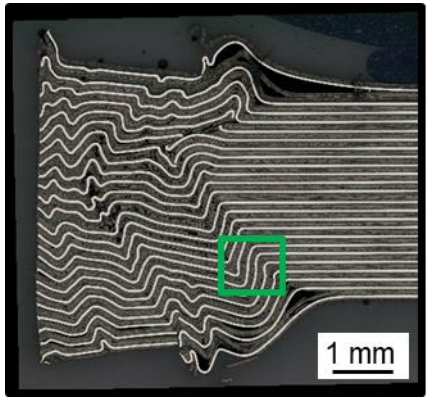
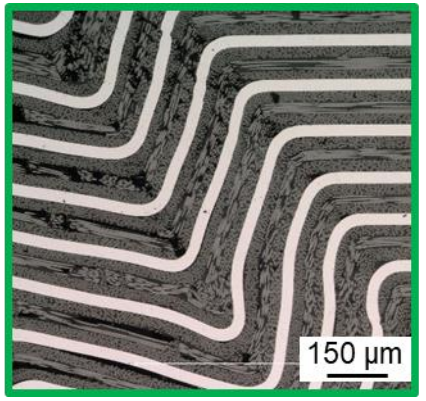
Polymer Composites

TUHH
Hamburg
University of
Technology

ICCM 2023

Bearing Strength High Performance Fibre Metal Thin-Ply Laminates





H. Wittich, B. Kötter, K. Yamada,
J. Körbelin, K. Kawabe, M. Nishikawa,
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Hamburg University of Technology

Belfast, 2023

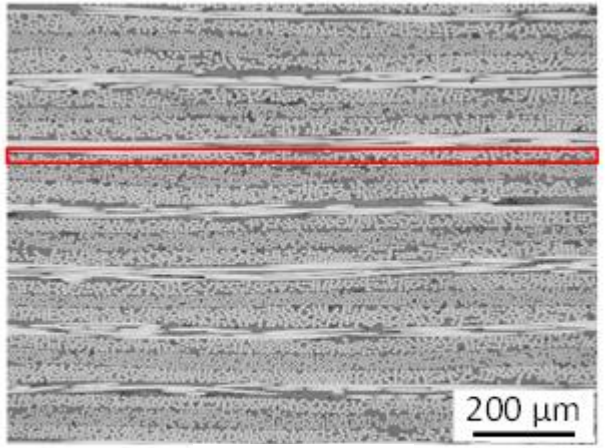
Thin-Ply

Thin-Ply composites

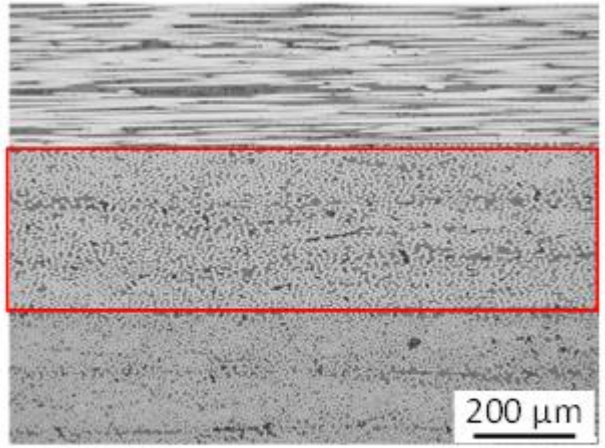
- Carbon fiber reinforced composite (CFRP)
- Layer thickness below 60 µm, typically 30 µm
- Tow spreading process

Increased lightweight potential

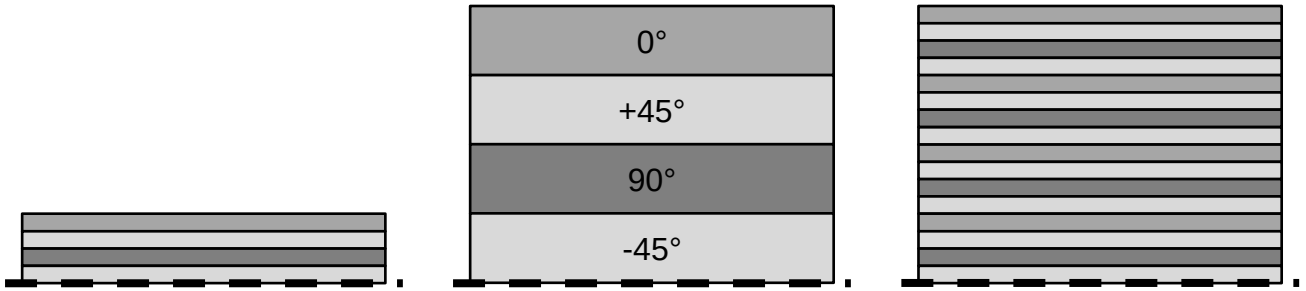
- More degrees of freedom in design
  - Low influence of design-rules
  - Possibilities to optimize the laminate
  - Thinner laminates
- Higher laminate qualities



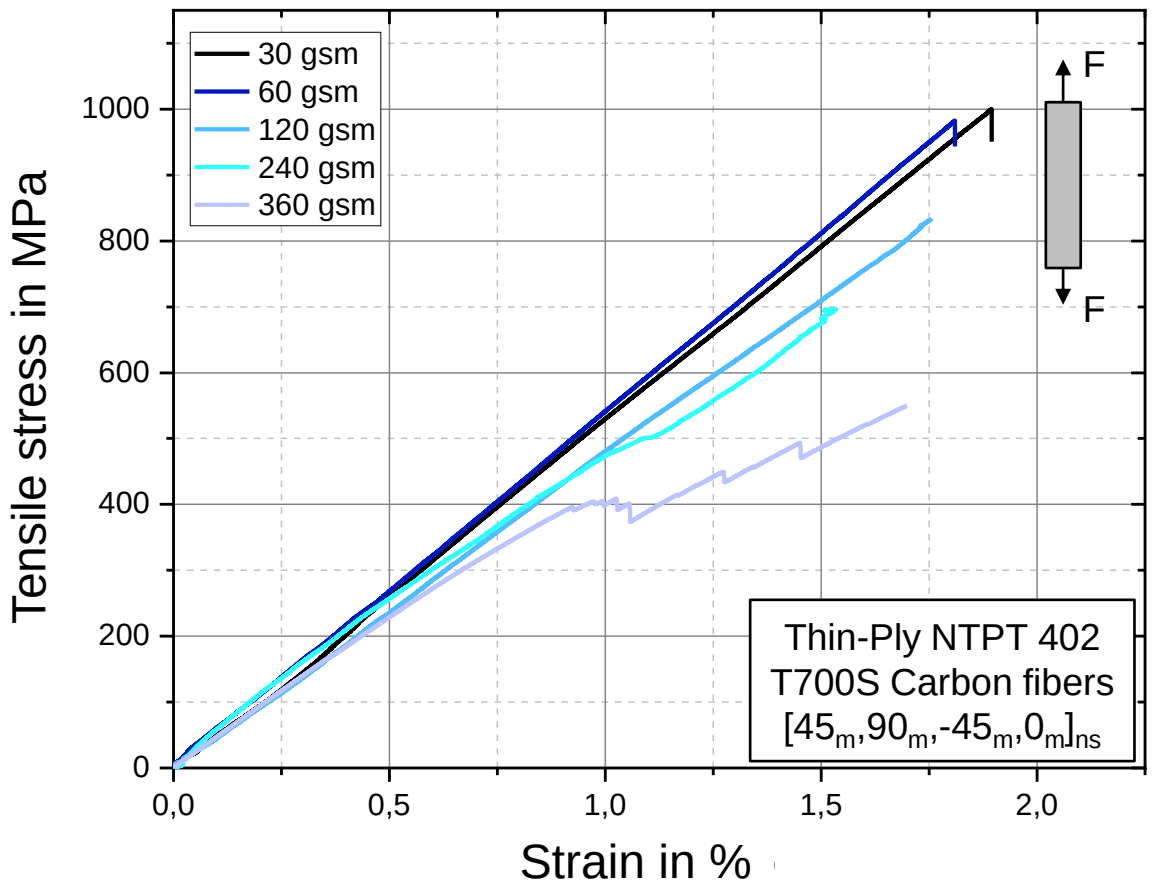
30 g/m²

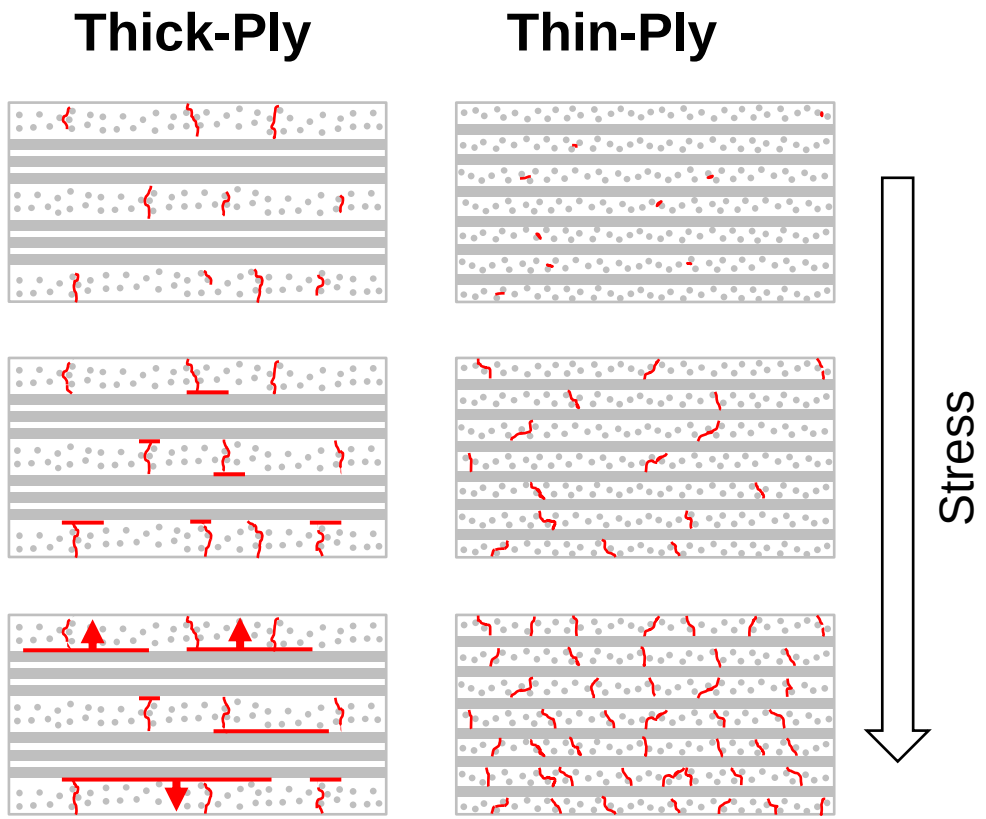


360 g/m²



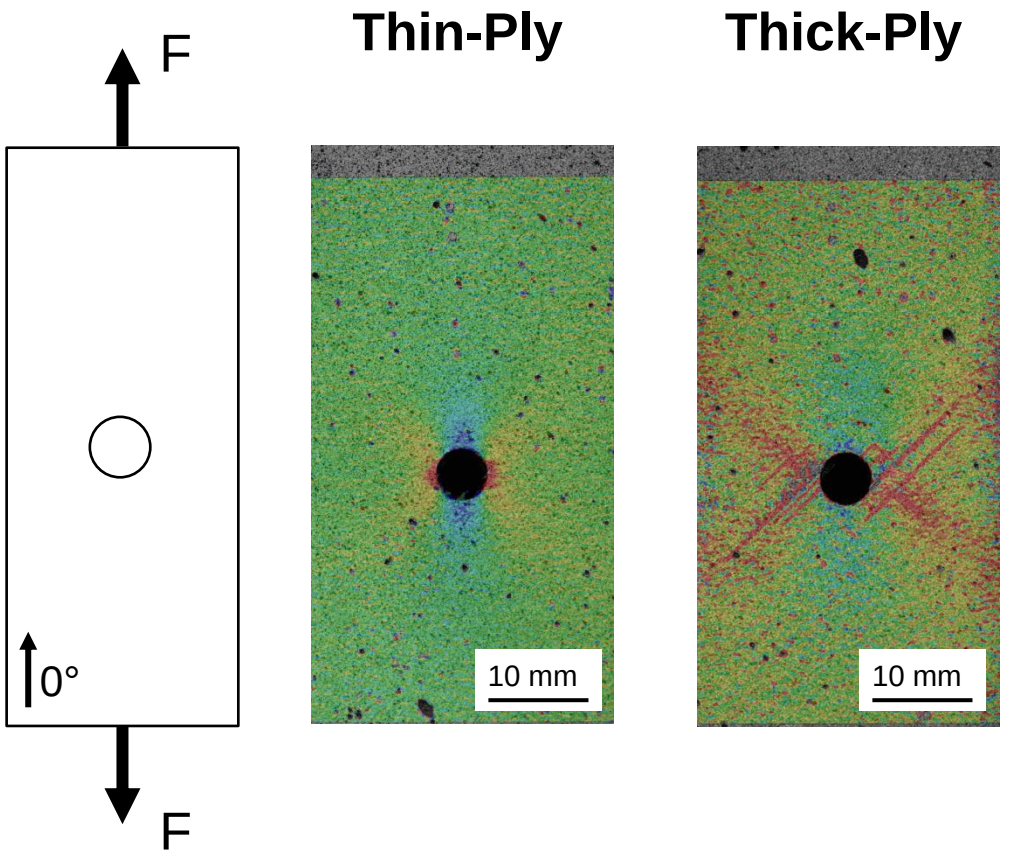
Damage mechanisms Thin-Ply





- In-situ strength: Higher strength with decreasing layer thickness
- Damage initiation shifts to higher stresses
- Suppression of delaminations

Damage mechanisms Thin-Ply



- Significantly reduced damage formation at stress concentration
- Significantly reduced strength with decreasing layer thickness (tension)
  - ➢ Stress concentrations are the limiting factor when using Thin-Ply composites

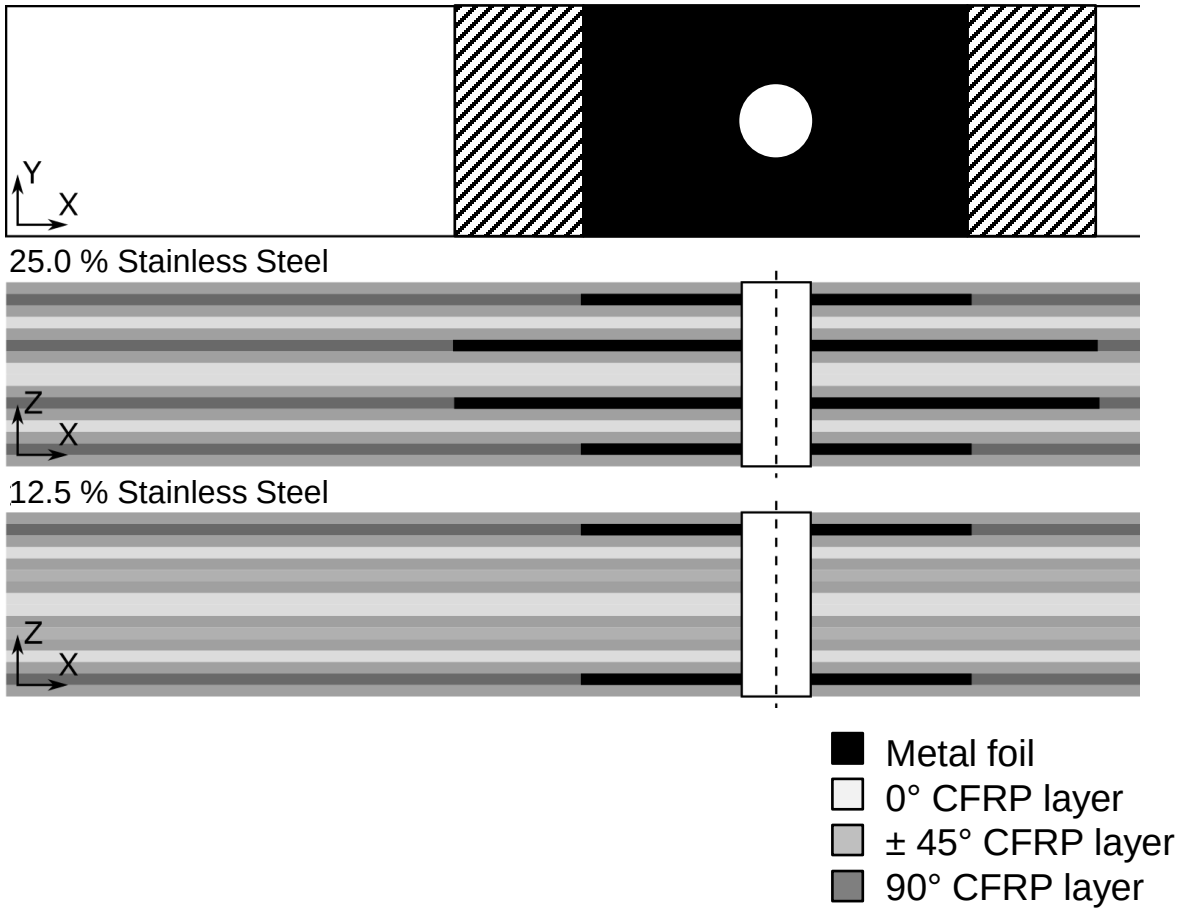
Thin-Ply Fibre Metal laminates (FML)

Concept: Hybridisation through metal

- Increased energy dissipation
  - Plastic deformation
  - Work hardening
- Distribution of stresses
  - Higher local stiffness

Potential of Thin-Ply FML

- Lower interlaminar shear stresses
  - Surface pre-treatment less critical
- Increased degrees of freedom in design
  - Weight proportion and position of metal layers
  - Complex geometries possible



Design of Experiments – Thin-Ply FML

Materials:
- TR50S Carbon fibers, Mitsubishi, Japan
- Bisphenol-A epoxy resin, ITCF (jER828:jER1001)
- Stainless steel foil 1.4310

Manufacturing:
Curing at 125°C and 4 bar pressure at the autoclave

Fiber weight per area
40 g/m² ≈ 40 µm
160 g/m² ≈ 160 µm

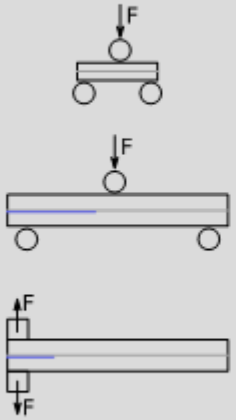
Thickness of the metal foil
40 µm
160 µm

Hybridization
25 Vol.-% Stainless Steel
12.5 Vol.-% Stainless Steel
6.25 Vol.-% Stainless Steel

Layup
$[45_m/90_m/-45_m/0_m]_{ns}$

Interlaminar properties:

Experiments:
ILSS
DCB – Mode I
ENF – Mode II

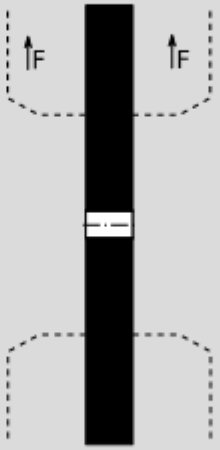


Pre-treatment
Sol-Gel Process
Etching
Abrasive
Plasma

Open Hole Tension:

Near field strain:
Optical measure-ment

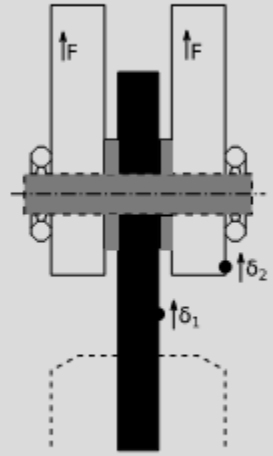
Bore diameter:
6 mm



Bearing:

Displacement:
Optical measure-ment

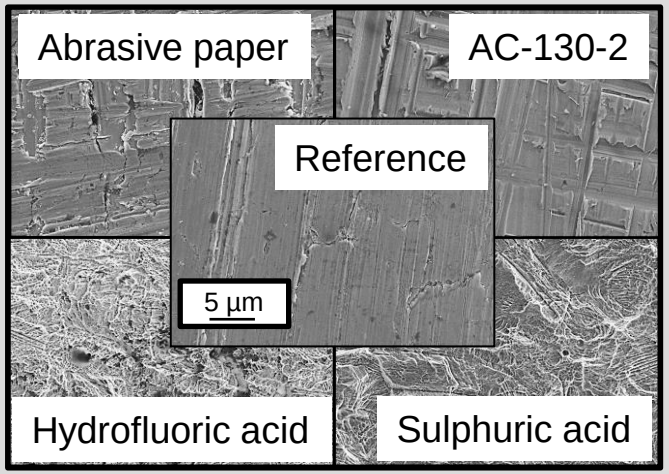
Bolt diameter:
6 mm

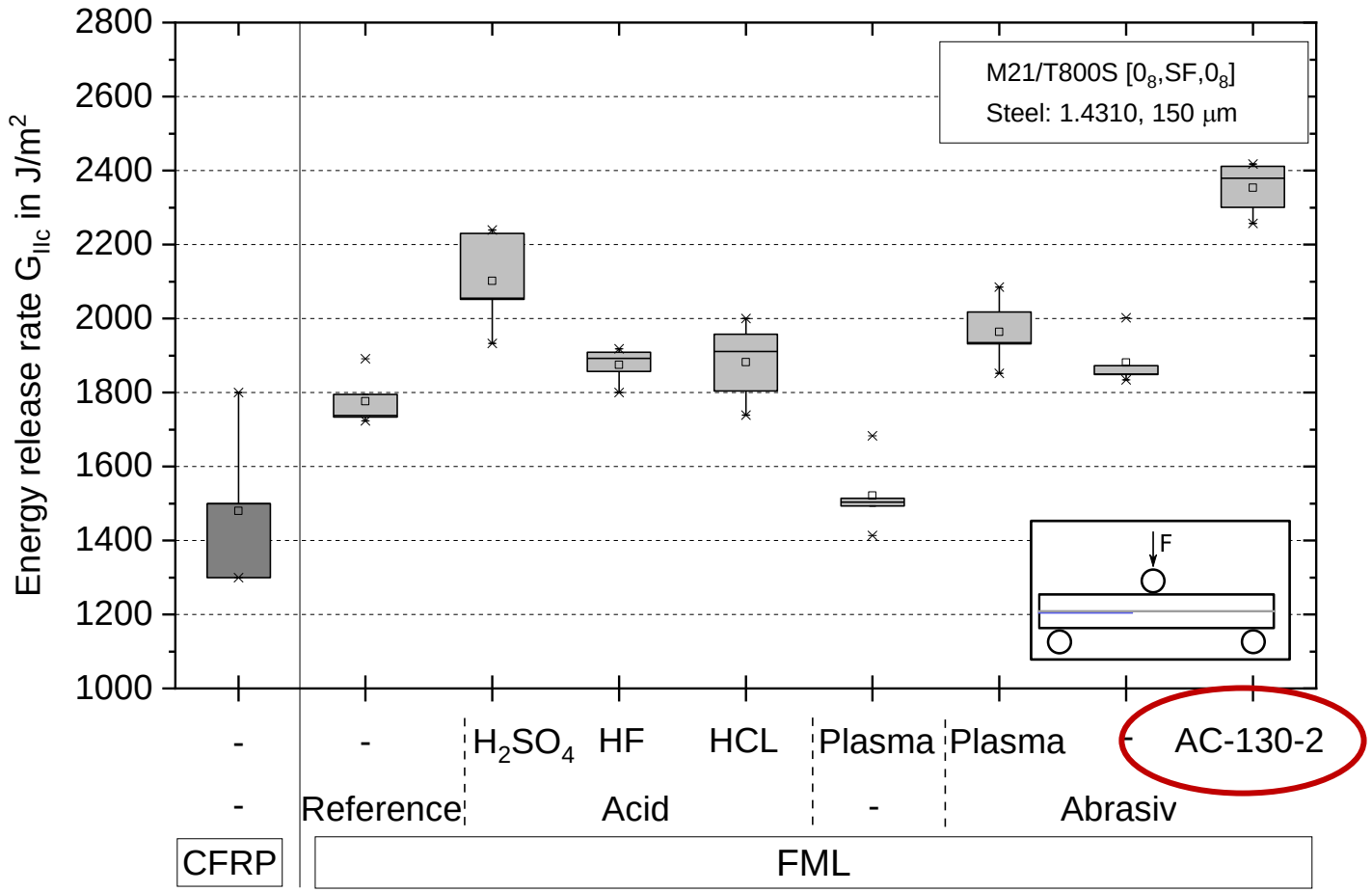


Surface Pre-Treatment

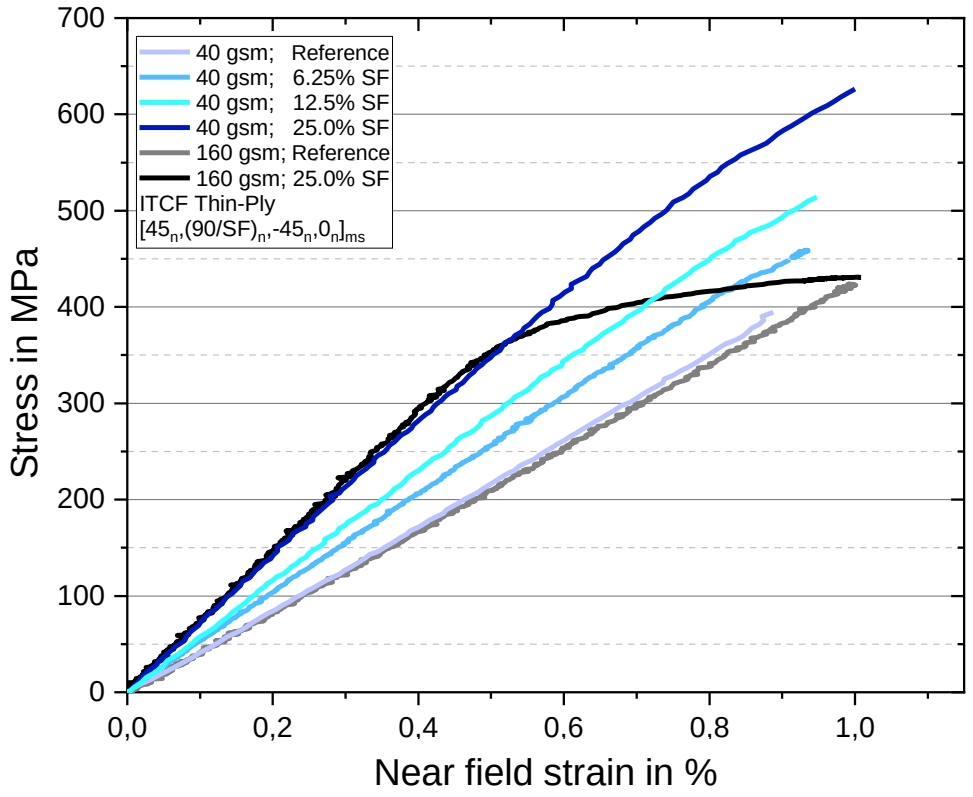
Surface Pre-Treatment:

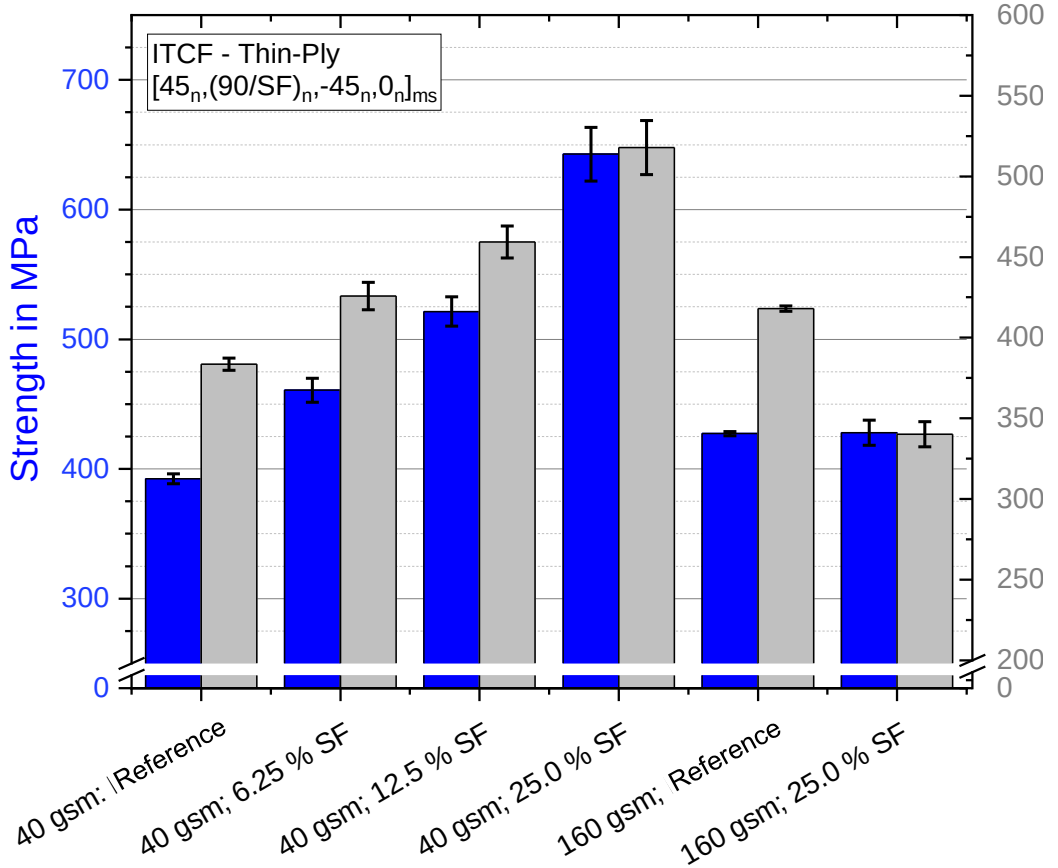
- Reference: Cleaned with alcohol
- Acids
  - Sulphuric acid (H_2SO_4)
  - Hydrofluoric acid (HF)
  - Hydrochloric acid (HCl)
- Cold Plasma-treatment
- Abrasive
  - #500 abrasive paper
  - #500 + cold plasma
  - #500 + Sol-Gel (AC-130-2)

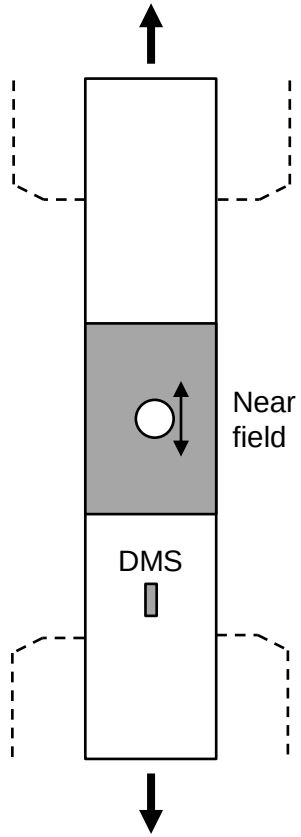




Open Hole Tension – Thin-Ply FML

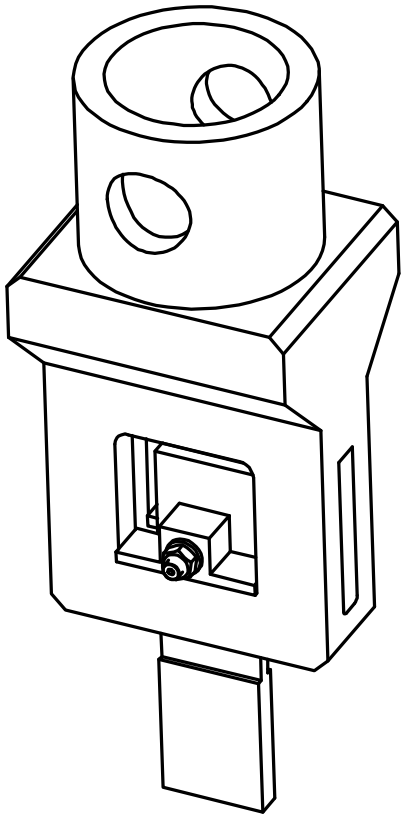


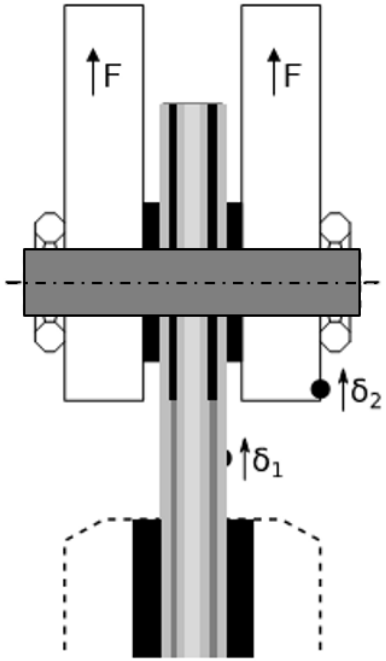


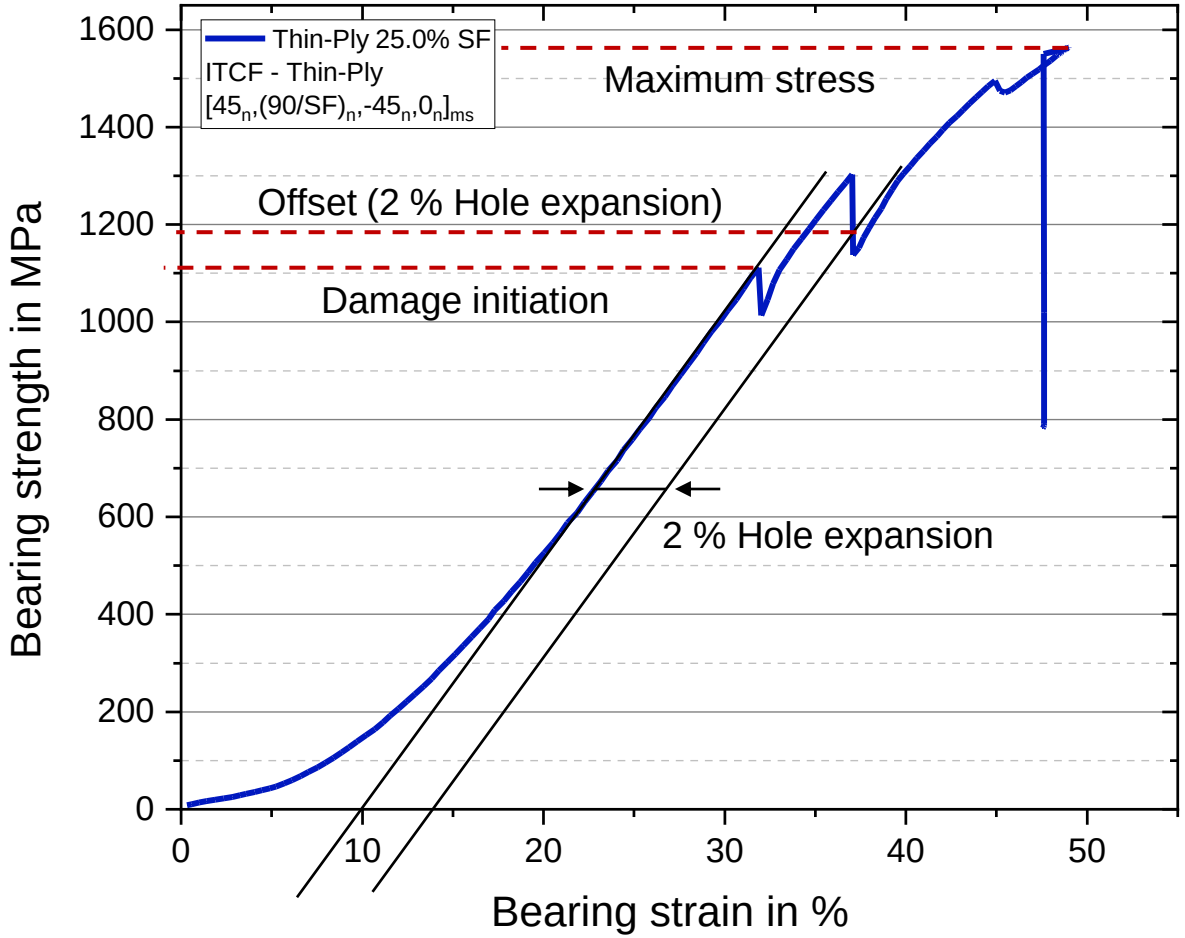


- Decreasing strength with decreasing layer thickness
- Increasing strength with increasing metal content
- Hybrid Thick-Ply specimens fail due to delaminations

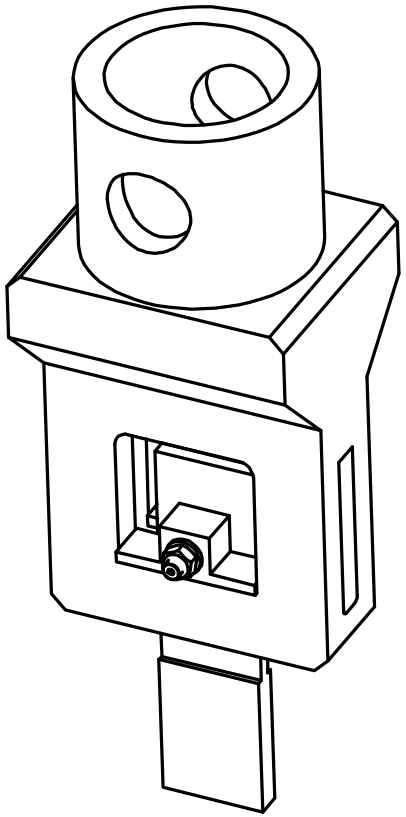
Bearing

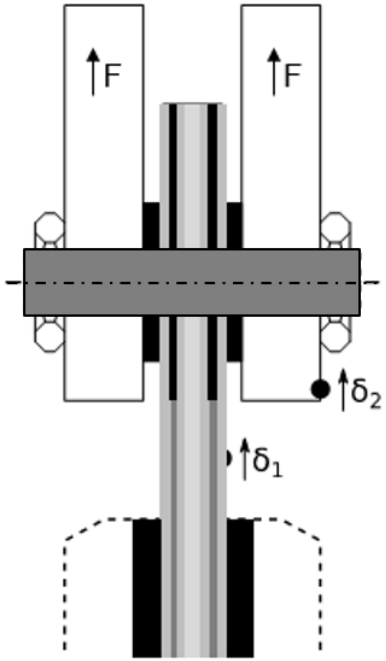


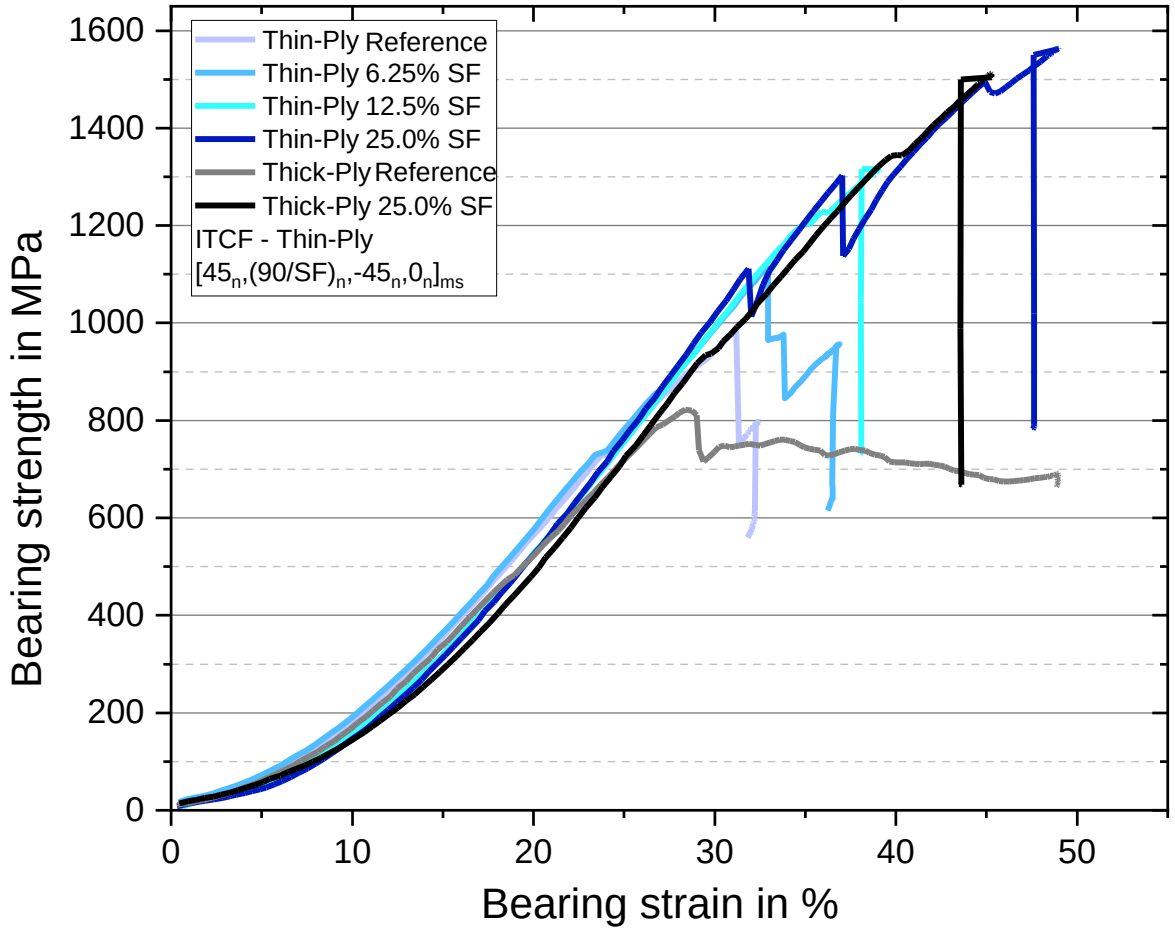

F
F
δ2
δ1


Thin-Ply 25.0% SF
ITCF - Thin-Ply
[45n,(90/SF)n,-45n,0n]ms
Maximum stress
Offset (2 % Hole expansion)
Damage initiation
2 % Hole expansion
Bearing strength in MPa
Bearing strain in %
0
200
400
600
800
1000
1200
1400
1600
0
10
20
30
40
50

Bearing

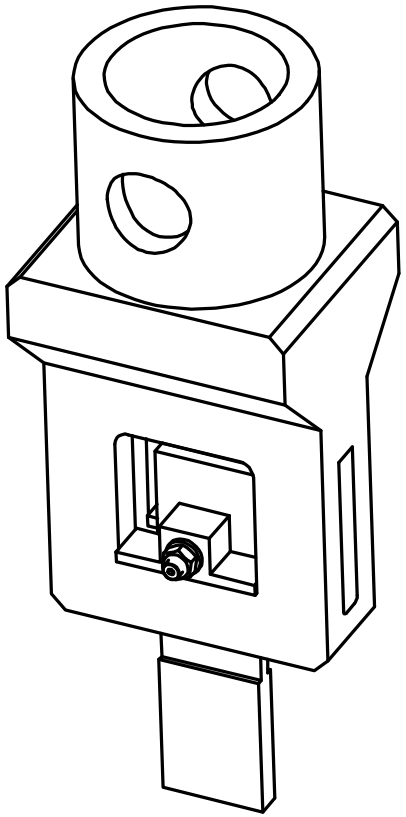


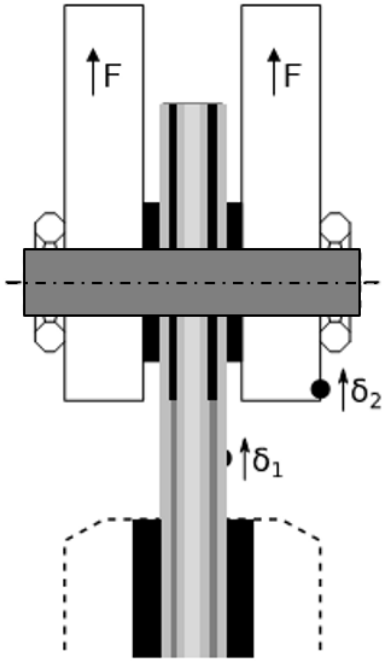


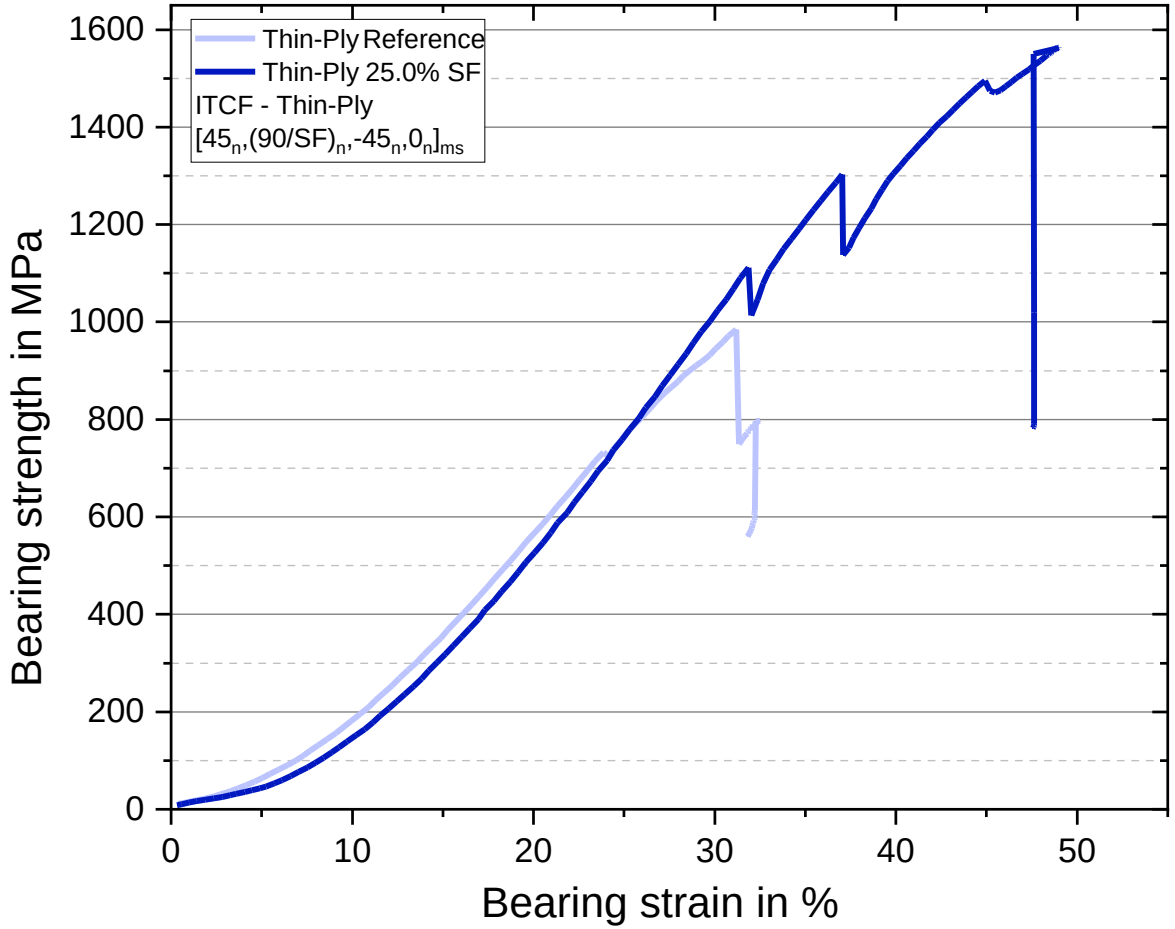


- Maximum achievable stress increases with increasing metal content
- Progressive failure behaviour of the hybrid Thin-Ply specimens

Bearing



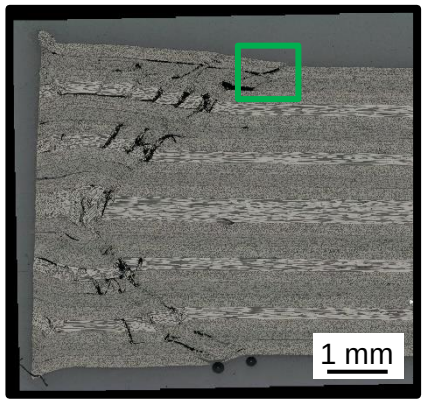


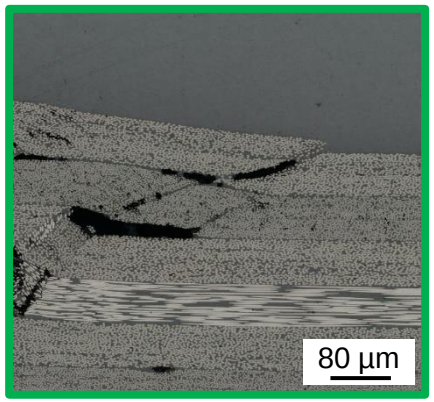


- Maximum achievable stress increases with increasing metal content
- Progressive failure behaviour of the hybrid Thin-Ply specimens

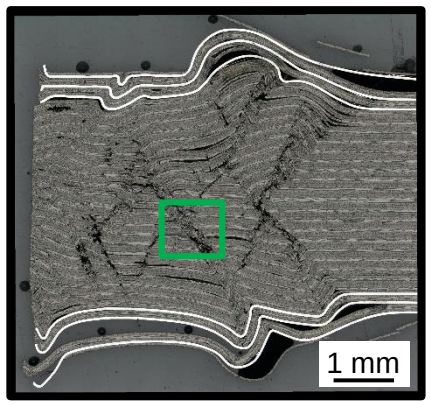
Bearing – Micrograpahs

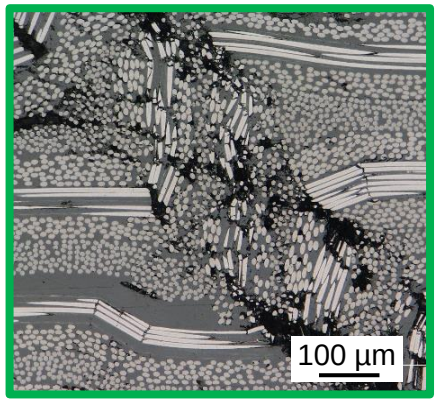
Thick-Ply Reference

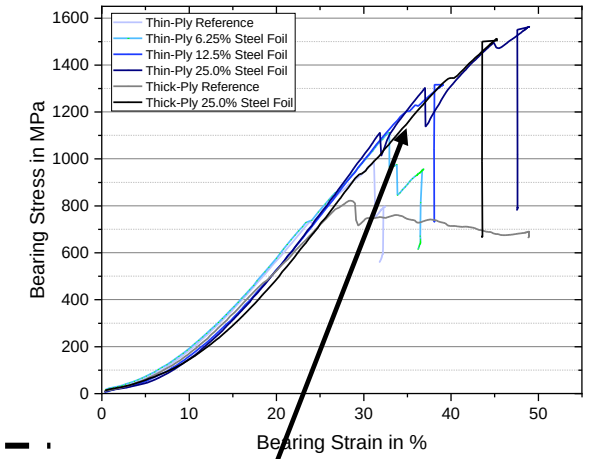




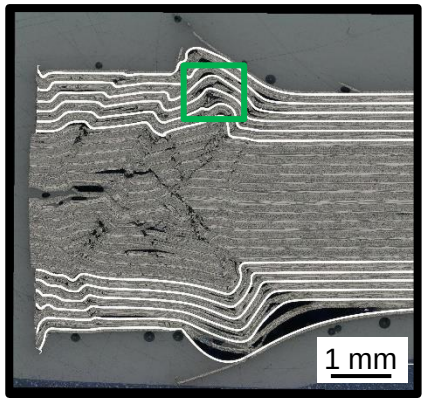
Thin-Ply 6,25 % SF

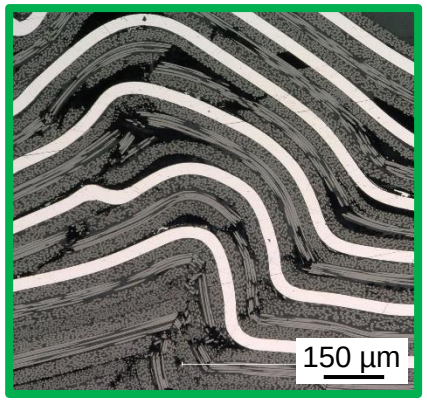




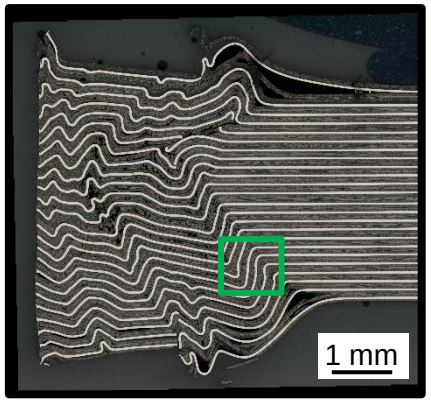


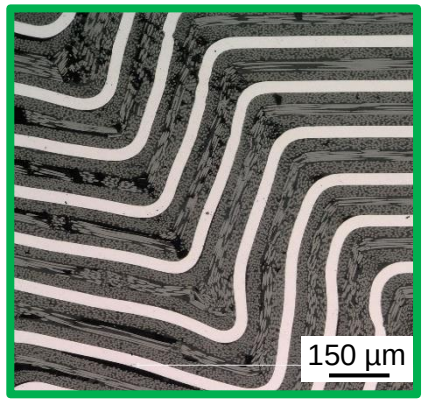
Thin-Ply 12.5 % SF





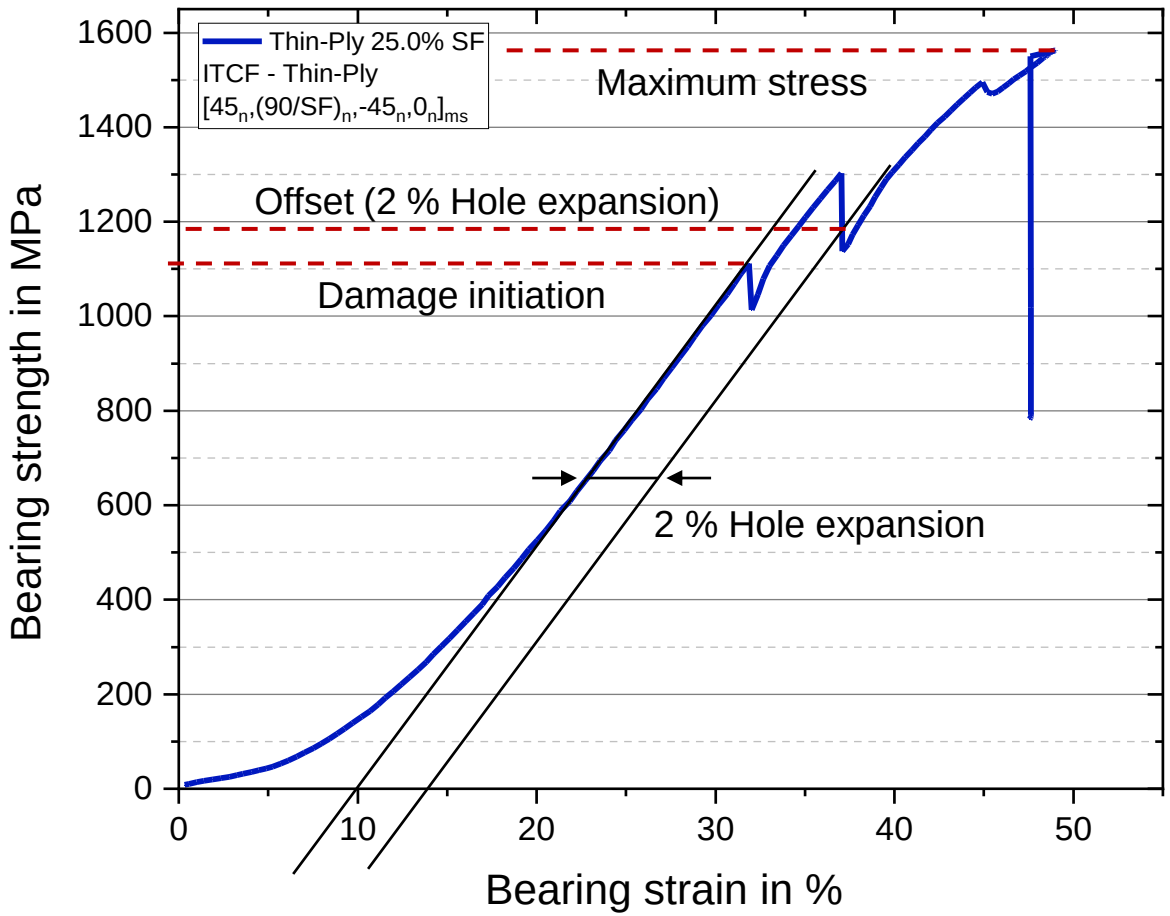
Thin-Ply 25.0 % SF

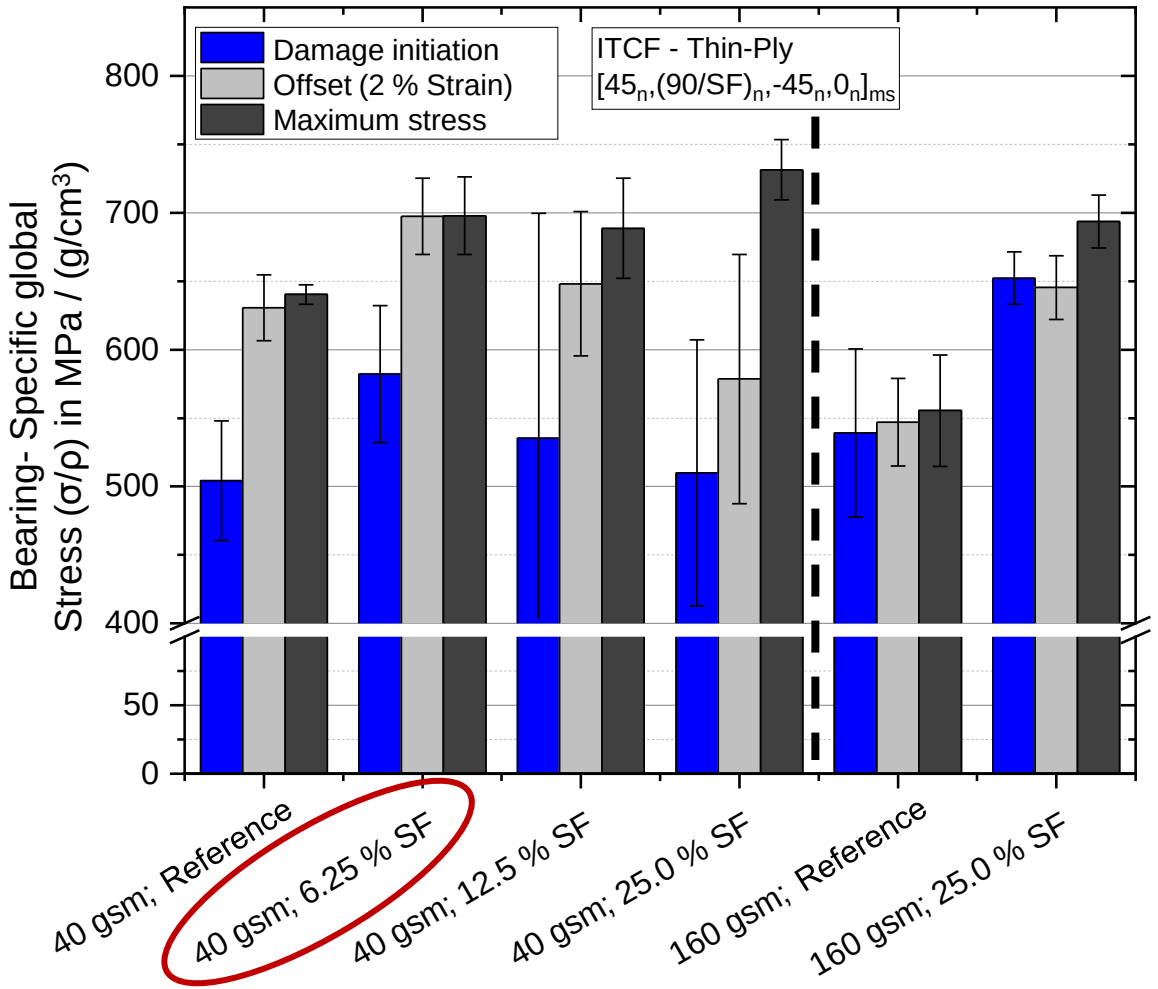




- Progressive failure behaviour due to local damage
- Metal foils increase bending stiffness → Resistance against buckling

Bearing – Thin-Ply FML



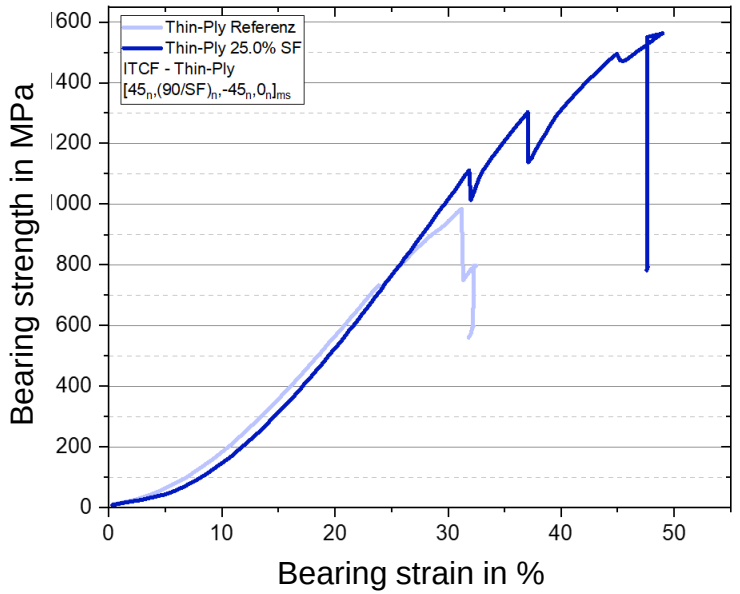


- Increasing bearing strength with increasing metal content
- Thin-Ply with a steel content of 6,25 % has the best specific performance

Conclusion

The drawback: Stress concentrations are the limiting factor when using Thin-Ply composites

Can be compensated and even improved by metal layers in the area of the bolt



Kötter, Benedikt and Yamada, Kohei and Körbelin, Johann and Kawabe, Kazumasa and Nishikawa, Masaaki and Hojo, Masaki and Fiedler, Bodo (2021).
Steel foil reinforcement for high performance bearing strength in Thin Ply composites.
Composites Part C: Open Access. 4. 100085

Thank you for your attention

Polymer Composites

Industrial Technology Center of Fukui Prefecture

DER ÜBERSEE-CLUB e.V.

KYOTO UNIVERSITY FOUNDED 1897 KYOTO JAPAN

Institut für Kunststoffe und Verbundwerkstoffe, Les Menuires, 2023

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Institute of polymer and composites
Hamburg University of Technology
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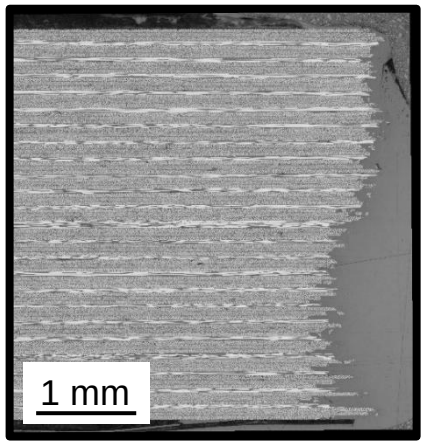
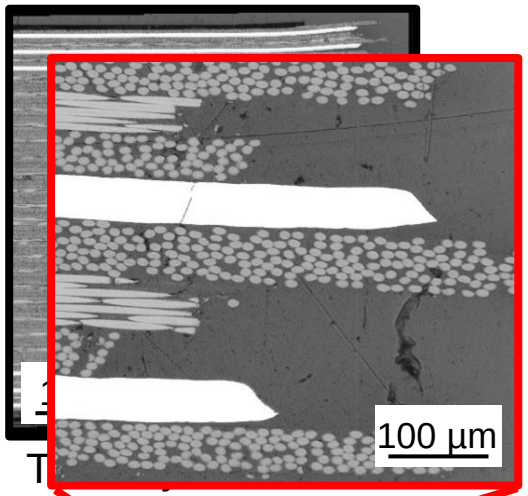
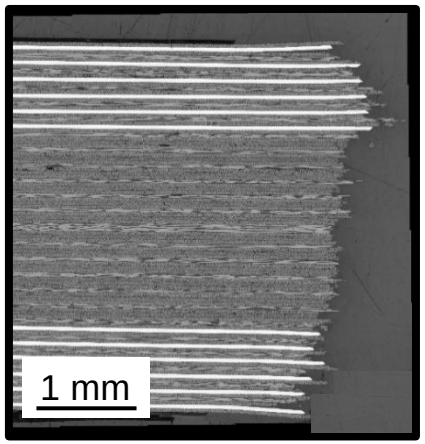
Open Hole Tension – Thin-Ply FML

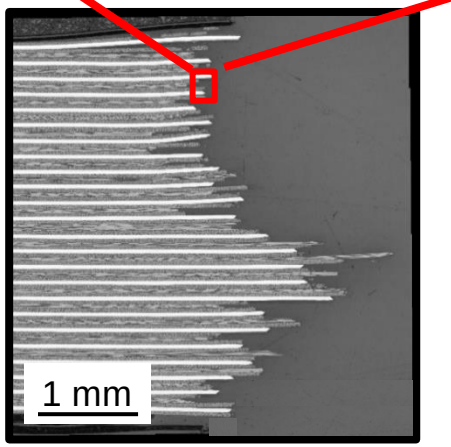


Thin-Ply Ref.

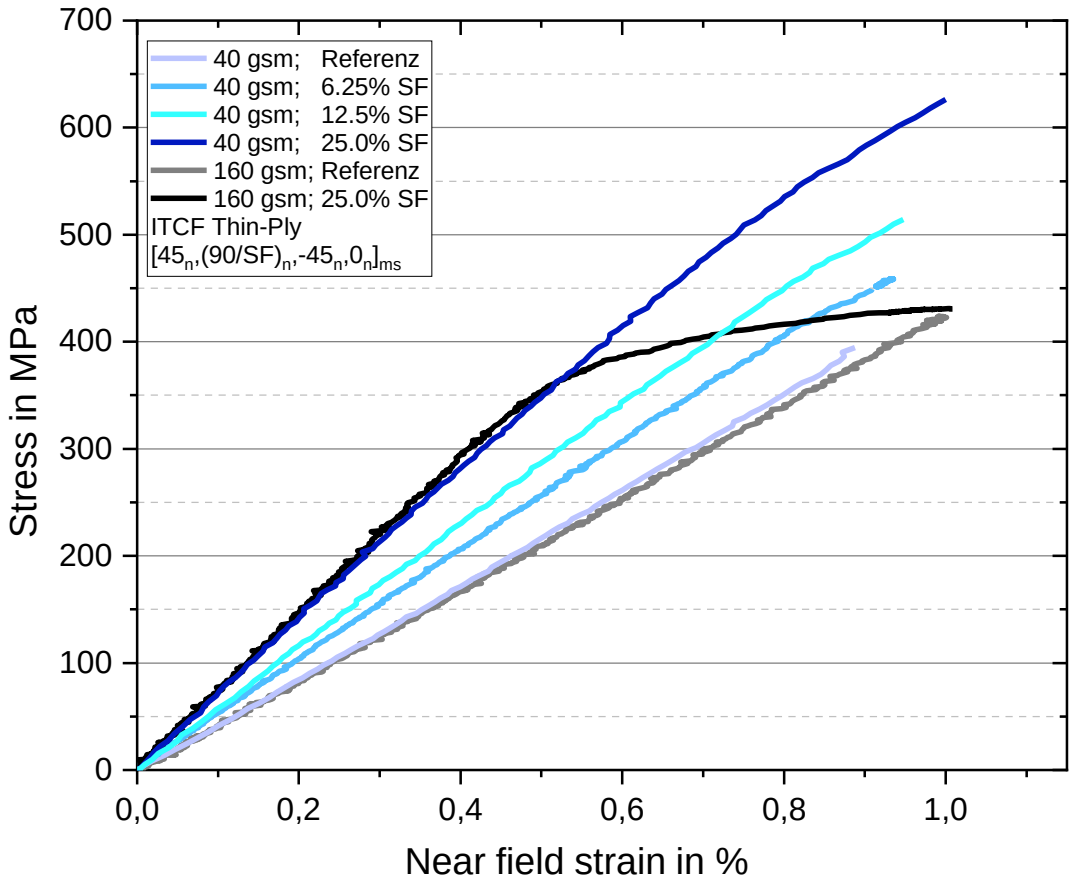


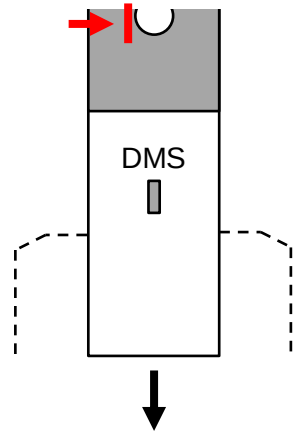


Thin-Ply 12.5 % SF



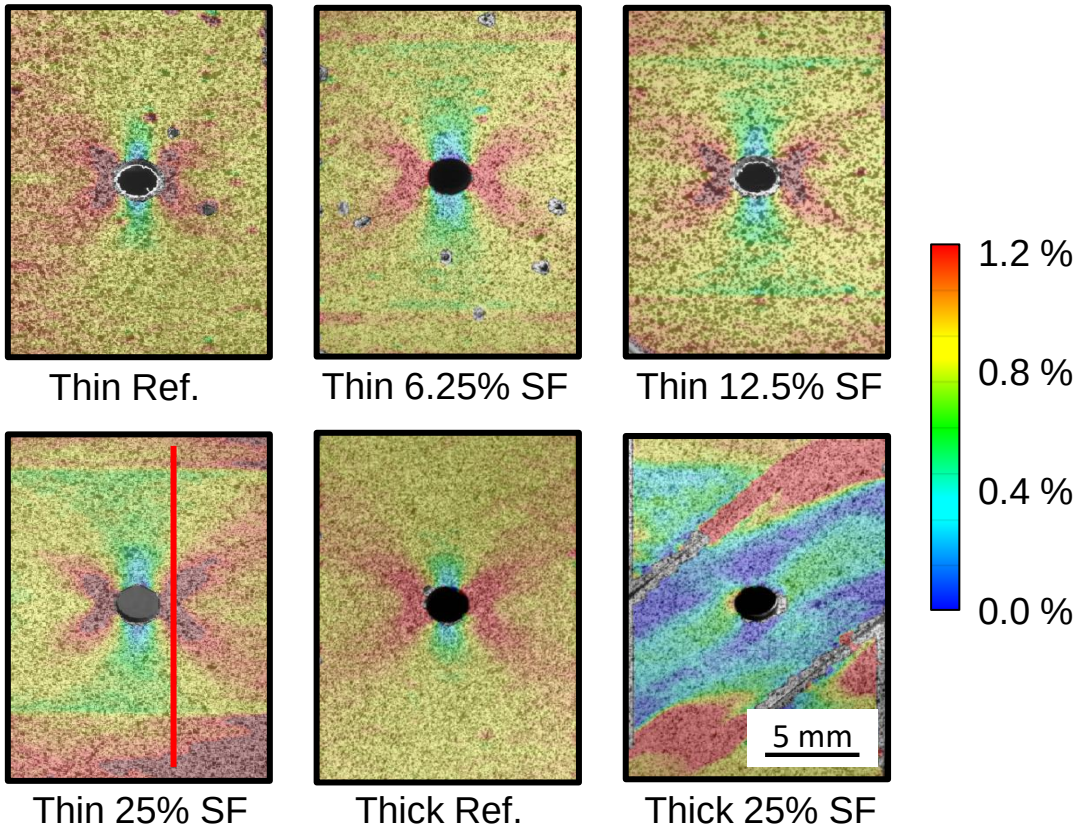
Thin-Ply 25 % SF

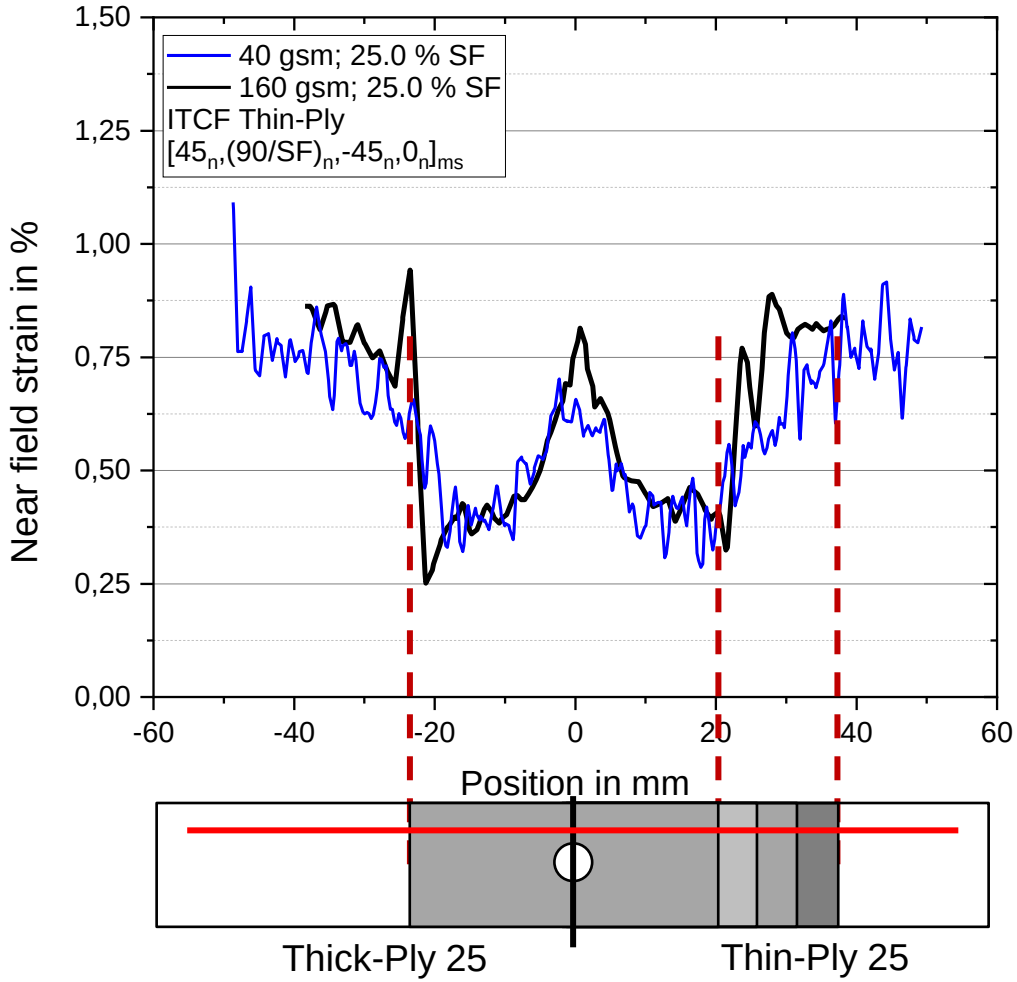




- Larger fracture surfaces with increasing metal content
- Plastic deformation of the metal

Open Hole Tension – Thin-Ply FML





Thin-Ply:
- Less interlaminar shear stresses
- Continuous stress gradient in the tranzition zone

} Suppression of delamination