A COMPARATIVE STUDY ON AGING OF HIGH TEMPERATURE POLYMER COMPOSITES REINFORCED BY CARBON FIBRE THIN-PLIES AND SATIN WEAVES

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OUTLINE

- Background
  - Temperature resistant composites in aeronautics applications
- Objective
- Materials
- Results
- Summary and conclusions

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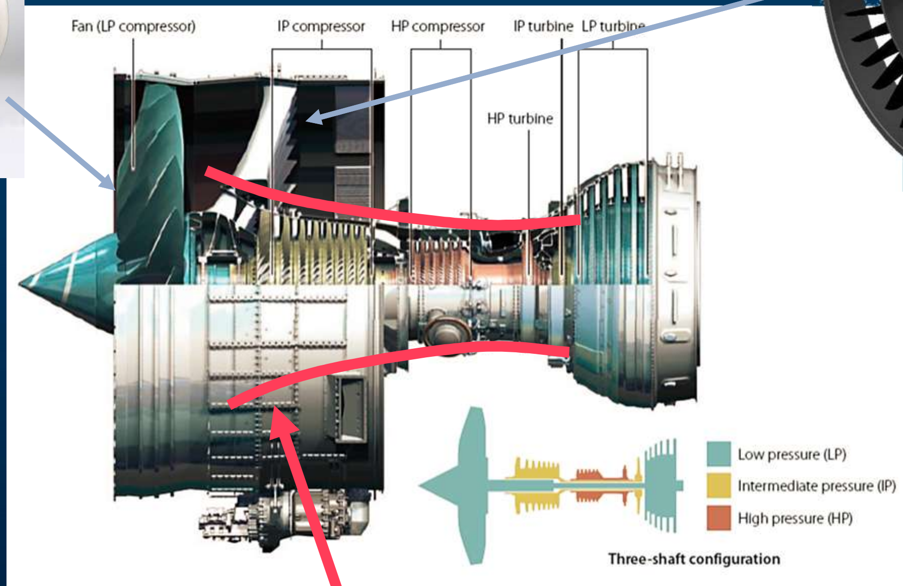
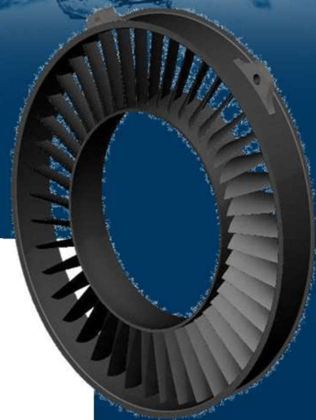
POLYMERIC COMPOSITES IN AERO-ENGINE APPLICATIONS

Fan blades





Outlet Guide Vanes (OGV)

Composites with high temperature ability required inside marked area

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COMPOSITES CONSTITUENT PROPERTIES

	Carbon fibers	Polymer matrix
Stiffness	Stiff (~ 230-300 GPa)	- Rigid (~ 5 GPa) when below glass transition temperature, T_g - Soft (~ 50 MPa) above T_g
Density	Light (~ 1800 kg/m^3)	Light (~ 1300 kg/m^3)
Thermal stability	Stable in inert environments and within typical use-temperature range	- Softens at elevated temperature (above T_g) - Tendency to degrade in presence of air at elevated temperature
Thermal expansion coefficient	$-0.1 \cdot 10^{-6}$ K^{-1} (in fiber direction)	$50 \cdot 10^{-6}$ K^{-1}

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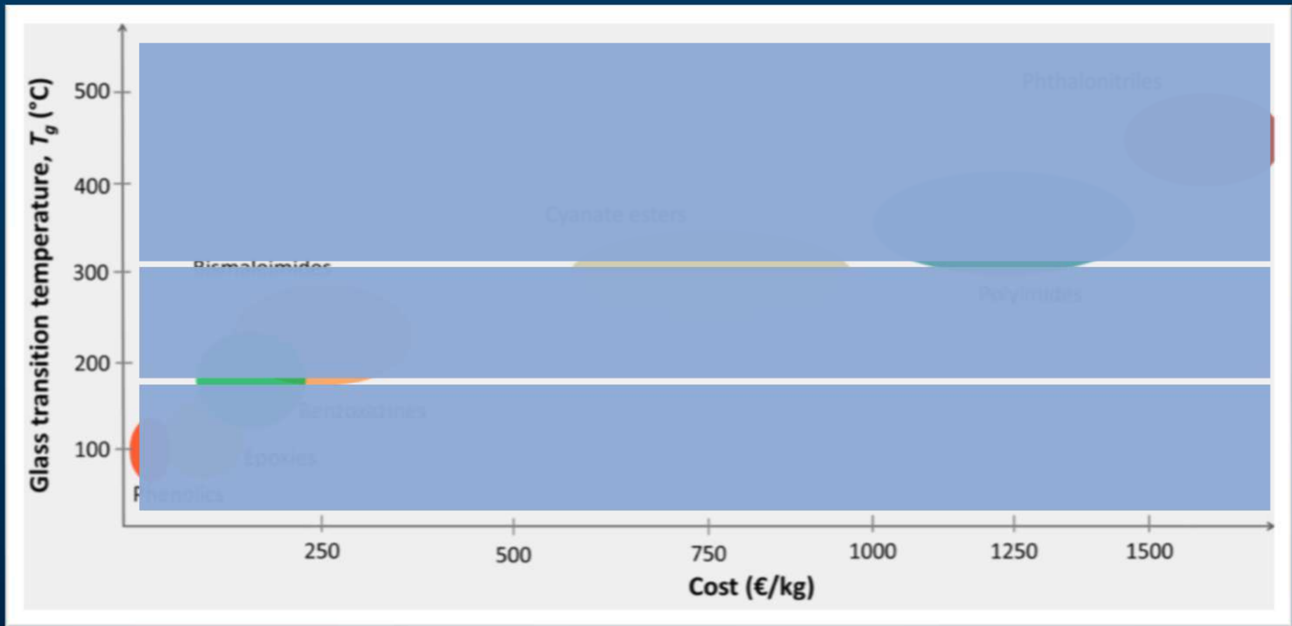
TEMPERATURE RESISTANT POLYMERS



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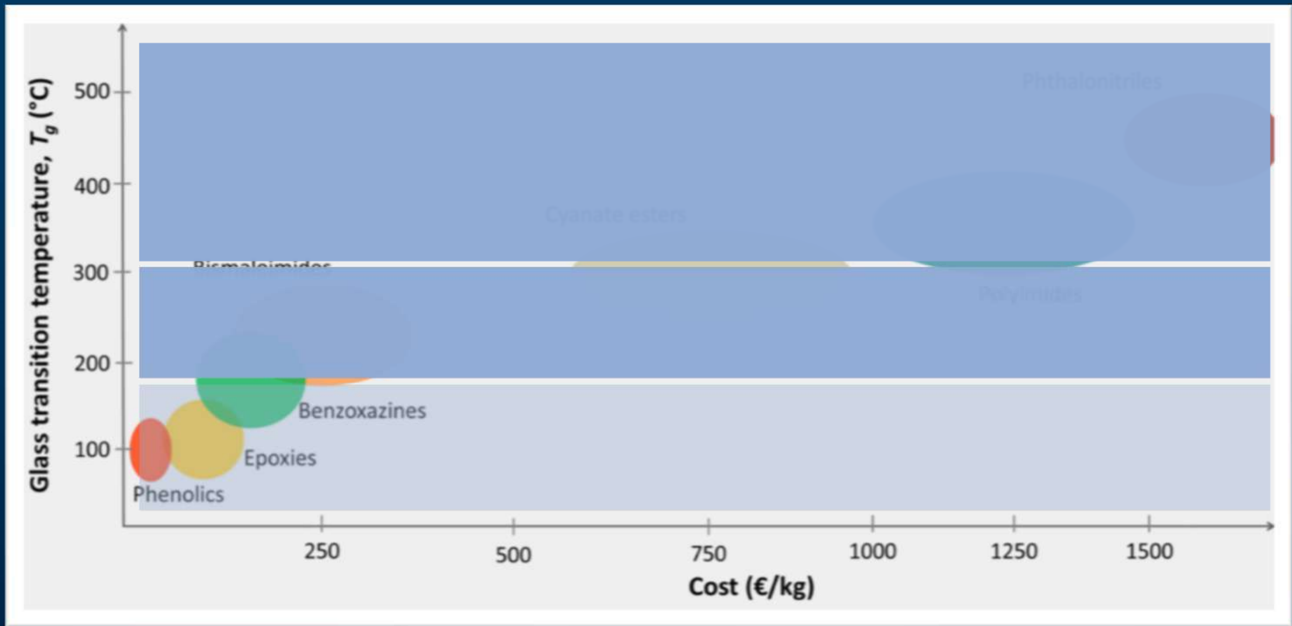

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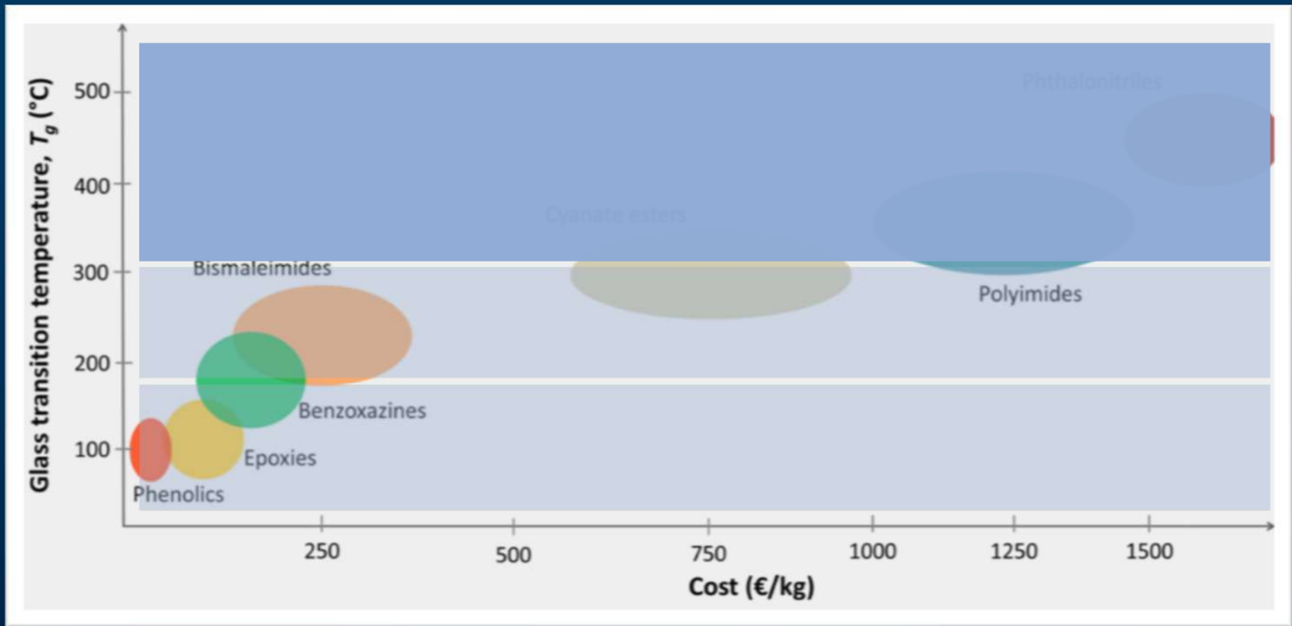

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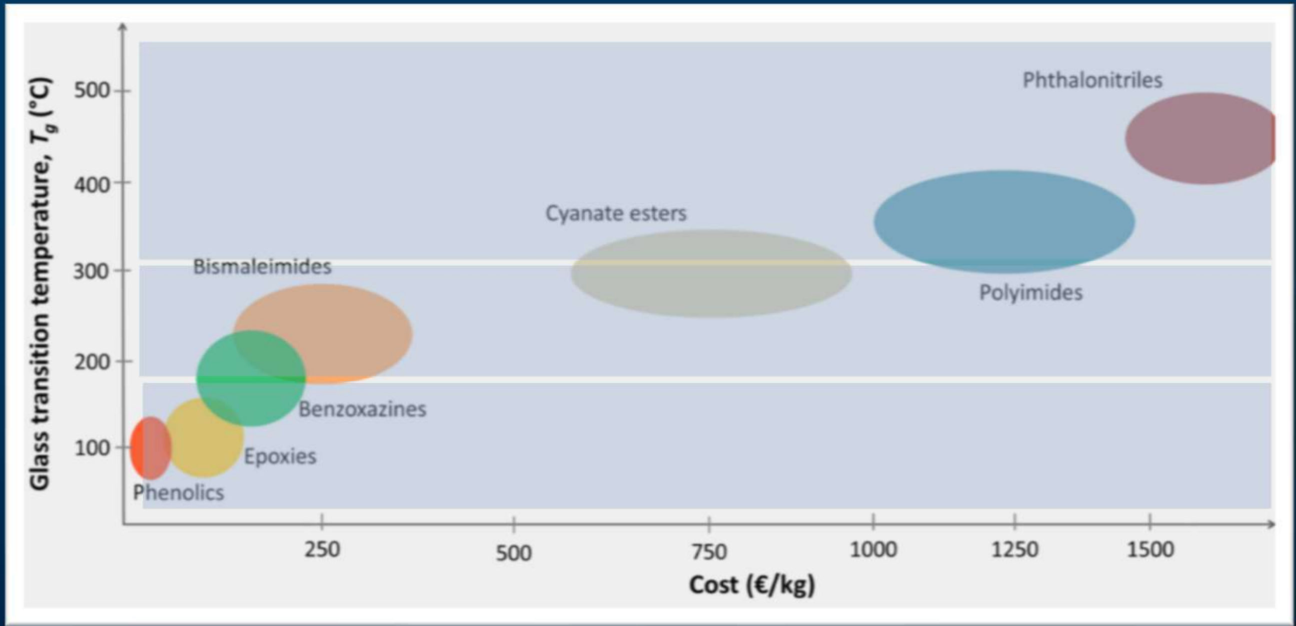

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OVERALL RESEARCH OBJECTIVE & GOAL

Objective:

- Develop and mature high temperature carbon fibre composites for use in future generation aero-engines

Goal:

- Investigate how the thin-ply effect can play a positive role for high temperature composites

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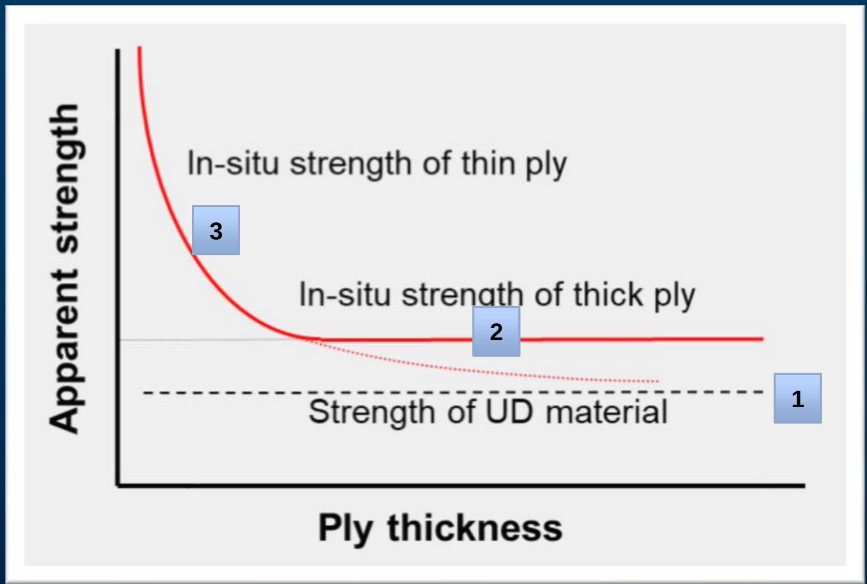
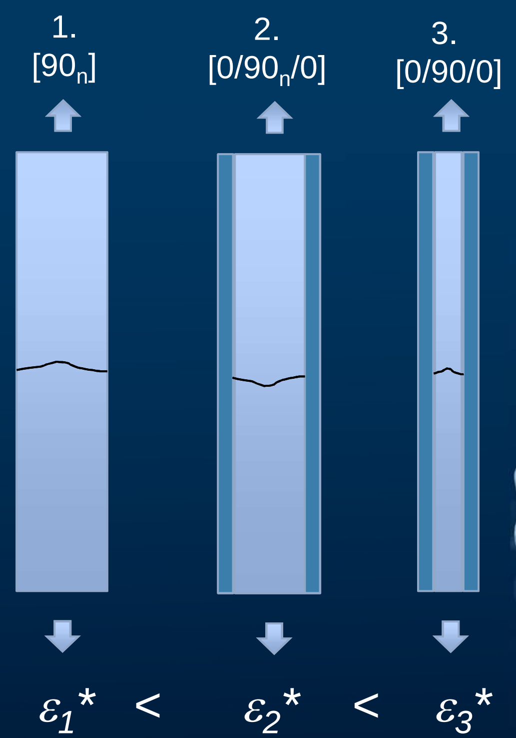
THIN-PLY COMPOSITES





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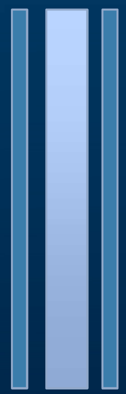
CURE RESIDUAL STRESSES

At cure temperature

”stress free”



[0/90/0]

orientation	0	90	0
$\alpha \cdot 10^{-6}$ [K^{-1}]	1	30	1

After cooling by ΔT to room temperature

”free ply shrinkage” **”actual stresses”**

<u>**Linear elastic laminate theory**</u>

Residual stress depends on

- α – different between layers
- E – stiffness differences
- ΔT – cooling from cure temperature

Assume a quasi-isotropic layup:

- $[-45/45/90/0]_{2S}$
- ΔT=300 K

Residual transverse thermal stress

- $\boldsymbol{\sigma_{22}}$ ~ 75 MPa
- UD strength ~ 53 MPa

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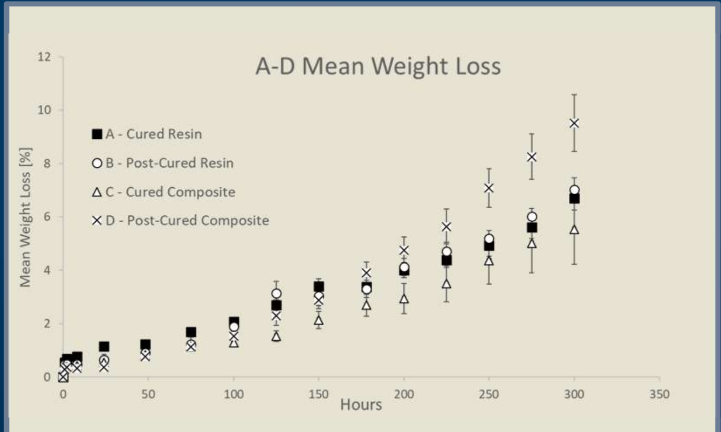
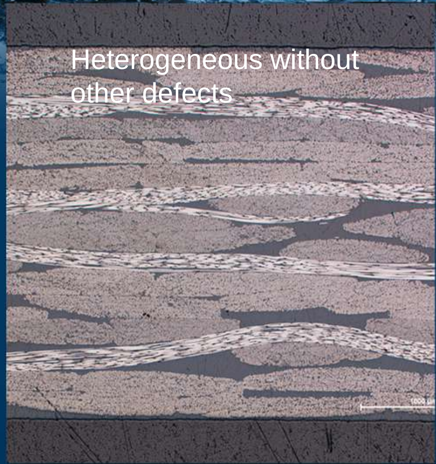
OXIDATIVE AGEING

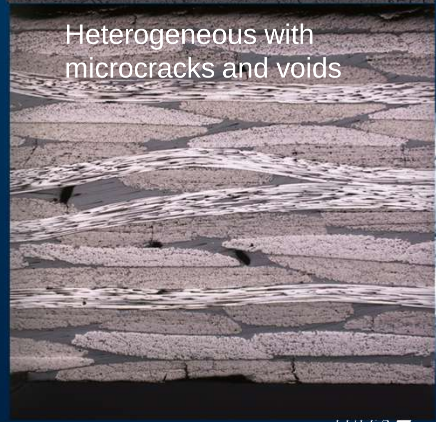


Aging of baseline composites at 350°C
from MSc thesis H McLaren, LTU 2015

Weight loss:
- Accelerating over time
- Experimental variability
- “Surface governed”

Micro-defects could explain variability





Thin-ply composites to mitigate
- occurrence of manufacturing induced cracks
- thermal oxidative ageing

MATERIALS

Baseline laminates:

- Resin: NEXIMID® MHT-R
  - Thermosetting formulation for RTM
    - 6F-dianhydride (6-FDA) backbone
    - 4-(Phenylethynyl)Phthalic Anhydride (4-PEPA) end-group crosslinker
    - ethynyl bis-phthalic anhydride (EBPA) main chain cross-linker
  - **Tg ~ 370° C**
- Composites
  - $[(-45/+45)/(90/0)]_{2s}$
  - **370 g/m²** 8-Harness Satin weave based on Cytec Thornel T650/35 (Sigmatex)
  - 3 mm thick
  - V_f 58%
  - **CPT ~0.375 mm**

Thin-ply laminates:

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  - **Tg ~ 370° C**
- Composites
  - $[(-45/+45)/(90/0)]_{6s}$
  - **82 g/m²** spread-tow biaxial fabric based on IMS65 Toho Tenax fibres (Oxeon)
  - 2 mm thick
  - V_f 51%
  - **CPT ~ 0,083 mm**

RESULTS

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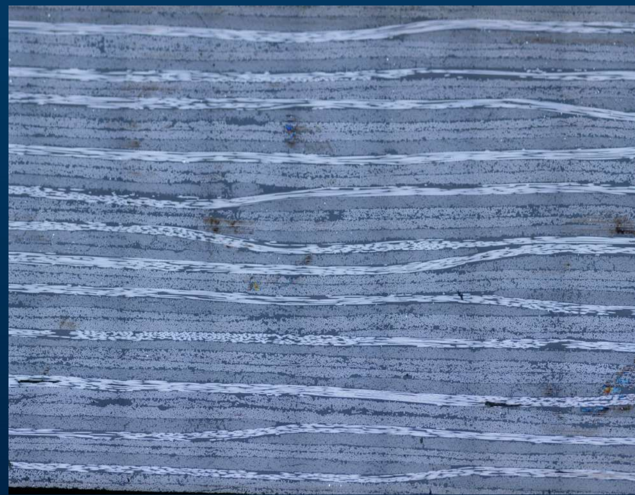
3 mm
2 mm
1 mm
0 mm

Baseline
$[(-45/45)/(90/0)]_{2S}$



Thin-ply
$[(-45/45)/(90/0)]_{6S}$

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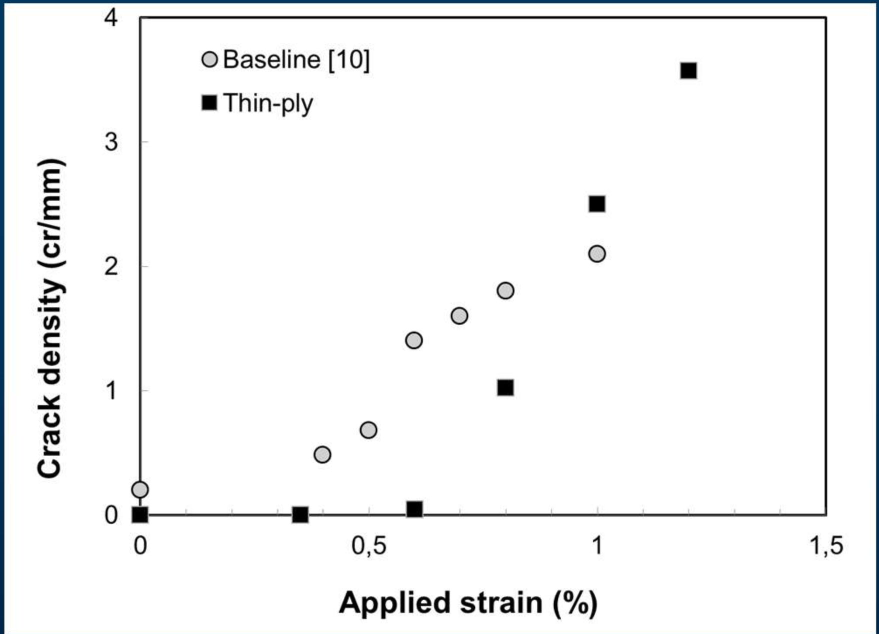
TRANSVERSE CRACKING DURING TENSILE LOADING



Quasi-static tensile loading – unloading test

- Examine specimen edges for occurrence of cracks after each loading cycle

- **Beneficial thin-ply effect**
  - **No cracks after manufacturing**
  - **Cracking onset strain shifted**
    - From about 0.3% to around 0.6%

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THERMAL OXIDATIVE STABILITY – WEIGHT LOSS @ 320˚ C

Sample dimensions:
75 mm x 11 mm x 2-3 mm

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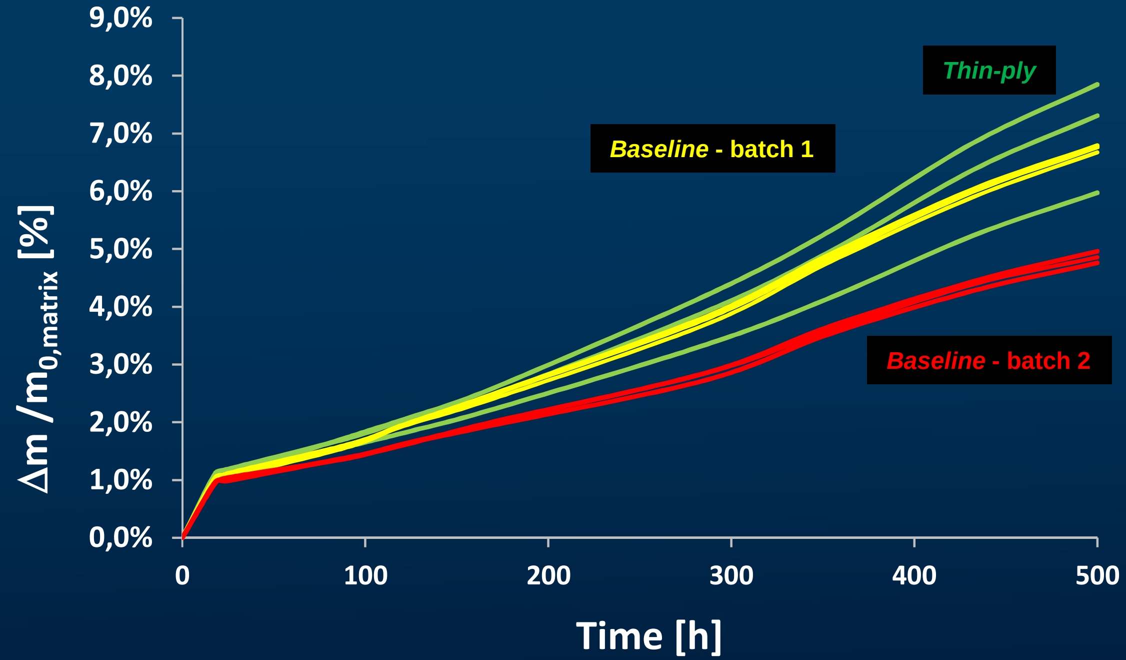
THERMAL OXIDATIVE STABILITY

weight loss relative to matrix weight @ 320˚ C



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THERMAL OXIDATIVE STABILITY

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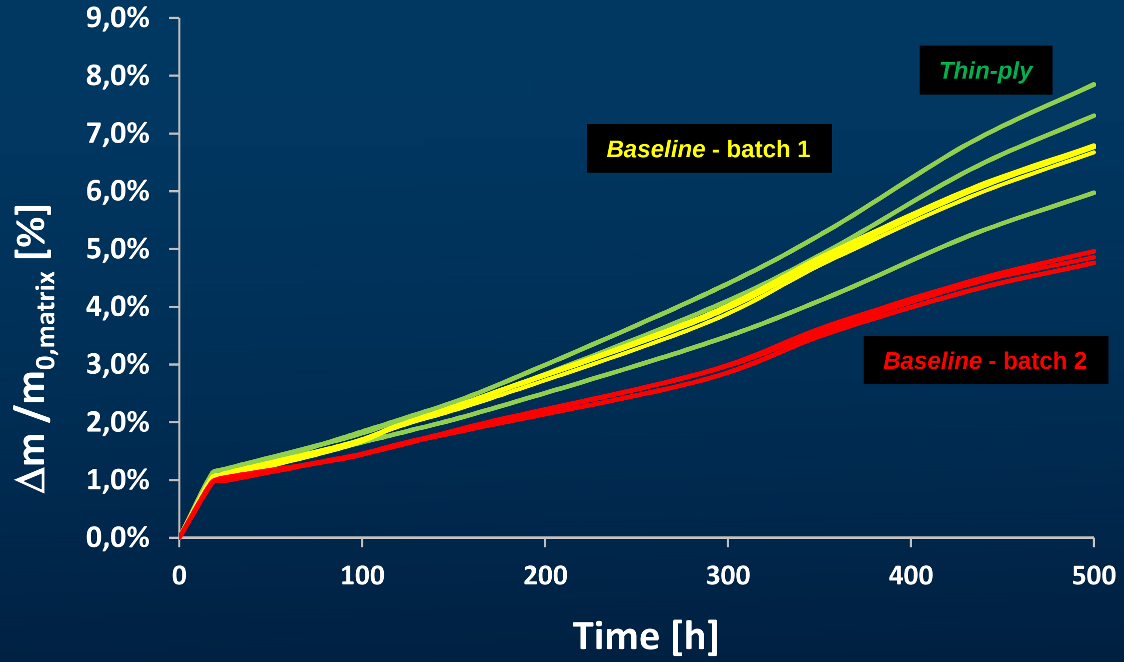

- Initial weight loss (1%) of moisture
- Accelerating trend (as previous)
- Large variations between batches
- Small variation within batches
- 5-8% matrix mass loss after 500 h
  - Corresponding to 2-3 % composite sample weight loss
- **No noticeable improvement from thin-plies**

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BASELINE – BATCH 1 VS. 2

Presence of voids and cracks

Flawless

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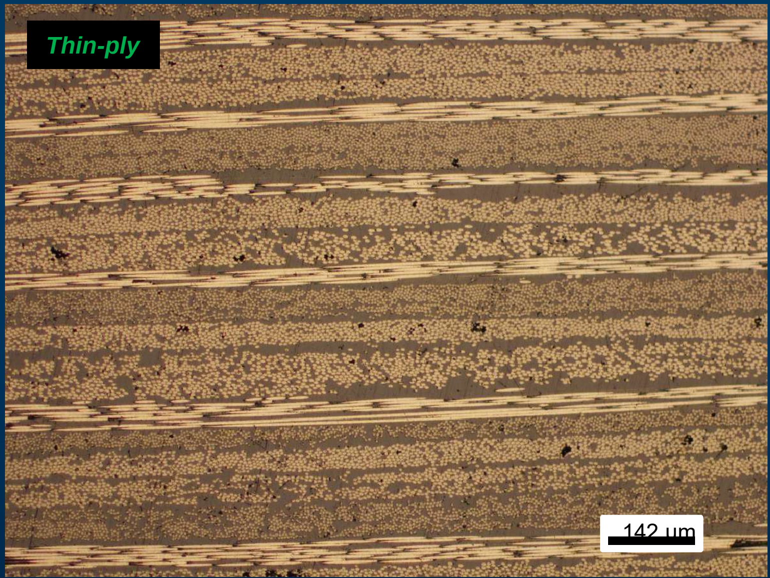
THIN-PLY VS *BASELINE* BATCH 2



“potentially micro-pores”

Flawless

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SUMMARY AND CONCLUSIONS

- Thin-ply composites samples based on spread-tow biaxial carbon fibre fabric and high temperature polyimide were successfully manufactured
- A thin-ply effect was observed in terms of
  - Close to zero manufacturing induced transverse cracks for thin-ply composites
  - Onset of transverse cracking in tensile tests shifted towards higher strains (from 0.3% (*Baseline*) to 0.6% (*Thin-ply*))

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SUMMARY AND CONCLUSIONS

- No detectable positive thin-ply effect with respect to thermal oxidative ageing
  - Difference in mass degradation rate appears to be dominated by presence of defects
    - Difference in void content and cracks between two different *Baseline* batches
    - Presence of what appears as micro-defects between individual fibres in *Thin-ply* laminates
- Mechanisms governing difference in degradation rate remains to verify and deserves more research
  - Influence of fibres (stiffness, sizing), interfaces
  - Stress relaxation and/or build up, evolution of matrix properties over time, …

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- RISE SICOMP staff, in particular Mr Magnus Edin and Mr Alf Bäckström, involved in the manufacturing and ageing tests

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THANK YOU FOR THE ATTENTION

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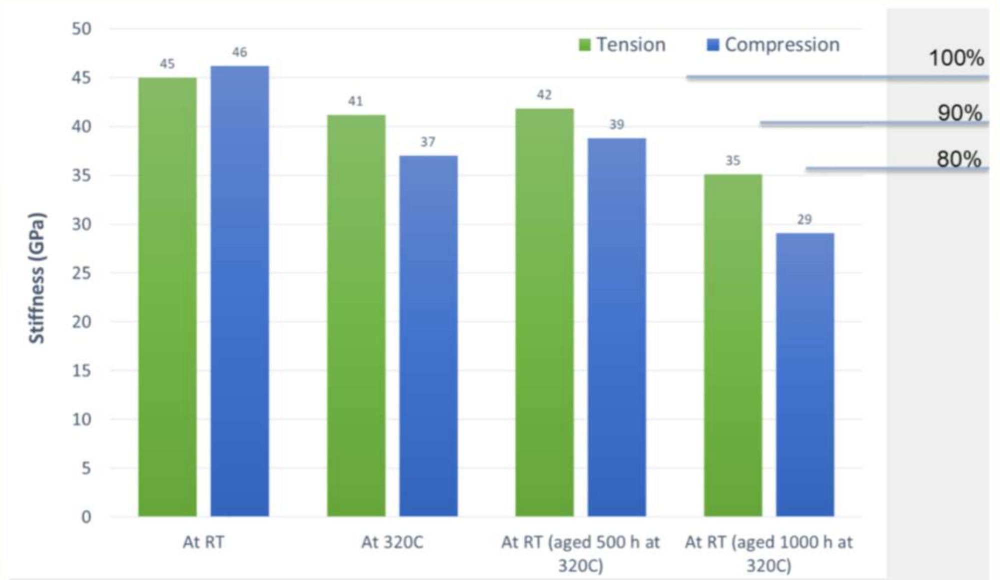
EXTRAS

MECHANICAL PROPERTY KNOCK-DOWN– *BASELINE MATERIALS*



Tsampas, Fernberg, Joffe J Comp Mat 52 (2) 2018

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COMPOSITE MANUFACTURING

Stage	T [°C]	Time [min]	P [Bar]
Melt and homogenize	240	30	1
Degass under vacuum	240	10	<0.005
Inject resin in to mould	320	~ 5	≤12
Isothermal cure	**320**	**60**	**12**
Heating of tool	320 - 370	30	12
Isothermal cure	370	120	12
Cooling of tool	370 - 80	720	1
Demould	80		1

RTM-facilities for high temperature RTM at RISE SICOMP. Ability to process liquid resins with temperature up to 300°C.

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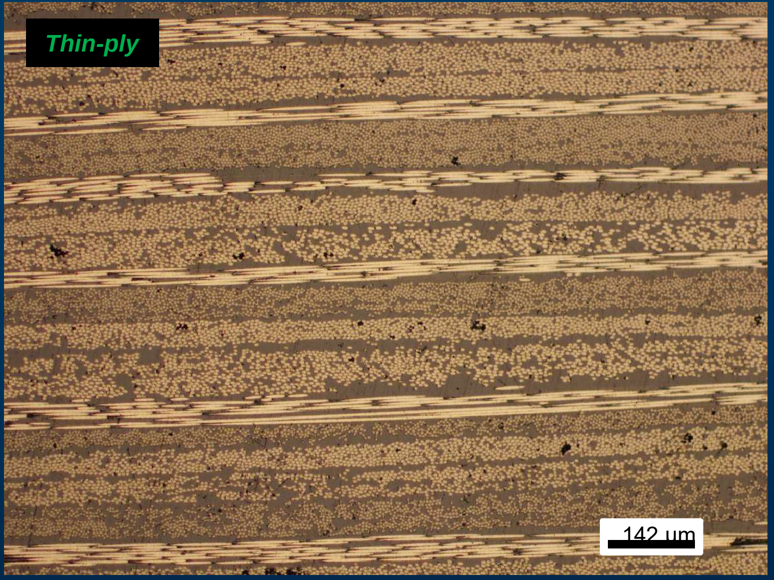
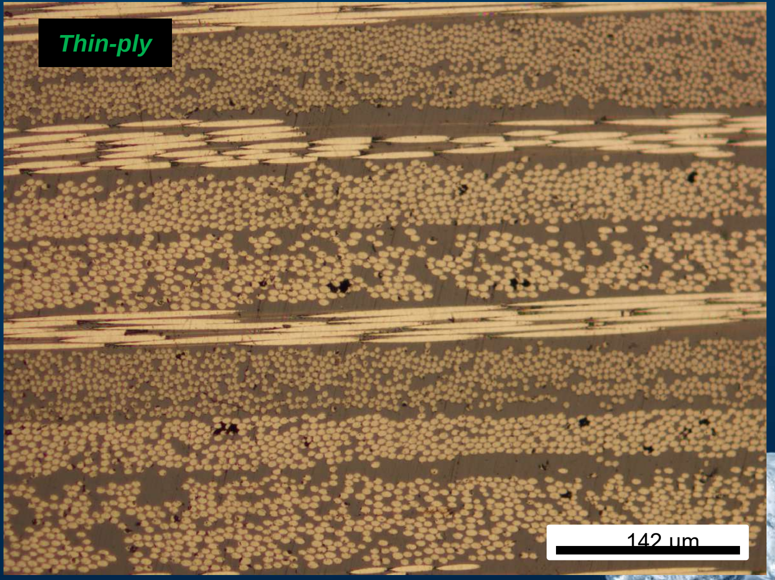
THIN-PLY COMPOSITES





“potentially micro-pores”

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