CRYOGENIC HYDROGEN STORAGE IN THERMOPLASTIC COMPOSITE VESSELS

A. R. Chadwick, L. Raps, S. Tröger, T. Guthoff

DLR

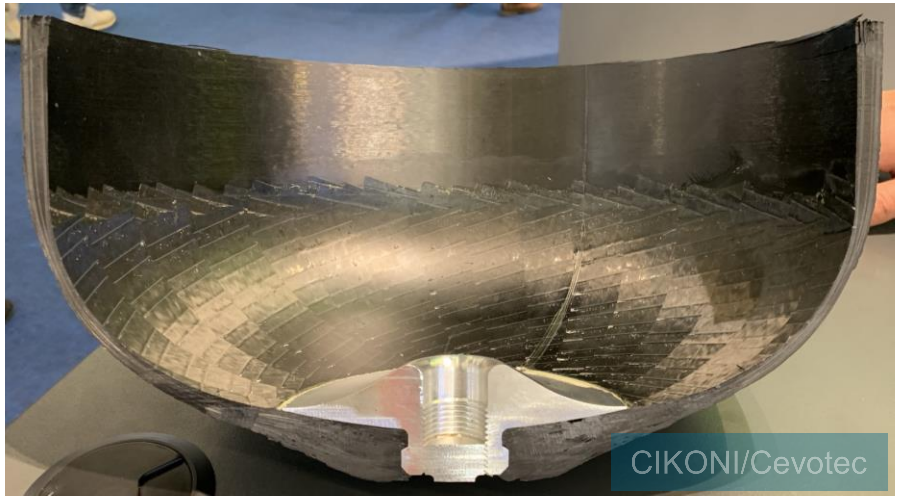
HYDROGENISATION GLOBALLY

Portrait of a Hydrogen Tank

- Efficiency currently limited by storage method, i.e. high pressure

P [MPa]	ρ_{H2} [kg/m^3]	c_g [%]
35-70	30-40	<7

- To **lower pressure-stresses** and **increase storage capacity**, **cryogenic storage** seems like „logical“ progression
  - **ρ_{H2} ~ 70 kg/m^3**
  - **P < 0.5 MPa**
  - **T = -253°C (20 K)**
- However, permeability and low-temperature properties remain critical to vessel success.



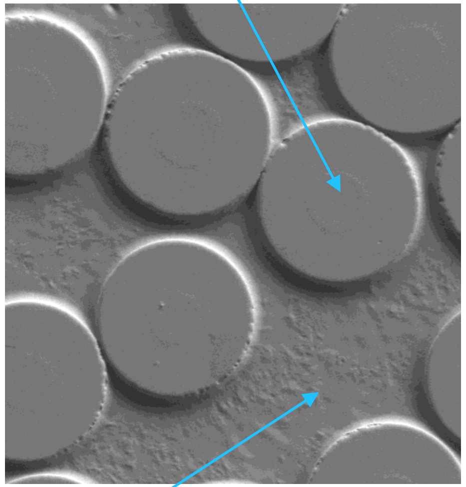
[CompositesWorld, 2022]

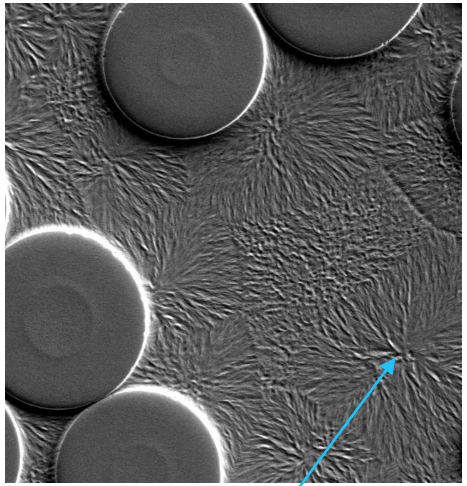
Literature Permeability and Low-temperature Properties

- Various studies since 1961

Permeability

Fibre content [Humpenöder, 1998]
Fibre type [Flanagan et al., 2017]

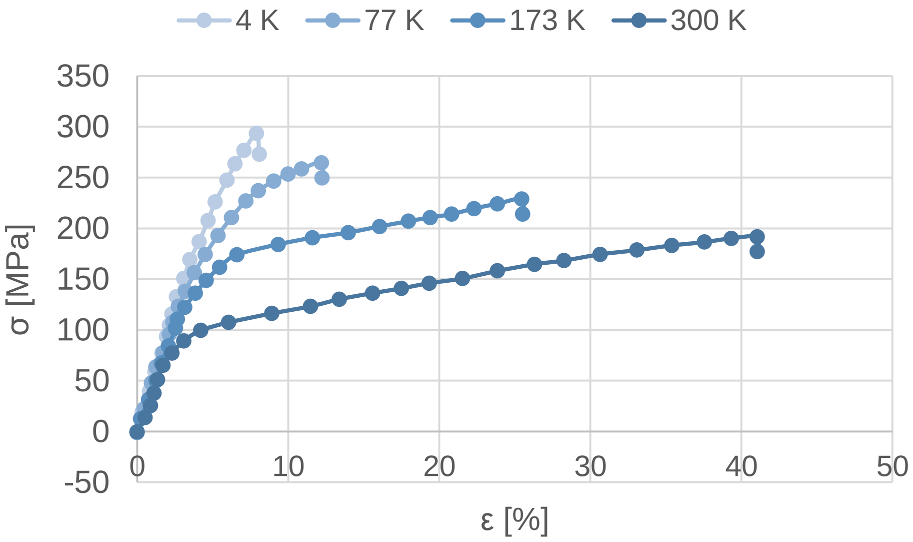




Polymer (amorphous) chain
[Su et al., 2021]

Crystallinity [Amanat et al., 2011]

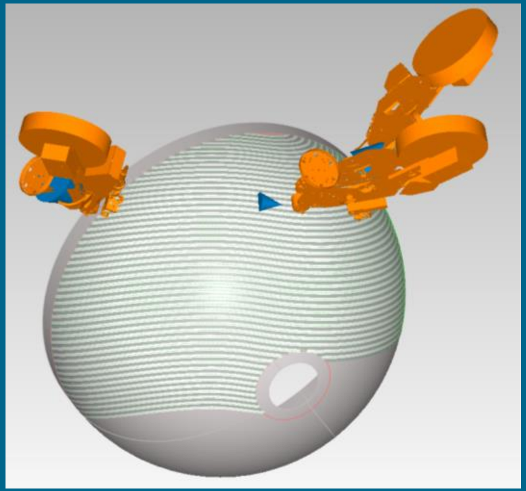
Low-temperature Properties



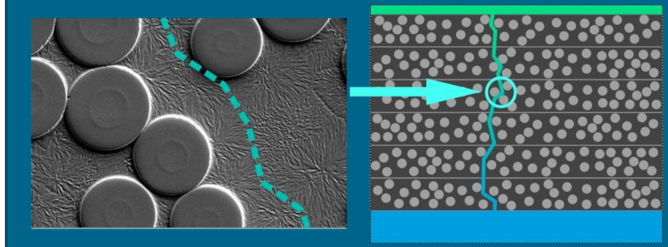
Effect of low temperatures on strength and strain of PPS
[recreated from Yano and Yamaoka, 1995]

Scope of DLR Activities

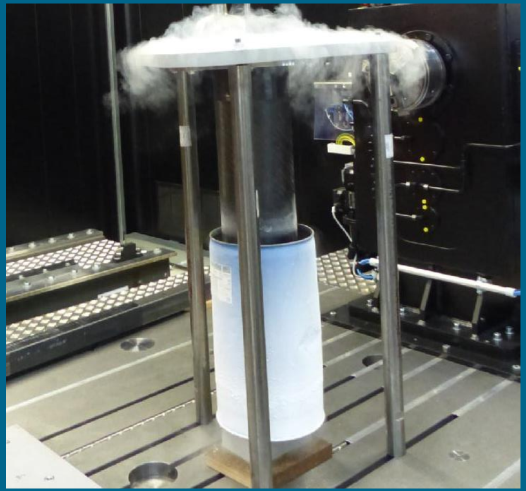
Achieving complex geometries



Permeability of high-performance thermoplastic composites



Influence of low temperatures



Scope of DLR Activities

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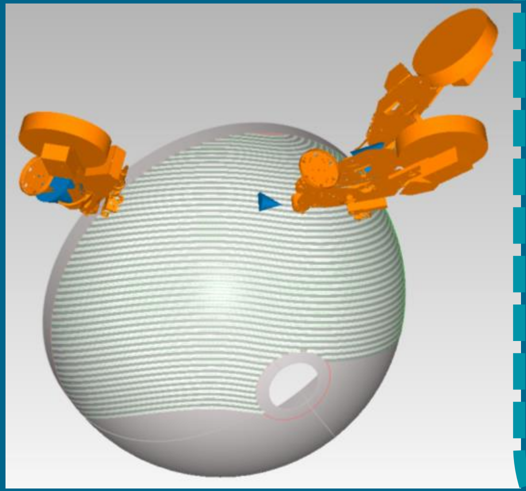

Lukas Raps
HH:MM
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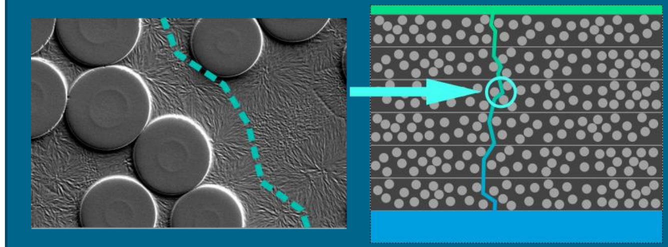
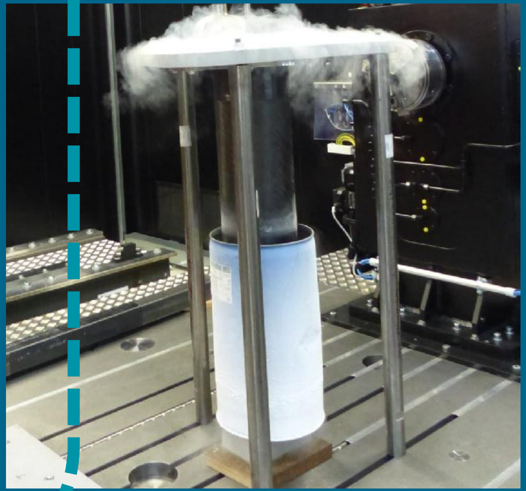
Permeability of high-performance thermoplastic composites



Today‘s topic

Influence of low temperatures



Simon Hümbert
HH:MM
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Fynn Atzler
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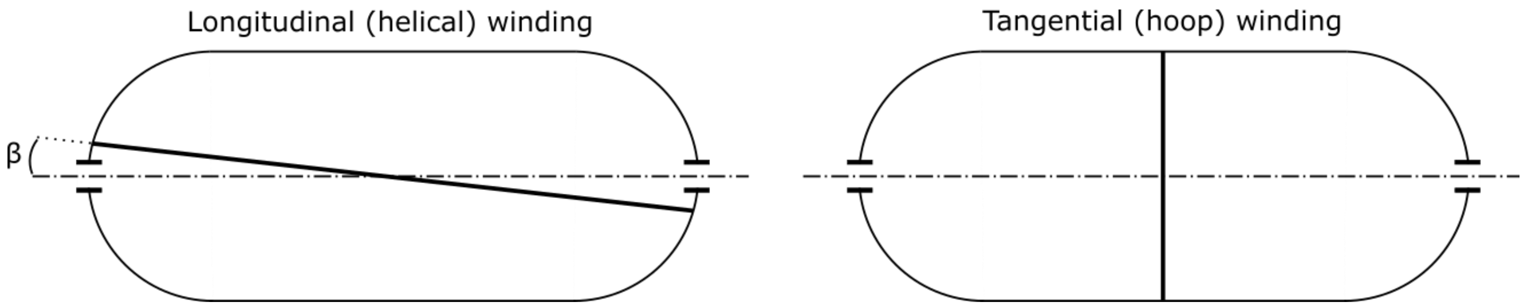
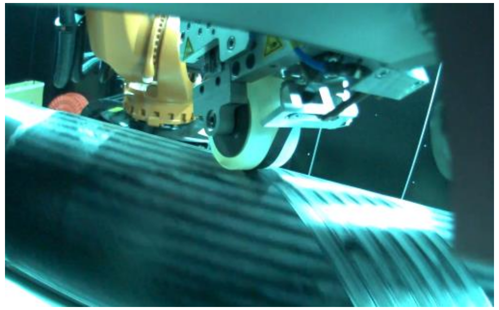
Manufacturing Hydrogen Storage Vessels

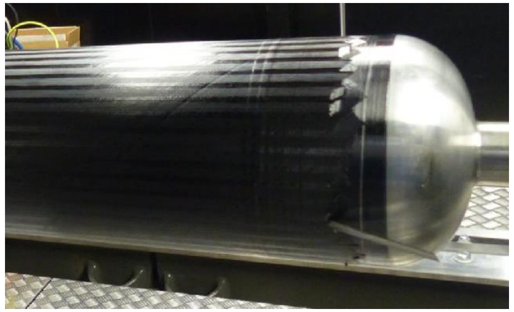
- Winding and infiltration – thermoset state-of-the-art

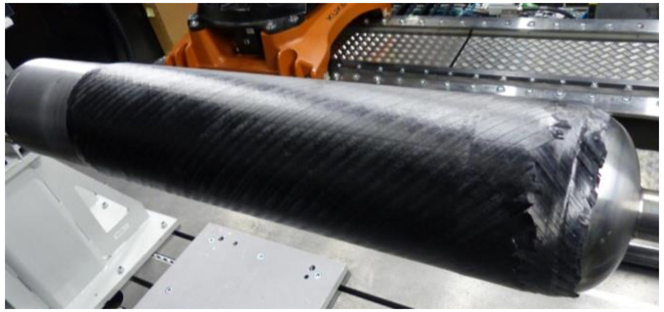


→ Infliltration → Autoclave cured

- In-situ layup – Disruptive thermoplastic technology







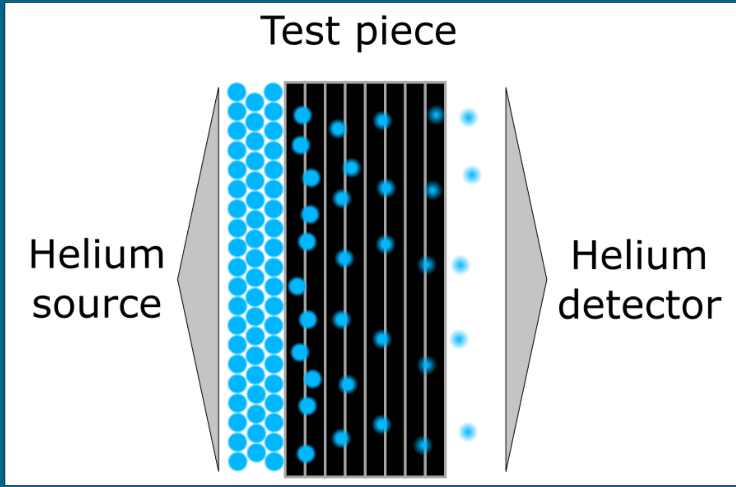
→ In-situ

→ In-situ + consolidation

Scope of Permability Study

- Manufacturing
  - In-situ AFP
  - In-situ AFP + consolidation
- Layup
  - $[0,45,90,-45]_{2s}$
  - $[0]_{12}$
- Prepreg
  - 60%
  - 55%
- Polymer
  - LM-PAEK
  - PPS

Permeability facility

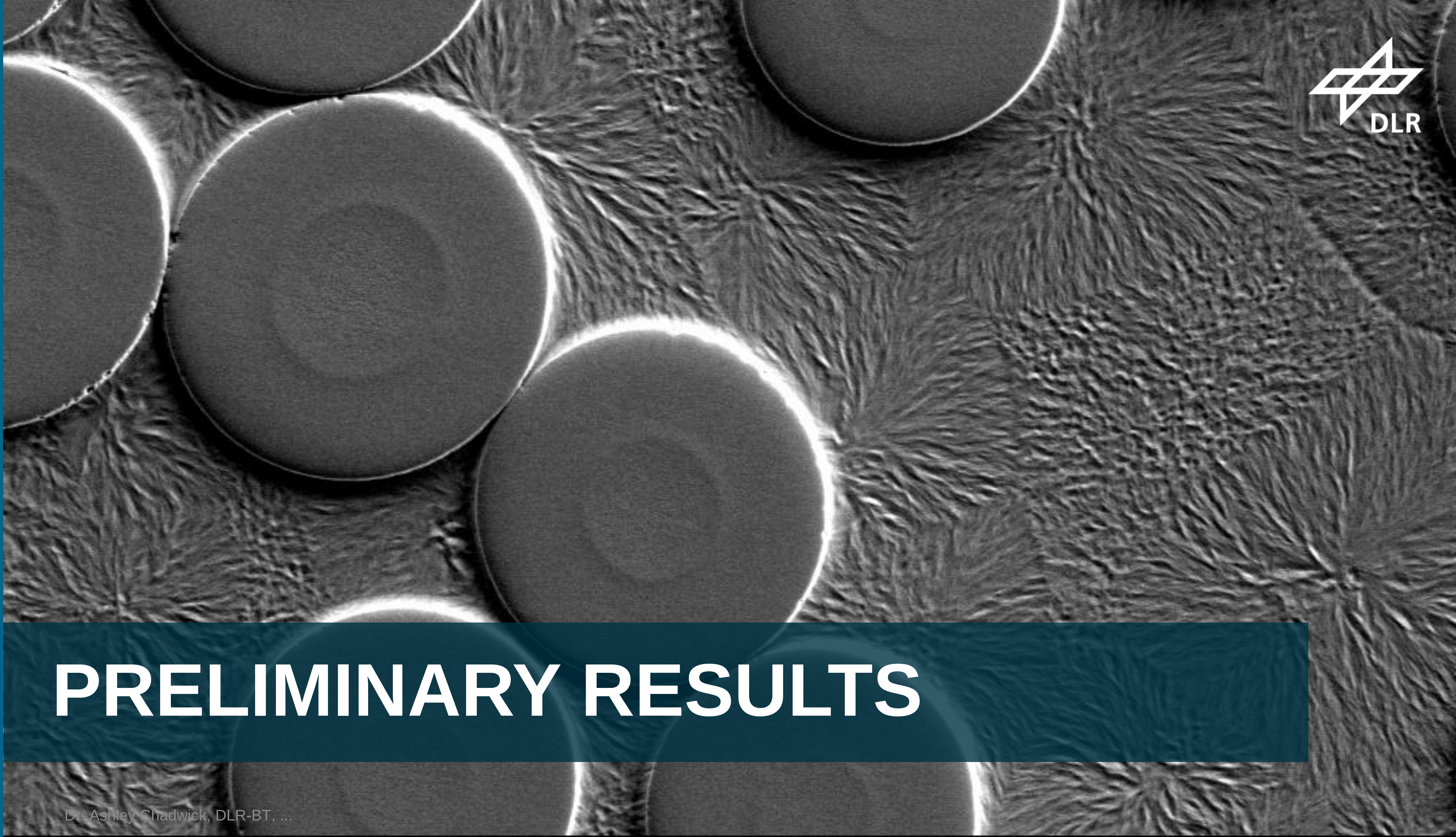


Supporting measurements

DSC

Microscopy

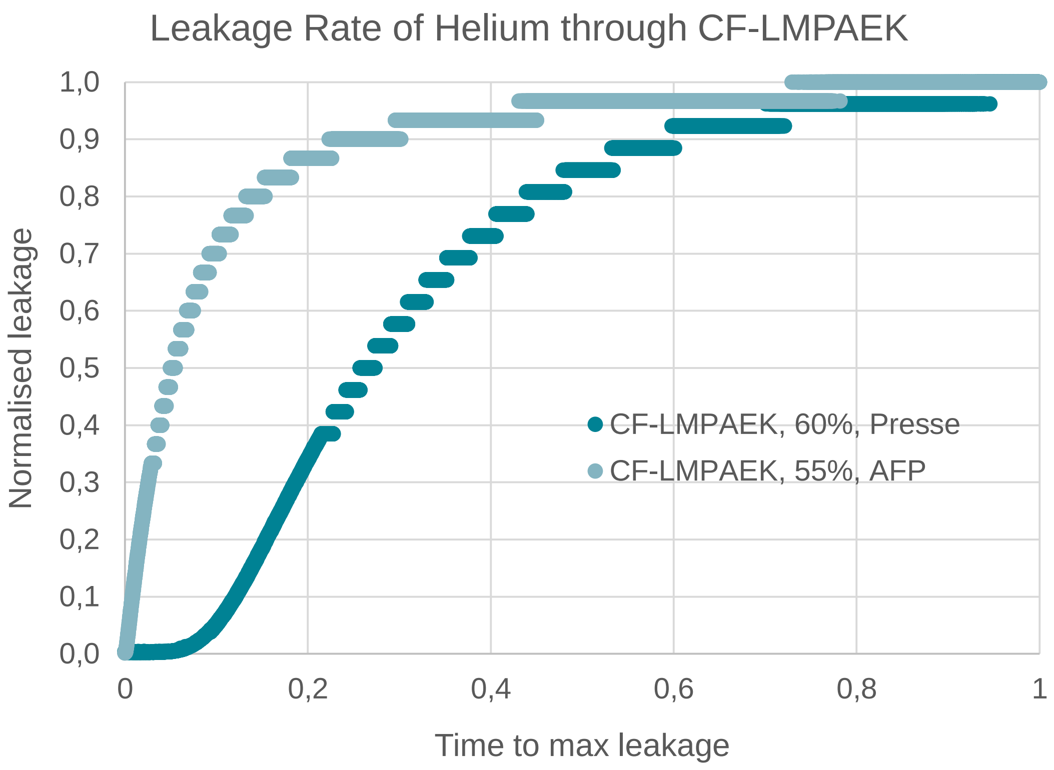
µCT



PRELIMINARY RESULTS

Preliminary Results – Permeability

- 5 bar (~ 5E5 Pa)
- RT (~ 295 K)
- Fickian/Non-Fickian behaviour
- Time to peak value
  - 25-30 Hr
- Conversion of He to H_2
  - [Humpenöder, 1998]



Preliminary Results – Permeability

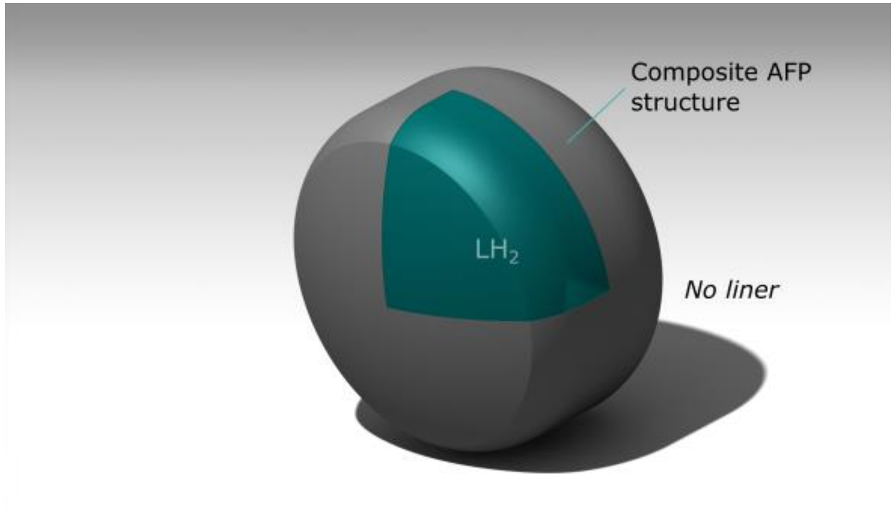
- Room temperature measurements as of 19.05.2023

	P [x10^{-16} mol.m/m^2.Pa.s]			
Config	**QI, normal**	**QI, thin**	**UD, normal**	**Literature**
Thermoset reference 60%	0,64	-	-	0,15
CF-LMPAEK 60%, press	0,61	-	-	0,42
CF-LMPAEK 55%, AFP	6,47	-	-	-
CF-LMPAEK 55%, AFP + press	-	-	0,36	-
CF-LMPAEK 60%, AFP + press	-	0,71	-	-

- mol.m/m^2.Pa.s?...

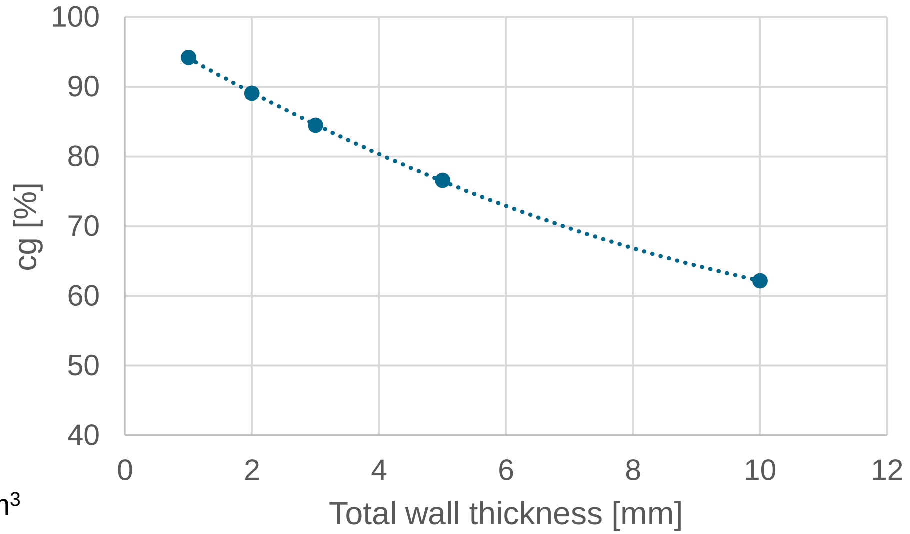
Preliminary Results – Permeability

- Reference tank:
  - ~Φ2300 mm (inner)
  - L = ~1670 mm (inner)
  - V_{H2} = 5.893 m^3
  - m_{H2} = 412.5 kg



- Reference tank:
  - Type-V (no liner)
    - No insulation
    - Single wall

d_{wall} [mm]	$m_{H2} + m_{tank}$* [kg]	c_g [%]
1	437.8	94.2
2	463.1	89.1
3	488.3	84.5
5	538.6	76.6
10	663.6	62.2



*Estimated laminate density = 1600 kg/m^3

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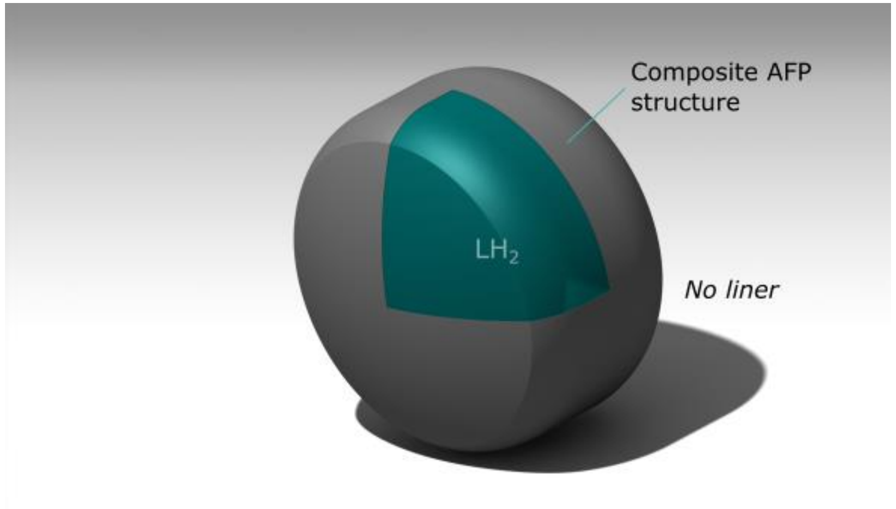

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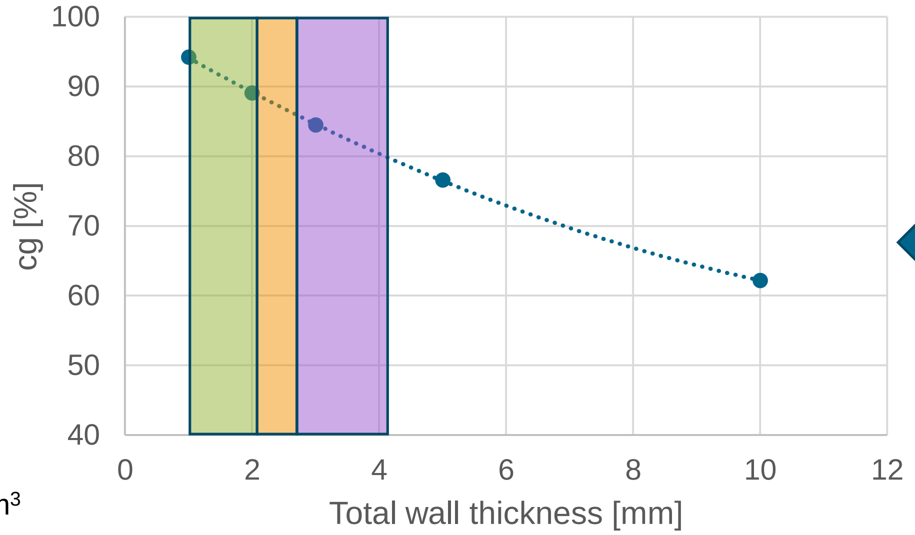

Supporting systems

Mechanical loads

Acceptable leackage

Preliminary Results – Permeability

- Room temperature measurements as of 05.05.2023

	P [$\times 10^{-16}$ mol.m/m^2.Pa.s]			
Config	**QI, normal**	**QI, thin**	**UD, normal**	**Literature**
Thermoset reference 60%	0,64	-	-	0,15
CF-LMPAEK 60%, press	0,61	-	-	0,42
CF-LMPAEK 55%, AFP	6,47	-	-	-
CF-LMPAEK 55%, AFP + press	-	-	0,36	-
CF-LMPAEK 60%, AFP + press	-	0,71	-	-

- **Still many measurements remaining**
- Interaction with **low temperatures** also crucial

Permeability at Cryogenic Temperatures – Next Step

- New facility
  - Φ100 mm (test)
  - d < 5 mm
  - 5E^{-10} Pa.m^3/s

Room Temperature

↓

Cryogenic

↓

Cycled


Other Ongoing Activities

Achieving complex geometries	Permeability of high-performance thermoplastic composites	Influence of low temperatures
Transfer of 3D geometries to 2D samples	Cryogenic/cycled permeability	Liner material investigations
Layup planning for different tank geometries and scales	Manufacture of cylinder test samples (Φ200mm x 400mm)	Cryogenic cylinder tests

THANK YOU; QUESTIONS?

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