Determination of a Stabile Stain Window for Highly Aligned Discontinuous Fiber Tapes using Stretch - Tape - Placement

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Motivation & Introduction

Previous steering experiments using the highly aligned short fiber material (TuFF) showed promising 10x reduction in steering radius which opens the design space for highly tailored structures. While it is important to determine the minimal steering radius, its definition lacks the comparability for discontinuous fiber tapes. This work focuses on defining an equivalent definition for discontinuous.

Definition of the minimal steering radius

The minimal steering radius is the radius at which an excessive number of defects are present in the placed tape.

- Outer radius (OD) tension defects
- Inner radius (ID) compression defects

This work presents a 3-sigma approach to identify the process limits and shows a stabile process window where thickness tailoring along a given path is possible.

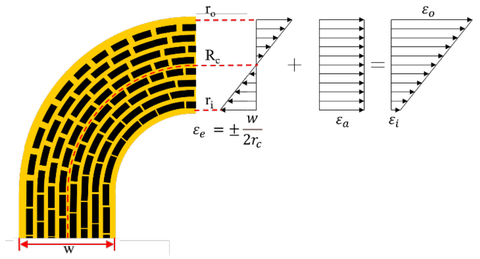
Approach

- Determine the upper limit of strain at which visual defects occur.
- Develop closed form solution based on strain limits
- Develop probabilistic solution based on strain limits
  - ➢ Evaluate the statistical distribution of the material / process combination.
  - ➢ Compute the strain limits that lead to a less the 1% change of defects.
  - ➢ Calculate the minimal radius based on the 1% chance limitation.

Minimal Steering Radius

Closed form solution (MSR 1)

- Stay with in strain limits assuming a liner relation ship between ID & OD
- Based on bending formular

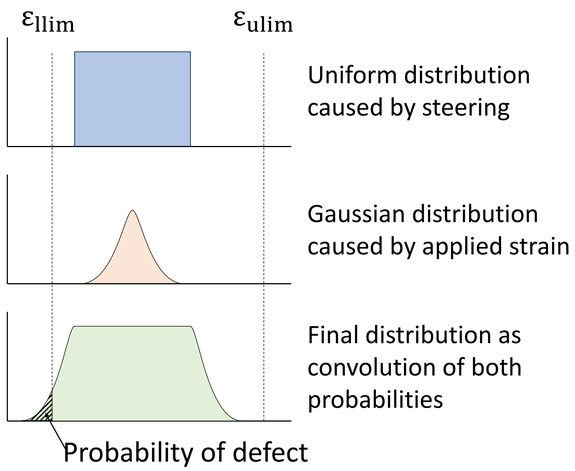


$$\varepsilon\left(\frac{w}{2}\right) = \varepsilon_{\text{ulim}} = \varepsilon_a + \frac{w}{2R_c} \xrightarrow{yields} R_c = \left|\frac{w}{(\varepsilon_{\text{ulim}} - \varepsilon_{\text{llim}})}\right|$$

$$\varepsilon\left(-\frac{w}{2}\right) = \varepsilon_{\text{llim}} = \varepsilon_a - \frac{w}{2R_c} \qquad \varepsilon_a = \frac{\varepsilon_{\text{ulim}} - \varepsilon_{\text{llim}}}{2}$$

Probability based form solution (MSR 2)

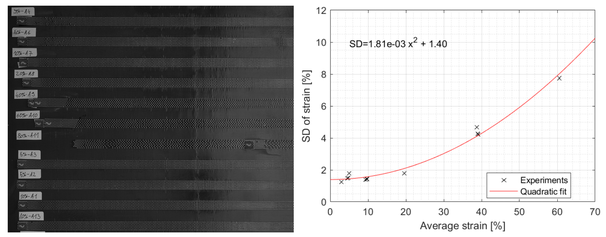
- Probabilistic approach demands a less then 1% chance of combined defect on OD & ID
- Assumptions:
  - Standard deviation is only a function of applied strain. (Probability density functions can be convoluted to obtain new probability density function)
  - Idealized liner profile led to a uniform distribution.



Experiments

Strain limit

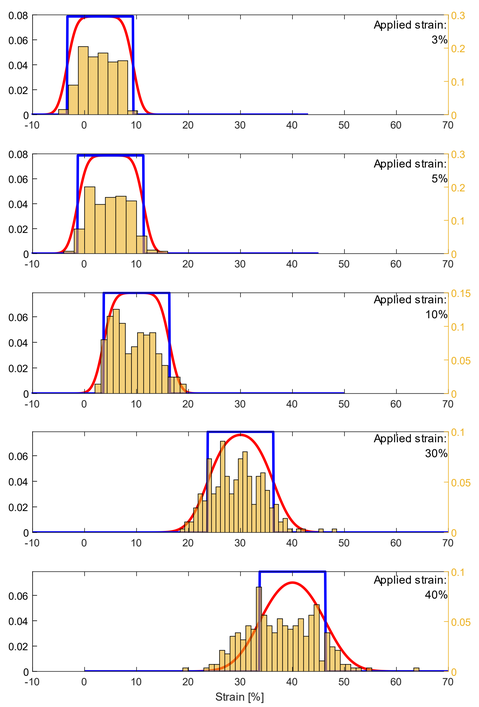
- Lower limit 0% (avoiding compression)
- Upper limit 43% (based on visual inspection and single tail probability, 60% - 2.3 * 7.4%)
- Statistical distribution is obtained



Experimental comparison

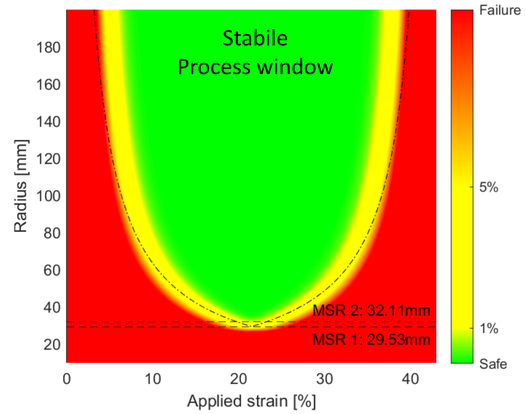
Comparison of closed form solution (blue) and probability density function (red) with 100mm steering experiments with different applied strains.

- Probability density function matches experiments better



Stabile Process Window

From the understanding that the convolution estimates the process correctly, the probability of the strain being less than 0% and more than 43% is calculated and plotted as a function of applied strain. The figure below shows the calculated critical radius where the combined probability for compression and tension defects is less then 1%.



Summary & Conclusion

This work defines the minimal steering radius for discontinuous fiber material in tape placement based on a 1% probability of defects based on upper and lower strain limits. The proposed range are 0 - 43%. This leads for a 0.5” wide tape to a minimal steering radius of 33mm which is 2 orders of magnitude lower than conventional tapes.

Acknowledgements

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