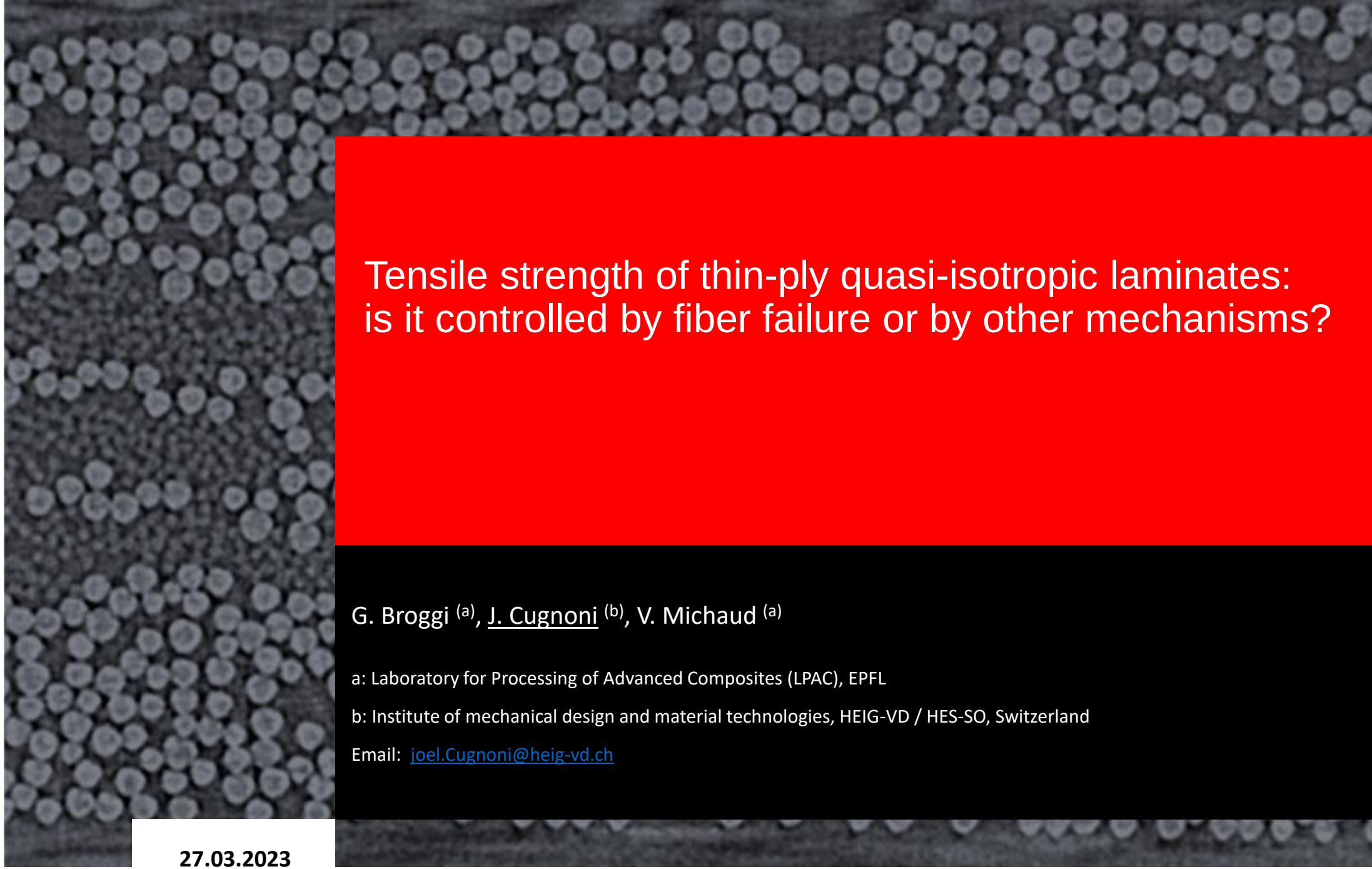


Tensile strength of thin-ply quasi-isotropic laminates: is it controlled by fiber failure or by other mechanisms?

G. Broggi [a], J. Cugnoni [b], V. Michaud [a]

a: Laboratory for Processing of Advanced Composites (LPAC), EPFL

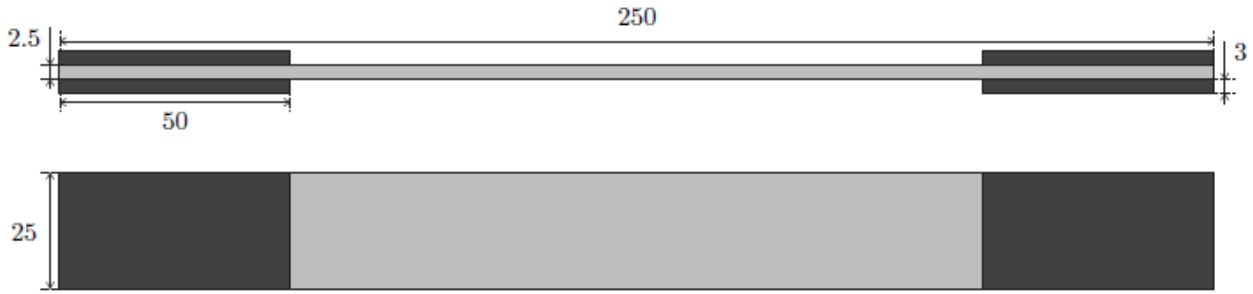
b: Institute of mechanical design and material technologies, HEIG-VD / HES-SO, Switzerland

Email: joel.Cugnoni@heig-vd.ch

27.03.2023

Context

- **PhD Thesis of Guillaume Broggi EPFL** on Hybrid thin ply composites
  - Low strain / high modulus fibre HR40: E = 375 GPa / ε_{ult} = 1.1%
  - High strain / low modulus fibre 34-700: E = 234 GPa / ε_{ult} = 2.0%
  - Resin NTPT TP415, 135˚C curing, rubber toughened
  - Prepreg: UD, ply fibre areal weight = 60 g/m^2 for 34-700; 29 g/m^2 for HR40; 37% resin weight
- Design of pseudo ductile laminates based on those hypotheses
- Unnotched tensile test specimens based on ASTM D3039 with glued aluminium tabs, layup $[45/90/-45/0]_{ns}$
- Several hybrids layups + baseline HR40 @29g/m^2 and 34-700 @60, 120 & 180 g/m^2
- Acoustic emission monitoring for detection of onset of damage + strain gage for strain measurement

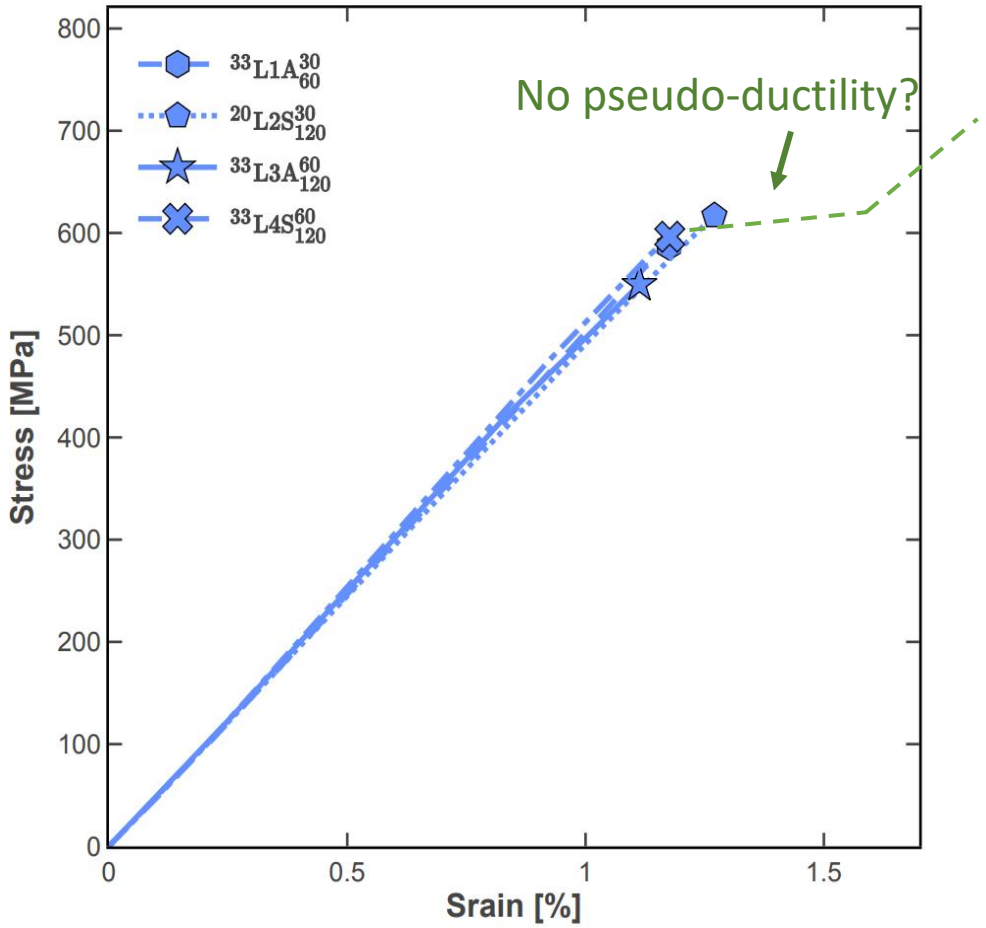


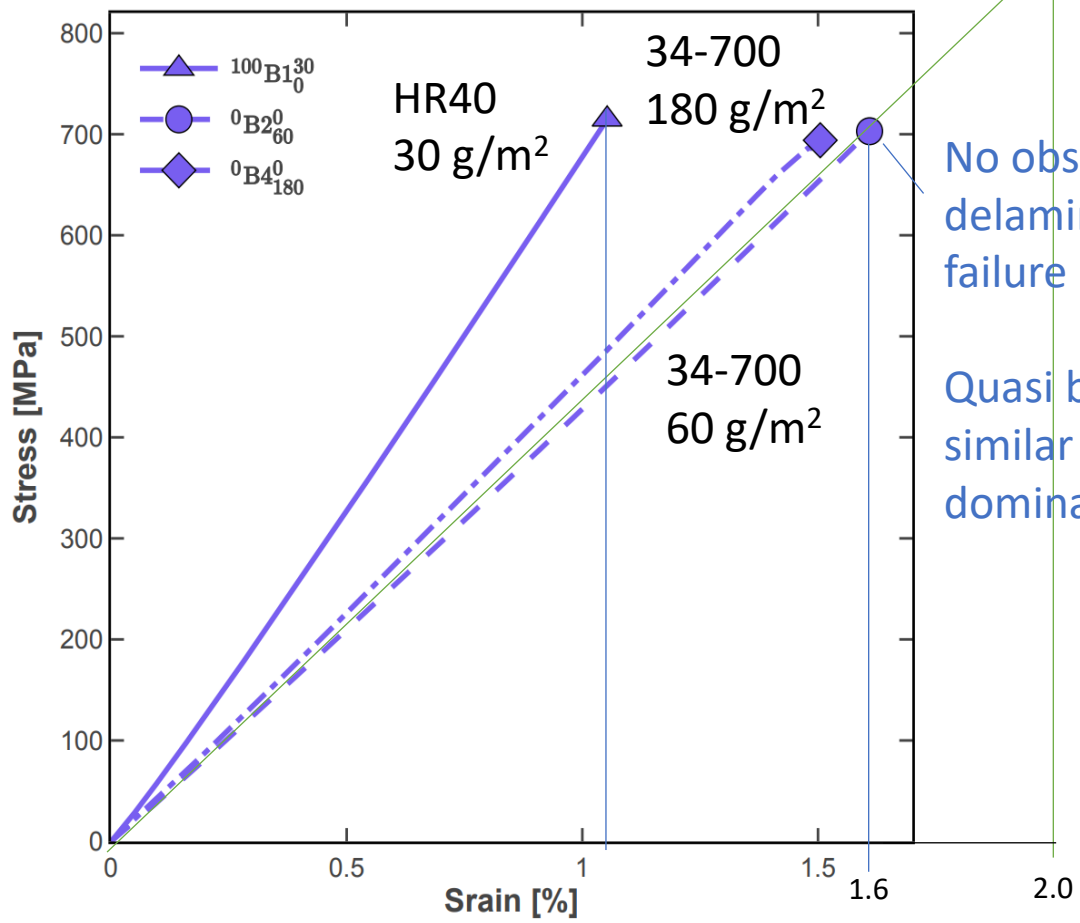
UD QISO tensile test results

Interlayer hybrids

Resin: TP415

Baselines





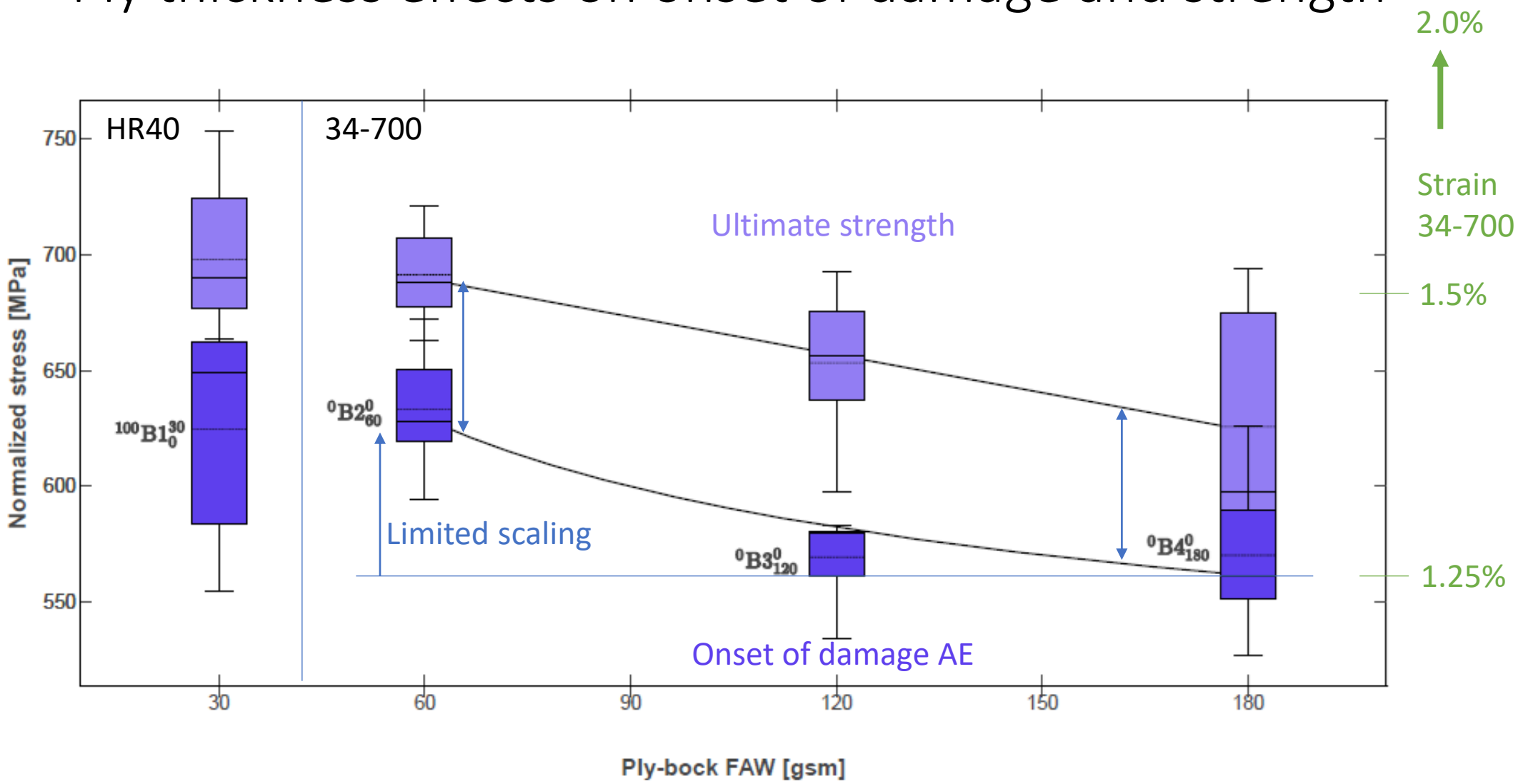
Datasheet
34-700 $\varepsilon_{ult} = 2\%$??

No observable delamination; failure outside of tabs.

Quasi brittle failure, similar to a fiber dominated failure…

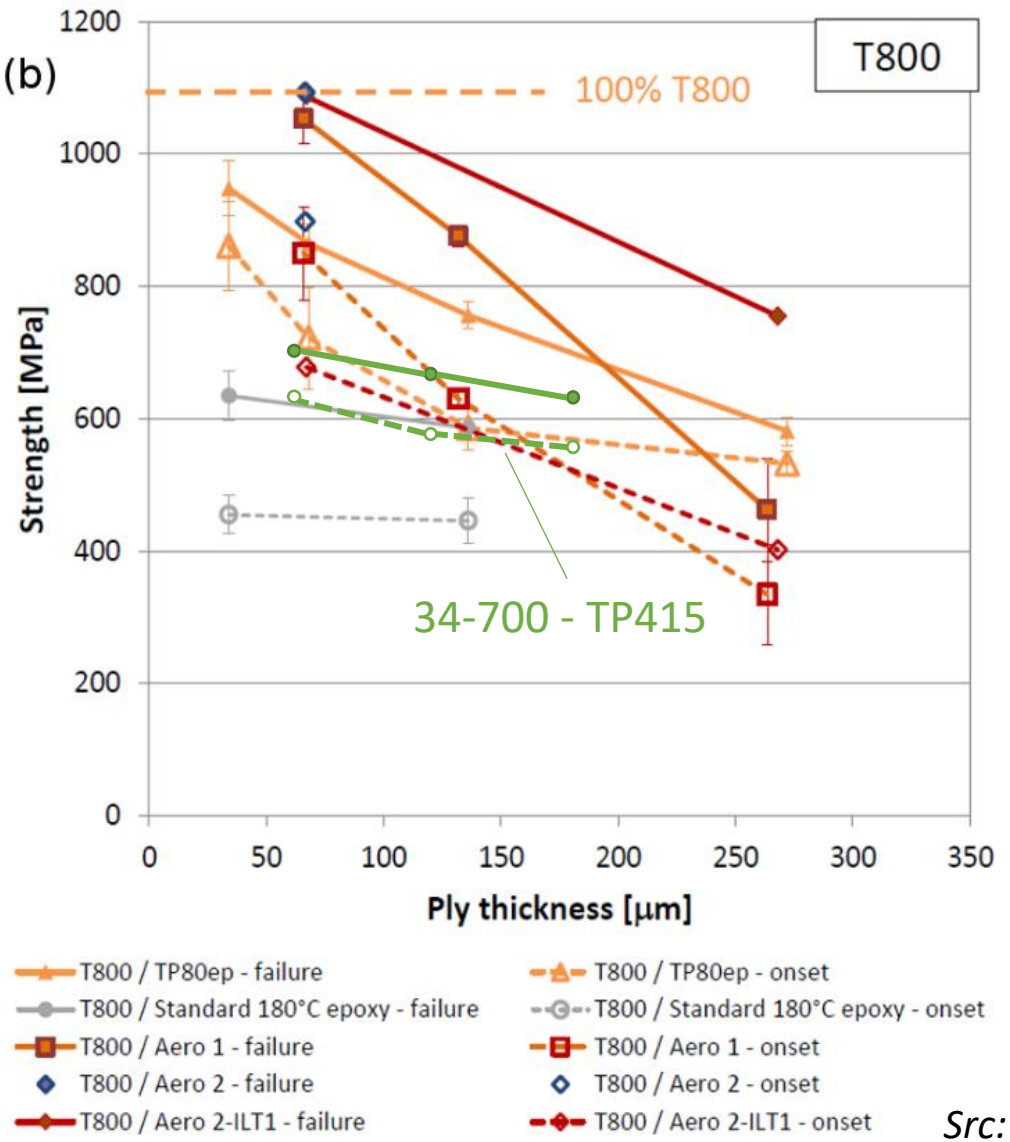
Src: PhD thesis EPFL Guillaume Broggi, 2023

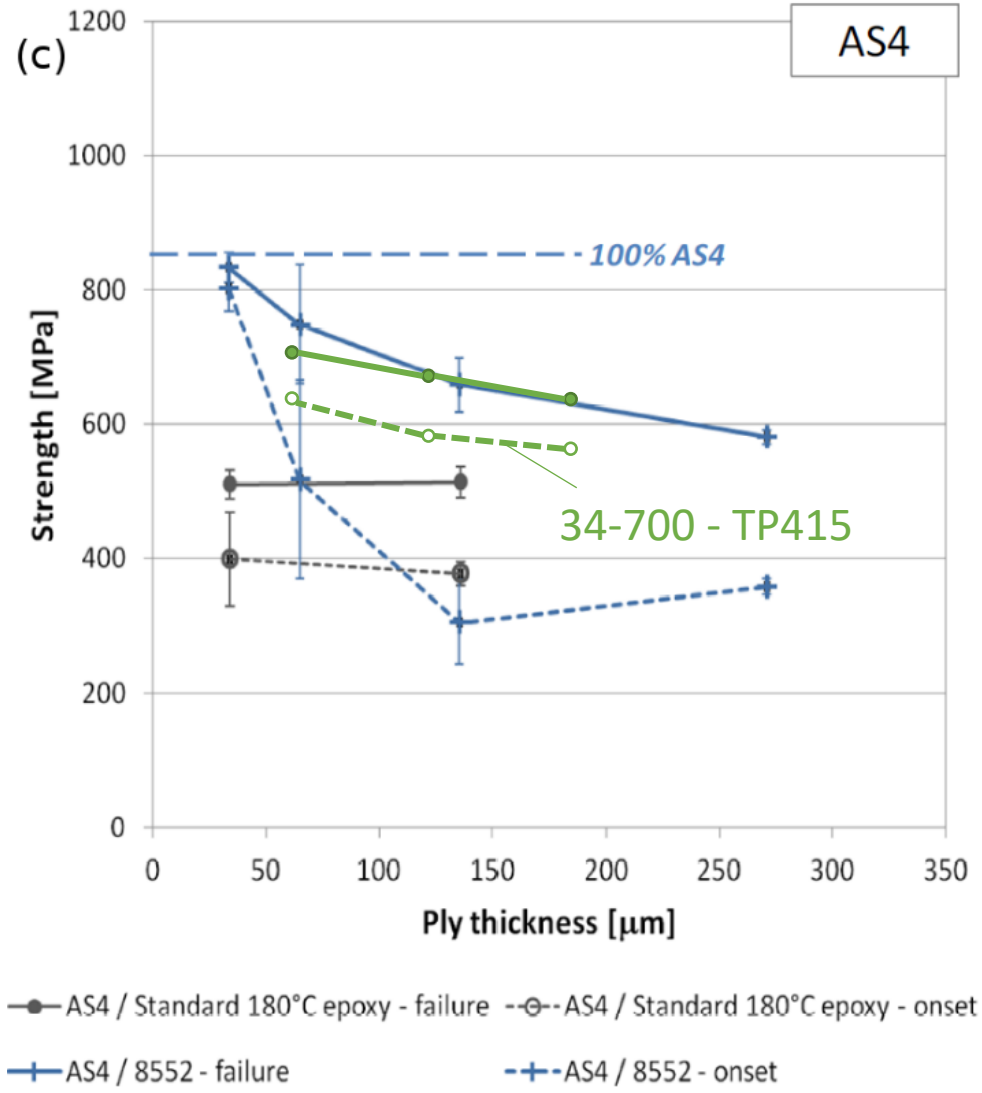
Ply thickness effects on onset of damage and strength



Src: PhD thesis EPFL Guillaume Broggi, 2023

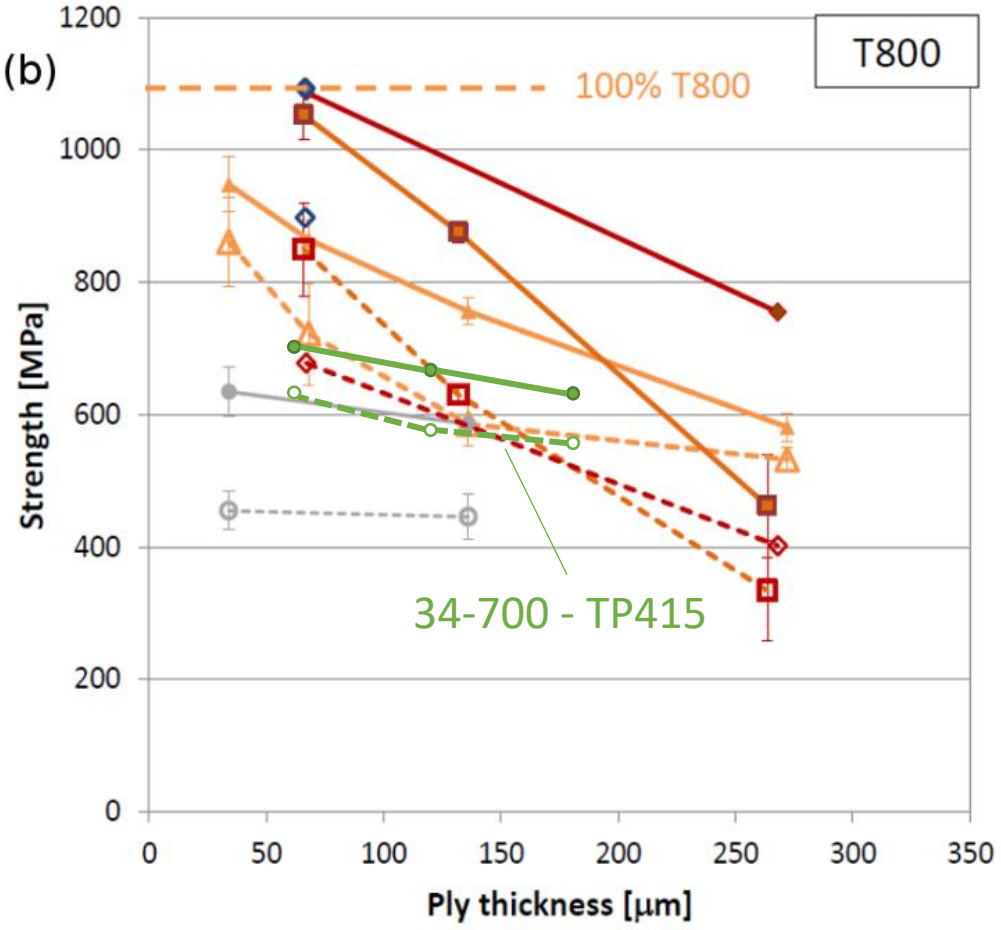
Comparison with other systems

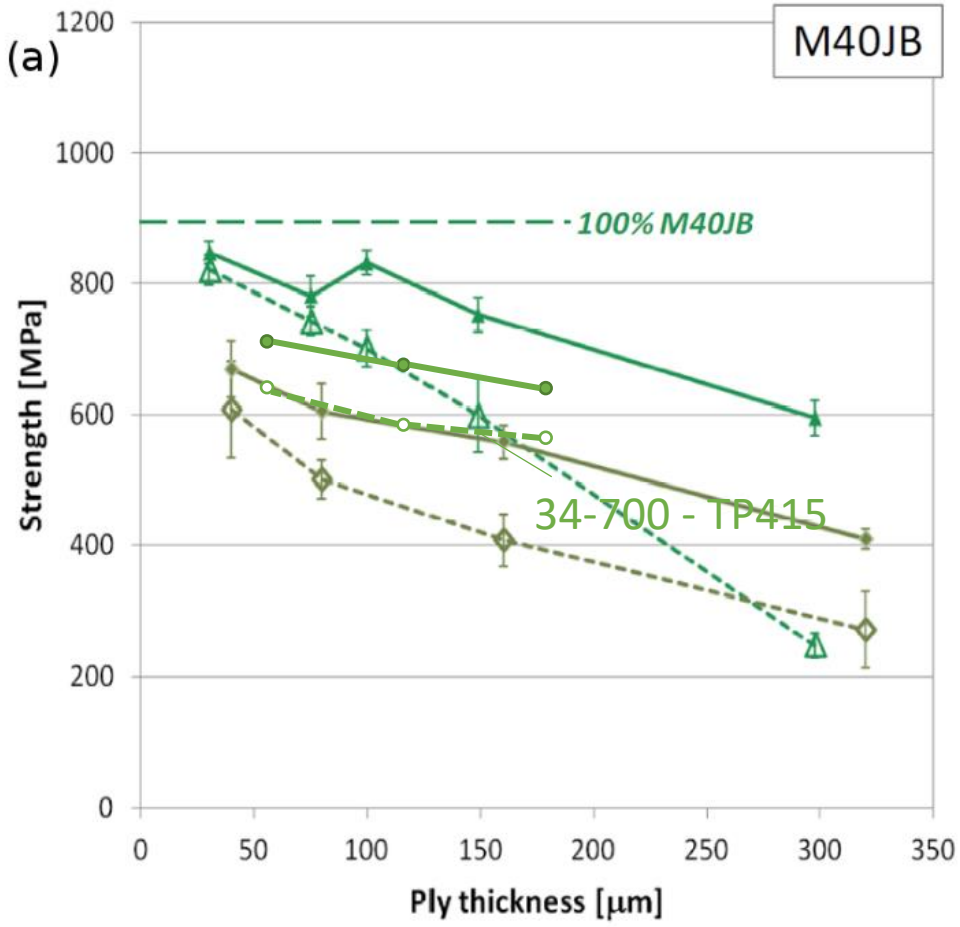




Src: J.Cugnoni et al, Comp Sci Tech 2018

Comparison with other systems

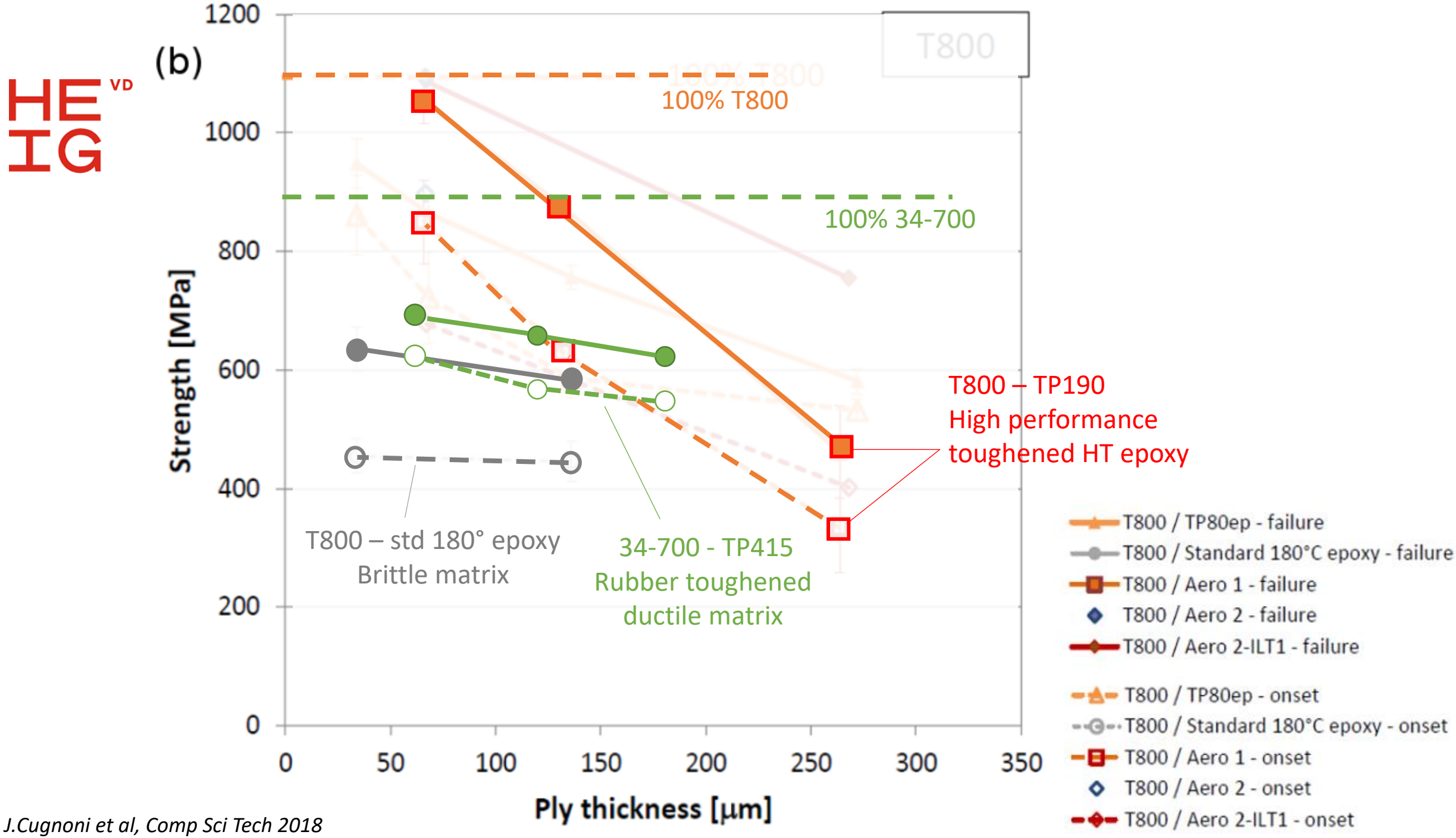




T800 / TP80ep - failure
T800 / TP80ep - onset
T800 / Standard 180°C epoxy - failure
T800 / Standard 180°C epoxy - onset
T800 / Aero 1 - failure
T800 / Aero 1 - onset
T800 / Aero 2 - failure
T800 / Aero 2 - onset
T800 / Aero 2-ILT1 - failure
T800 / Aero 2-ILT1 - onset

M40JB / TP80ep - failure
M40JB / TP80ep - onset
M40JB / TP120ep - failure
M40JB / TP120ep - onset

Src: J.Cugnoni et al, Comp Sci Tech 2018



Src: J.Cugnoni et al, Comp Sci Tech 2018

Effect of matrix on very thin-ply QISO UNT

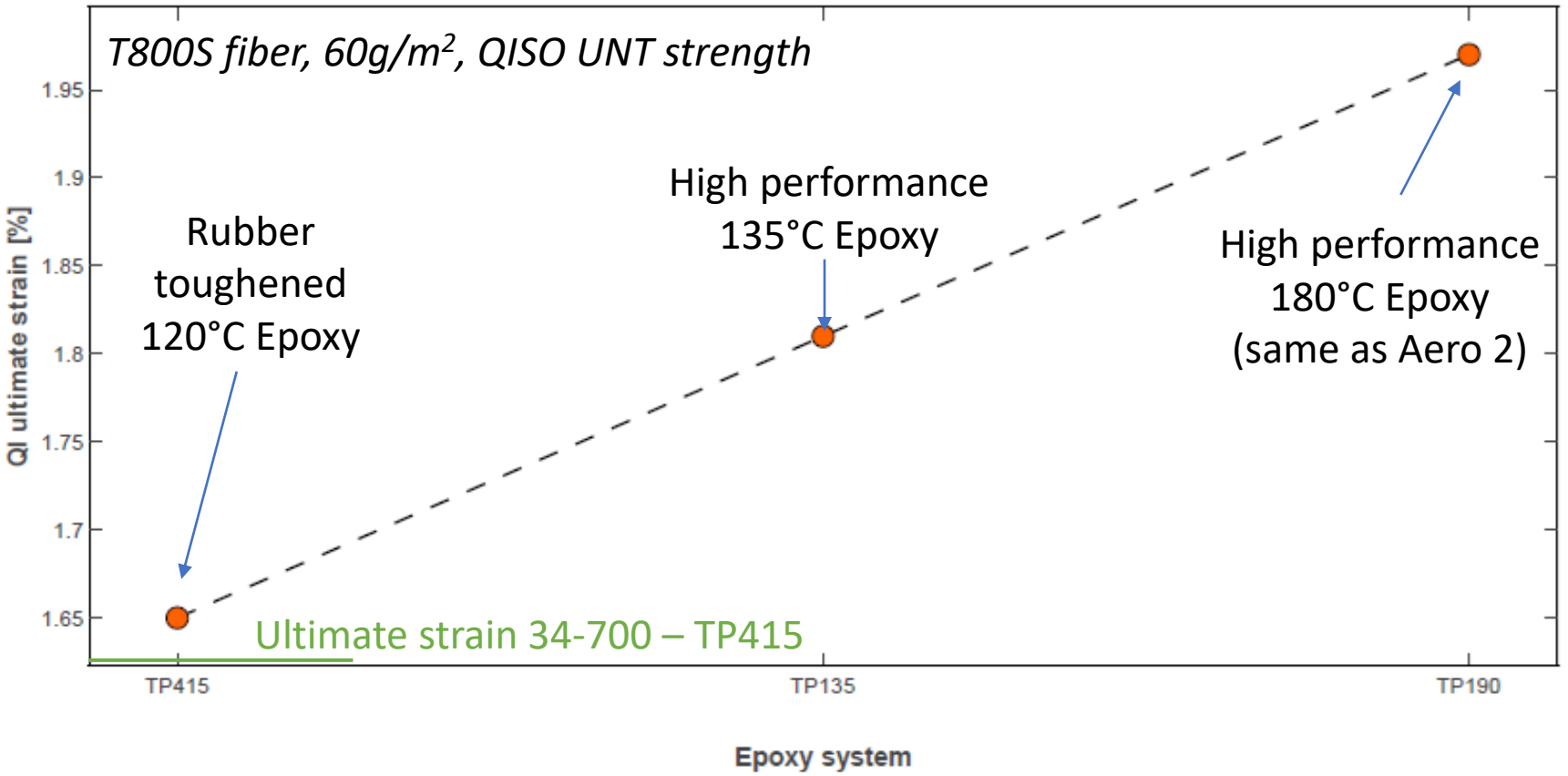
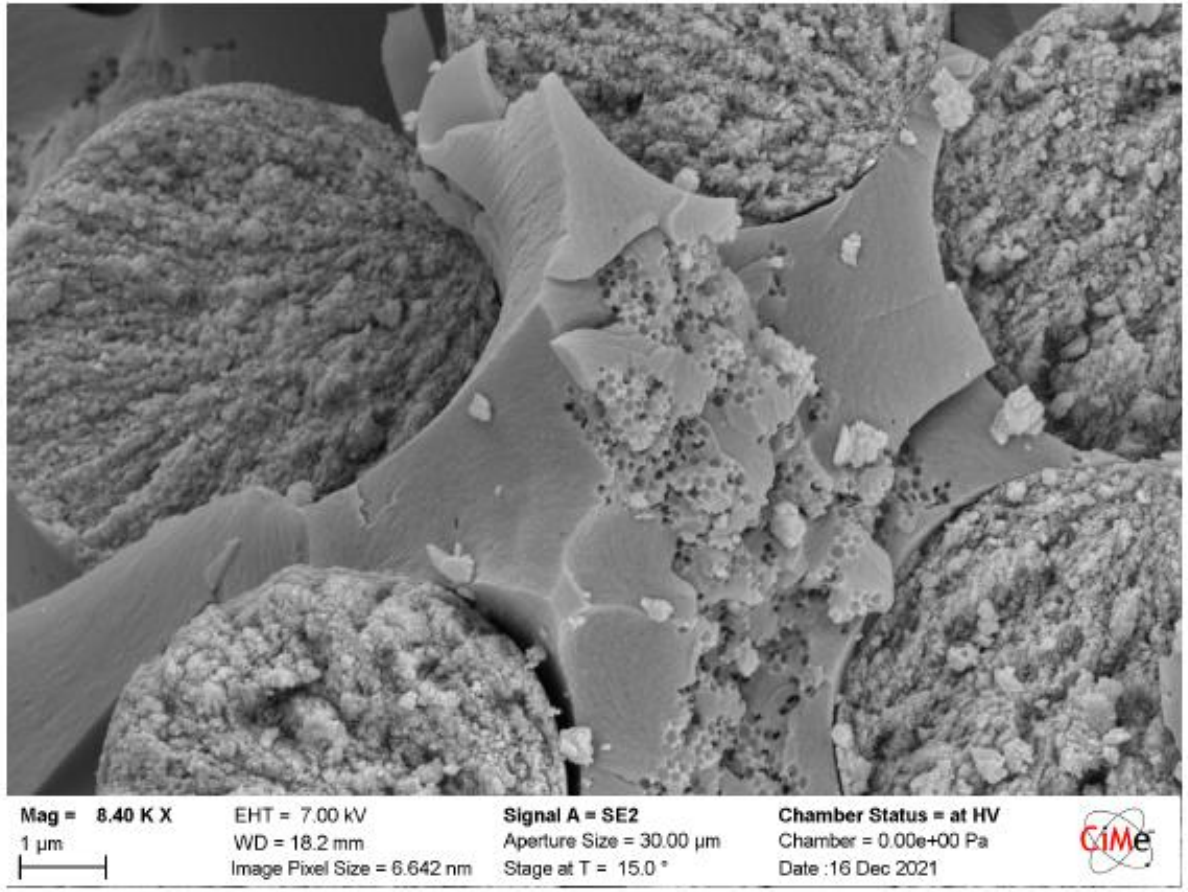
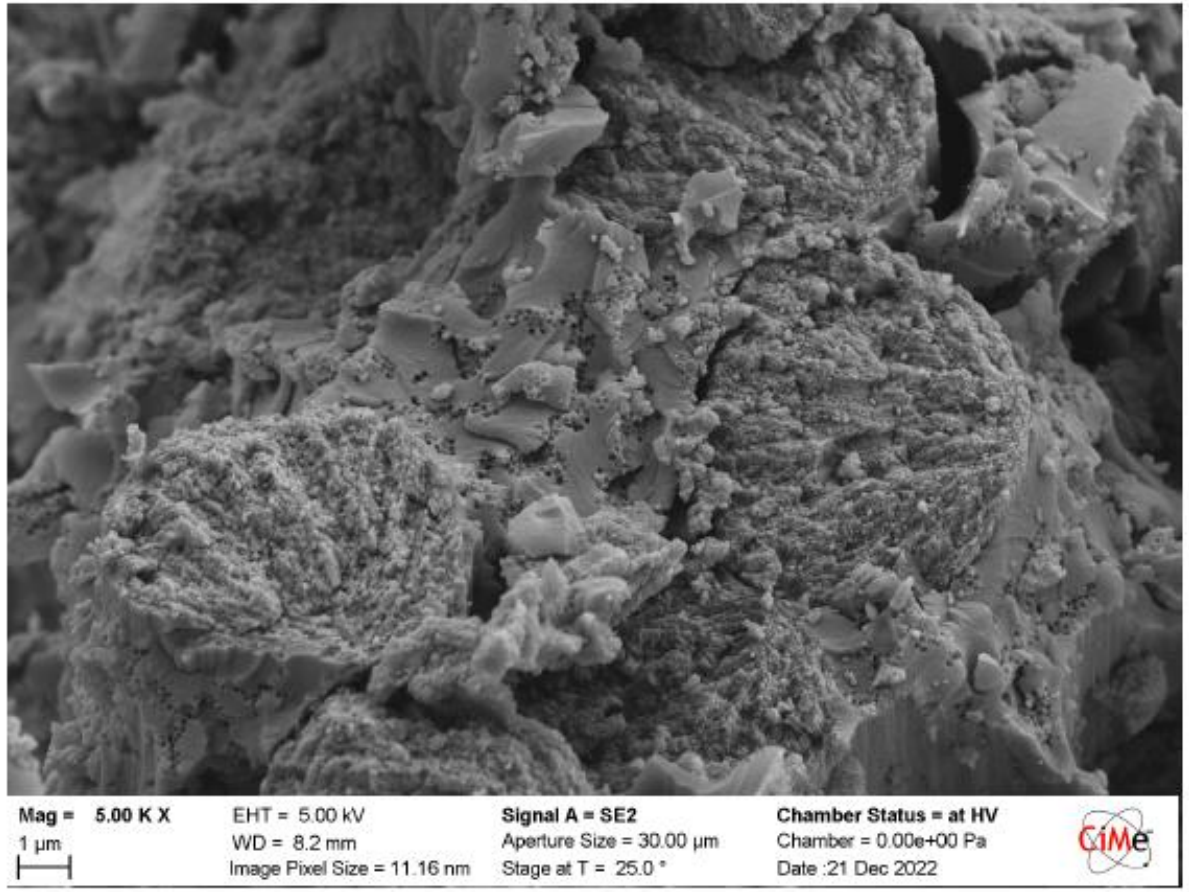


Figure 7.31: QI ultimate strain achieved with T800S carbon fibers and a plt FAW of $60\,\mathrm{g}\cdot\mathrm{m}^{-2}$ for NTPT epoxy systems TP415, TP315 and TP190, according to their datasheet. An higher ultimate strain indicates a better thin-ply effect. For reference, the T800S ultimate strain reported by its datasheet is 2 %.

Src : https://www.thinplytechnology.com/datasheets

Fracture surface investigation SEM

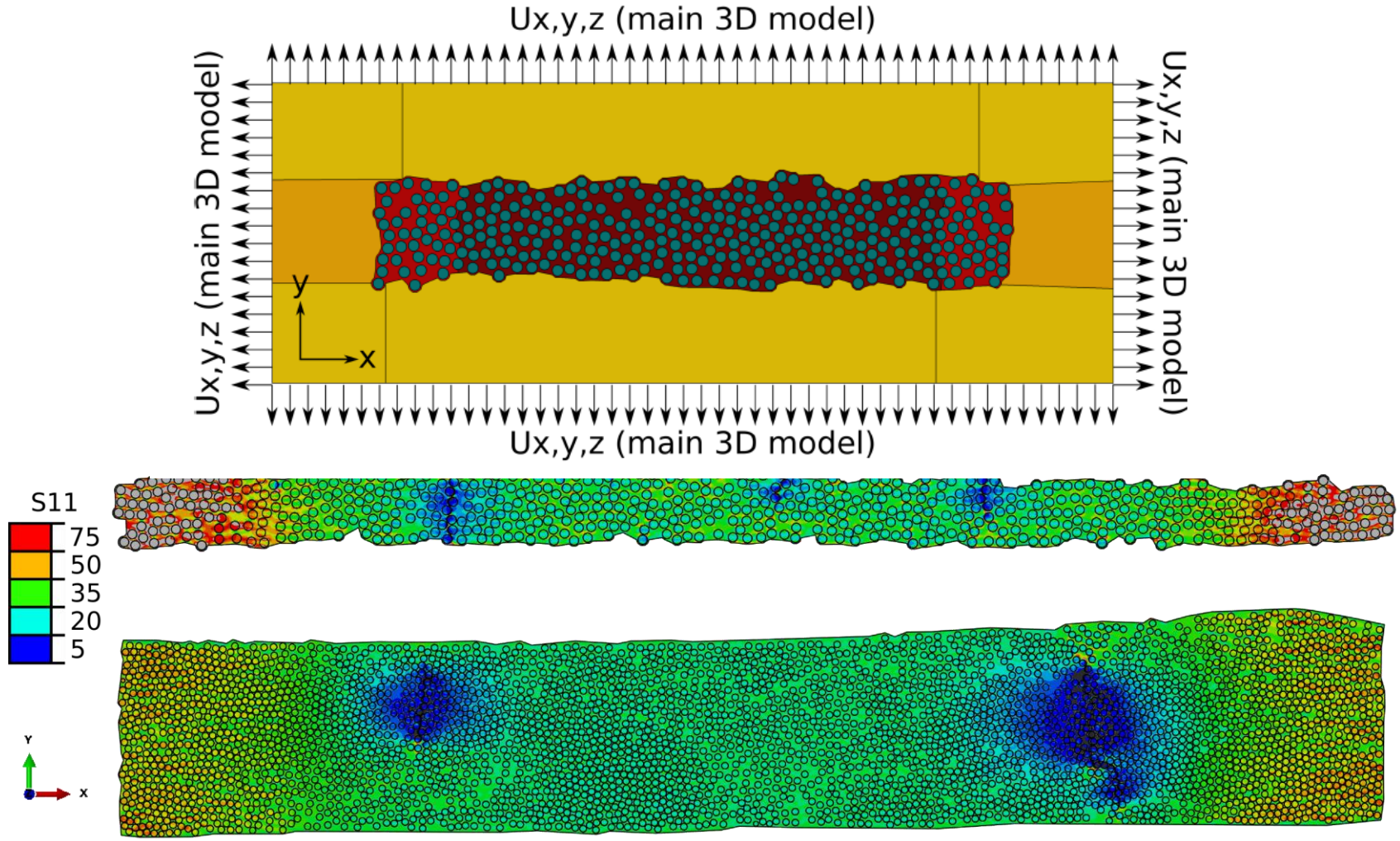




Rubber Toughener = Void nucleation sites in the matrix?

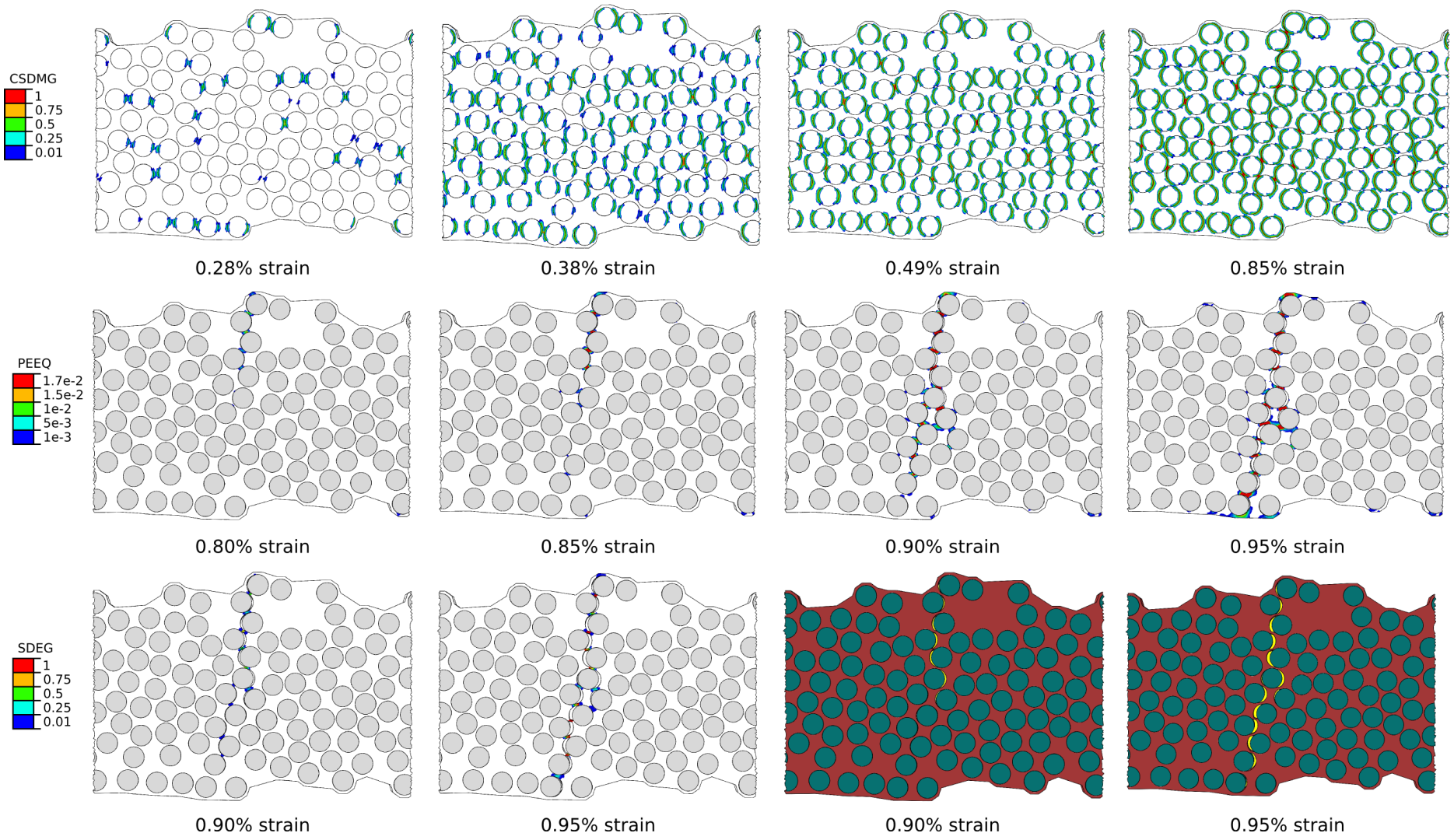
Src : PhD Thesis G. Broggi

Effect of matrix on very thin-ply QISO UNT



Src : PhD Thesis S. Kohler, EPFL, 2019, https://infoscience.epfl.ch/record/263781?ln=fr
S. Kohler et al., Composites Part A, 2019, https://doi.org/10.1016/j.compositesa.2019.05.036

Effect of matrix on very thin-ply QISO UNT



Src : PhD Thesis S. Kohler EPFL

Effect of matrix on very thin-ply QISO UNT

Matrix yield surface : Drucker-Prager model

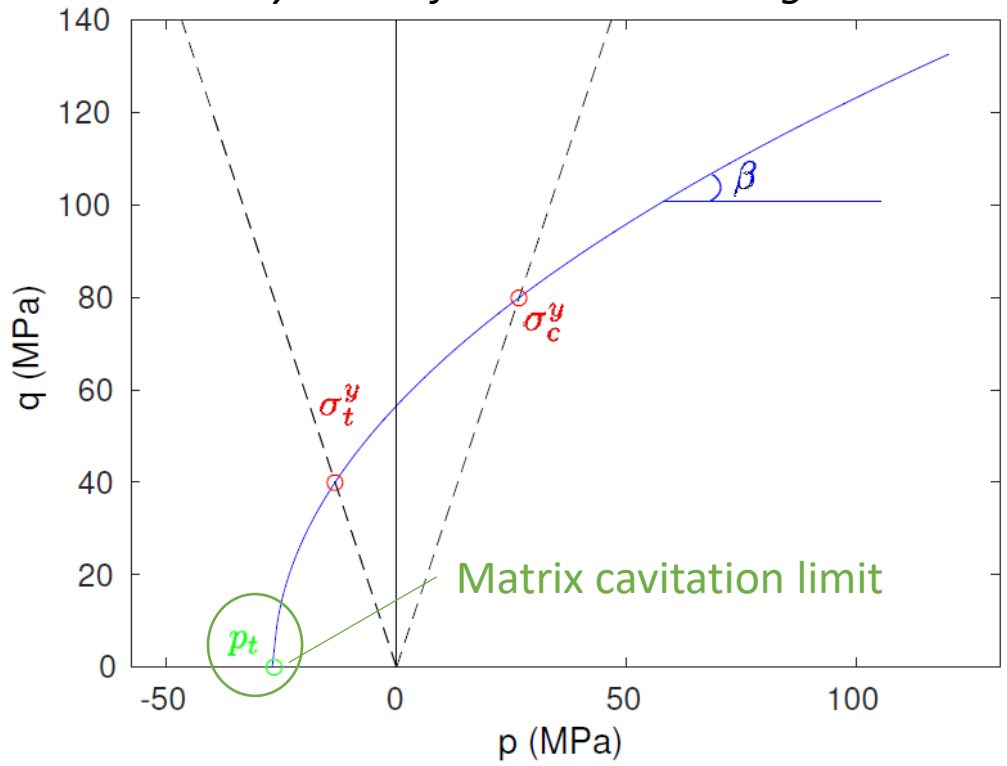
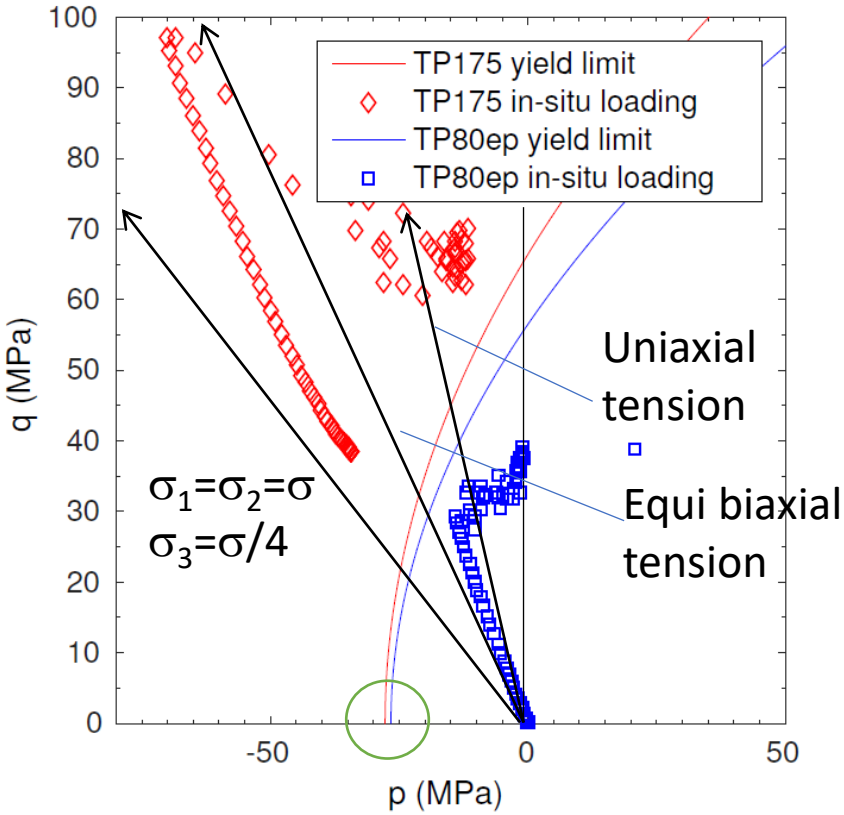


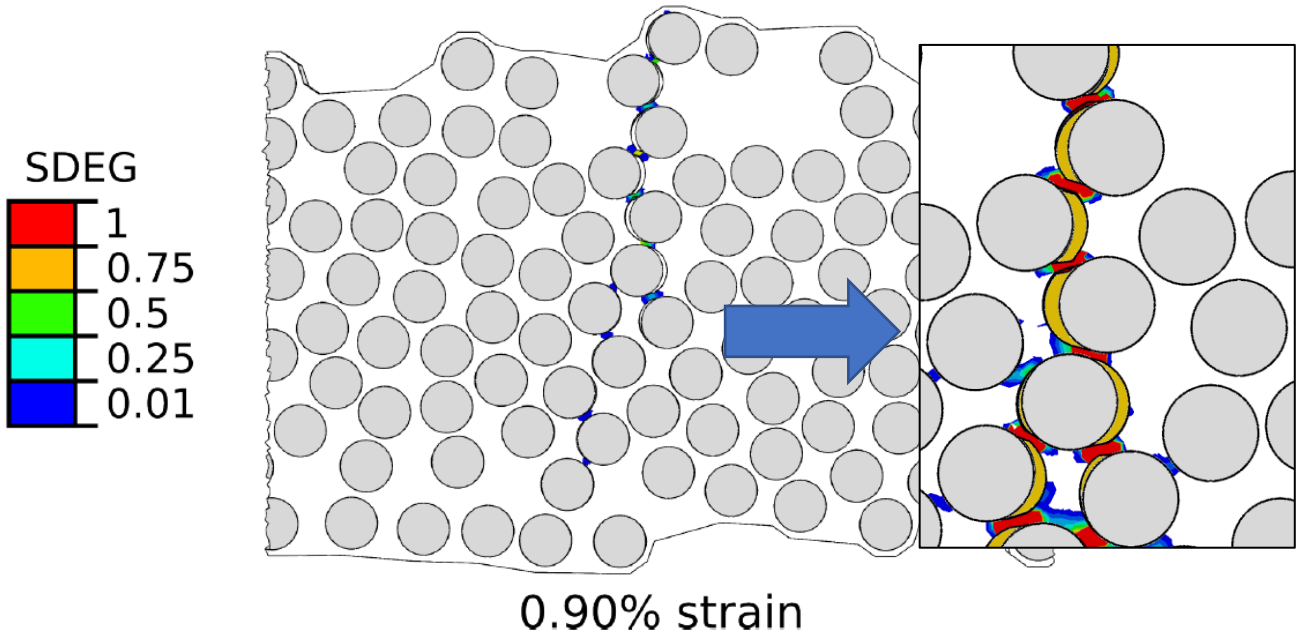
FIGURE 6: Identified Drucker-Prager model, with the experimentally measured uniaxial results shown in red and the deduced hydrostatic strength shown in green. p is the hydrostatic pressure and q the equivalent von Mises stress



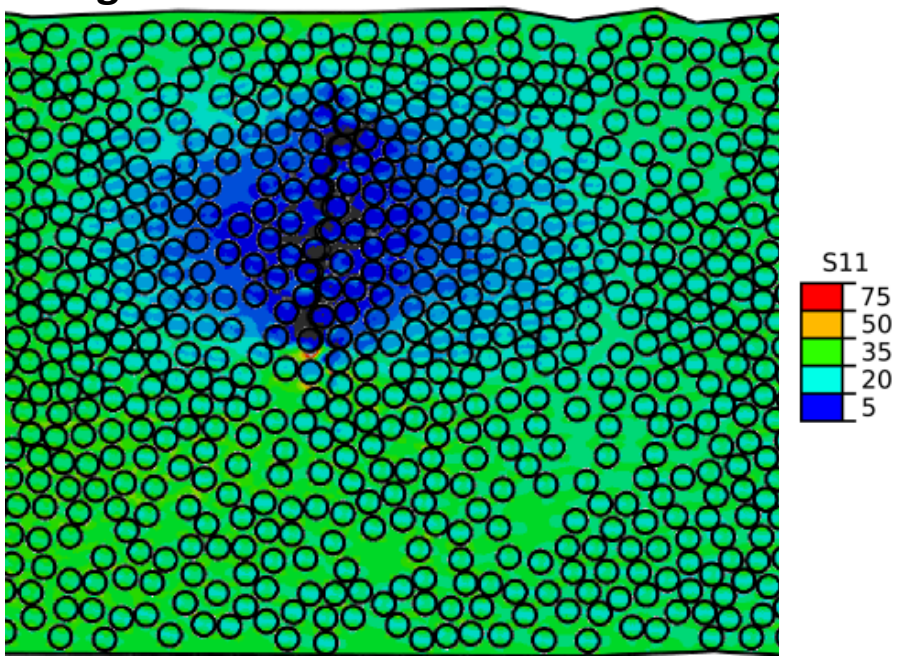
(a) Matrix P-Q graph

Src : PhD Thesis S. Kohler EPFL

Effect of matrix on very thin-ply QISO UNT



Longitudinal stress S11



High triaxial stresses between closely packed fibers : potential site for void nucleation and early transverse fracture

Src : PhD Thesis S. Kohler EPFL

Conclusion

- With optimized resins, possible to reach a ultimate strain in quasi isotropic UNT of ~98% of the fiber with (very) thin-ply composites
- Other resin systems show early transverse cracking due to:
  - Resin brittleness: resin need to be able to sustain at least 2x the ultimate strain of the fiber under biaxial loading
  - Possible early cavitation due to weak inclusions / additives or weak toughener
- In the case of the TP415 -34-700 system, the fracture looked like a brittle fracture of the 0° ply without sign of early transverse cracking or delamination
- The resin can affect the ultimate strength of even very thin ply quasi isotropic composites
- Optimal resin for thick plies = high toughness to prevent cracking; for thinner plies = high cavitation limit , fiber adhesion and ductility

THANK YOU FOR YOUR ATTENTION

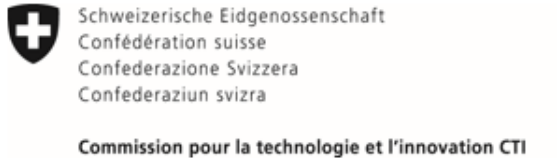
This research was supported by :

EU Horizon 2020 , Marie Sklodowska-Curie grant agreement No 765881

HyFiSyn

https://www.hyfisyn.eu/

Swiss National Science Foundation , SNF grant 200021_156207



Innosuisse / CTI
CTI Project 17092.1 PFIW-IW

ntpt

HUNTSMAN

DECISION

Together ahead. RUAG