ESA Clean Space Industry Days – 10 to 13 October 2022

EXPERIMENTAL DEMISE STUDY OF NOVEL MATERIALS COMBINATIONS FOR SPACECRAFT STRUCTURAL PANEL ASSEMBLIES

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Context

Uncontrolled reentry events

Multifactorial global risk

- On-ground direct threat from planned or accidental uncontrolled reentering objects

Causes:

- Rising numbers of satellited objects, +400% in Q1 of 2022 compared to 2019
- Incomplete and inaccurate demise models for composite materials
- The use of of critically resistant materials for external panel and/or joining systems leading to shading and late demise exposure

CFRP element remaining from Crew-1 capsule trunk reentry - Australia, July 2022

nzherald.co.nz

space.com

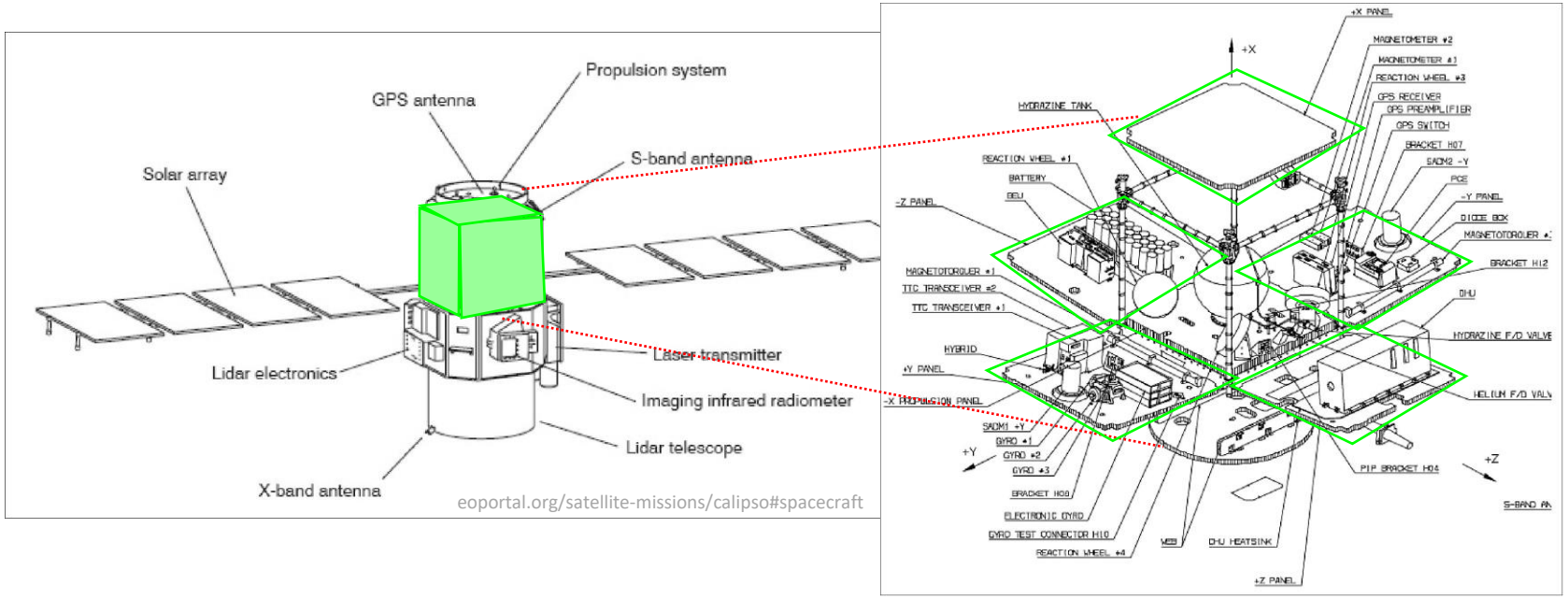
youtube.com/watch?v=s4x... Kcm8uj...

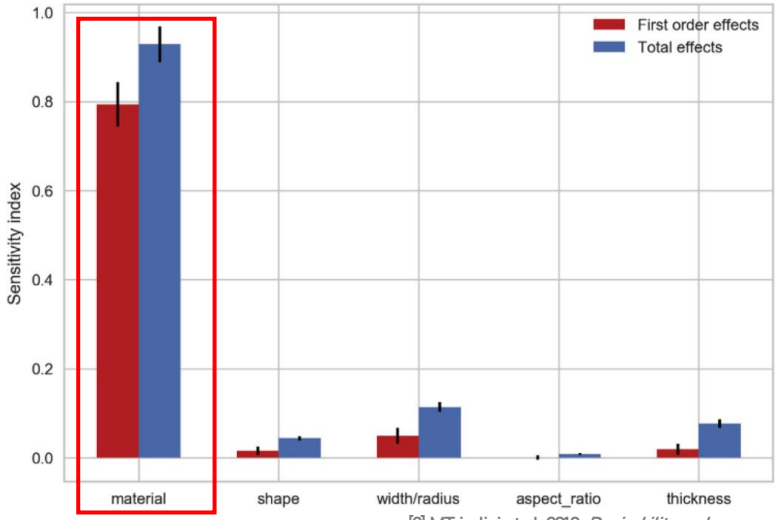
October 2021 over Michigan (USA) – Kosmos/2551 uncontrolled reentry

Ground impact probability is increasing everyday !
We need to act now to push for a sustainable space safety

Project Goal

D4D applied to S/C external sandwich panel

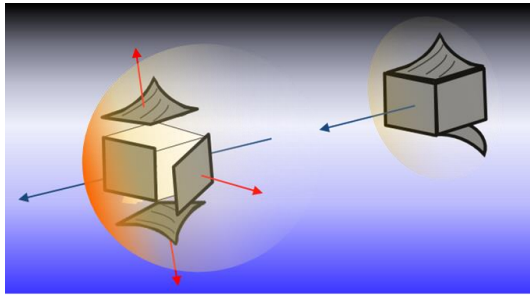




[2] MTrisolini et al. 2018, *Demisability and survivability sensitivity to design-for-demise techniques*

⇒ Highest impact on demise depends on <u>material selection</u> and <u>exposure altitude</u> parameters, MTrisolini et al. 2018 [2].

- Our project focus on material substitution of external panel by optimal demisable composite design



Project Goal

⇒ Improve <u>overall S/C demisability</u> by earlier demise/release of the external panels

Dual Approach

Novel composite design

Benchmark design = sandwich panel with through-thickness bolted joint insert system

Sandwich panel skin

BASELINE

Aluminium

Al2024-T81

NEW DESIGNS

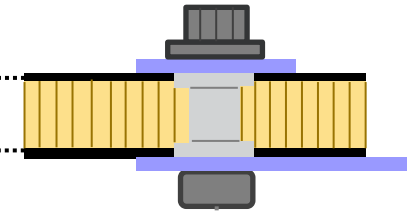
Reinforcement
- Carbon Fiber
- Flax Fiber
- Hybrids
  - CF/FF Tow-Tow
  - CF FF Ply-Ply

+

Matrix
- Thermoset - Epoxy
- Blend thermoset/thermoplast

+

Reactive Filler
- None
- AlMg µ-powder



Bolted fastener


Credits: RUAG Schweiz AG

BASELINE

Stainless steel
Ti-6Al-4V
Al 7075

NEW DESIGN

CF/PEEK

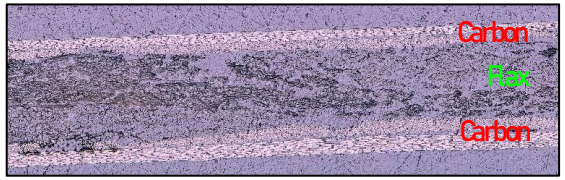
Continuous | Short Carbon Fiber
+
PEEK

- **Best Trade off between mechanical and demise performance**
  - Hybrid carbon + flax in a ply-by-ply configuration with AlMg µ-powder filled epoxy
  - Short carbon fiber reinforced PEEK bolt

Evaluation methods

Hybrid reinforced composite skin

CF+FF ply-ply hybrid

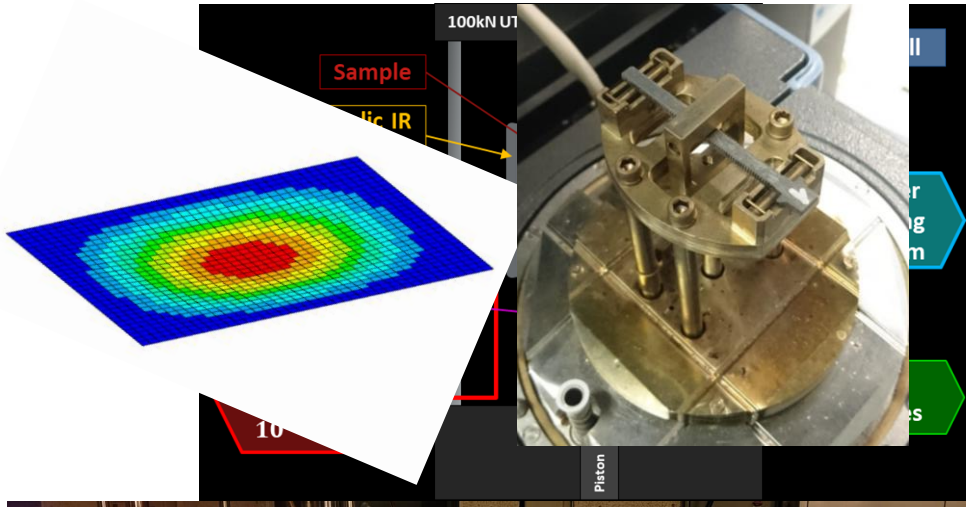


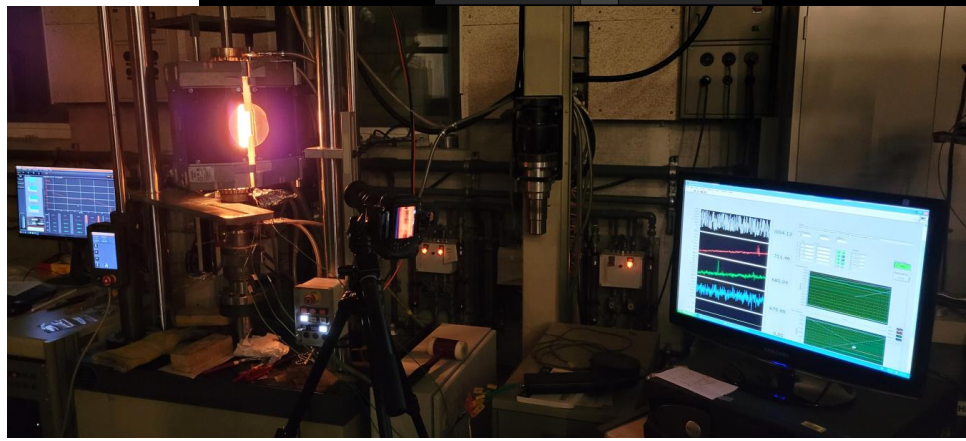
- **Thermomechanical evaluation** | EsaComp, Dynamic mechanical analysis - DMA
  - Stiffness/mass ratio: +117% improvement vs Al-2024 | +8% vs CFRP
  - Specific Elastic modulus (E'/ρ) : +45% vs Al-2024 | +31% vs CFRP

- **Demise evaluation** | TGA, Static reentry chamber with creep loading, PWT
  - 1%wt AlMg matrix filler integration:
    → 10-45°C earlier degradation onset (390°C -> 355°C with epoxy)
    → +10-50% degradation rate
  - Mechanical failure during static reentry test @370°C vs NO failure for CFRP up to 850°C

Self-developed static reentry chamber - 100kW/m2

DMA 3-point bending setup





Evaluation methods

Plasma Wind Tunnel testing

IRS PWK-4 wind plasma facility

Heat flux – 520 kW/m² | Ambiant pressure 41 Pa

CFRP

CF+FF ply-ply hybrid

CF+FF hybrid shows

- High ablation rate
- Faster CF tow erosion
- Full ply spallation due to the flax layer

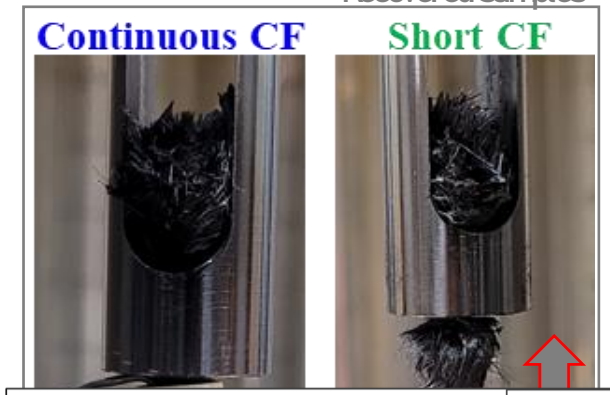
Evaluation methods

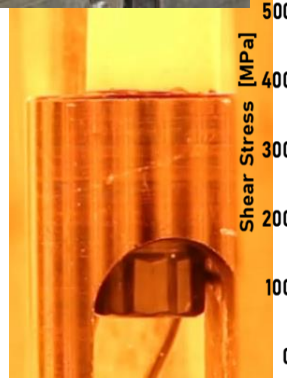
Short-CF/PEEK fasteners

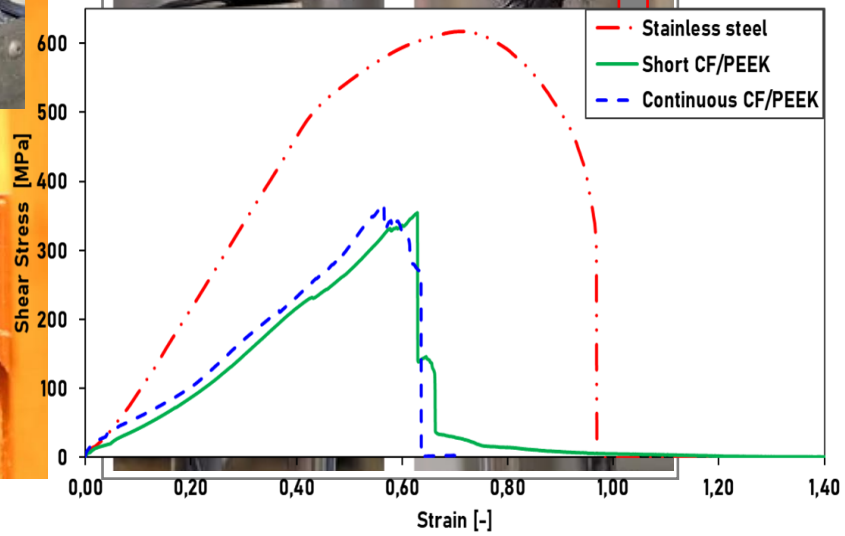
Static reentry chamber test

Single lap shear setup

Recovered samples

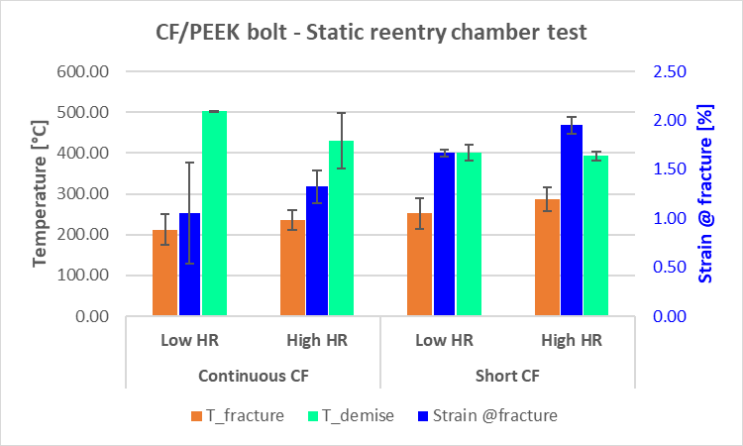






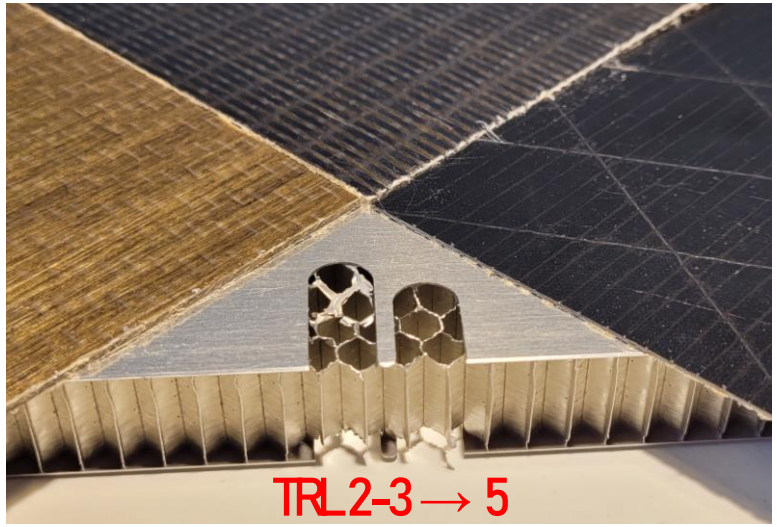
- **Thermomechanical evaluation** | DMA, tensile, shear testing
  - No significant differences in tensile and shear properties between continuous and short CF reinforcement
  - Specific tensile failure stress (σ_{UTS}/ρ) : +80% vs stainless steel
  - Specific shear failure stress (τ_{USS}/ρ): +295% vs stainless steel

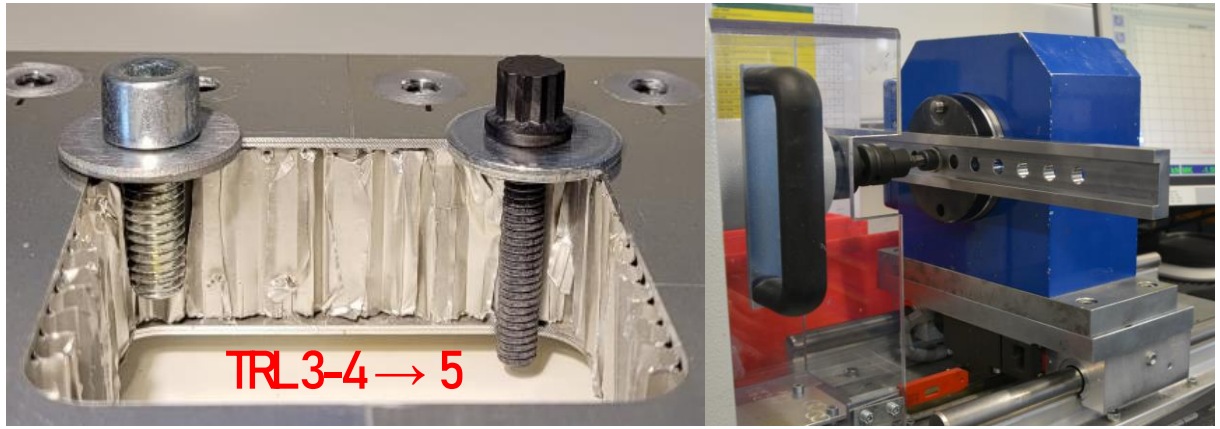
- **Demise behaviour evaluation** | TGA, Static reentry chamber with creep loading
  - High heating rate induce higher failure temperature
  - Higher strain at fracture with short fiber +30%
  - Complete bolt separation with Short-CF design ⇒ Allowing panel release !



What's next ?

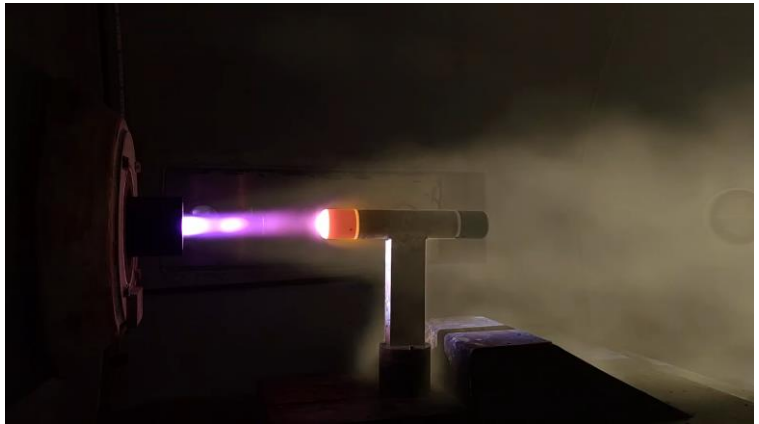
- Novel hybrid skin sandwich panel manufacturing
- Space qualification test (vibration, TVAC cycling)





- Composite fasteners Torque-Load evaluation
- Space qualification test (vibration, TVAC cycling)

- Increase novel assembly design TRL with PWT testing | highest environmental conditions relevancy
- Further development of an Experimental-to-Model correlation

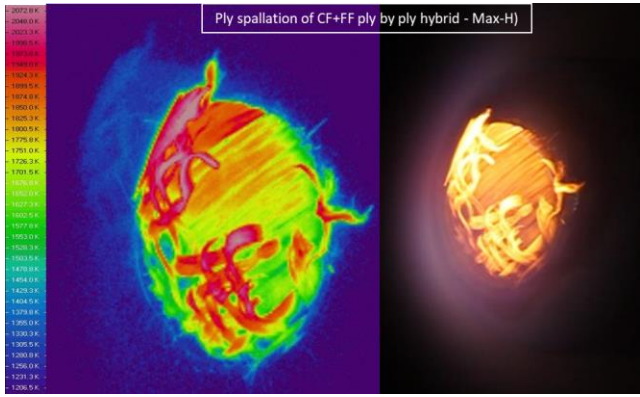


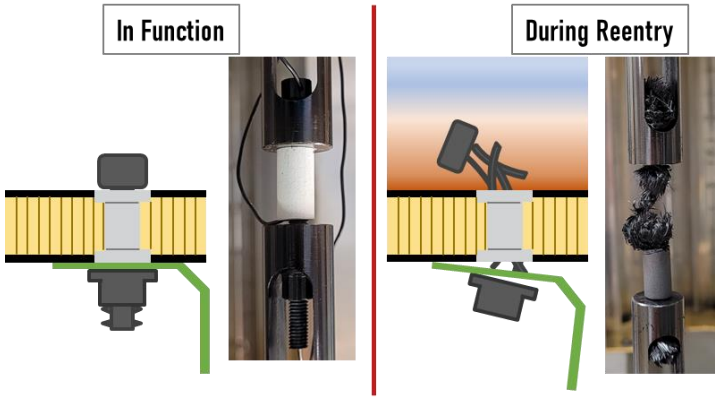
Conclusion

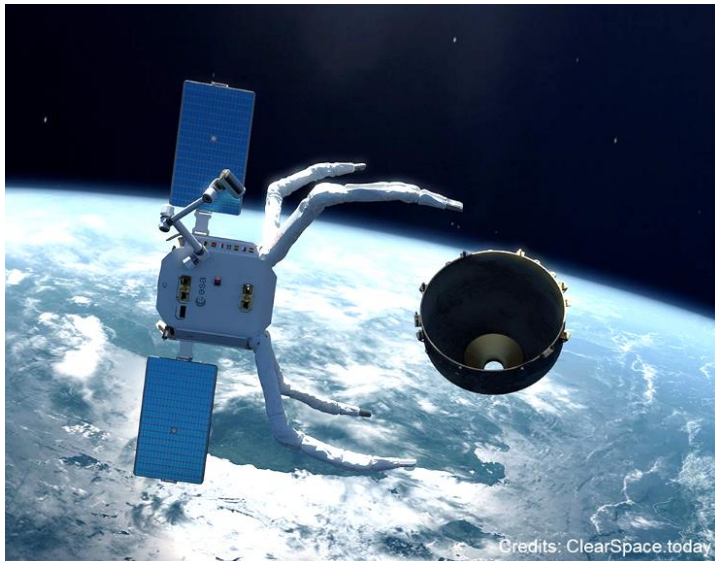
- Promising composite demise improvement with a combination of carbon and natural fiber (flax) in addition with active metallic filler

- An optimal short-CF/PEEK fastener design has been identified by comparative evaluations and relevant testing approaches to replace current critical baselines

- Safe and sustainable uncontrolled re-entries can be achieve by selecting and applying efficient material selection and break-up sequence.







Acknowledgments

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- LPAC team

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Adam Pagan

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Tank you for your attention !

Any questions ?

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Annexes

Evaluation methods

Demise testing

- Thermogravimetry analysis TGA – Thermophysical

  15 µg samples | 40°C/min heating rate | T sweep [30 ; 900]°C | Air or N2 atm | ASTM E1131-20

  ➢ Degradation onset temperature | Weight loss rate (T)

- Dynamic mechanical analysis DMA – Thermomechanical

  3point bending | 0.1% strain | 10°C/min heating rate | T sweep [-150 ; 350]°C | ASTM D4065-20

  ➢ Storage modulus (T) | Melting temperature onset

- Self-designed static reentry chamber with creep load – Thermo-physico-mechanical

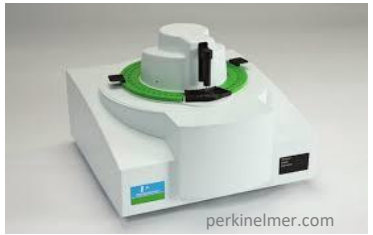
  2.9 kN creep preload | Heat flux up to 100 kW/m2 | medium vacuum 10^{-5} mbar | 3 high acquisition thermocouples | HD camera

  ➢ Full samples demise behaviour

  ➢ Mechanical loosening onset (T, t)

  ➢ Demise temperature onsets (t)

Perkin&Elmer TGA 4000



TA Q800 – 3pt bending setup