Damage Resistance Properties of Thin-ply Carbon Fiber/Epoxy Laminates

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CompTest
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Outline

- Objective
- Quasi-static tests
- Thermal fatigue tests
- Fatigue tests
- Conclusions

Concept

Loads:

Temperature, inner pressure and sloshing

SpaceLiner 7

Motivation: to find a composite material that can withstand these extreme loads

Objective

- **To study micro-damage initiation and evolution in thin-ply CF laminates**
  - **Quasi-static tests**
  - **Thermal fatigue tests**
  - **Fatigue tests**

Manufacturing

- **Filament winding of flat plates with Oxeon tape only, dry winding + RTM (LY556 epoxy)**

Property	UD composite
Longitudinal tensile modulus (GPa)	138
Transverse tensile modulus (GPa)	8.1
Longitudinal tensile strength (MPa)	2390
Transverse tensile strength (MPa)	25
Thermal expansion α_T (μm/m °C)	26.7

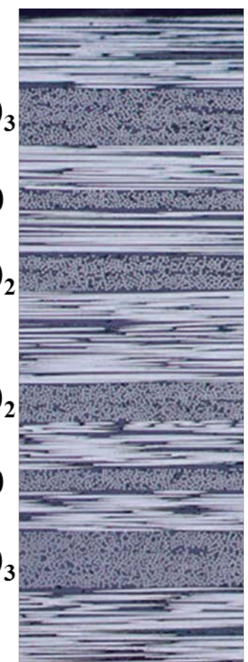
Quasi-static tests

- **2 different lay-ups:** Plate A $[0_4/\mathbf{90_3}/0_2/\mathbf{90}/0_2/\mathbf{90_2}/0_2]_s$, Plate B $[\mathbf{90_4}/0_3/\mathbf{90_2}/0/\mathbf{90_2}/0_2/\mathbf{90_2}]_s$

- **Average one ply thickness ~50μm**

- **Nomenclature: 90° layers are named by their thickness: L1 ≈ 50μm, L2 ≈ 100μm, etc.**

Plate A



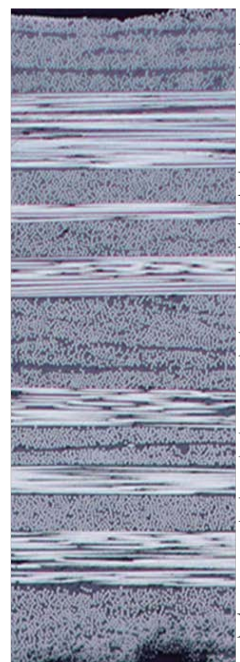


Plate B

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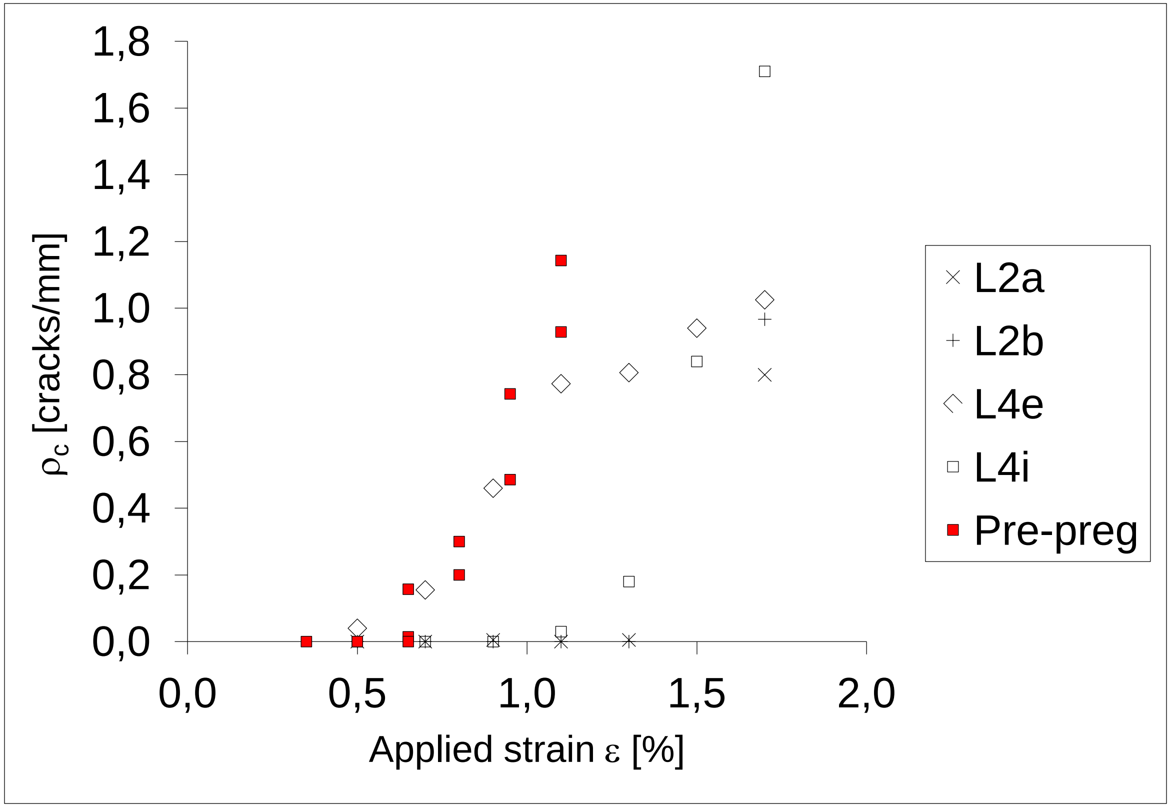
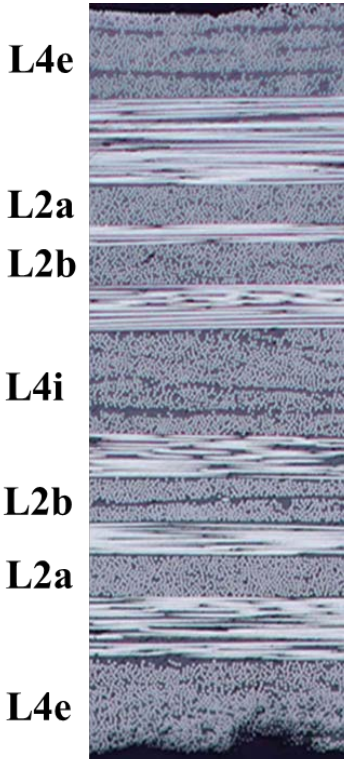
Crack density at -50°C
Plate B $[90_4/0_3/90_2/0/90_2/0_2/90_2]_s$

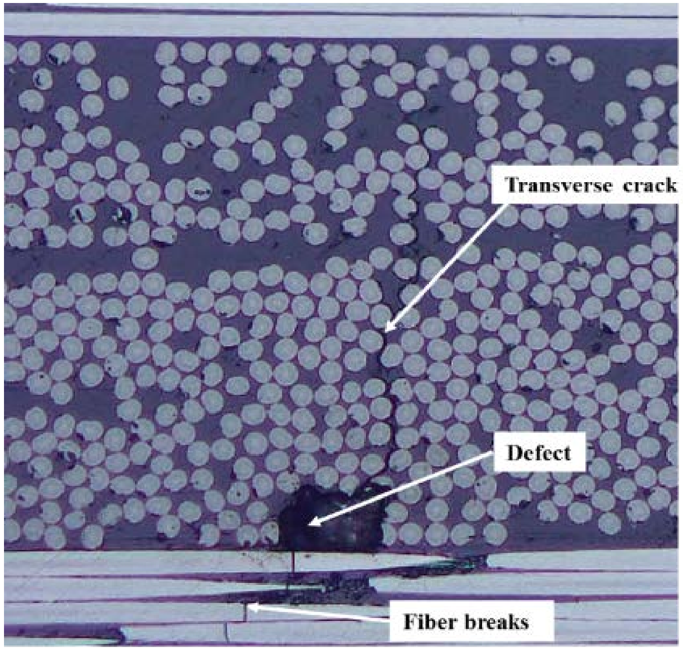


Layer thickness

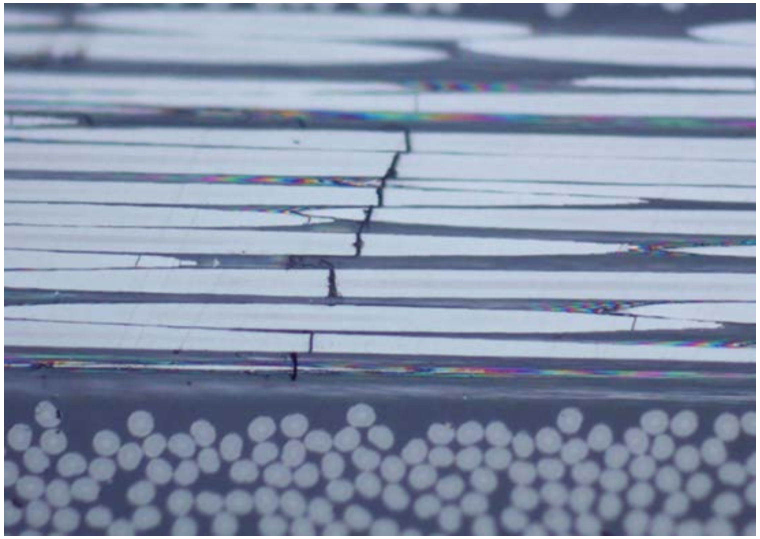
Pre-preg ≈ 300 μm



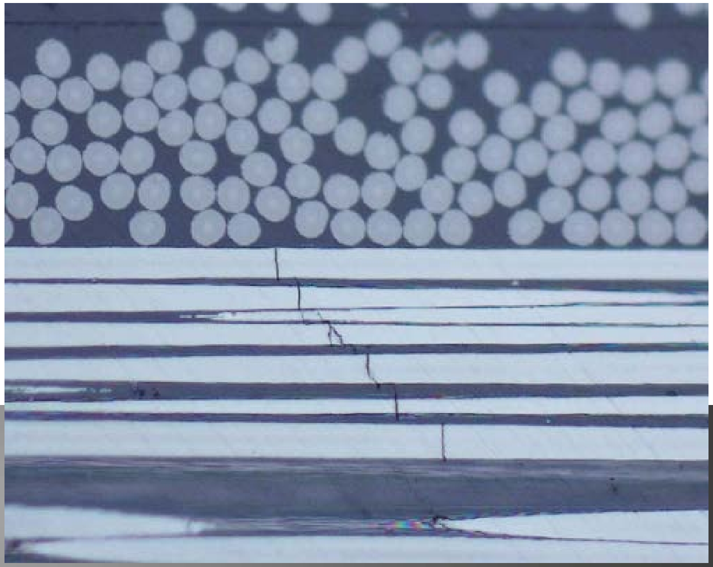
Microscopy: Plate A



L3 after 1.1% applied strain



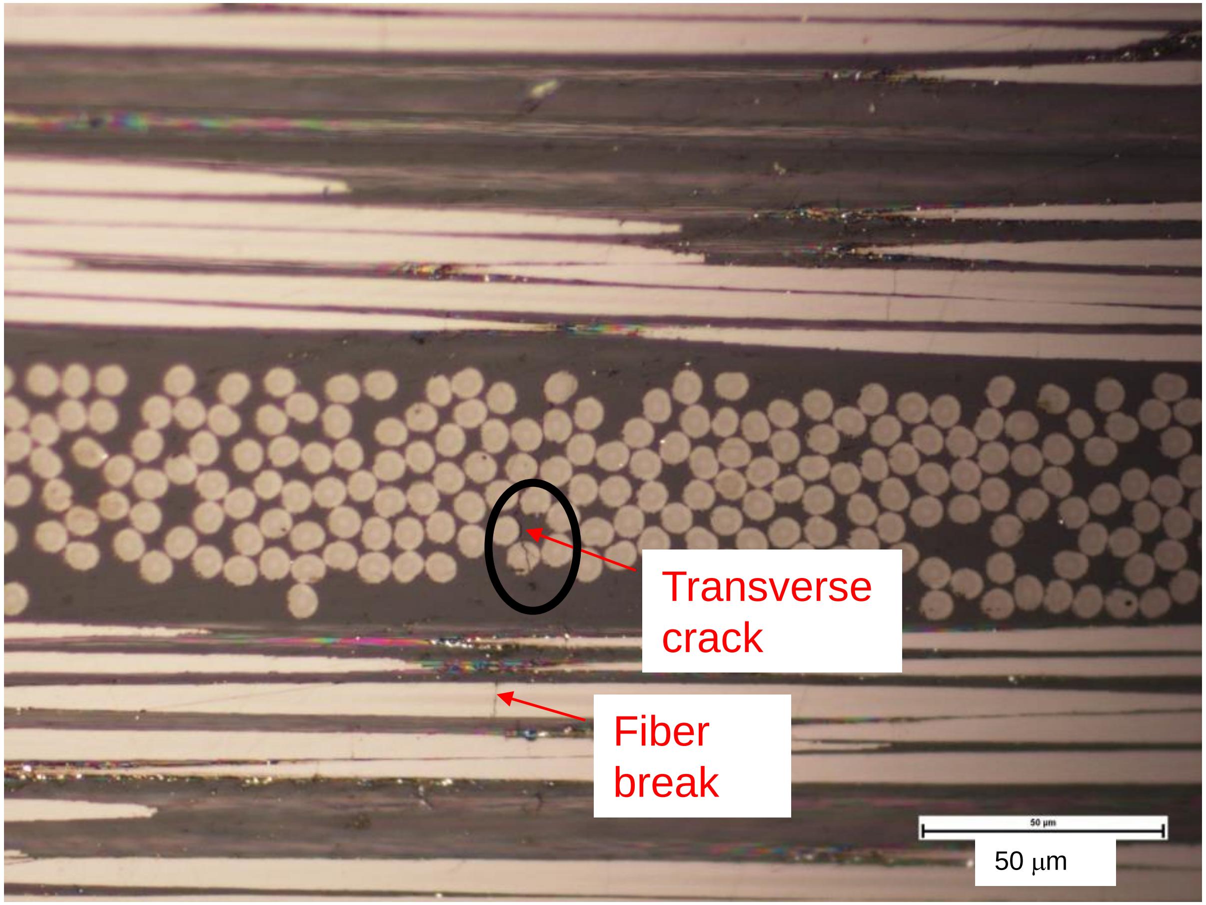
Fiber breaks at 1.3% applied strain



Microscopy

- **Optical microscopy images of transverse cracks in different layers**

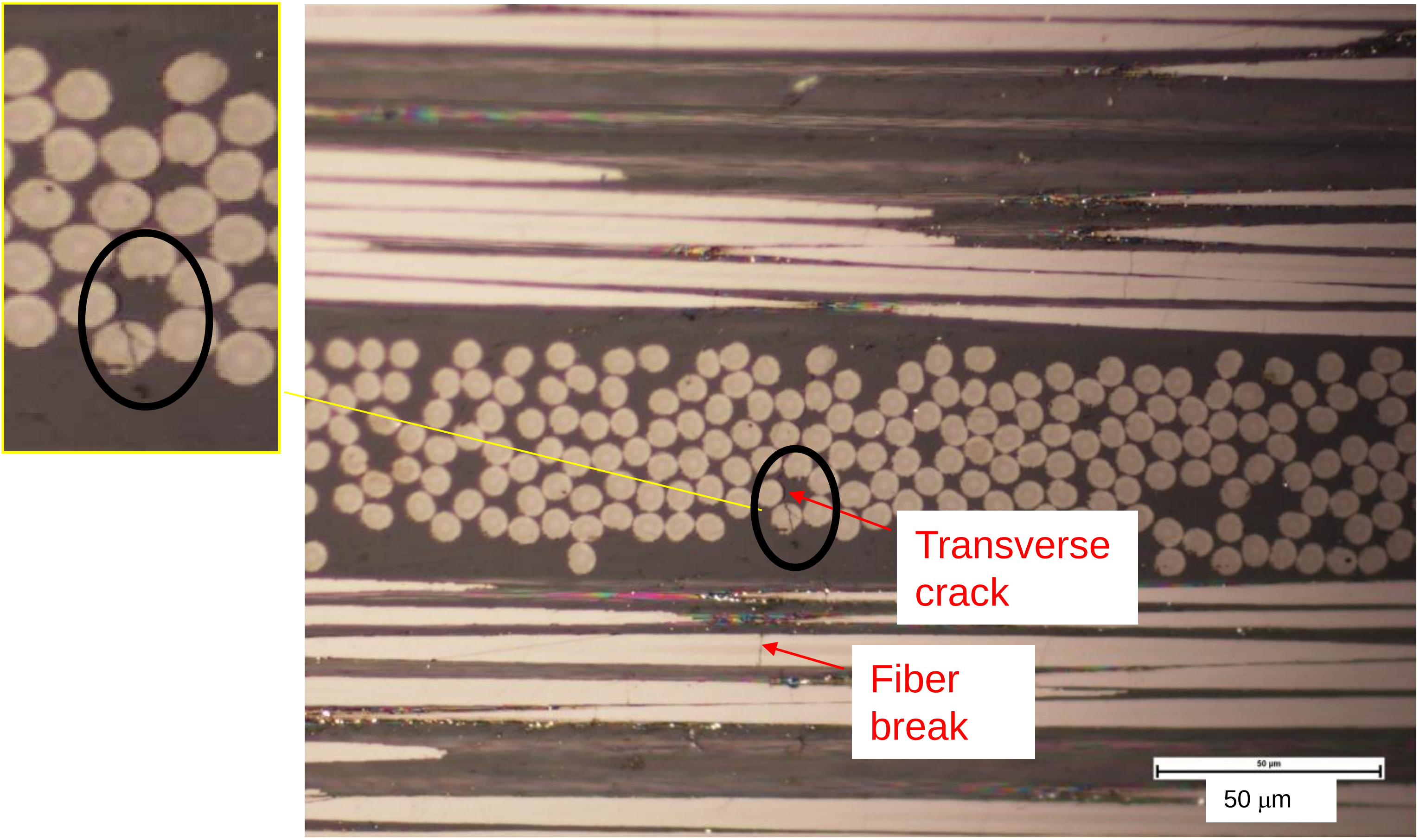
Layer L1 after 1.5% strain



Microscopy: Plate A

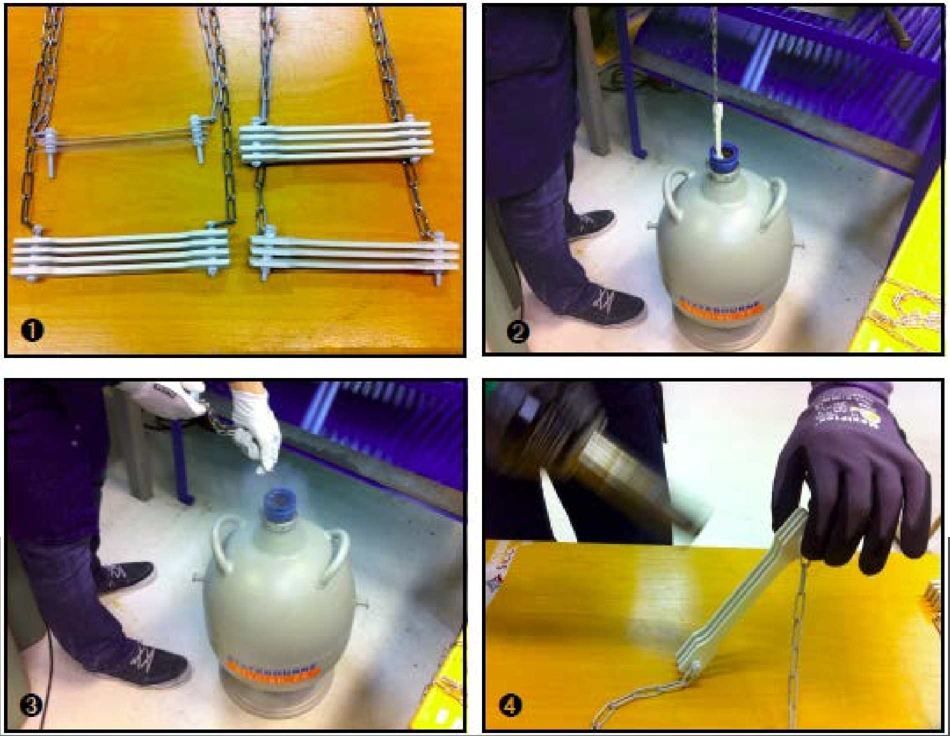
- **Optical microscopy images of transverse cracks in different layers**

Layer L1 after 1.5% strain



Thermal fatigue tests

- **Themal fatigue tests: cyclic thermal loading from -196°C to RT.**
- **Micro-cracking due to thermal shock (high gradients in temperature)**
- **Procedure: Samples attached in chains, immersed in LN_2 container, resetting to room temperature by hot air flow**



Thermal fatigue tests

- **Micro-cracks were only found in layers L3 (Plate A) and layers 4e (Plate B)**

L3			
Sample	N cycles	Total length	ρ_c
	[-]	[mm]	[cr/mm]
1	100	200	**0.02**
2	100	200	**0.01**
3	100	200	**0.03**

L4e			
Sample	N cycles	Total length	ρ_c
	[-]	[mm]	[cr/mm]
1	100	200	**0.26**
2	100	200	**0.17**
3	100	200	**0.19**

Fatigue tests: Experimental Setup

- Max strain levels in fatigue: 0,5 and 0,9%
- Frequency: 5 Hz
- R=0.1
- RT and -50°C
- Measurement of crack density (optical microscopy) after selected number of applied loading cycles

Laminates used for fatigue

Plate C = [0_2/**90_3**/0/**90_2**/0_2]s, where 90_3 is L3 and 90_2 is L2.

Plate D = [**90_2**/0_3/**90**/0_2/**90_2**]s, where 90_2 is L2e, 90 is L1 and 90_4 is L4.

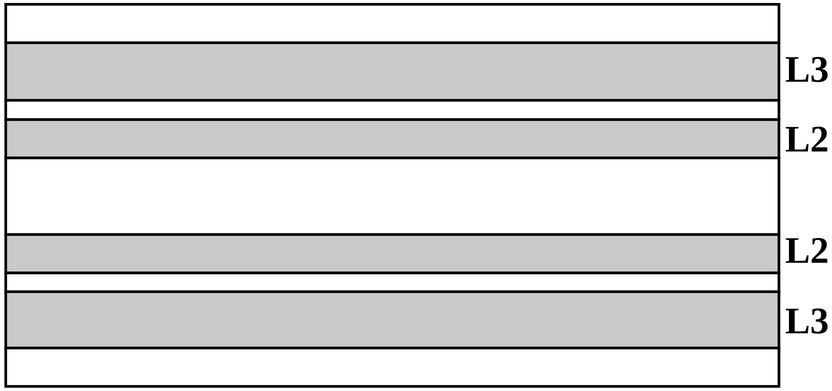


Plate C

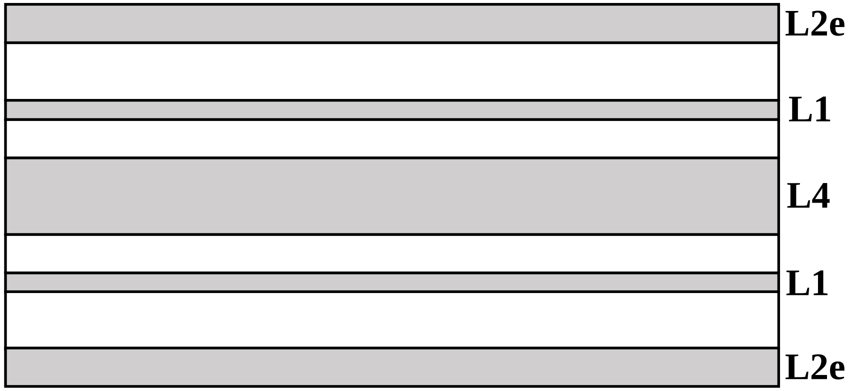
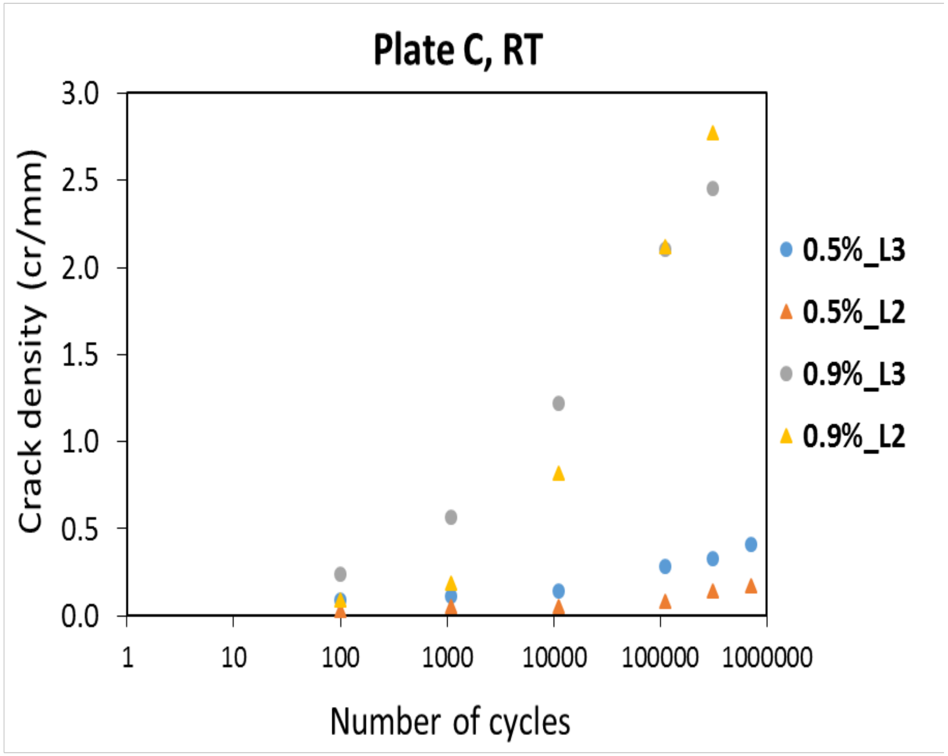
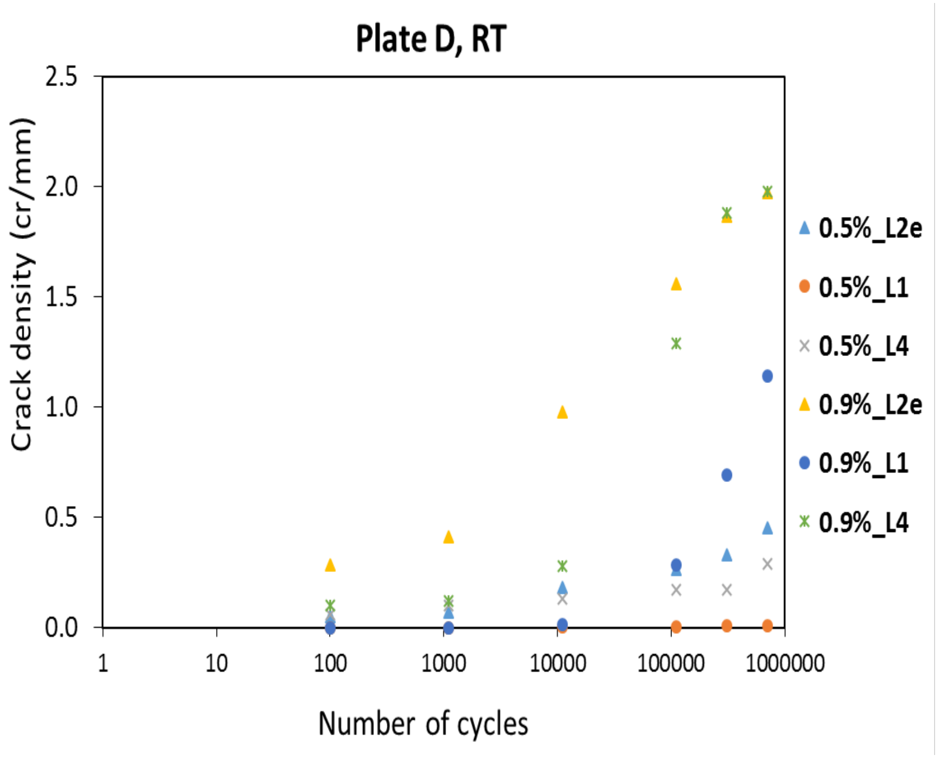


Plate D

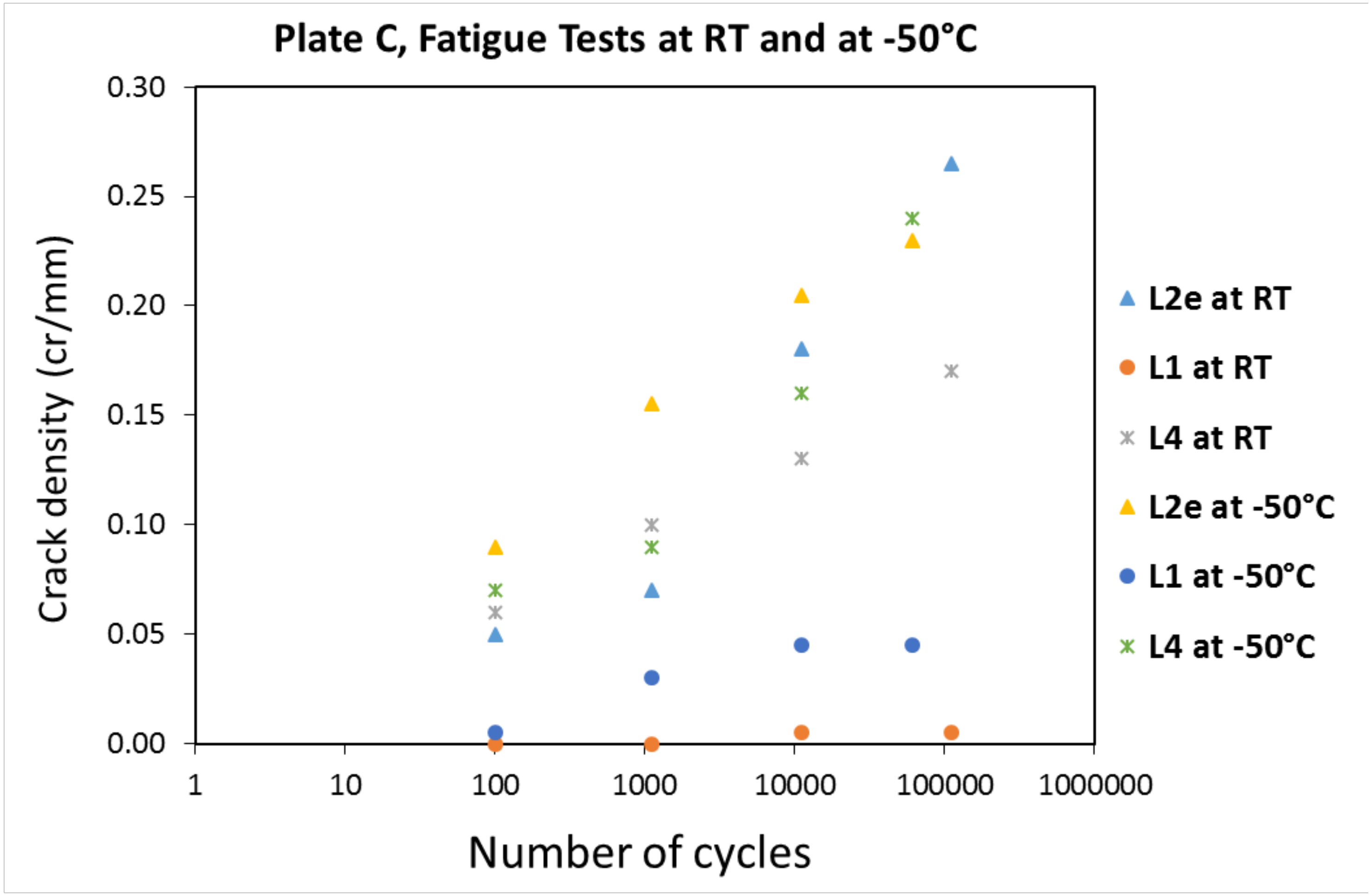
Fatigue tests: Results at RT





- Both layers, L2 and L3, have similar crack densities
- The internal thin layer L1 has less cracks than L2 and L4 in both cases

Comparison: RT, -50°C



Layer L1 has higher crack density at -50°C than at RT

Micro-damage initiation and evolution

Strength or Fracture Mechanics?

- If the stress level needed for initiation is higher than the stress level needed for propagation: cracking is unstable and initiation (**strength**) governed

- If the stress to initiate defect is low, the propagation will not start until required stress level is reached and then it grows according to **Fracture Mechanics**

Modelling approach - Weibull distribution

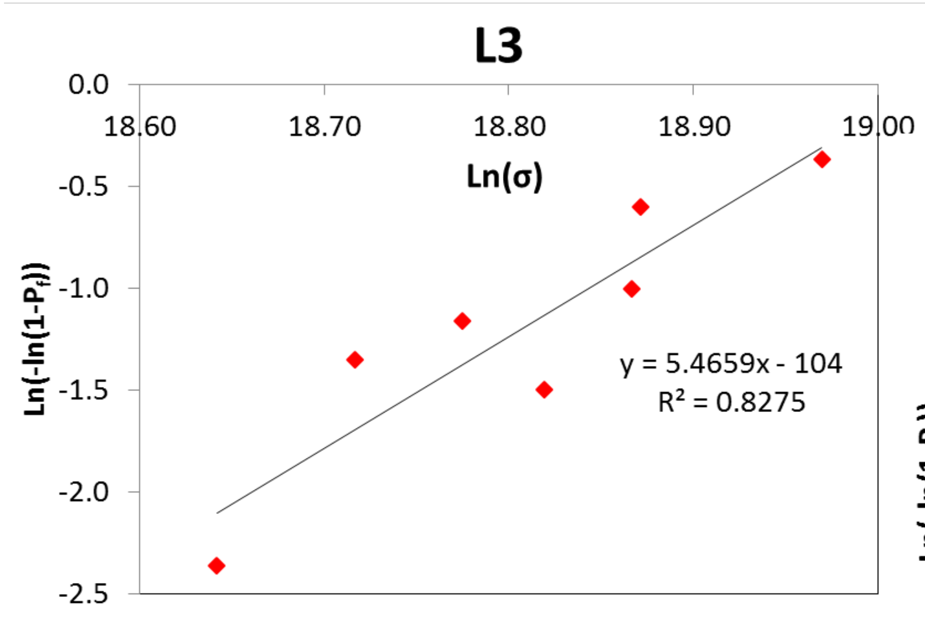
Weibull's proposal

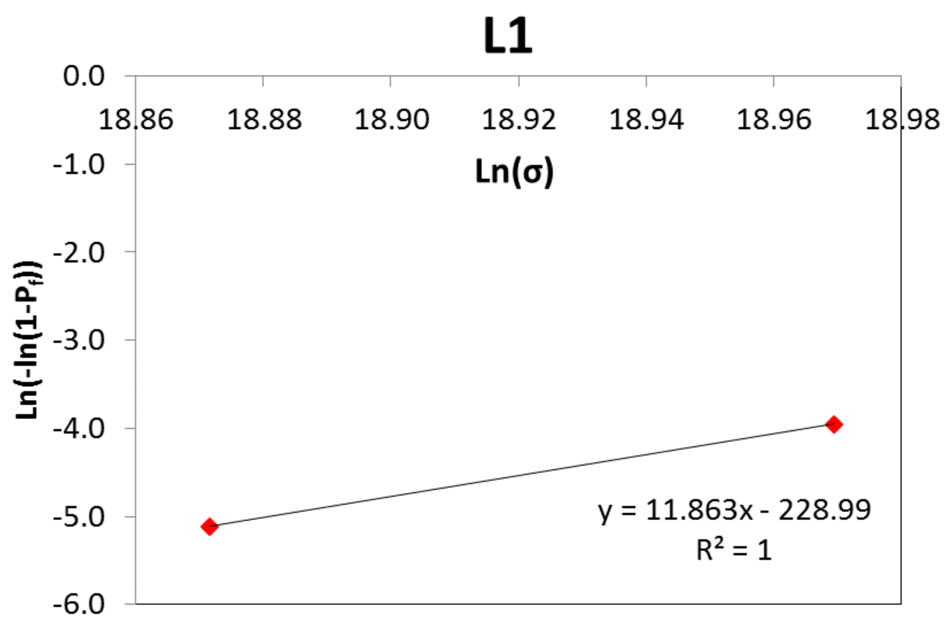
$$n_{\sigma} L_0 = \left(\frac{\sigma}{\sigma_0} \right)^m$$

L_0 - reference length
m - Weibull shape parameter
σ_0 - scale parameter

$$P_f = 1 - \exp\left(-\frac{L}{L_0}\left(\frac{\sigma}{\sigma_0}\right)^m\right)$$

Weibull distribution





Very thin-Ply: Weibull distribution can not be used

➢ Fracture mechanics approach should be used

Conclusions

- Tensile tests of Oxeon thin-ply laminates have been performed at -50°C:
  - The obtained results proved that formation of micro-cracks is significantly delayed in the thinnest layers.

- A fatigue tests were performed at RT and -50°C:
  - The thinnest layers contained lower number of cracks.
  - For the same layer, higher crack density was shown at -50°C comparing to RT.

- Fracture mechanics approach should be used for thinner layers (less than 100 μm)

Acknowledgement

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Thank you for your attention!

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