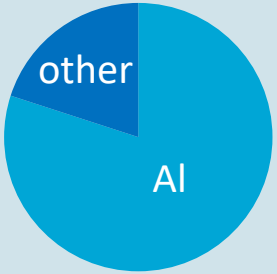
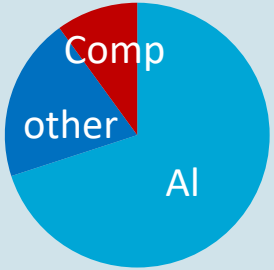
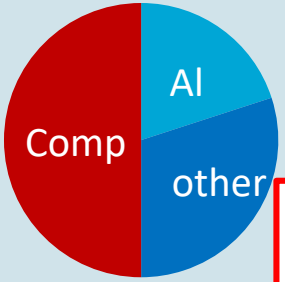
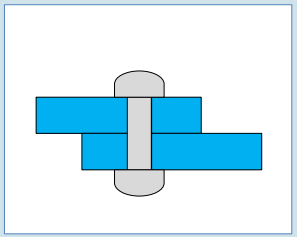
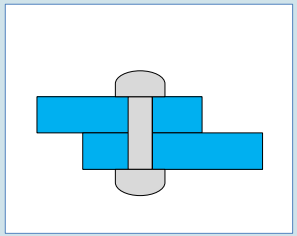
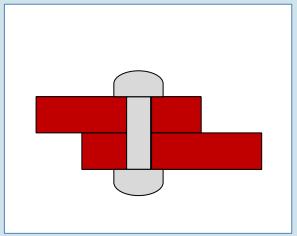
On the influence of the laminate properties on the failure of adhesively bonded composite structures

Sofia Teixeira de Freitas

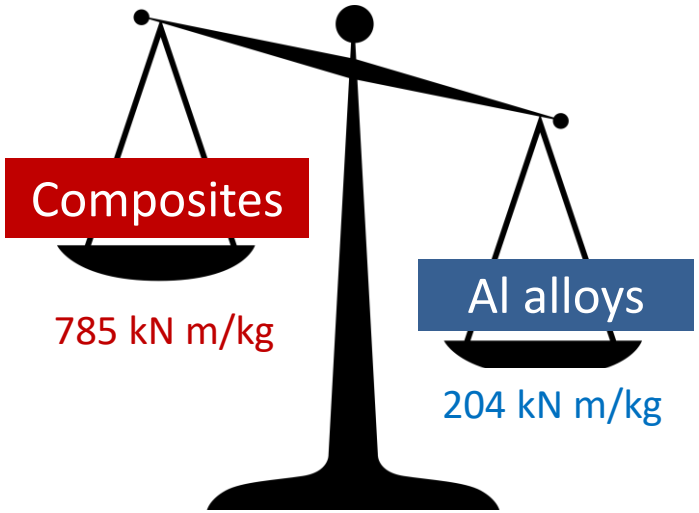
Assistant Professor, Aerospace Engineering TU Delft

Recent aircraft history

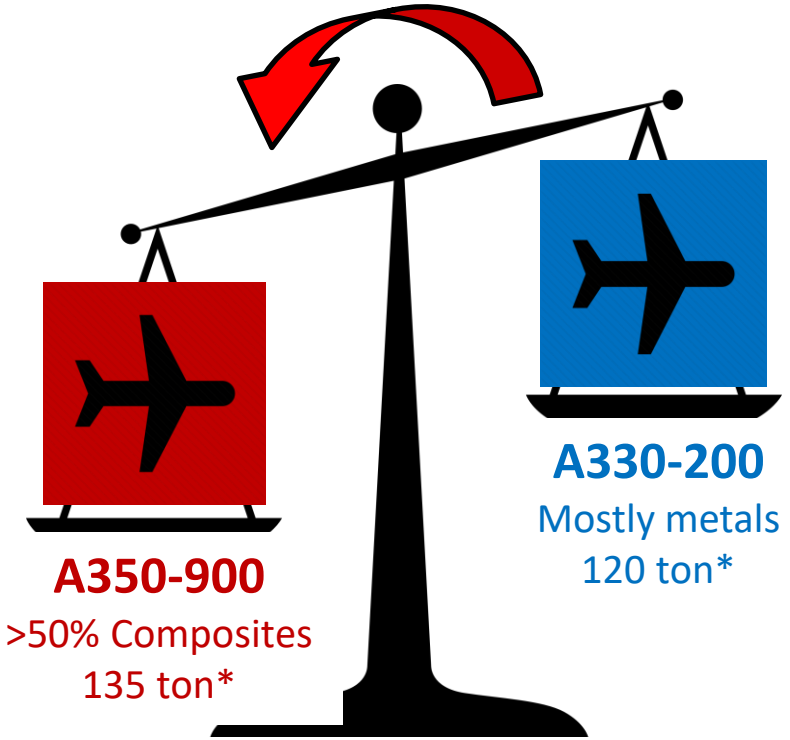
	1970's B747	1990's B777	2010's B787
Materials			
Joints	Fasteners 	Fasteners 	Fasteners 
	Metal Design	Metal Design	**Metal Design**

Today's inefficient 'Black Metal' design

LIGHTer material = LIGHTer structure ?



Materials



Aircraft structure

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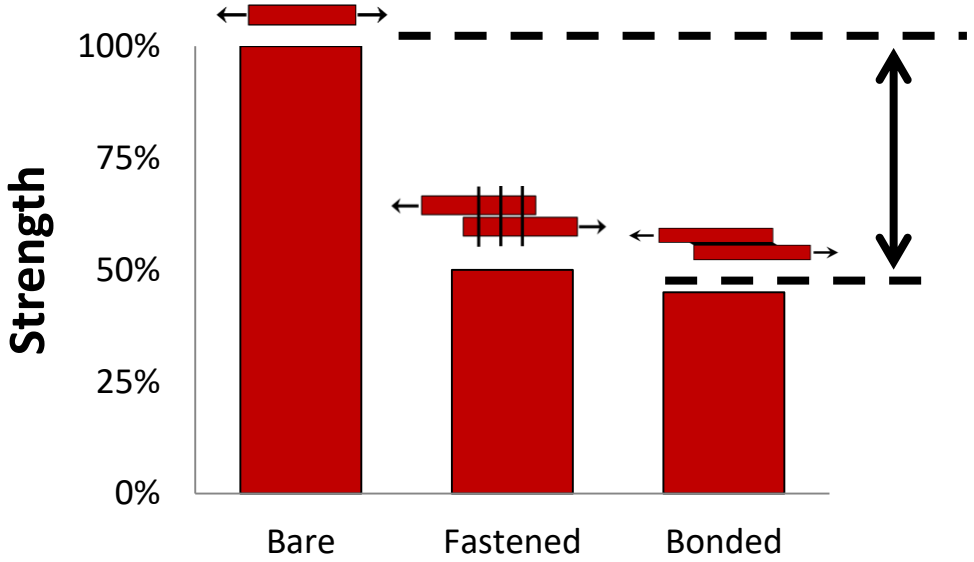
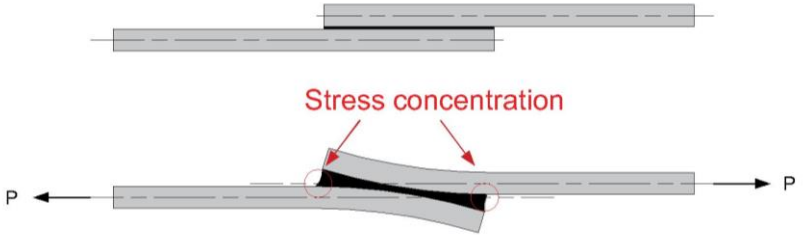
*OEW: operating empty weight

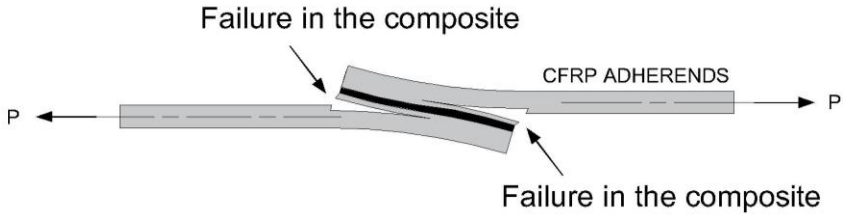
Composite bonded joints



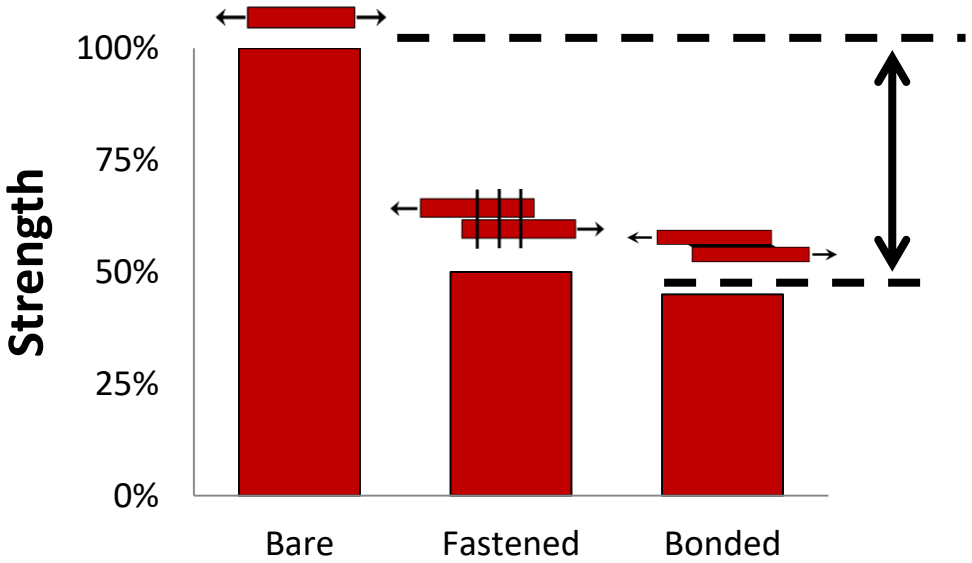
Example:
Single Lap Bonded Joint (SLJ)



- **Premature** and **sudden** failure
- **Limited** strength and damage resistance



Efforts to improve: literature



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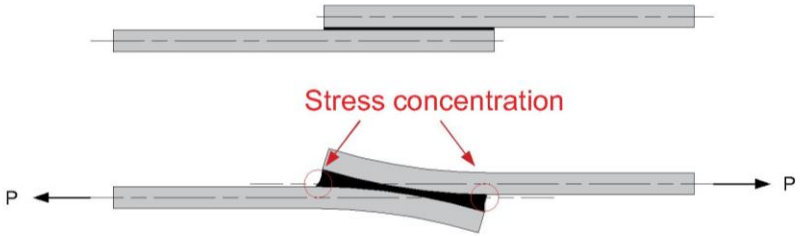
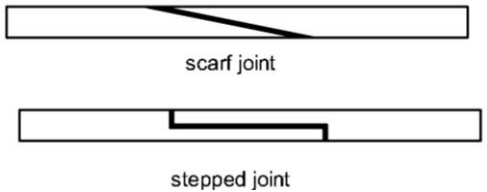
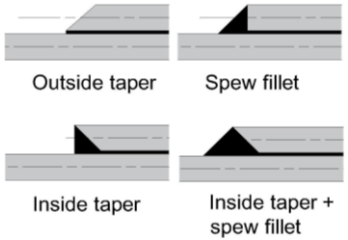


Joint Topology





Bondline/adhesive

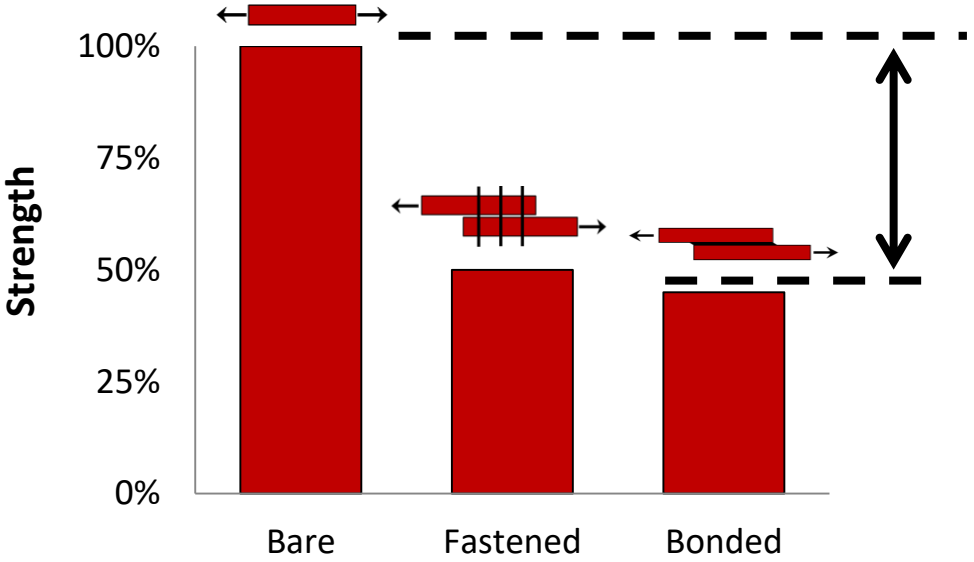
- Mixed adhesive joints
- Functionally graded bondlines
- …

Banea MD, da Silva LFM, *Journal of materials Design and Applications 223*, 1-19, 2009.

Da Silva LFM, Adams R., *International Journal of Adhesion & Adhesives 27*, 227-235, 2007.

Carbas R, Da Silva L, Critchlow G , *International Journal of Adhesion and Adhesives 4*8, 110-118, 2014.

Efforts to improve: FRP



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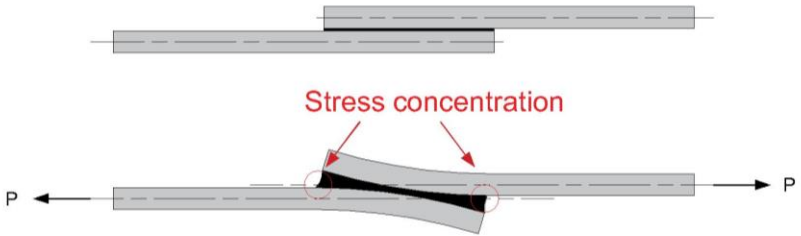
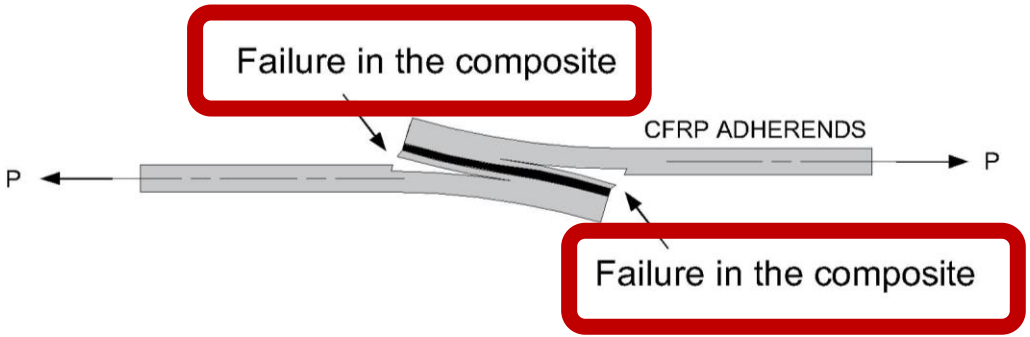


What about the influence of the FRP-adherend properties?



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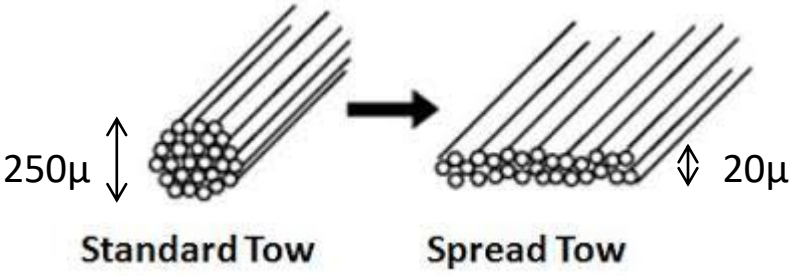
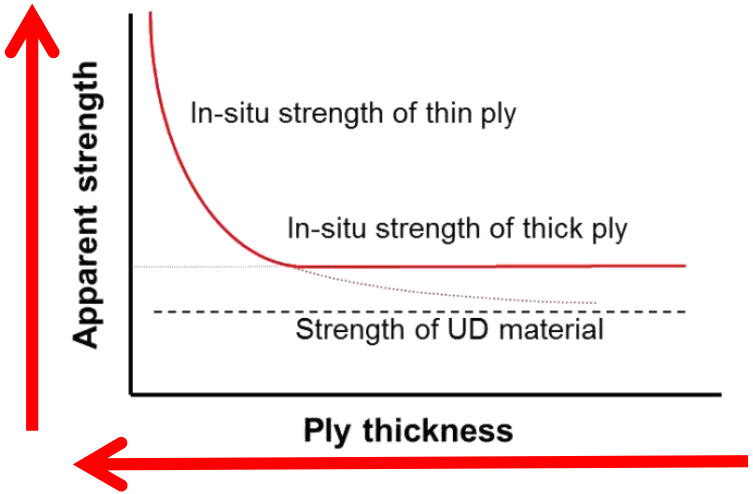
Thin ply composites: could it help?



Ply thickness as thin as 20 microns

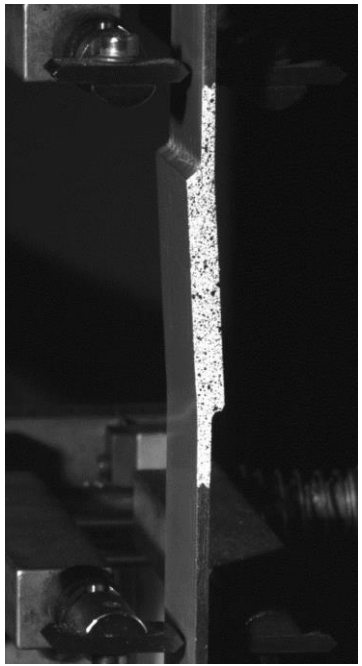


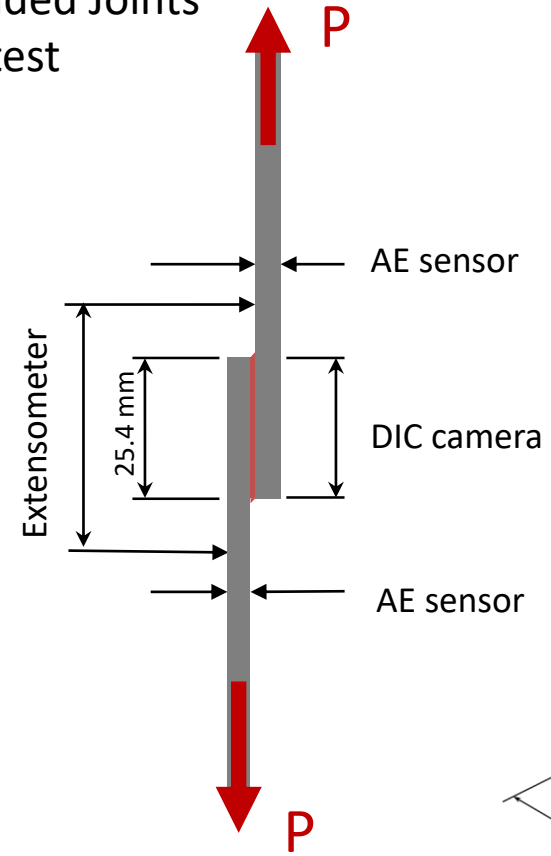
- Improved resistance to delamination
- Improved resistance to ply cracking (*in-situ effects*)

Can thin-ply composites help to improve strength of bonded joints?

Experimental and Finite Element Analysis

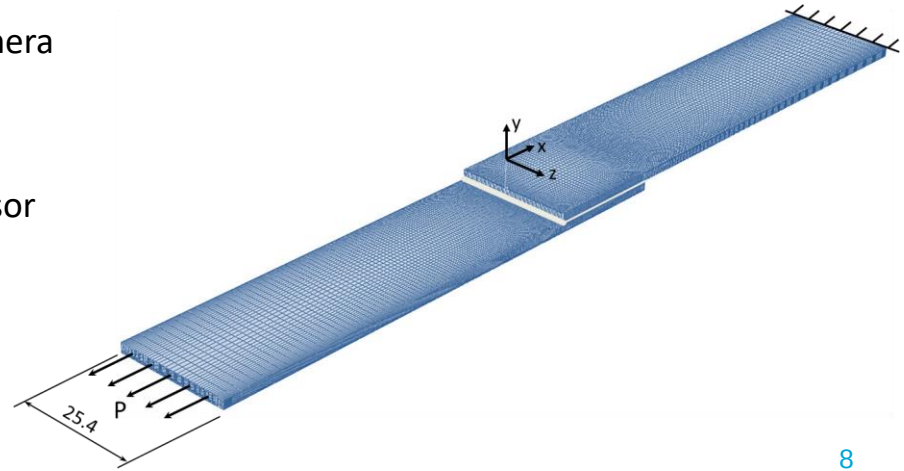
- CFRP-Single Lap Bonded Joints
- Quasi-static tensile test





FEA

- ABAQUS 3D solid-linear elements
- Non-linear geometry effects
- Linear elastic CFRP
- Linear-plastic Adhesive



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Materials

Adhesive

AF163-2K (3M ®)

Epoxy film adhesives

Autoclave Cure cycle 120°C for 90 min

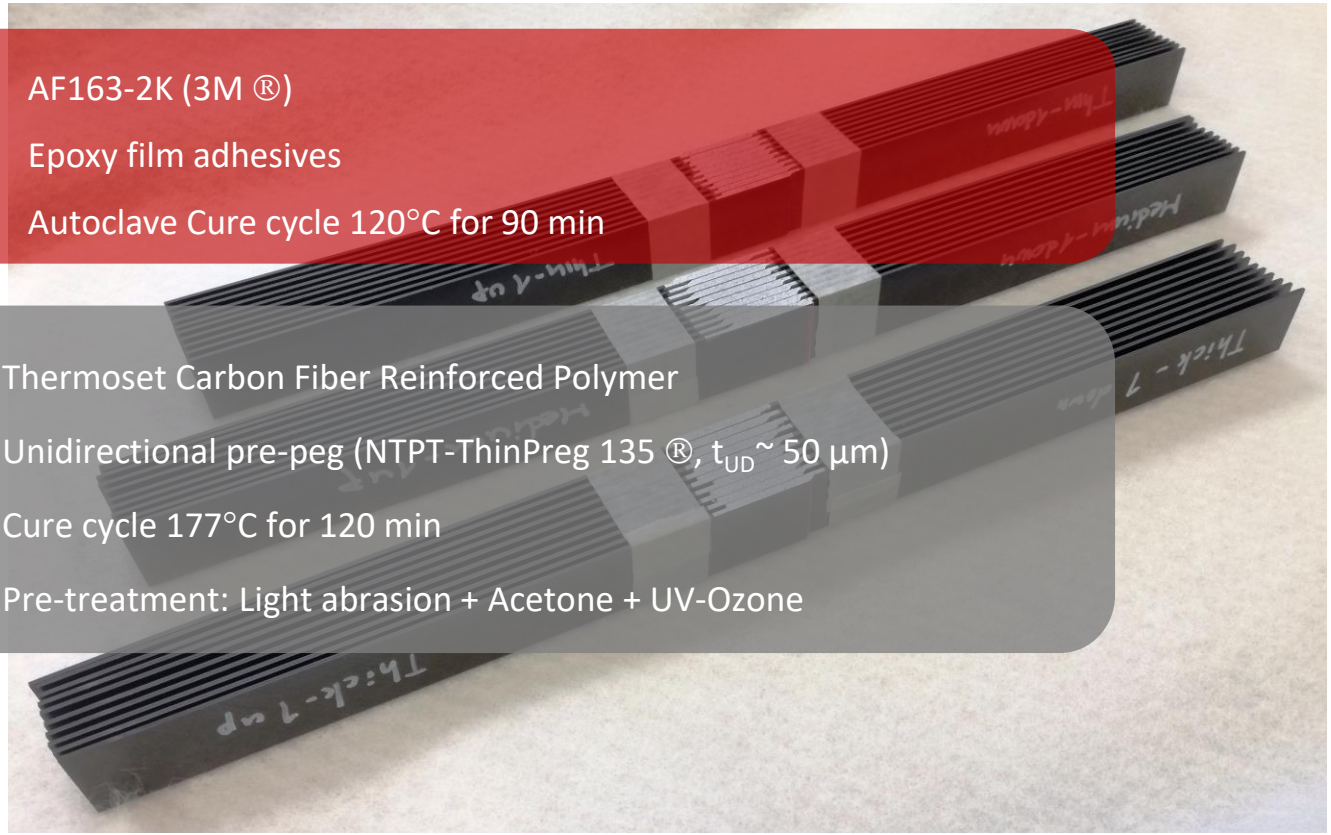
Adherend

Thermoset Carbon Fiber Reinforced Polymer

Unidirectional pre-peg (NTPT-ThinPreg 135 ®, t_{UD}~ 50 µm)

Cure cycle 177°C for 120 min

Pre-treatment: Light abrasion + Acetone + UV-Ozone



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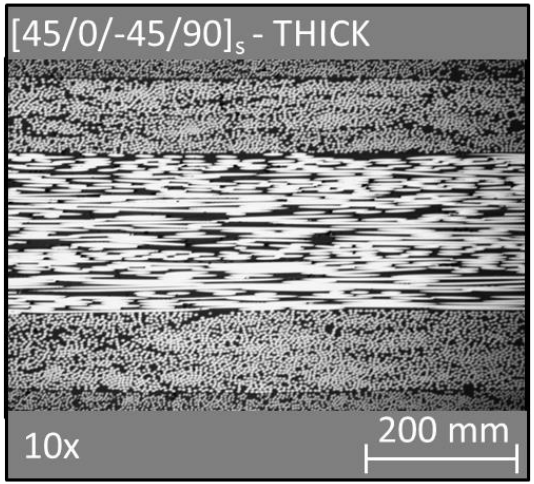
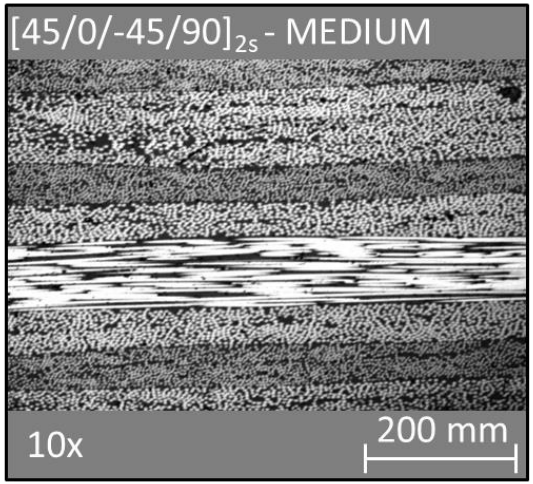
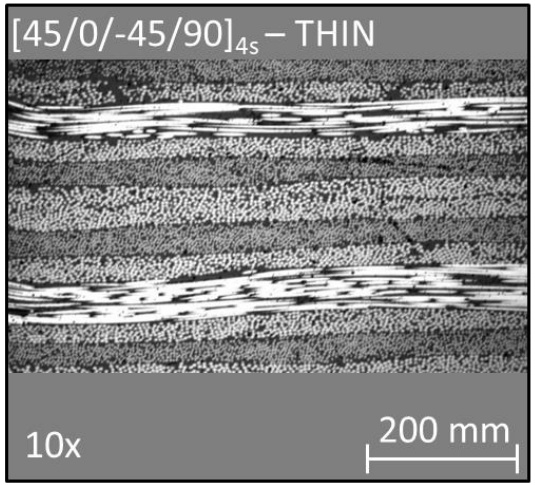
CFRP adherends: ply thickness and layup

THICK	MEDIUM	THIN
$[45°/0°/-45°/90°]_s$ or $[4x45°/4x0°/4x-45°/4x90°]_s$	$[45°/0°/-45°/90°]_{2s}$ or $[2x45°/2x0°/2x-45°/2x90°]_{2s}$	$[45°/0°/-45°/90°]_{4s}$ or $[1x45°/1x0°/1x-45°/1x90°]_{4s}$
t_{UD_eq} 200 µm	> 100 µm	> 50 µm







CFRP adherends: ply thickness and layup

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$(E_x)_{equiv}$	57 GPa	~	56 GPa	~	55 GPa
Pos. first 0 °	2nd-ply	=	2nd-ply	=	2nd-ply
Interface ply	45°	=	45°	=	45°

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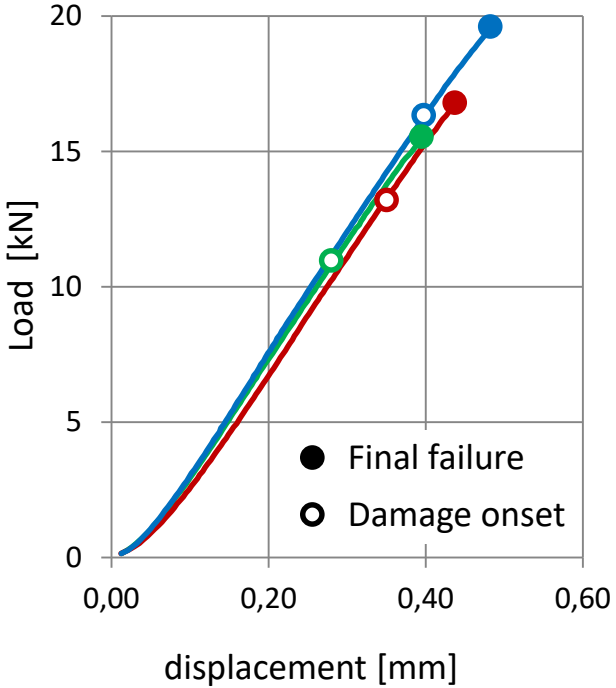
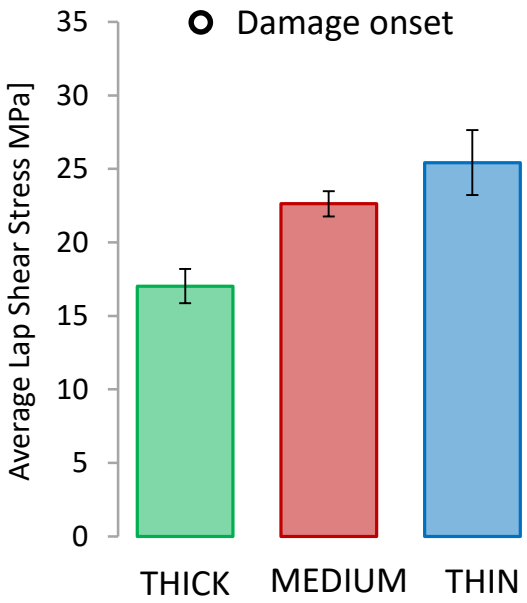
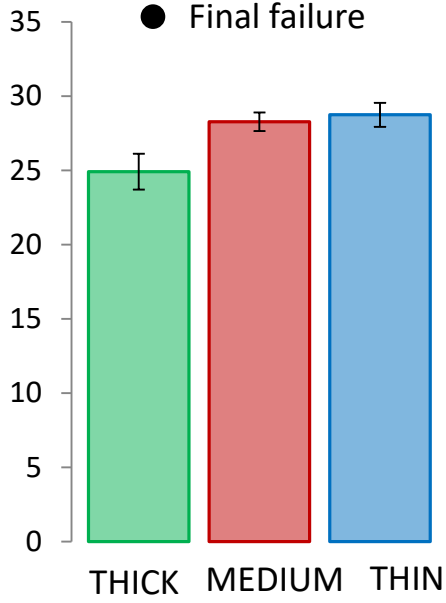
Experimental results – L-d curves





THICK → THIN

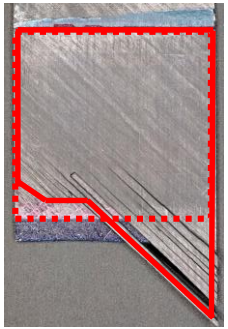
+50% damage onset

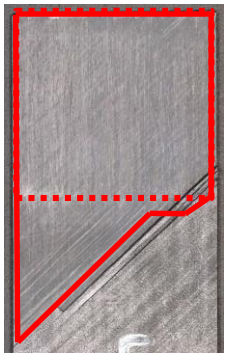


THICK → THIN

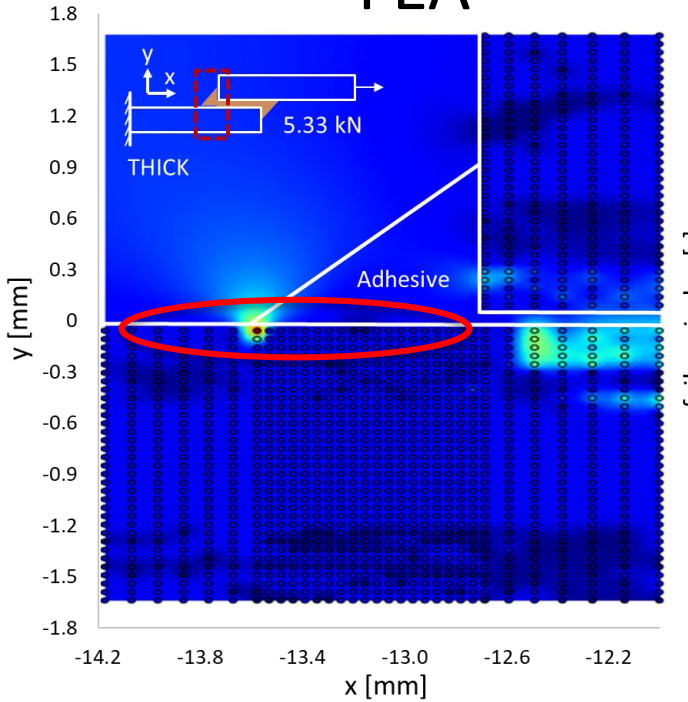
+15% final strength

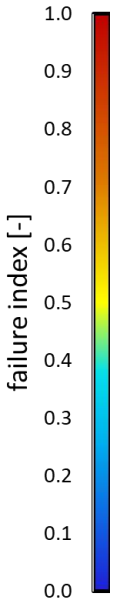
Failure analysis - THICK



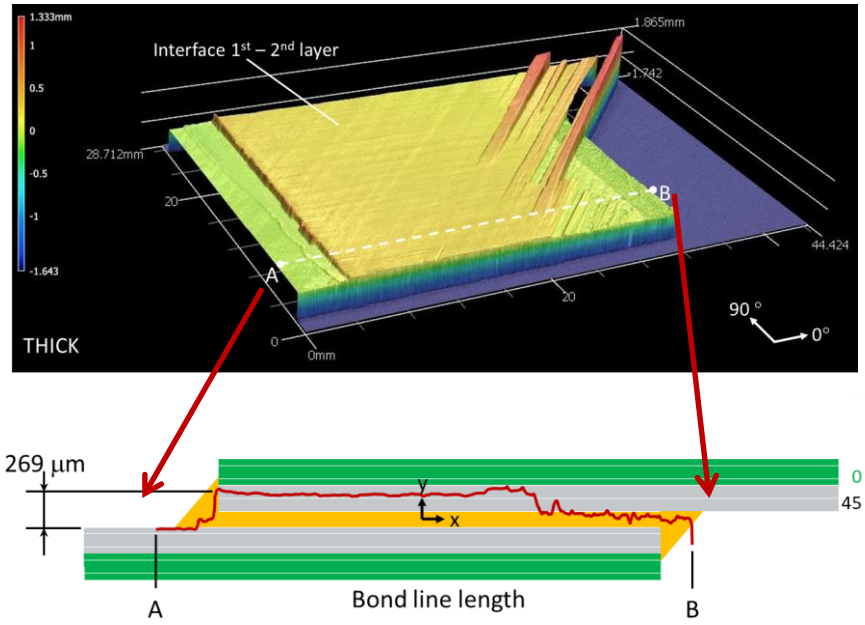


FEA





Final fracture

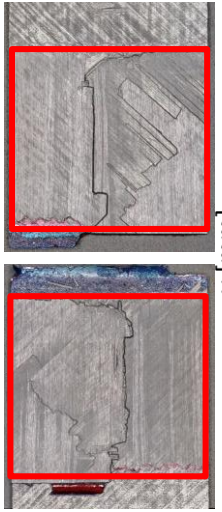


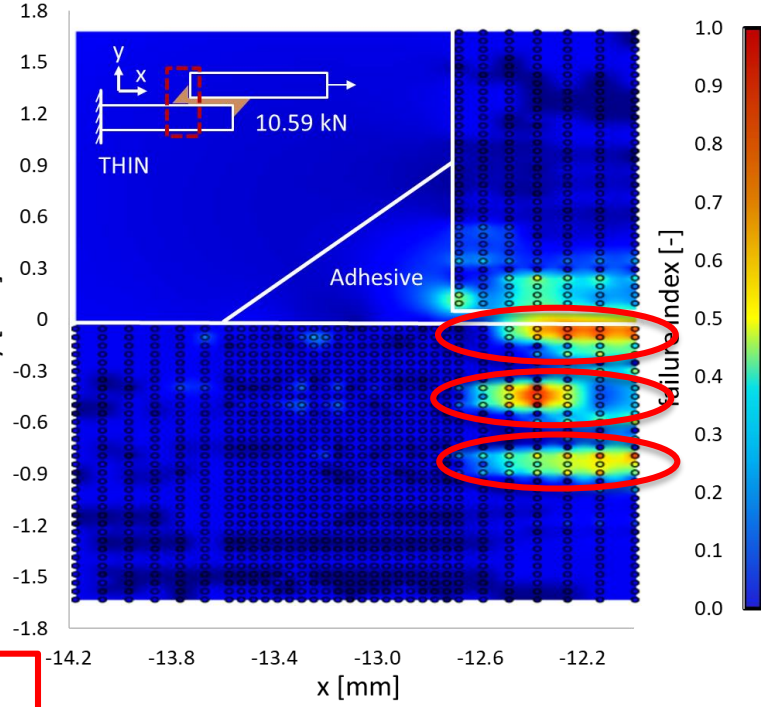
A_{FC}=120% A_{OL}

Crack path: interface 1st-2nd layer

Failure analysis - THIN

FEA

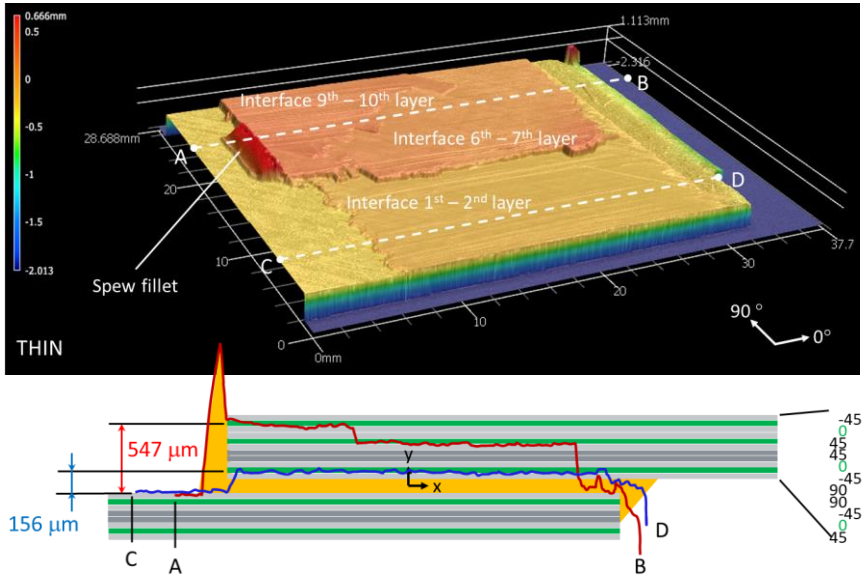




A_{FC}=95% A_{OL}

(THICK: A_{FC}=120% A_{OL})

Final fracture



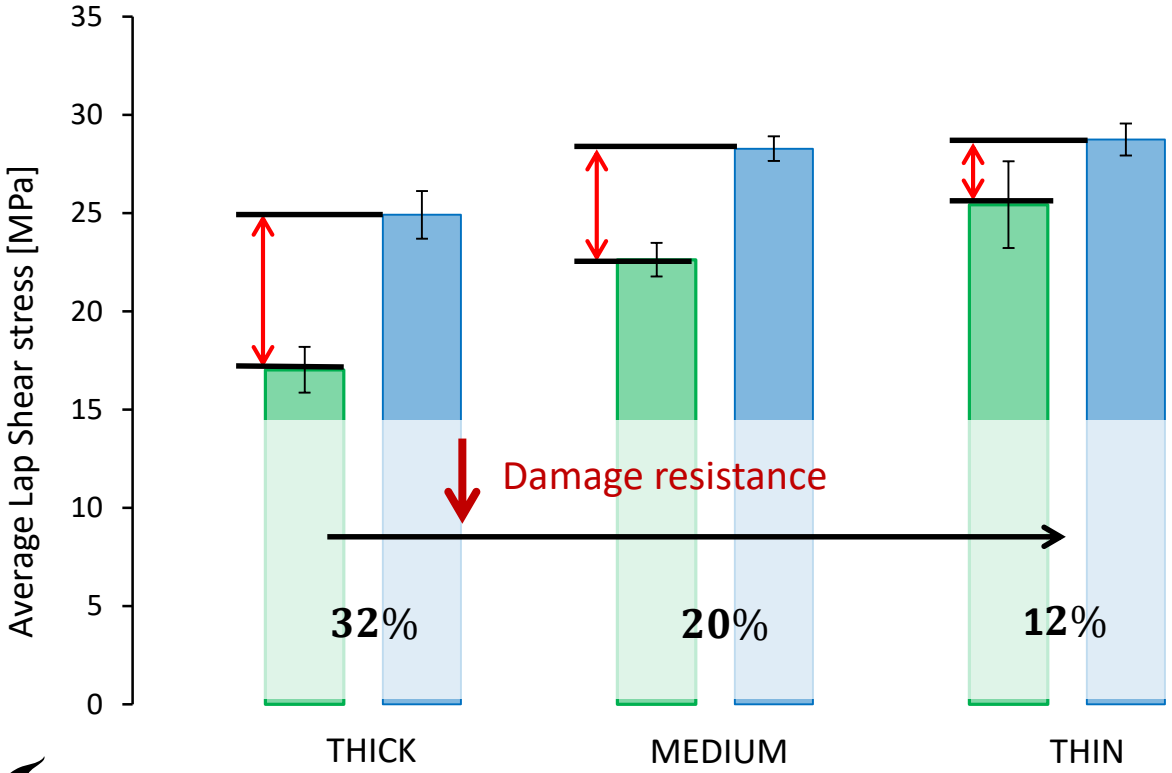
Crack path:

interface 1st-2nd ply

interface 6th-7th ply

interface 9th-10th ply

Damage resistance: onset vs. final failure



Damage resistance

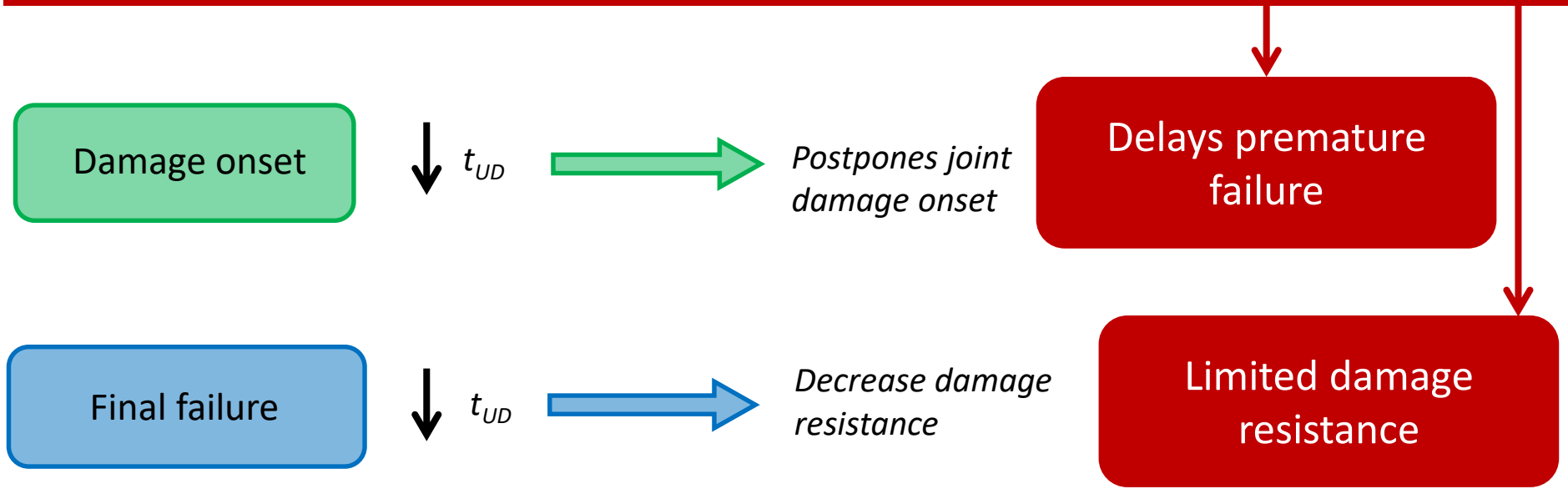
$$1 - \frac{LSS_{onset}}{LSS_{final}}$$

Damage onset

Final failure/Max Load

Conclusions

Can thin-ply composites help to improve strength in bonded joints?



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Thank you

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Dimitrios Zarouchas, TU Delft

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