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Determination of the longitudinal compressive strength of a Carbon/Epoxy UD ply with bending, compressive and tensile tests

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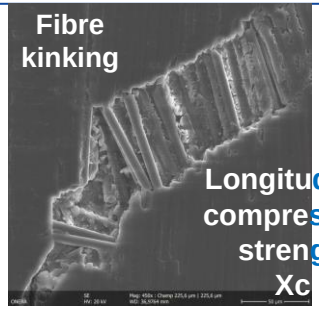
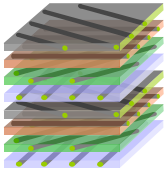
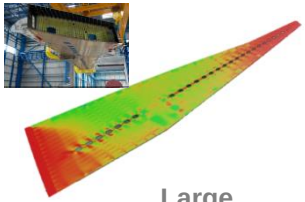
Introduction

- **X_c is critical for design of large parts**
- **Different tests to characterize X_c:**
  - Are the experimental data consistent ?
  - Choice of the modelling scale ?





Mesoscale strength

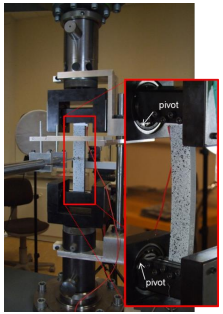


Large structures

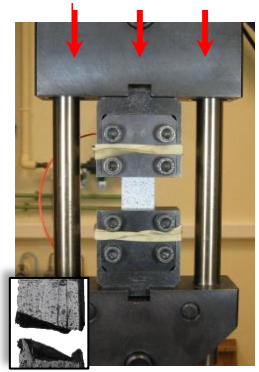
Bending tests

Alternative tests

- 4-point bending test
- Compression with pivot device test
- Analysis with FE non linear models
- High strength value



Compression tests

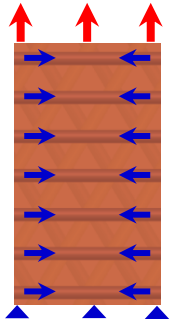


Standard tests

Load introduction:
- ASTM D695-15
- ASTM D3410
- ASTM D6641

- Compressive tests on UD plies or laminates

Innovative tensile test



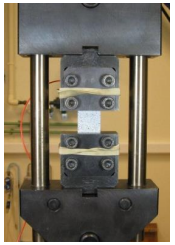
Innovative tests

- Optimization of lay-up to fail central 90-ply in longi. compression without any damage
- Tensile tests on a specific laminate

Compressive tests on UD plies

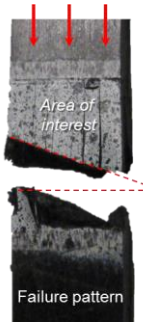
Standard compression tests

- **T700GC/M21 material (268g/m²)**
  6 specimens 16 plies - $[0_8]_s$
  manufactured with heating-press at Onera

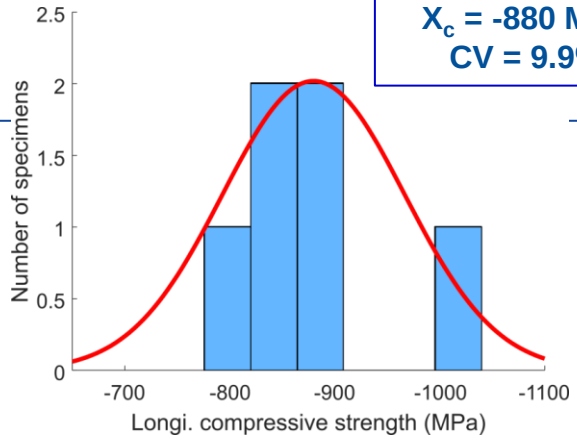


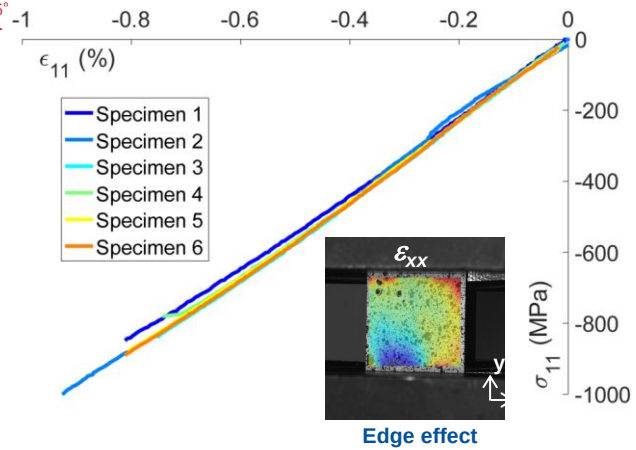
- **Specimens with small free lengths**
  10mmx10mmx4.2mm 📖 *[DIN-EN-2850 97]*
  Loading introduced by pushing on edges

- **Failure pattern analysis:**
  Premature kinking within the tab region 📖 *[Welsh 96]*
  Failure close to the jaws (angle at 15º) 📖 *[Vogler 01]*
  Large scattering (10%) on strength



X_c = -880 MPa
CV = 9.9%





Edge effect

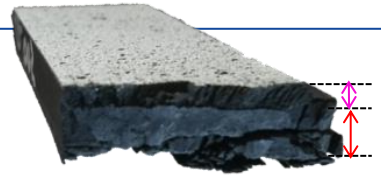
Bending tests on UD plies

Bending tests

📖 [Callus 07, Laurin 16]

- **Failure mode relevant** (no buckling, far from jaws)
- **Test analysis with complex FE simulations**
  Geometrical and material non linearities (with $E^t_{11} \neq E^c_{11}$)
- **Very high compressive strengths** (from FE simulation)

16 plies

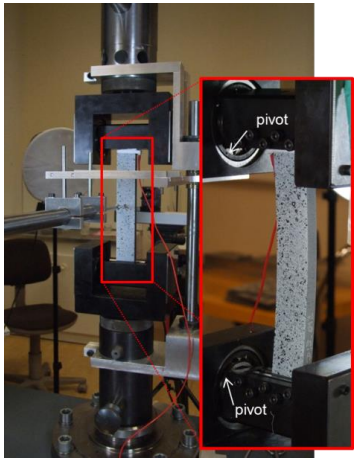


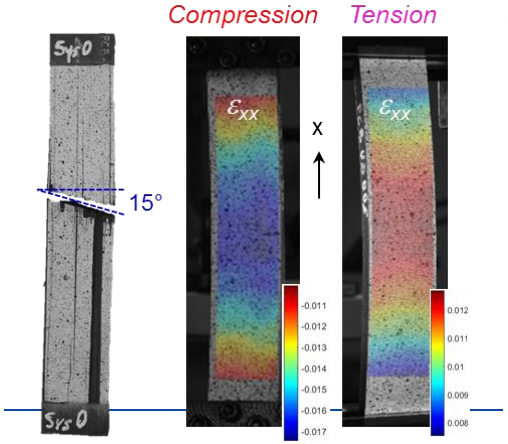
X_c = -1350 MPa
CV = 4.5%

32 plies

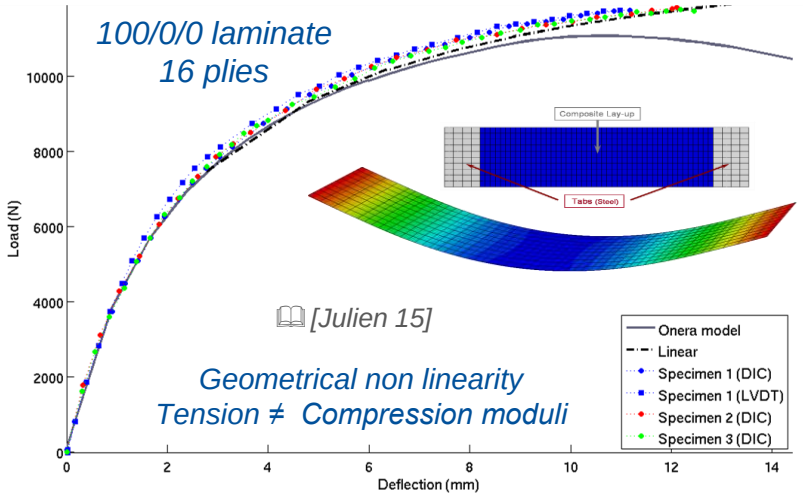
X_c = -1220 MPa
CV = 2.8%

Compression with pivot





📖 [Laurin 16]



Innovative tensile tests on a specific laminate

$X\varepsilon_c$ = -1025MPa
CV = 1.9%

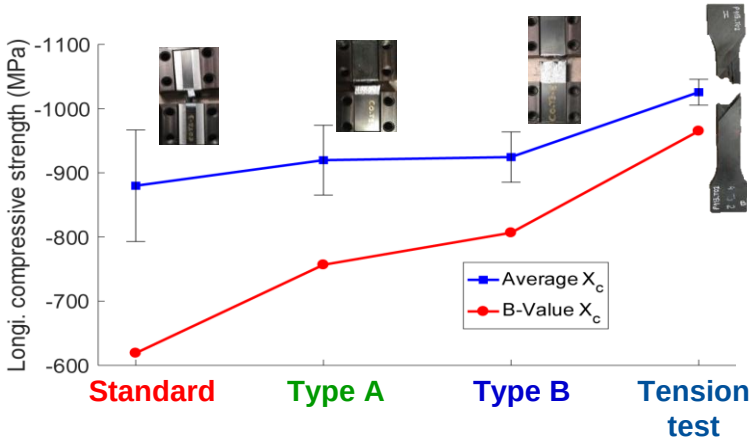
Proposition of innovative tests

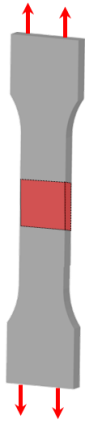
Tensile test which fails in compression

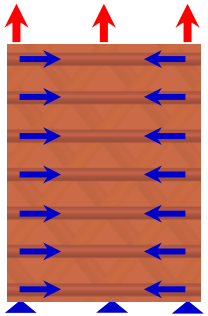
- Tension test on a specific laminate failed by fibre kinking
- Failure is due to ***Poisson effect*** located at mid-width
- Analysis with CLT extended to non-linear behaviour
- No transverse crack prior failure in compression

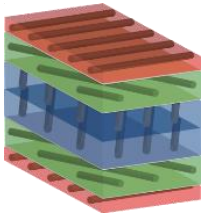
High compressive strengths with low scattering

Value embedded between compression and bending on UD plies

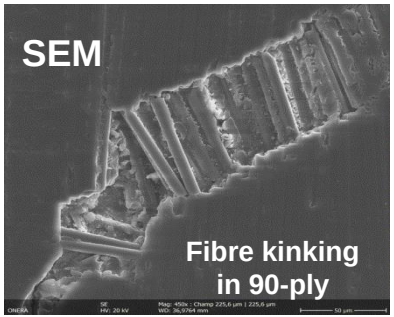








Tensile test
on specific laminate
$[-30/-45/-30/0_2/30_2/45/90_{1/2}]_s$



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Analysis of the available tensile tests

Model proposed by Grandidier *et al.*

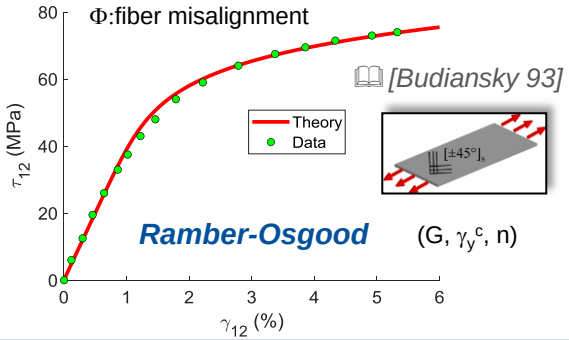
[Grandidier 12]

Analytical formula for longi. compression strength σ_c

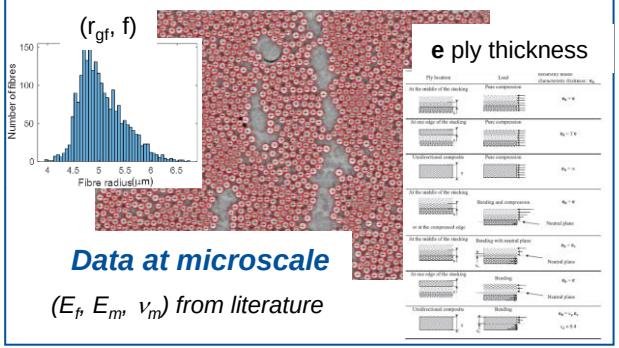
- Based on FE simulations at microscale — [Drapier 99], [Gardin 02]
- Take into account type of loadings, ply position, ply thickness

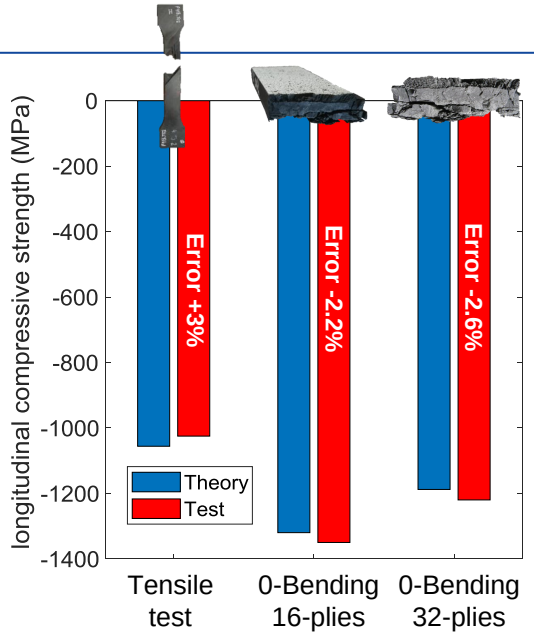
$$\sigma_c = \frac{G}{1 + n\left(\frac{3}{7}\right)^{1/n}\left(\frac{\bar{\phi}/\gamma_y^c}{n-1}\right)^{(n-1)/n}} + (2r_{gf})\frac{\pi}{\mathbf{e}}\sqrt{\frac{E_M E_F}{(1-\nu_M^2)}f(1-f)}$$

Micro-buckling mechanism



Structural effect





Microscale is promising

Test data are consistent
(except standard test)

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