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CRACK DENSITY GROWTH OF HIGH TEMPERATURE CROSS-PLY LAMINATES SUBJECTED TO ELEVATED TEMPERATURES

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Contents

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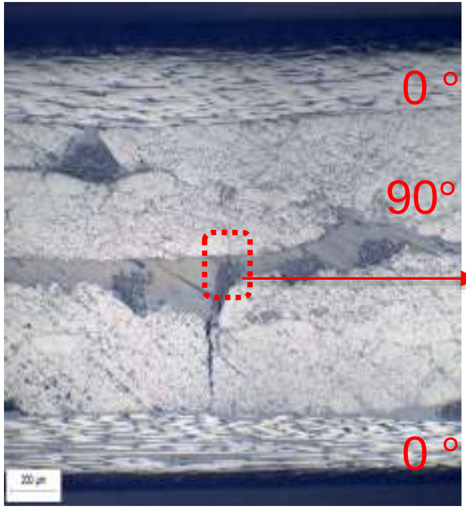
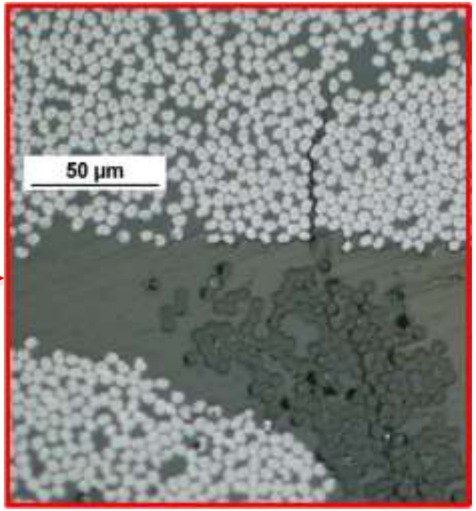
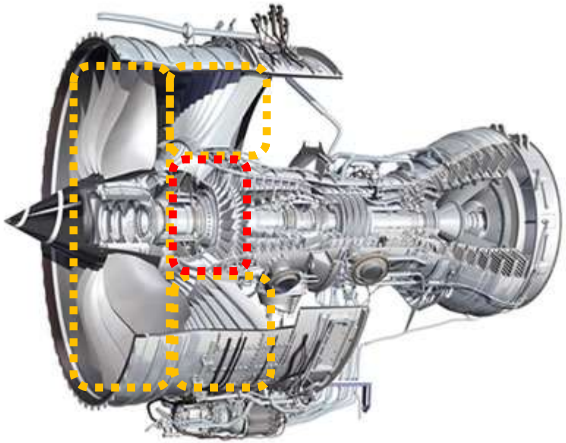
High Temperature Polymer Composites

UD carbon fabric + High temperature polymer $[0/90_2]$s, $[0/90/0/90_{1/2}]$s

Plate	Layup	90-layer thickness mm	Vf %
1	$[0/90_2]$s	0.80	46
2	$[0/90_2]$s	0.73	52
3	$[0/90_2]$s	0.64	58
4	$[0/90/0/90_{1/2}]$s	0.16	57







- Long term thermal exposure, and thermal cycling
- Moisture ingression
- Quasi-static tensile load
- Tension-tension fatigue load

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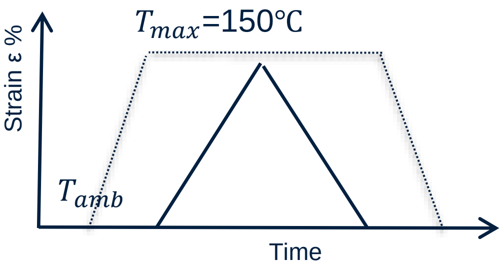
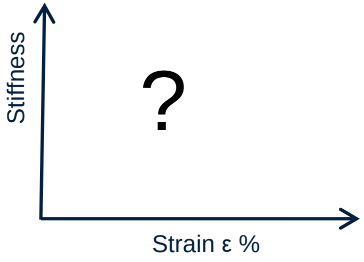
Test methodology and damage

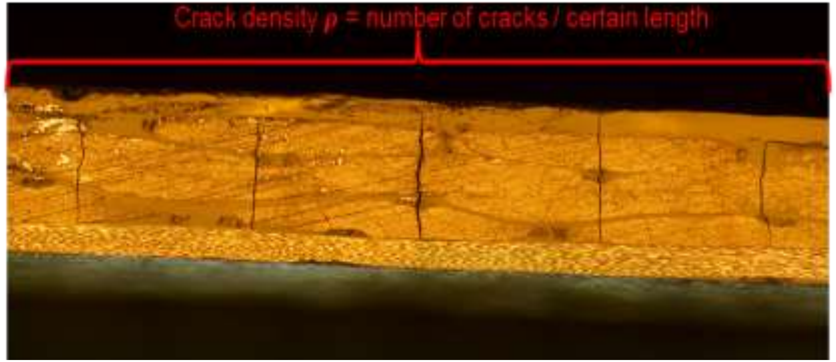
Carbon fiber high temperature polymer

- Quasi-static tensile test at room temperature and elevated temperature

Crack density → Stiffness reduction







Quasi-static Test Plan

Plate 2: $[0/90_2]s$; 90-layer thickness = 0.73mm; Vf = 52%

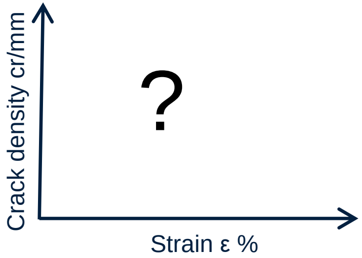
As-built specimens

- Quasi-static test at RT
- Quasi-static test at 150℃

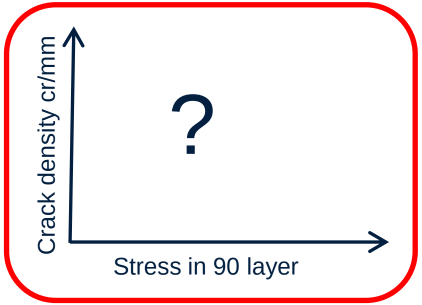
Heat treated specimens

Iso-thermally aged at 150℃ for 500 hours and 1000 hours

- Quasi-static test at RT
- Quasi-static test at 150℃



CLT →



← Presentation focus

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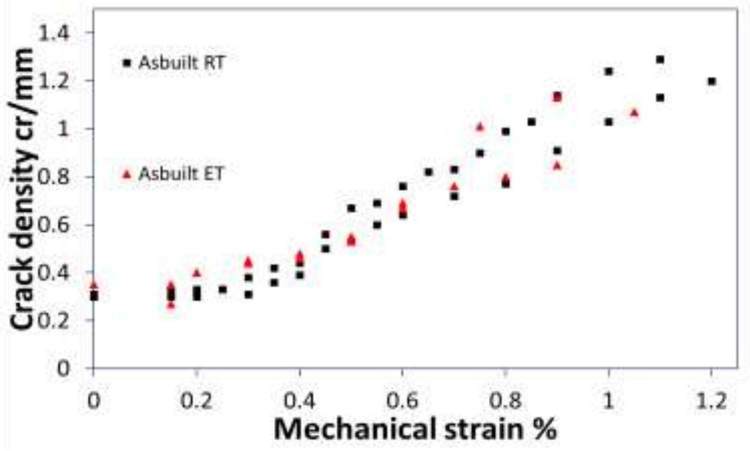
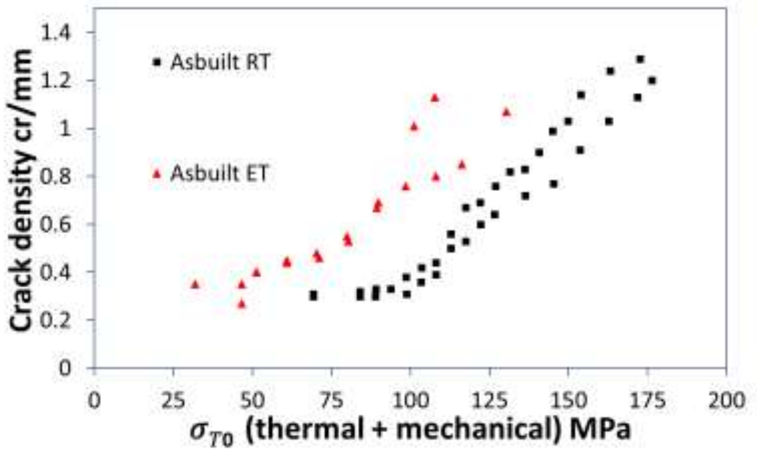
As-built Specimens Static Tested at Room and Elevated Temperature

Plate 2: [0/90$_2$]s; 90-layer thickness = 0.73mm; Vf = 52%





ET=150℃

EDGE TRANSVERSE CRACKS

Crack density is determined from average of crack density in both edges

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Statistical modelling

Different fiber clusters (with stress concentrations) in different positions; different failure stress in different positions

Initiation of cracks at edges

Weibull distribution

Quasi-static tensile loading: $P_f = 1 - exp\left(-\left(\frac{\sigma_T}{\sigma_0}\right)^m\right)$

Shape parameter m
Scale parameter σ_0

Assumptions:

σ_0 depends on temperature and conditioning, $\sigma_0 = f(stress, temperature, time, \ldots)$

At reference temperature and condition (at room temperature and as-built condition), Scale parameter is σ_0;
otherwise scale parameter is $\sigma_0^* = \sigma_0 * k_1 * k_2; k_1 = f(test\ temperature),\ k_2 = f(heat\ treatment)$

When as-built specimens quasi-static tested at an arbitrary temperature, k_2=1, and

From empirical fitting,

$$k_1 = 1 - c * \Delta T; c = 0.002$$

$\Delta T = T_{test} - T_{Ref\_T}$ (difference between test and reference temperature)

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Statistical modelling

Different fiber clusters (with stress concentrations) in different positions; different failure stress in different positions

Initiation of cracks at edges

Weibull distribution

Quasi-static tensile loading: $P_f = 1 - exp\left(-\left(\frac{\sigma_T}{\sigma_0}\right)^m\right)$

Shape parameter $m = 3.3$
Scale parameter $\sigma_0 = 142\ MPa$

Assumptions:

σ_0 depends on temperature and conditioning, $\sigma_0 = f(stress, temperature, time, \dots)$

At reference temperature and condition (at room temperature and as-built condition), Scale parameter is σ_0; otherwise scale parameter $is\ \sigma_0^* = \sigma_0 * k_1 * k_2; k_1 = f(test\ temperature),\ k_2 = f(heat\ treatment)$

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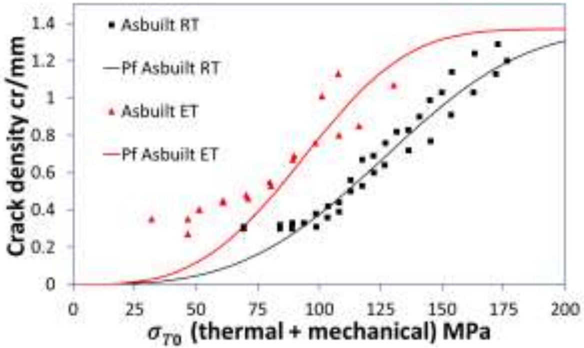

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Heat Treatment at Elevated Temperatures

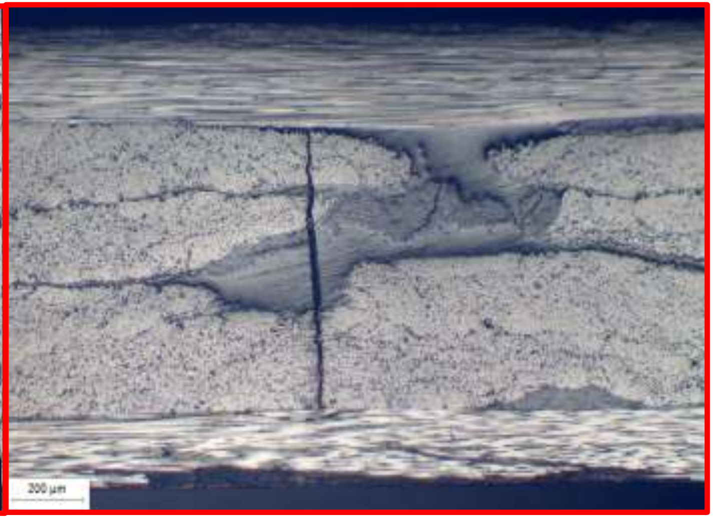
Plate 2: [0/90_2]s; 90-layer thickness = 0.73mm; Vf=52%

Before static tensile tesing

Isothermal heat treatment at 150℃ for 500 hours and 1000 hours

- 500 hours includes 7 thermal cycles
- 1000 hours includes 10 thermal cycles

As-built



Heat treated for 1000 hours

- Thermal cycling effect
- Long term thermal exposure
- Rapid cool down
- Hygroscopic shrinkage

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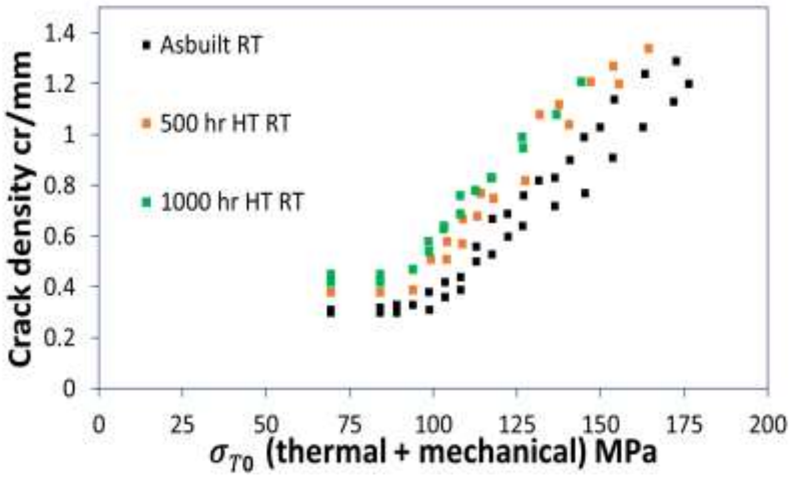
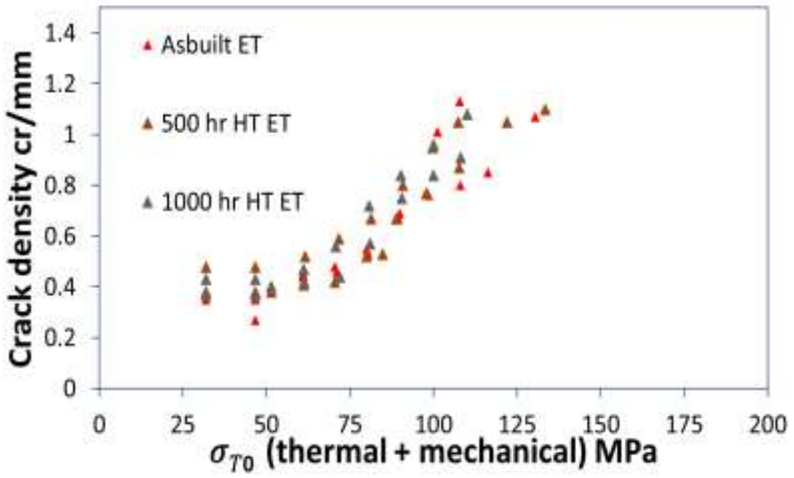
Heat Treated Specimens Static Tested at Room Temperature and Elevated Temperature

Plate 2: [0/90₂]s; 90-layer thickness = 0.73mm; Vf=52%

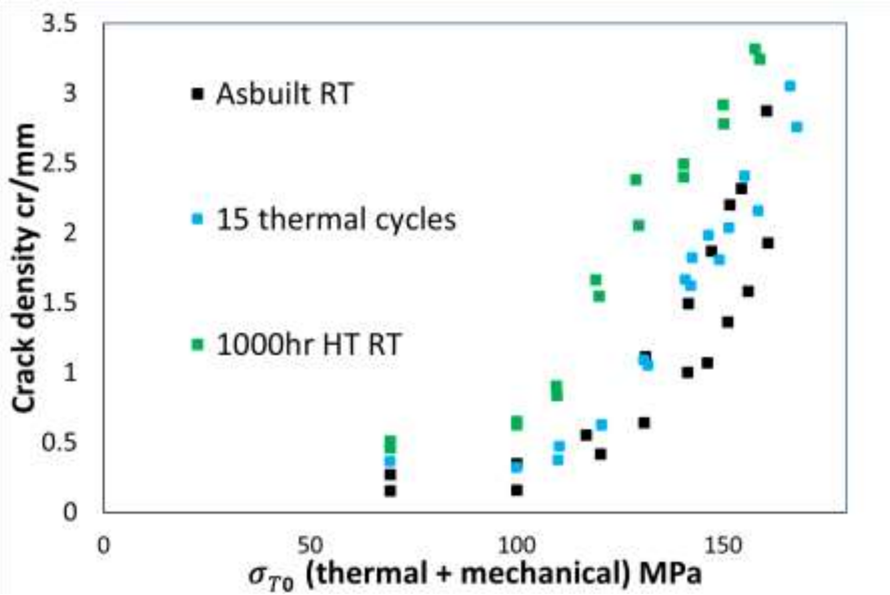




ET = 150℃
HT = Iso-thermal ageing at 150℃

Heat Treated Specimens Static Tested at Room Temperature

Plate 4: [0/90/0/90$_{0.5}$]s; 90-layer thickness=0.16mm; Vf=57%



RT → 150℃ → RT
25 minutes at 150℃

≫25minx15cycles=6.5hrs

HT = Iso-thermal ageing at 150℃

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Statistical modelling

Different fiber clusters (with stress concentrations) in different positions; different failure stress in different positions

Initiation of cracks at edges

Weibull distribution

Quasi-static tensile loading: $P_f = 1 - exp\left(-\left(\frac{\sigma_T}{\sigma_0}\right)^m\right)$

Shape parameter $m = 3.3$
Scale parameter $\sigma_0 = 142\ MPa$

Assumptions:

σ_0 depends on temperature and conditioning, $\sigma_0 = f(stress, temperature, time, \dots)$

At reference temperature and condition (at room temperature and as-built condition), Scale parameter is σ_0; otherwise scale parameter is $\sigma_0^* = \sigma_0 * k_1 * k_2;\ k_1 = f(test\ temperature),\ k_2 = f(heat\ treatment)$

When heat treated specimens quasi-static tested at an arbitrary temperature,

From empirical fitting,

$k_1 = 1 - c * \Delta T; c = 0.002$

$\Delta T = T_{test} - T_{Ref\_T}$ (difference between test and reference temperature)

$k_2 = 0.89$; for 500 hours at 150℃
$k_2 = 0.82$; for 1000 hours at 150℃

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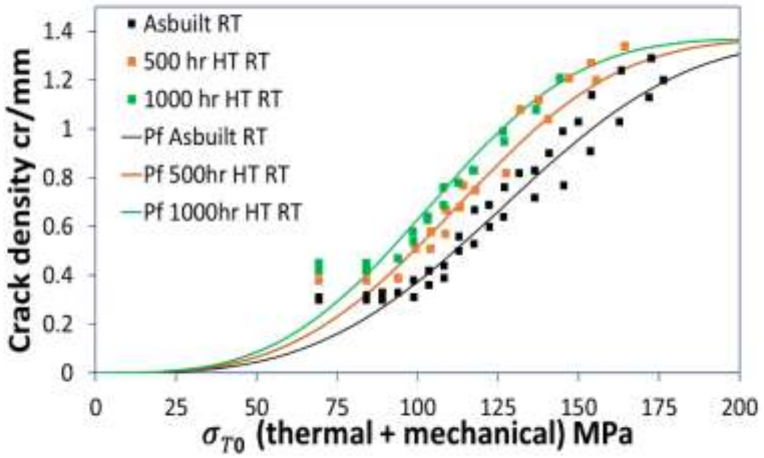
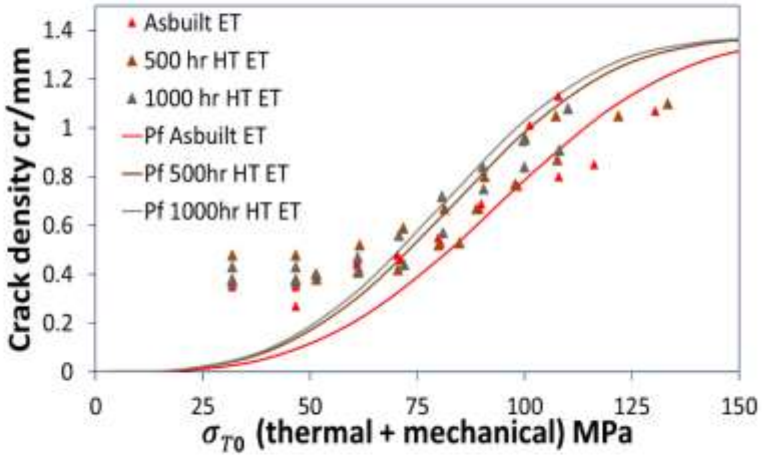
Prediction – Plate 2

Plate 2: $[0/90_2]_s$; 90-layer thickness = 0.73mm; Vf=52%





Scale parameter $\sigma_0^* = \sigma_0 * k_1 * k_2$

$k_1 = 1 - c * \Delta T;\ c = 0.002$

$k_2 = 0.89$; for 500 hours at 150°C

$k_2 = 0.82$; for 1000 hours at 150°C

ET = 150°C

HT = Isothermal ageing at 150°C

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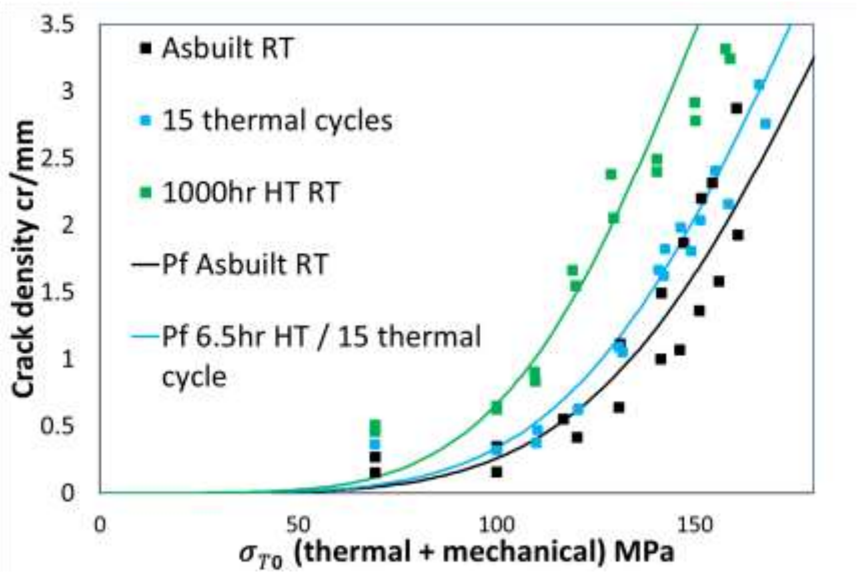
Prediction – Plate 4

Plate 4: [0/90/0/90$_{0.5}$]s; 90-layer thickness=0.16mm; Vf=57%

From as-built specimens quasi-static tested at room temperature,
Shape parameter $m = 4.87$
Scale parameter $\sigma_0 = 190.41\ MPa$



Scale parameter $\sigma_0^* = \sigma_0 * k_1 * k_2$
$k_1 = 1$
$k_2 = 0.95$; for 6.5 hours at 150℃
$k_2 = 0.82$; for 1000 hours at 150℃

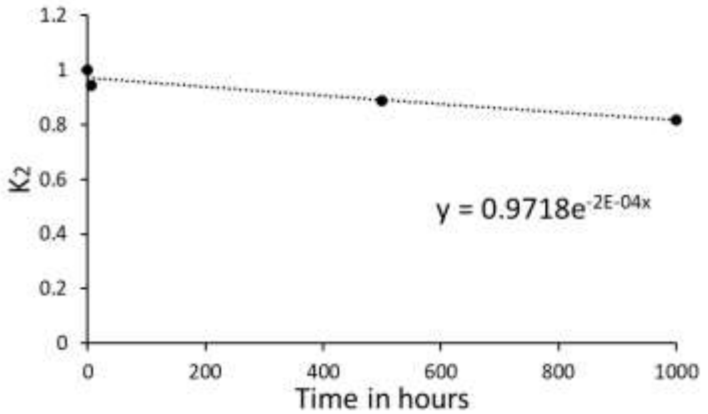
HT = Isothermal ageing at 150℃

k_2 degradation

$$k_2 = f(material, temperature, time, ageing\ ambience \ldots)$$

Assumption: When iso-thermal ageing (at 150℃) with air, for the tested material system, k_2 degradation can be described in terms of ageing time.

Remains to be studied in the future



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Conclusion

- Transverse cracking resistance has decreased in laminate when quasi-static tested at elevated temperature.
- Thermal cycling influenced crack density growth however negligible effect was found in transverse cracking resistance when quasi-static tested.
- Isothermal ageing significantly affected the transverse cracking resistance when quasi-static tested.
- Weibull failure stress model with k_1 and k_2 in scale parameter predicted crack density growth in all tested specimens with good agreement.

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Master thesis student: Alessia Cardin

***LUNA Project** – Life and durability prediction of aero-engine composites*