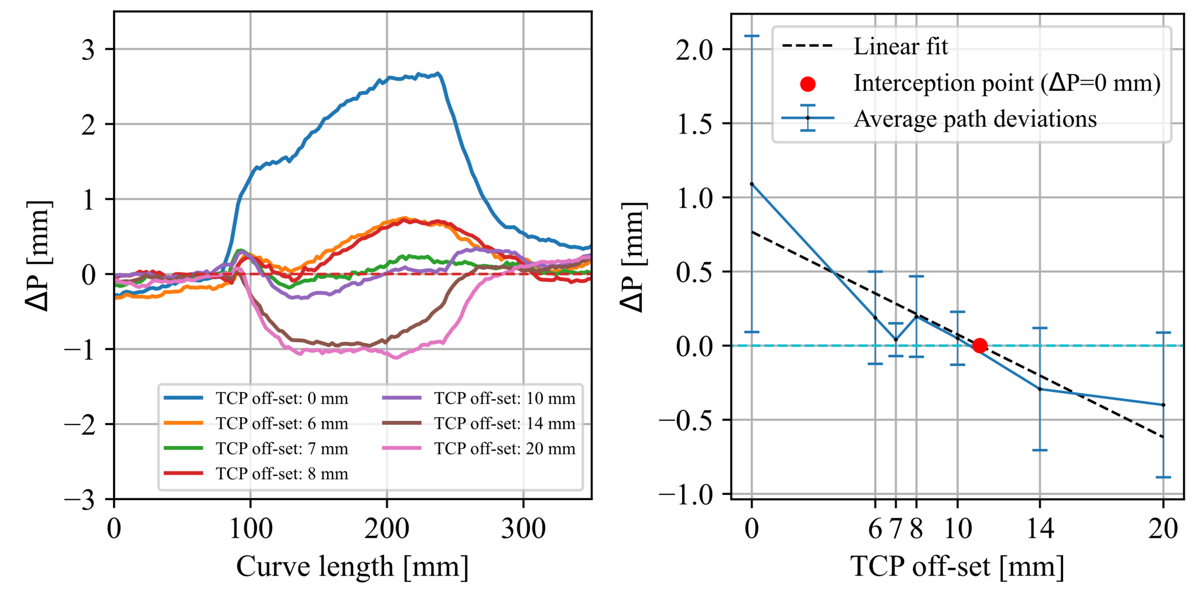

Fig. 7: Path deviation of whole placement length (left), Calculation of optimal TCP off-set (right)

Strain Measurement Accuracy

- Strain measurements on straight paths are highly reproducible. The variability increases with applied strain

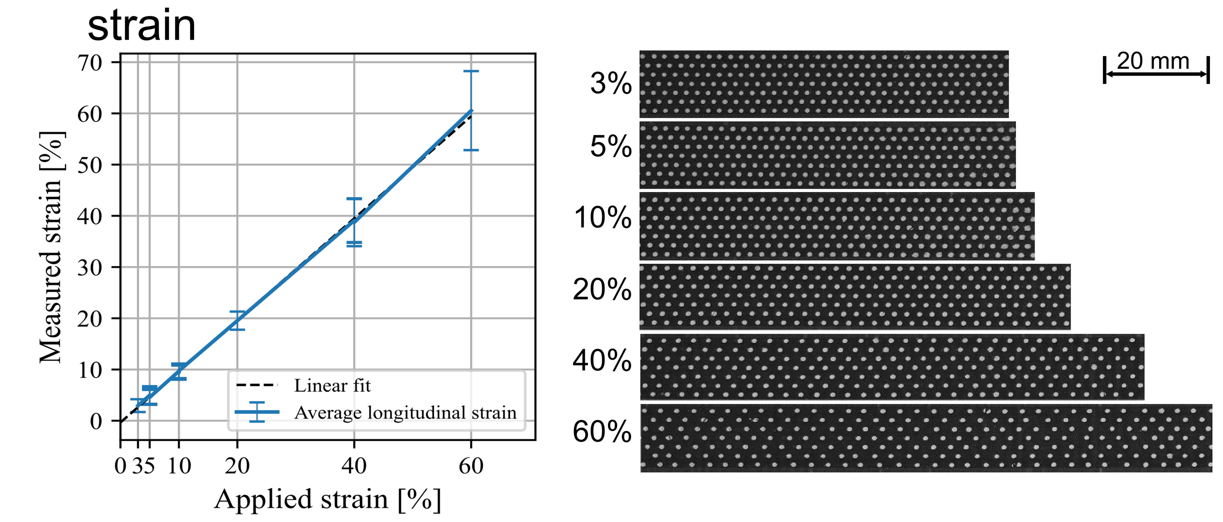

Fig. 8: Strain measurements of straight paths (left), deformation of point pattering due to strain (right)

Validation of Longitudinal Strain Gradient

- The strain is computed with a series of sections across the tape width
- The strain gradient closely follows the predicted gradient

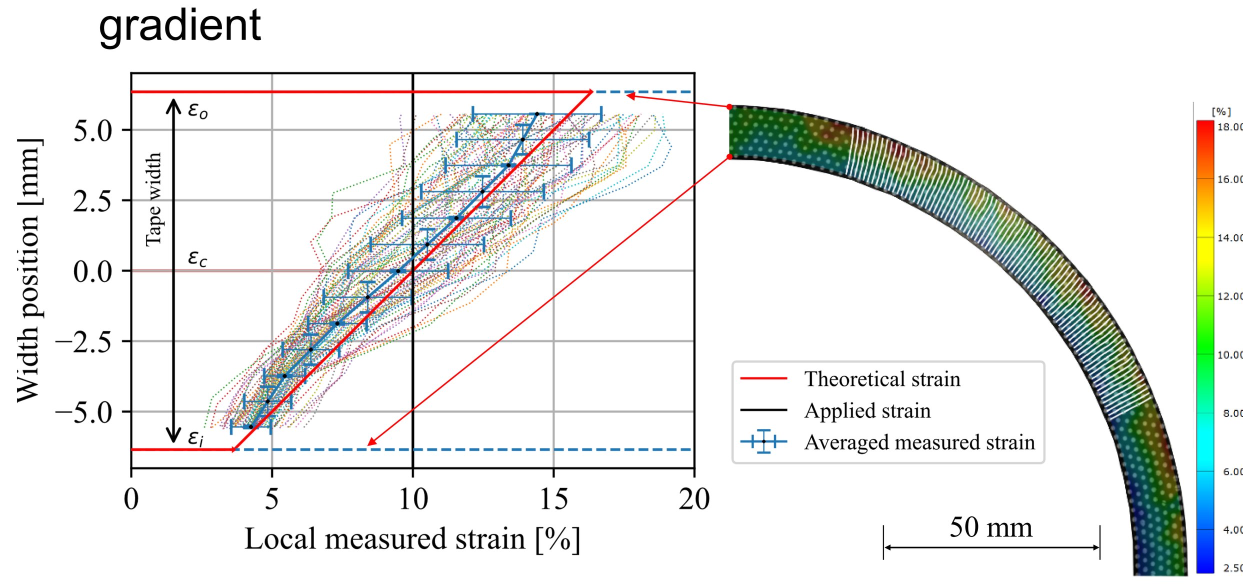

Fig. 8: Strain gradient across the width with ε_a= 10% (left), Steered section with transverse lines in steady state steering section (right)

Minimum Steering Radius 0.5 in *TuFF*/PEI

- Applied strains were chosen based on the predicted strain gradient and set at 18% for the 50 mm steering radius and 32% for the 25 mm radius
- The tape placed at 50 mm steering radius showed no defects, whereas the tape at 25 mm steering radius showed slight folding on the inside and fraying on the outside edge
- The path deviation for both tapes is within the tolerance

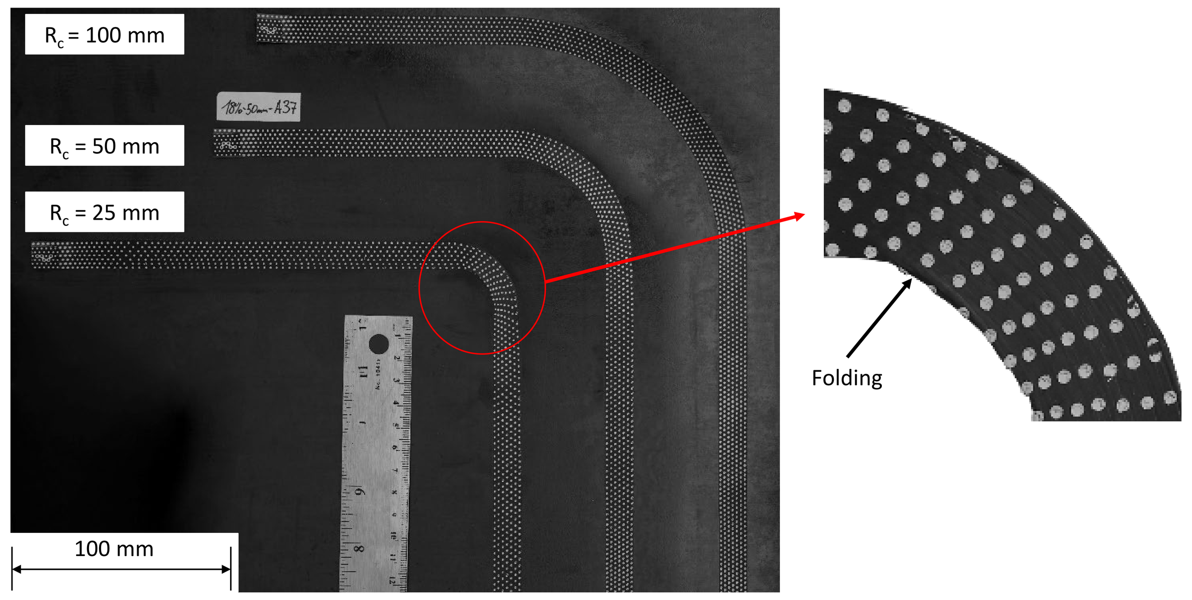

Fig. 10: ½ in tape steering at 100, 50 and 25 mm radius

Summary and Conclusion

- A concept for the measurement of strains for tapes placed at processing conditions was developed
  - The predicted longitudinal strain gradient across the tape width was validated
- A methodology to quantify and minimize the path deviation was implemented:
  - Optimal TCP can be found with few experiments
  - Improved path following reduces defects and enables smaller steering radii
- Steering of 0.5 in *TuFF*/PEI tape was demonstrated
  - A minimum steering radius of around 50 mm can be achieved without defects and steering at a radius of 25 mm is possible with minor defects

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