Tensile performance of Fibre-Oriented scarf repair coupons for wing skin materials

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Presentation outline

Design of repairs

Sample preparation

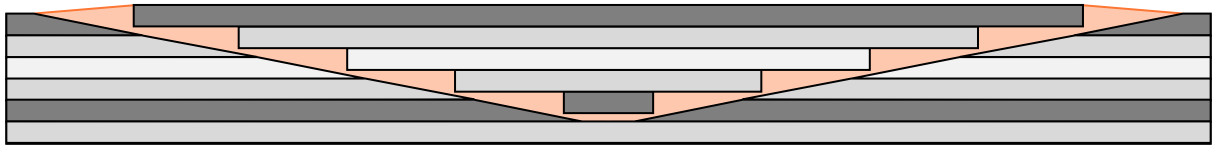
Testing and failure

Conclusions

Design of repairs

Adhesively bonded scarf repairs

- **Structurally efficient** and **aerodynamic**, particularly for thicker composite parts
- However, for high performance applications, tapers of 20:1 (2.86°) to 100:1 (0.57°) are necessary, meaning **significant material removal and practical expertise is required**
- Subsequently, there is **considerable interest to optimize repair designs**
- This field has been well reviewed in recent literature [1], but **new technologies allow for greater complexity**



Example of an adhesively bonded scarf repair

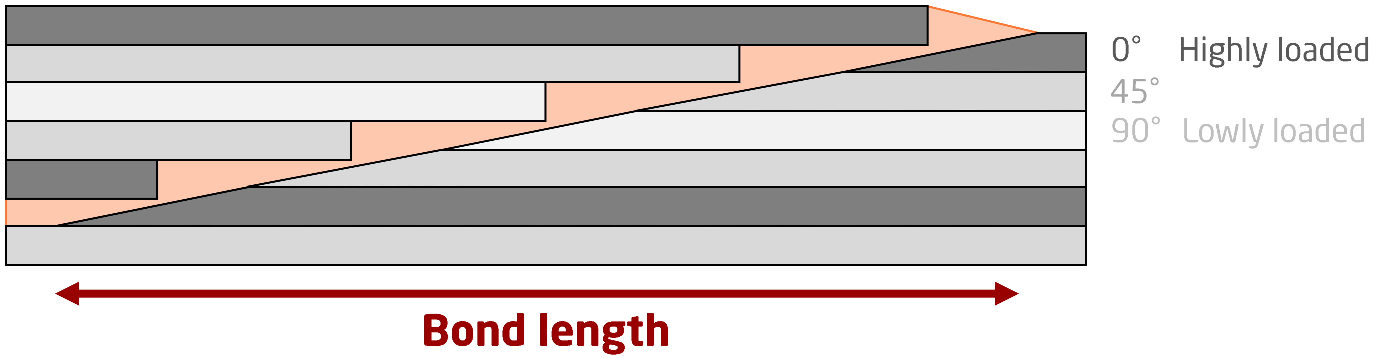
ULTRASONIC mobileBLOCK 5-axis milling unit (DMG MORI/SAUER) [2]

[1] J. B. Orsatelli et al., *Compos. Struct.*, vol. 304, 2023
DOI: 10.1016/J.COMPSTRUCT.2022.116338

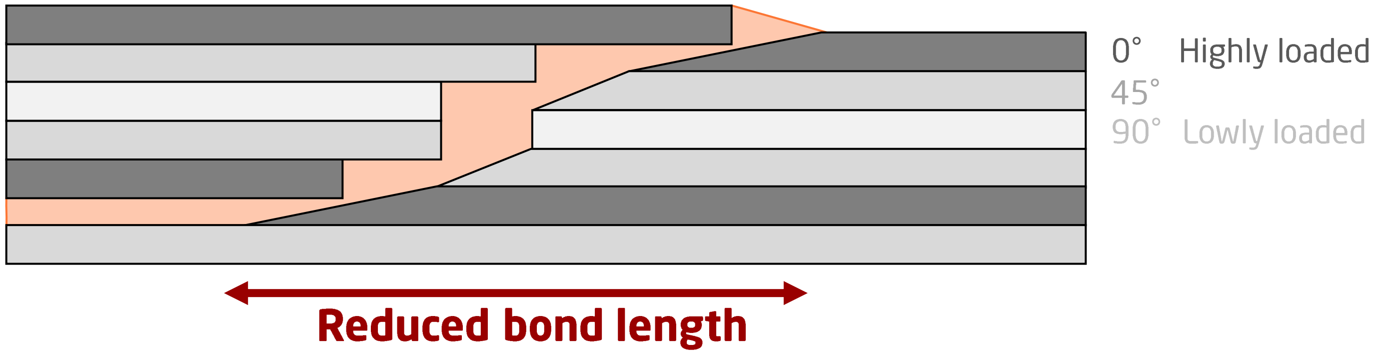
[2] G. Gardiner, "Aircraft composites repair moves toward maturity", *CompositesWorld*, 2016
https://www.compositesworld.com/articles/aircraft-composites-repair-moves-toward-maturity

Fibre-Oriented scarf design

Conventional scarf
(constant taper)



Fibre-Oriented scarf
(reduced taper in off-axis plies)

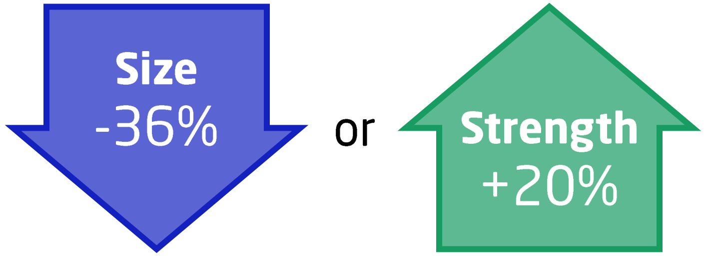


- Modification of the “Fibre-Oriented step” concept [3], accounting for individual ply loading

[3] M. Niedernhuber et al., *Compos. Part B Eng.*, vol. 94 , 2016
DOI: 10.1016/ J.COMPOSITESB.2016.03.027

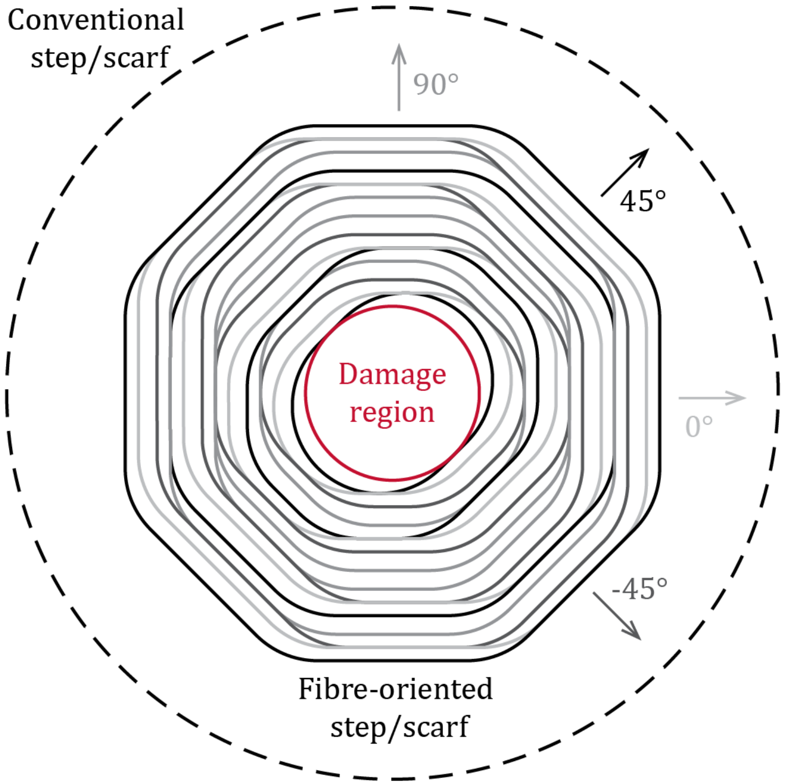
Predicted benefits of Fibre-Oriented scarf design

- Previous work has shown **promising theoretical and simulated performance** [4] :



- **But missing experimental validation!**

- **Note:**
  Similarly-optimised hard patch joints have been tested [5] :
  - 60% reduction in length for a 36% reduction in strength

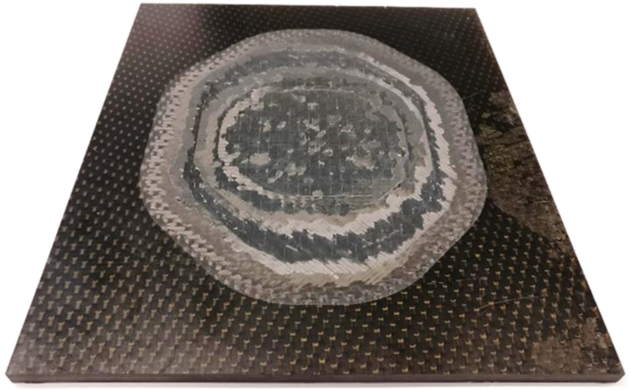


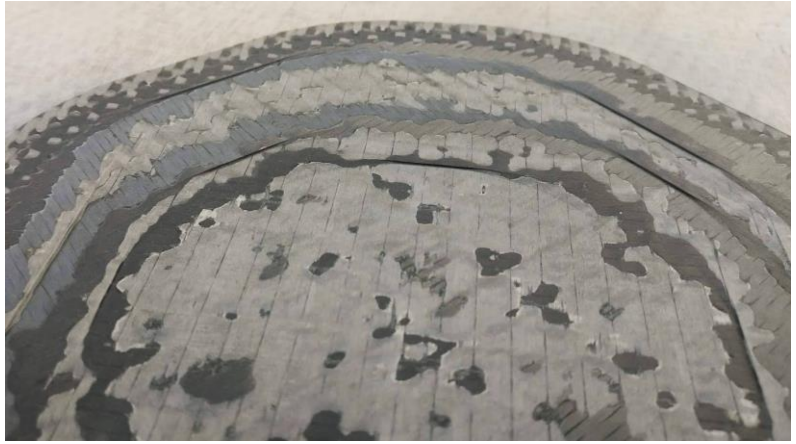
[4] R. S. Pierce and B. G. Falzon, *Compos. Part B Eng.*, vol. 173, 2019
DOI: 10.1016/J.COMPOSITESB.2019.107020

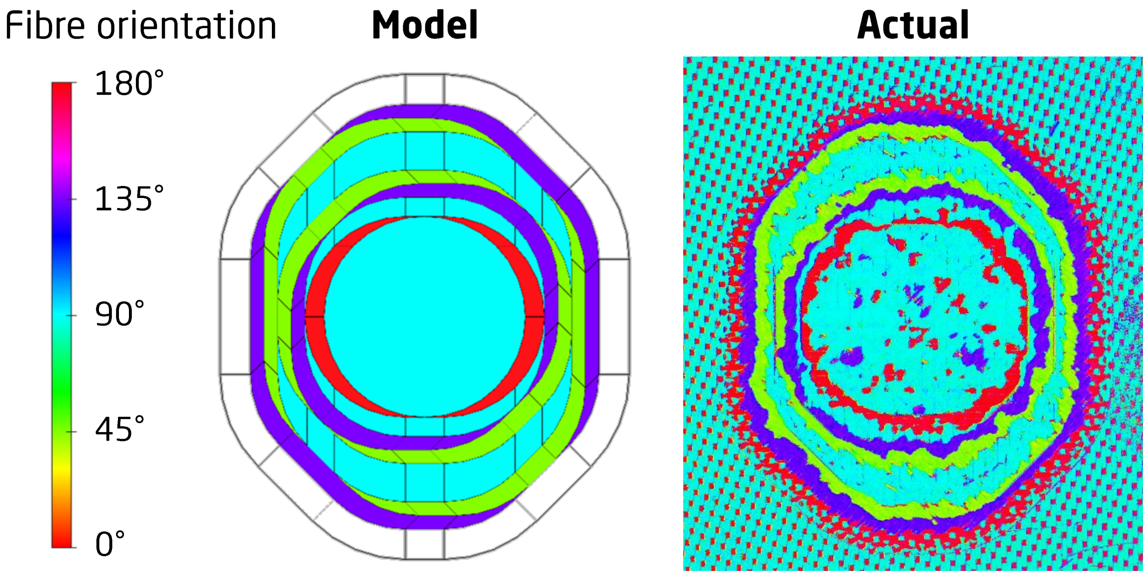
[5] M. Y. Pitanga et al., *Int. J. Adhes. Adhes.*, vol. 104, 2021
DOI: 10.1016/J.IJADHADH.2020.102752

Fibre-Oriented scarf repair demonstrator

- To assess the feasibility of precision machining a variable 3D scarf
- Fibre orientation analysis [6] :
  - General agreement with modelled design
  - Some deviations, due to laminate tow waviness







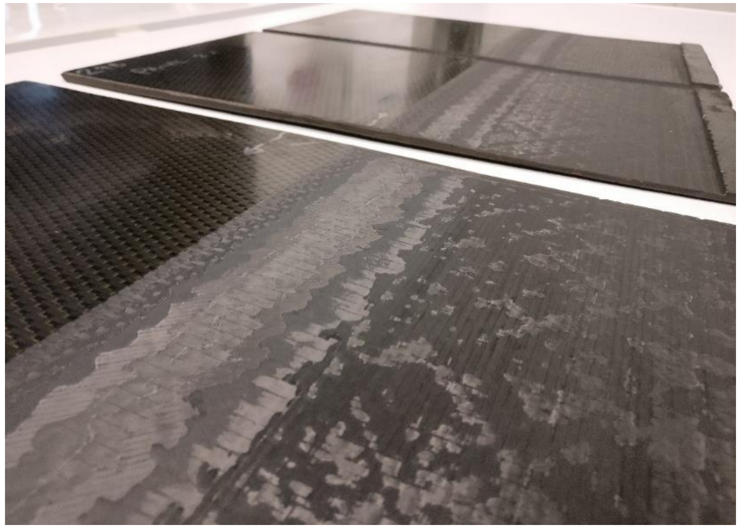
[6] R. S. Pierce and X. Liu, *J. Reinf. Plast. Compos.*, vol. 39, 2020
DOI: 10.1177/0731684420934868

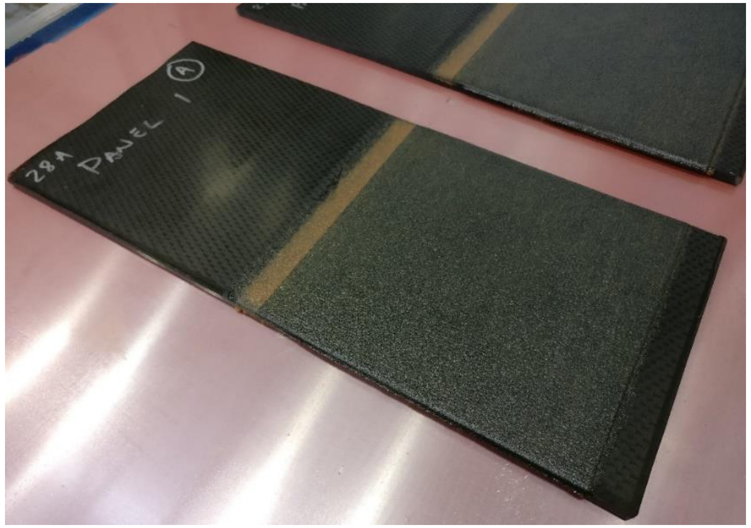
Sample preparation

Repair configurations

- Three different soft patch repair configurations for a representative wing skin laminate:
  - **Conventional scarf** (continuous taper)
  - **Size-optimised scarf** (based on ply fibre orientations, “same strength with reduced length”)
  - **Strength-optimised scarf** (based on ply fibre orientations, “same length with greater strength”)

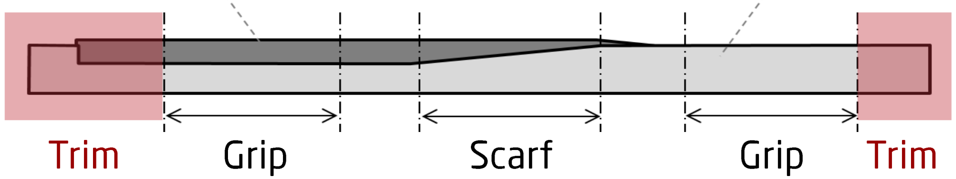
- All partial-depth (33%), matched-ply, repairs with a nominal 30:1 scarf taper (1.91°)

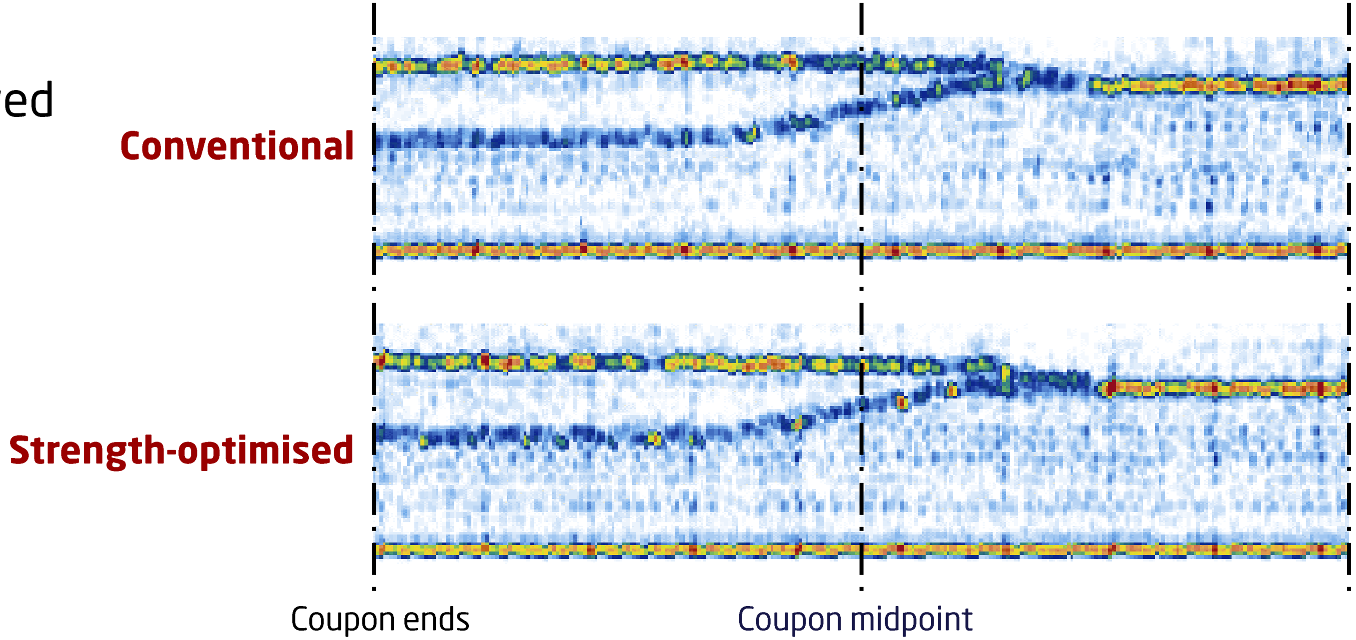


Coupon design and inspection

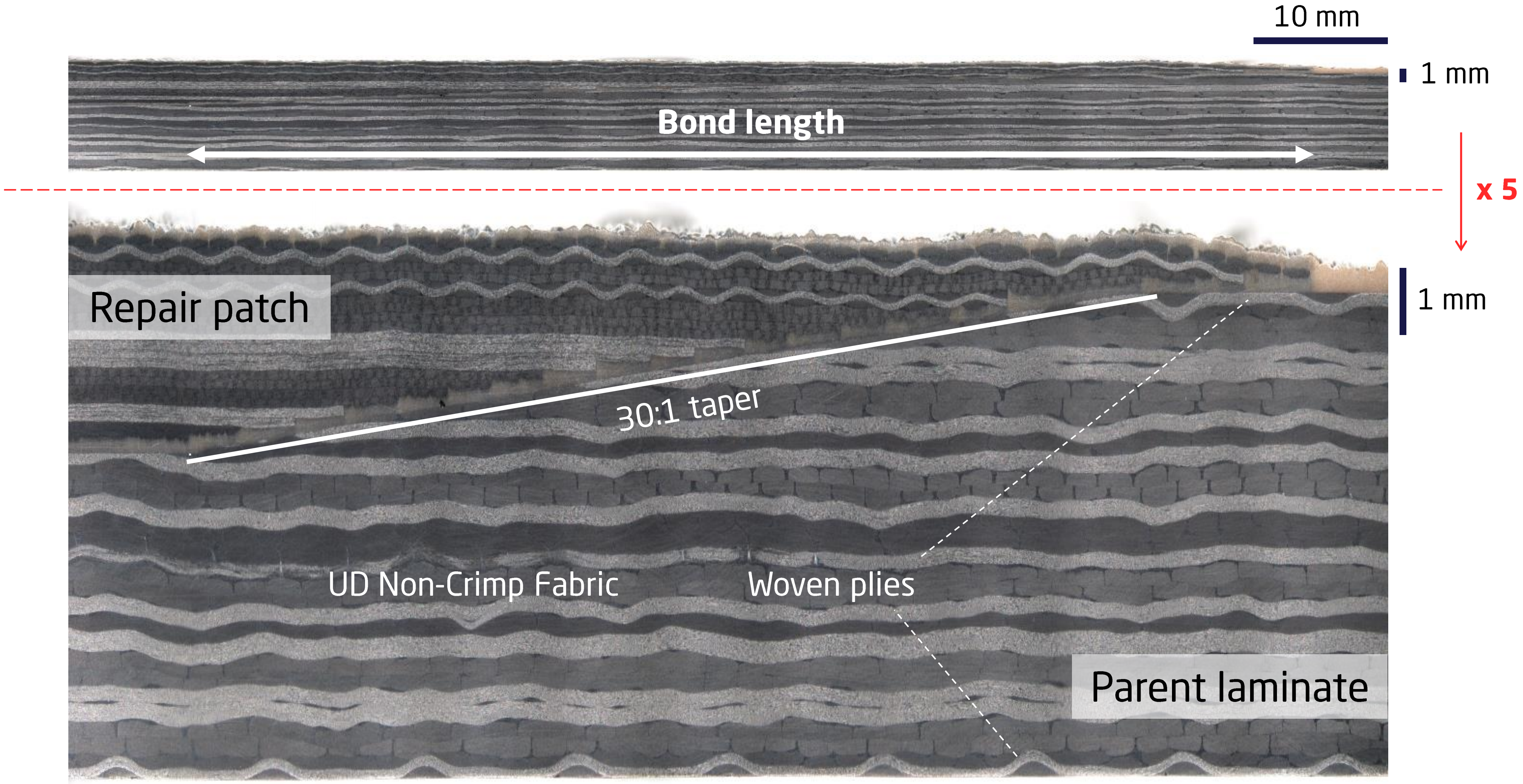
- Dimensions: 250 x 25 mm
- Overplies used to protect scarf tips
- Batches of 5+ coupons per design
- NDT of repaired panels showed minimal bond-line defects



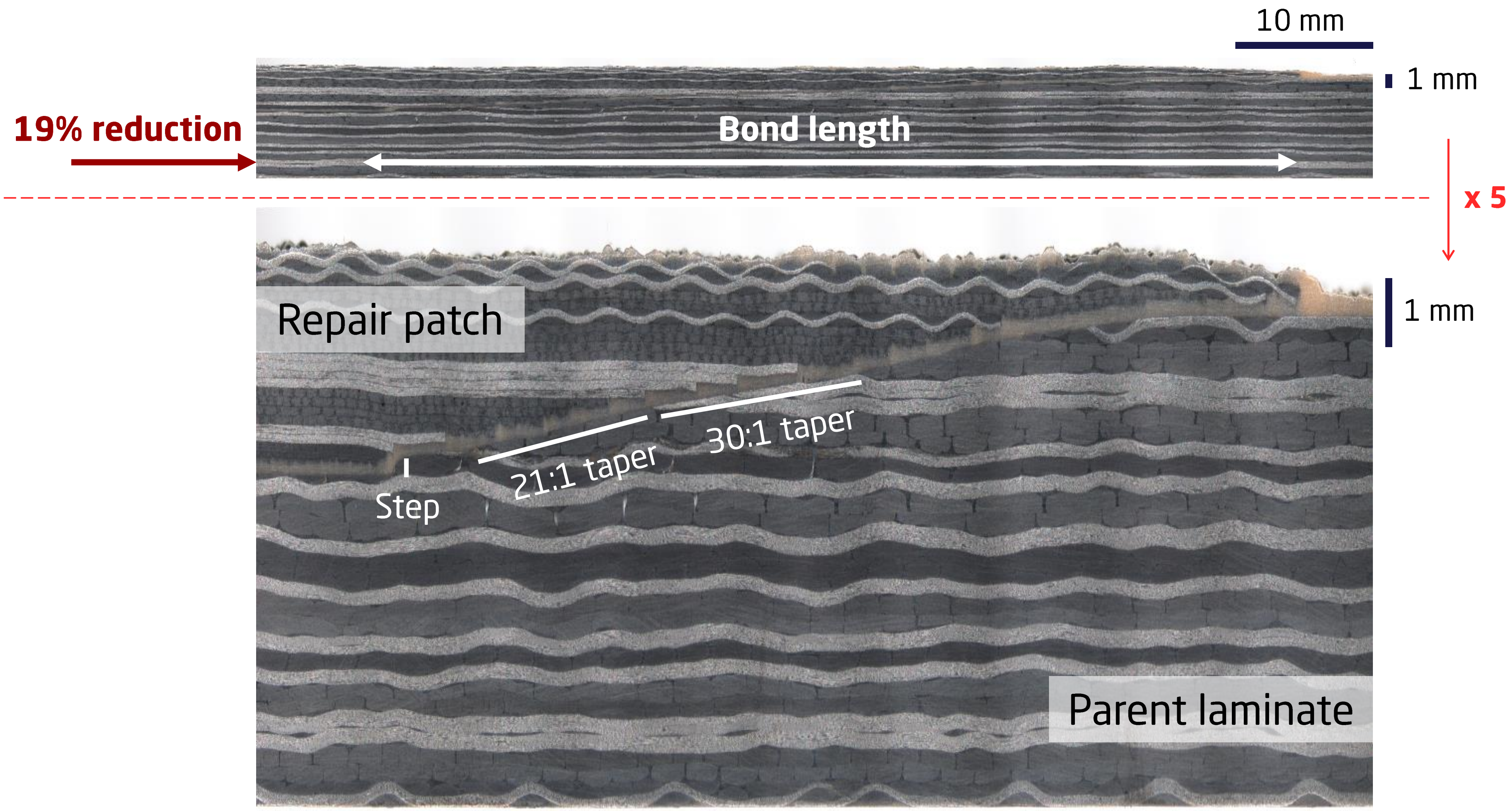
Representative Ultrasonic B-scan results



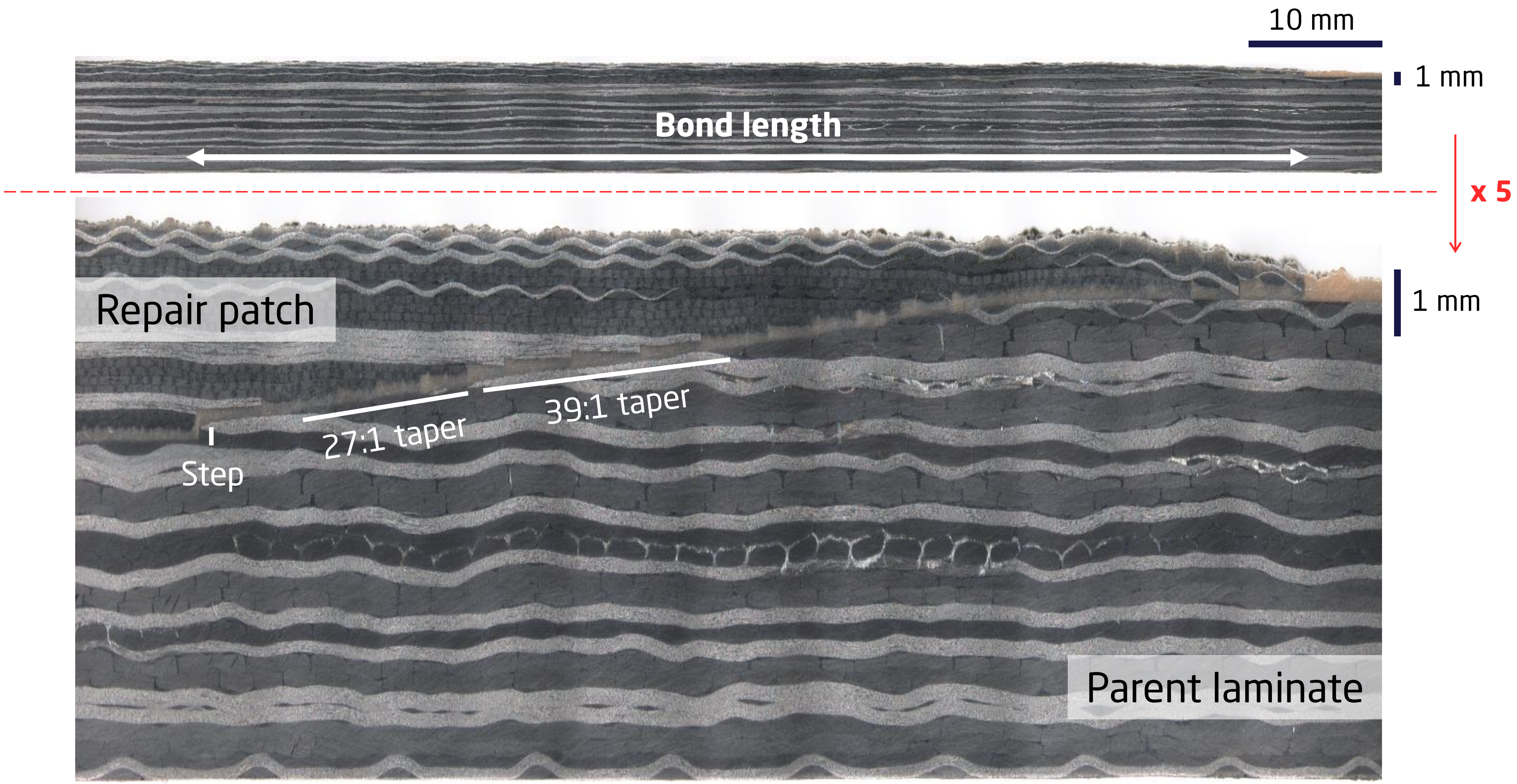
Bond-line microscopy: Conventional scarf



Bond-line microscopy: Size-optimised scarf



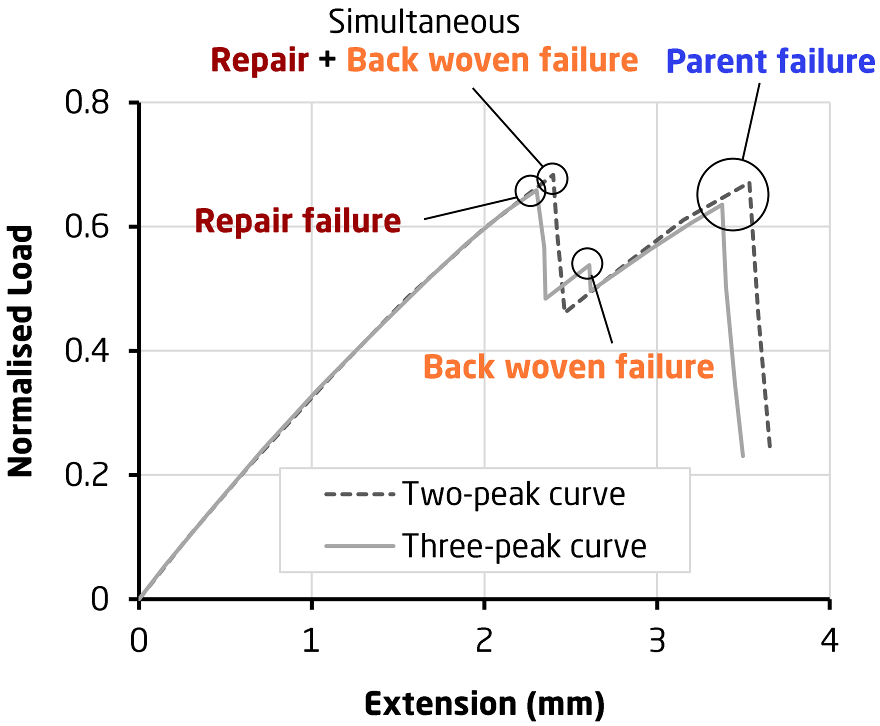
Bond-line microscopy: Strength-optimised scarf

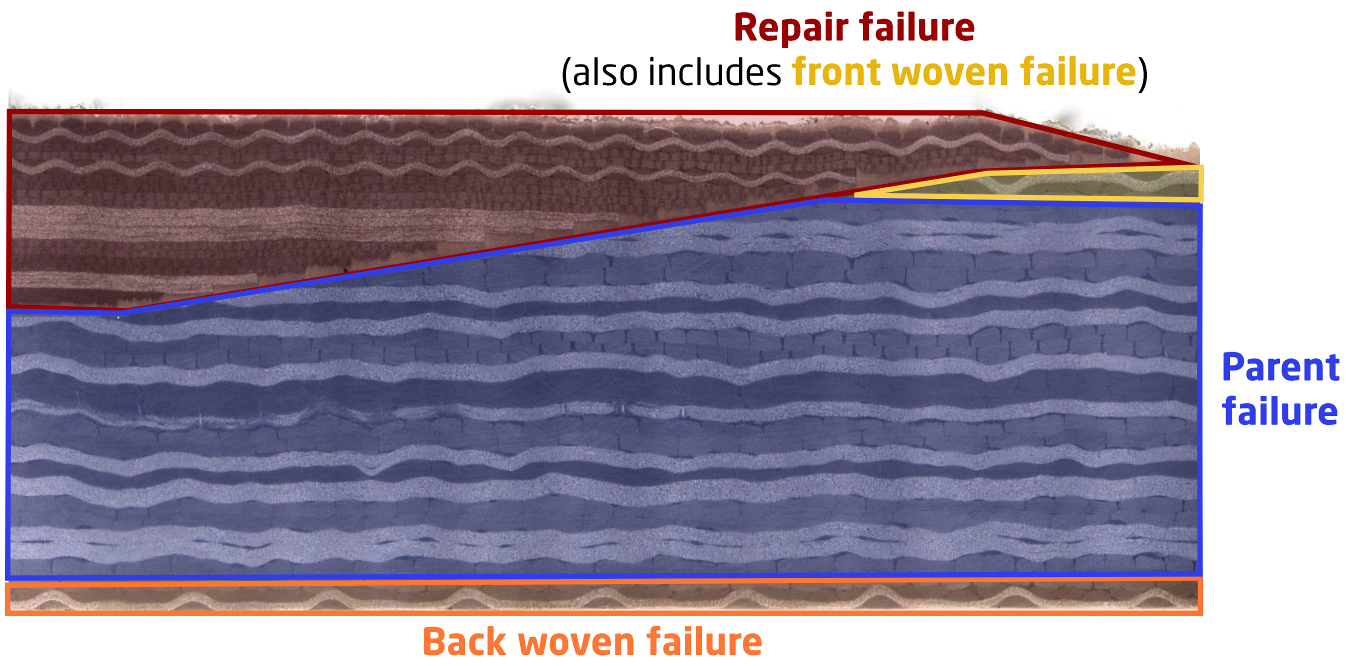


Testing and failure

Tensile testing

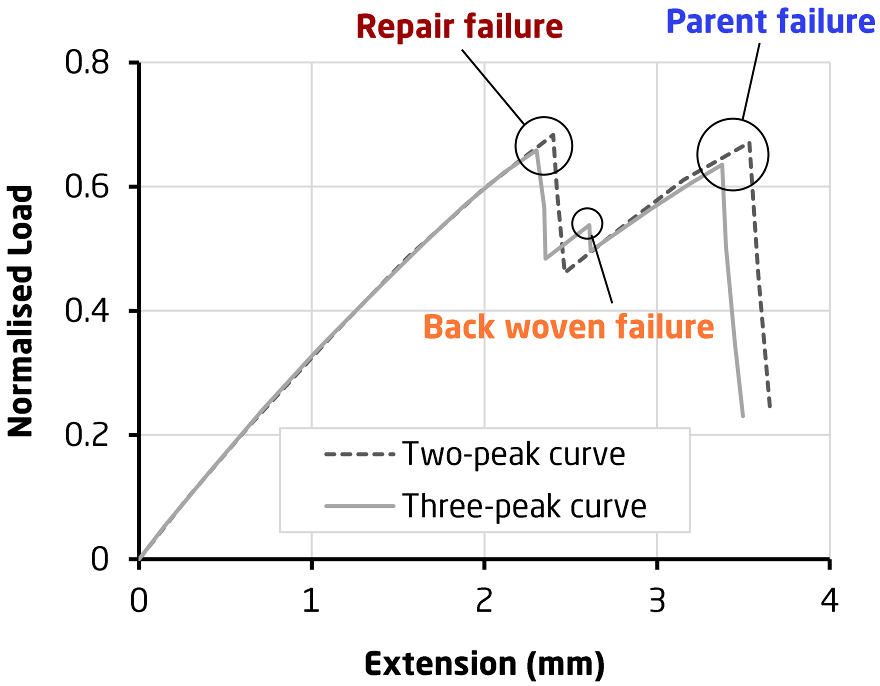
- Static constant rate of extension testing to failure (1mm/min)
- Two characteristic curves representative of all samples (across all batches)
- **Repair failure may be initiating in the front woven ply…**

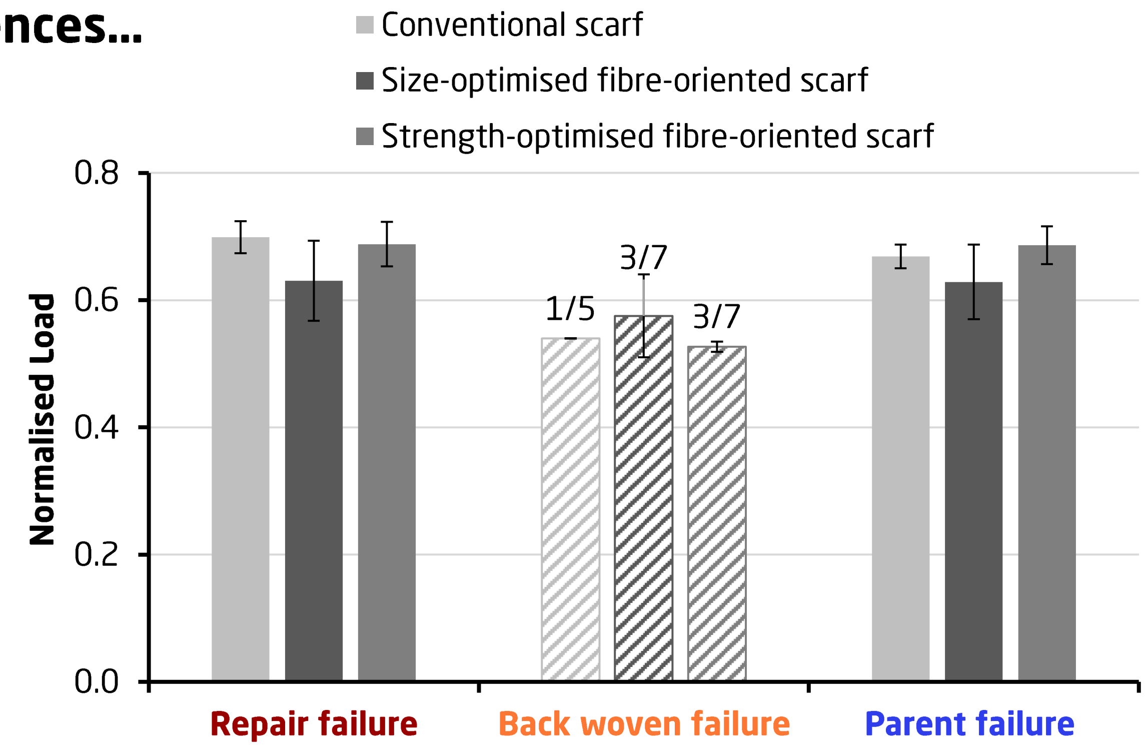




Failure loads

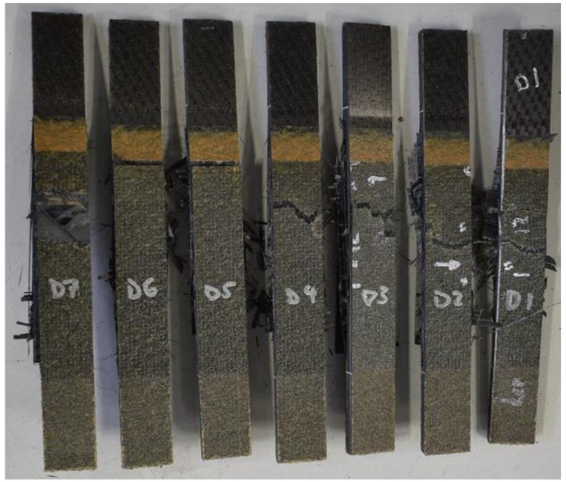
- Similar results for all repair configurations
- Failure around 65% of pristine laminate strength
- **Difficult to distinguish any differences…**





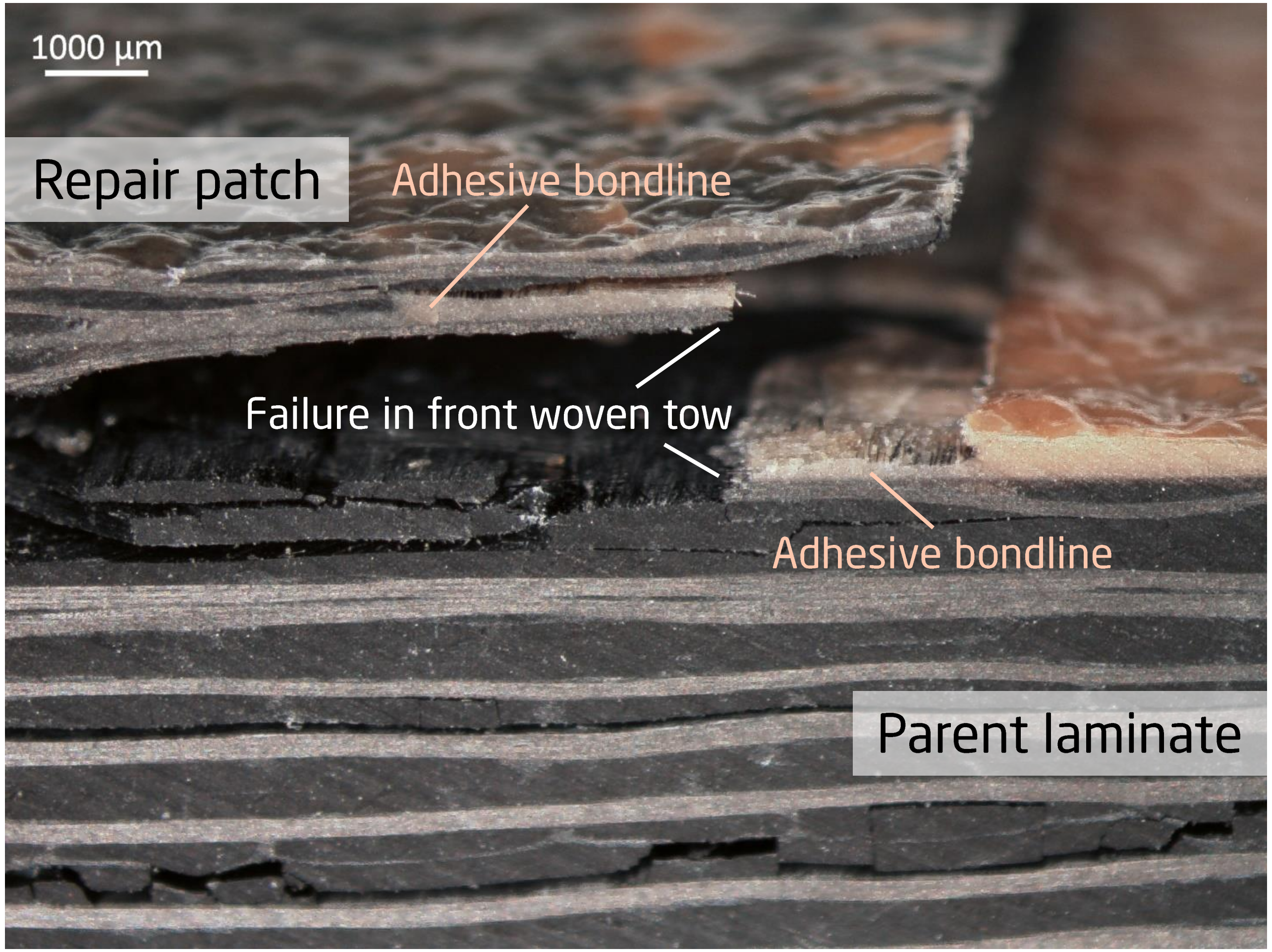
Fracture analysis

Front



Back

Detail of “repair failure”



Conclusions

Conclusions

- Proof-of-concept for complex fibre-oriented scarf repairs…
  …comparable quality to conventional scarf repairs with good ply matching

- However, inconclusive testing of mechanical performance
  (due to poor experimental design with coincident woven ply, repair, and parent failure)

Future work

- Improved mechanical tests for novel scarf repairs
  - Longer coupons with complete repair transition parent-patch-parent
    (to allow for more natural load distribution and avoid clamping on patch)
  - Coupons made from purely UD material (to avoid issues of woven first ply failure)
  - Alternative repair depth (to better compare the performance of different configurations)

- Demonstration and mechanical testing of 3D repair case

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Questions ?

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DOI: 10.1016/J.COMPSTRUCT.2022.116338

2 G. Gardiner, "Aircraft composites repair moves toward maturity", *CompositesWorld*, **2016**
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3 M. Niedernhuber, J. Holtmannspötter, and I. Ehrlich, "Fiber-oriented repair geometries for composite materials," *Compos. Part B Eng.*, vol. 94 , **2016**
DOI: 10.1016/ J.COMPOSITESB.2016.03.027

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