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?

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

Determination of the longitudinal compressive strength of UD plies
Compressive tests on UD plies

Standard compression tests

T700GC/M21 material (268g/m²)
6 specimens 16 plies - [0₈]ₙ
manufactured with heating-press at Onera

Specimens with small free lengths
10mmx10mmx4.2mm
Loading introduced by pushing on edges

Failure pattern analysis:
Premature kinking within the tab region
Failure close to the jaws (angle at 15°)
Large scattering (10%) on strength

$X_c = -880$ MPa
CV = 9.9%

Determination of the longitudinal compressive strength of UD plies
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 $E_{11} \neq E_{c11}$)

- **Very high compressive strengths** (from FE simulation)

**Compression with pivot**

16 plies

$X_c = -1350 \text{ MPa}$

CV = 4.5%

32 plies

$X_c = -1220 \text{ MPa}$

CV = 2.8%

**100/0/0 laminate**

16 plies

Failure mode relevant (no buckling, far from jaws)

Test analysis with complex FE simulations

Geometrical non linearity

Tension ≠ Compression moduli

[Callus 07, Laurin 16]

[Julien 15]
Innovative tensile tests on a specific laminate

**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

\[ \sigma_c = -1025 \text{MPa} \]
\[ \text{CV} = 1.9\% \]

- **Standard**
- **Type A**
- **Type B**
- **Tension test**

![Tensile test on specific laminate](image)

**Fibre kinking in 90-ply**

**SEM**

**X-Ray CT**

**Determination of the longitudinal compressive strength**
Analysis of the available tensile tests

Model proposed by Grandidier et al.

Analytical formula for longi. compression strength $\sigma_c$
- Based on FE simulations at microscale
- Take into account type of loadings, ply position, ply thickness

$$\sigma_c = \frac{G}{1 + n\left(\frac{3}{2}\right)^{1/n} \left(\frac{\phi/n}{\gamma_c/n-1}\right)^{(n-1)/n} + (2r_g)f\pi \frac{E_mE_F}{(1-\nu_m)^2}(1-f)}$$

Micro-buckling mechanism
- $\Phi$: fiber misalignment

Structural effect
- $\gamma_{12}$: longitudinal compressive strength (MPa)
- $\ell$: ply thickness

Data at microscale
- $(E_p, E_m, \nu_m)$ from literature

Test data are consistent (except standard test)

Microscale is promising

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