Dissemination workshop

21th of September 2022

CETIM Nantes

THOR – DISSEMINATION WORKSHOP

	Presentation of THOR European project	21st of September
08.45 – 09.15 am	Welcome	
09.20 – 09.35 am	Challenges of H_2 tanks – Path for a solution adapted to usage	*Faurecia*
09.35 – 09.55 am	Presentation of Thor project – Consortium, role, and objectives	*Faurecia*
09.55 – 10.15 am	Materials aspect	Faurecia
Break		
10.35 – 10.55 am	Design and modeling strategy	*Sirris*
10.55 – 11.15 am	Safety of tanks in fire	*CNRS*
11.15 – 11.35 am	Fire detection sensor device	NTNU
Lunch		
12.40 – 13.30 pm	Visit of the thermoplastic winding equipment & samples	*Cetim workshop*
13.30 - 13.40 pm	Tank manufacturing	*Cetim*
13.40 - 13.55 pm	Validation of hydraulic tests	*RINA*
13.55 - 14.15 pm	Correlation from manufacturing to burst tests	*Cetim*
14.15 - 14.30 pm	Material characterization improvements for tanks	*Cetim*
14.30 - 14.45 pm	Recycling	*Cetim Grand Est*
14.45 - 15.00 pm	Tank performance regarding usage	*Air Liquide*
15.00 - 15.30 pm	All partner – roundtable : Next development for thermoplastic hydrogen tank.	*Cetim*
15.30 pm	Open discussions - networking	

Outlines

- Introduction – Objectives of the call
  - JTI-FCH-2018-1-3
  - Strengthening of the European supply chain for compressed storage systems for transport applications.

- Presentation of the THOR project
  - The partners
  - The goals

Challenges of H2 Tanks

JTI-FCH-2018-1-3 - RIA

Strengthening of the European supply chain for compressed storage systems for transport applications:

- Tanks for H_2 storage are key to enable the rollout of the fuel-cell mobility
- The 2013-01-3 call was launched to broaden the number of players to insure a quick take-off of the market

- **THOR** (Thermoplastic tank for Hydrogen Optimized & Recyclable) was built to respond to this point
  - Instead of developing a well known type IV concept, the bet of the consortium was to prepare a **Type V tank** (mono-material Carbon fiber reinforced composite).
- The challenge for the consortium was to well prepare the distribution of the H_2 in compressed gaseous state, by applying a technology allowing very low pressure in the tank (even under-pressure)
  - To facilitate the use of composite tanks for distribution without the risk of collapse
- Current type IV performances were expected (450 €/kg in 2030, burst pressure, Wt over 5.3 %)
  - Improved temperature range is also expected (-60 to 100 °C) for fast filling/emptying
  - Safety aspect was also to be looked on.

Challenges of H2 Tanks
JTI-FCH-2018-3-1 - RIA

The THOR project

- RIA on 36 + 9 months
  - Start the 1st of January 2019
- Initial budget : 2.85 M€
  - Budget was for a type IV tank
- COVESS was involved at the beginning of the project.
  - Was replaced by **CETIM Nantes** after the withdrawal of COVESS in M18
- COVID has delayed the project
  - No face to face meeting since 2020 ☹, no exchange for tests or prototype preparation

Challenges of H2 Tanks

JTI-FCH-2018-3-1 - RIA

The **THOR** consortium, industrial partners

- Faurecia, France - coordinator,.
  - Industrialisation & mass production aspect
- Air Liquide, France
  - End user for high pressure Hydrogen distribution
  - Expertise for the fuelling/defueling
- CETIM, France
  - Process definition with laser Assisted Tape Winding
  - Modelling and prototyping of tanks
- CETIM Grand Est, France
  - Recycling process
- RINA-CSM, Italy
  - Testing facilities of tanks

The **THOR** consortium, Research partners

- SIRRIS, Belgium
  - Modelling, winding definition and optimization
- NTNU
  - Optical fiber instrumentation, data analysis
- CNRS – PPRIME, France
  - Thermomechanical modelling and material behaviour in fire

Thanks for your attention

Material aspect

Work Package Leader: Faurecia

Participants: CETIM, Sirris

Outlines

Introduction – Objectives

Product overview

Process overview

Material selection

Product

step 1: Barrday tape PA11

step 2: Suprem tape PA12 “off the shelf”

step 3: Suprem tape PA11 “specific”

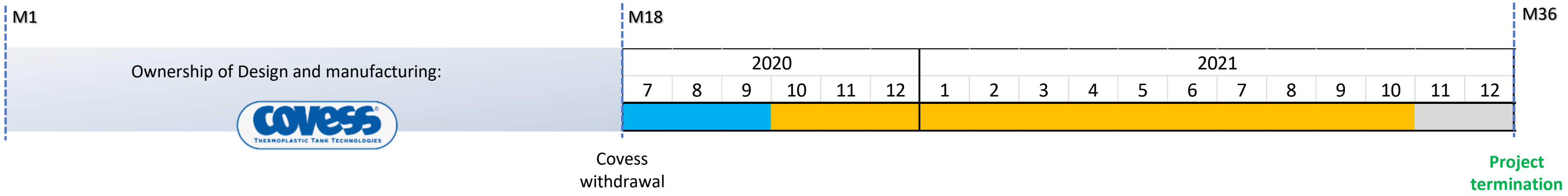
Conclusions

Introduction – Objectives

Design objectives

Develop a H2 composite pressure vessel:

- With 63L water volume, 700b NWP
- Monolithic structure (type V or 4.5) for transportation use case
- Thermoplastic matrix for recyclability
- Validate the Proof of Concept until pre homologability hydraulic + gas tests)



Because of Covess withdrawal, the project restarted at mid-term:

- From almost scratch due to lack of data sharing by Covess
- With CETIM as newcomer for manufacturing
- With SIRRIS – CETIM – Faurecia as new Design lead
- With only 50% time left and budget greatly reduced, and activities to restart

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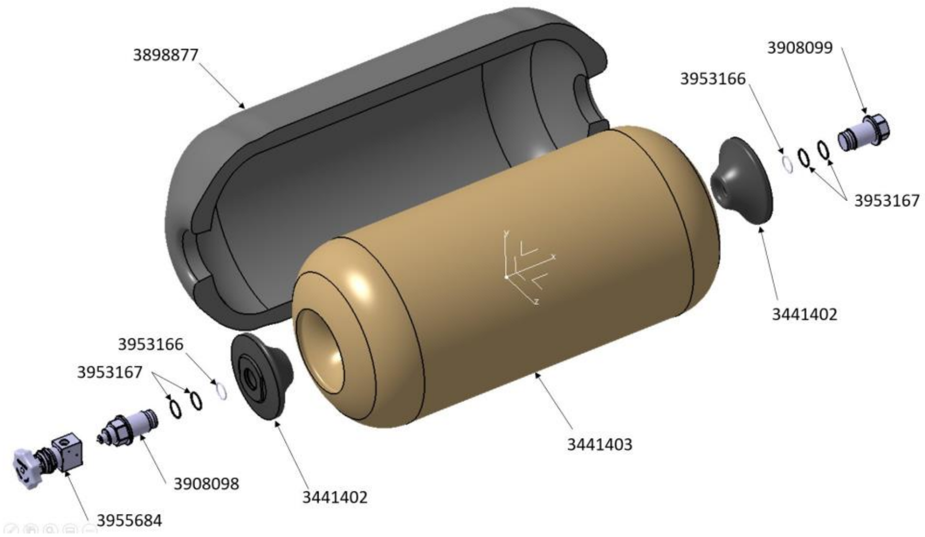
Product overview

Type IV CPV

Faurecia state-of-the-art type IV H_2 CPV as reference:

- Rotomolded liner with PA11 resin from Arkema
- Carbon fiber Toray T700
- Wet winding process with epoxy resin

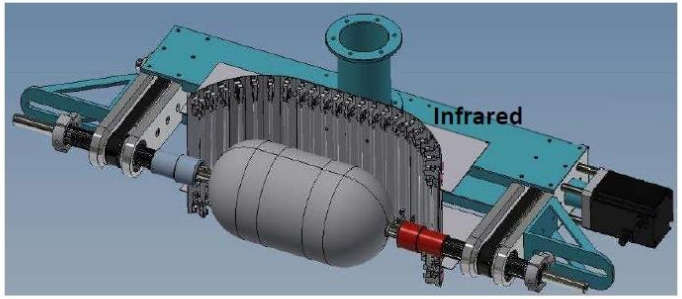


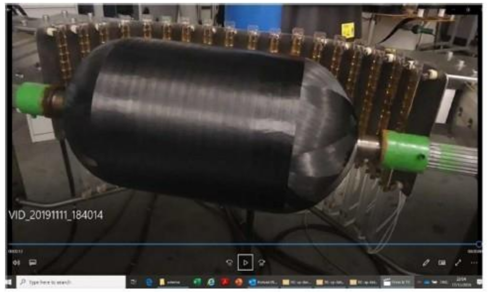
Part number	Name
3441403	**LINER**
3898877	**CARBON COMPOSITE – CARBON FIBER & RESINE**
3441402	**BOSS**
3953166	O-RING
3953167	BACK-UP RINGS
3908099	OUTLET PLUG
3908098	INLET VALVE ADAPTATOR
3955684	HIGH PRESSURE VALVE

Process overview

Process change COVESS to CETIM

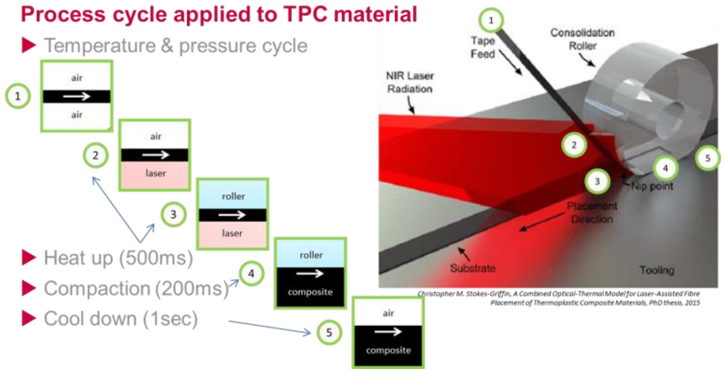
COVESS → tape winding with INFRARED heating

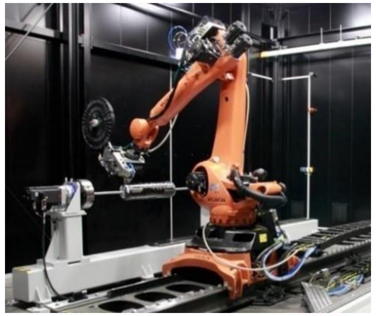


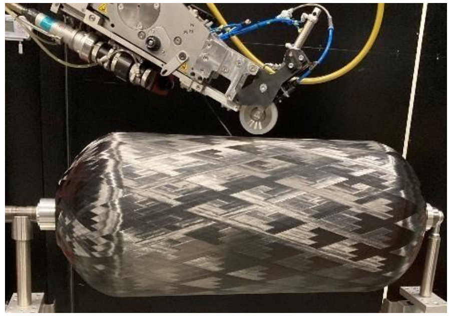


Process change COVESS to CETIM

CETIM → AFP (automated Fiber Placement) with laser







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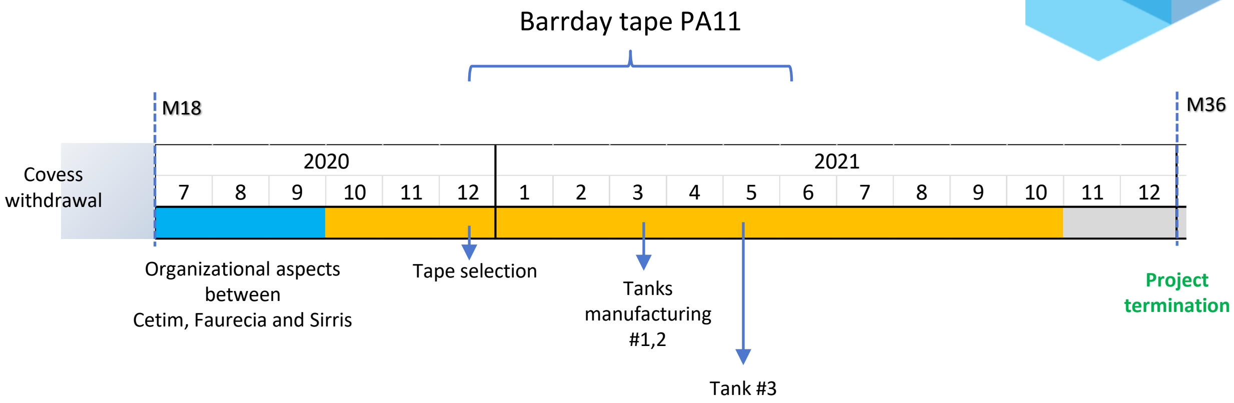
Material selection

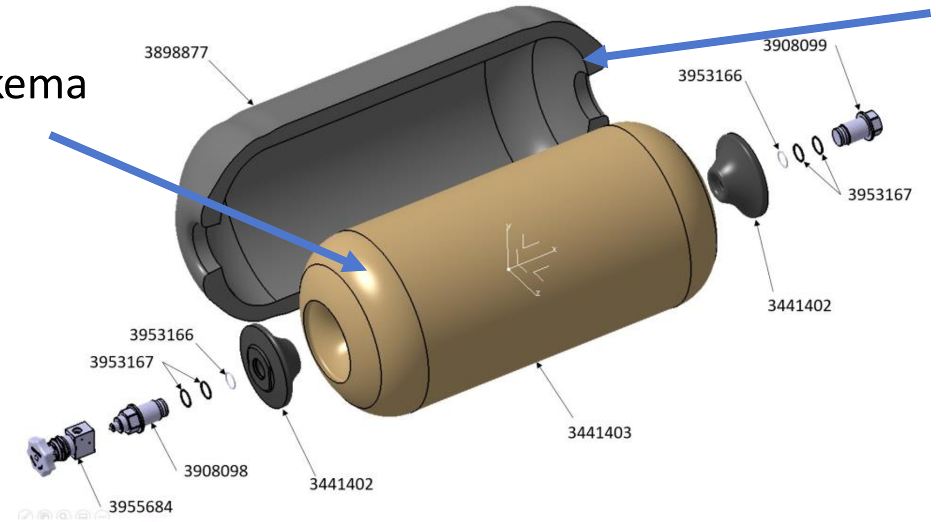
Product :

Specifications / Constrains of tapes:

- Compatible with Faurecia liner
- Compatible with CETIM Process
- Quickly available in the market



Liner: rotomolded PA11 from Arkema
→ unchanged



Support for sourcing: Arkema
→ Barrday tape
Arkema PA11/Toray T700

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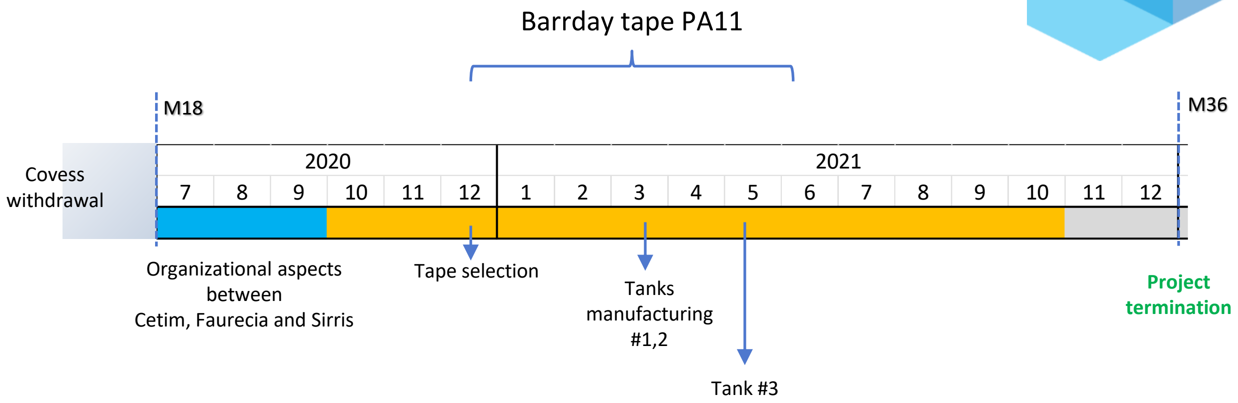
Material selection

Step 1 - Barrday tape PA11 :

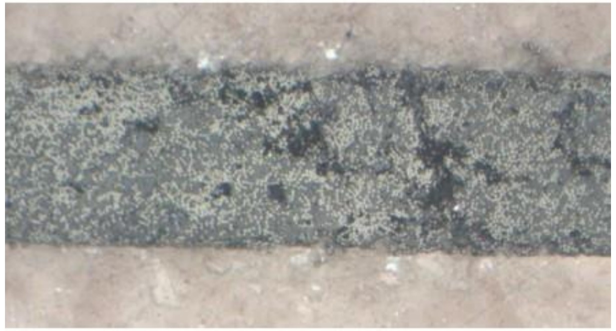
Quality not suitable for LA (laser assisted) AFP

- Tank #1: burst @738b << 1575b
- Tank #2: burst @350b after ASR (thermal ageing)
- Tank #3: not usable



Root causes:

- Poor homogeneity → low mechanical behaviour
- Dry tape surface → difficult to consolidate



Action:

- Sourcing of another tape mandatory

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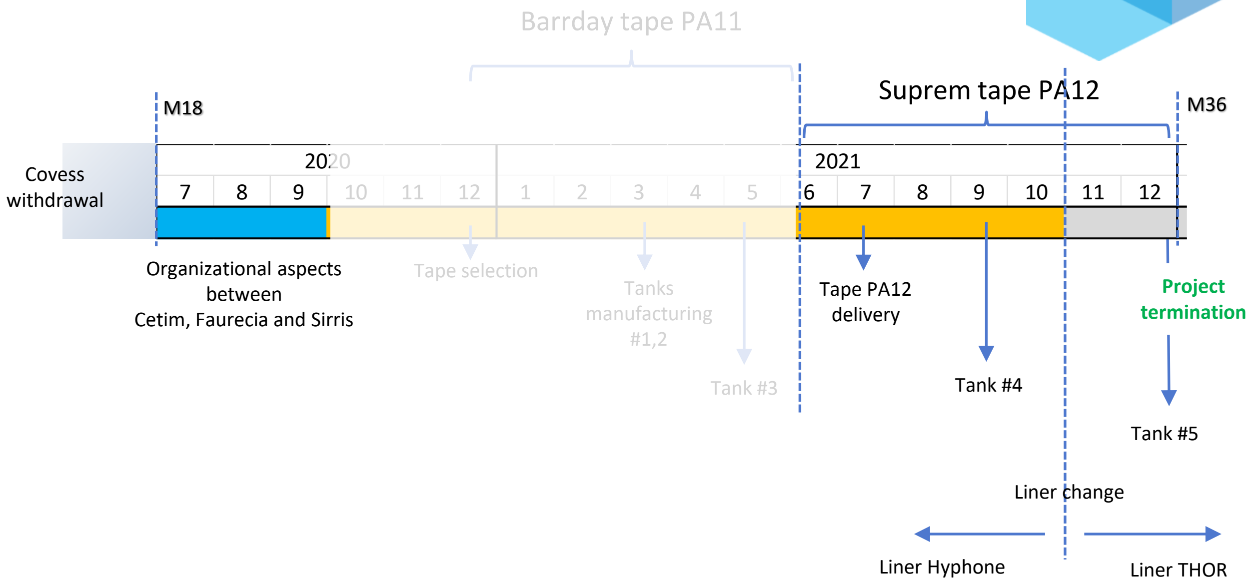
Material selection

<u>Step 2 - Suprem tape PA12 "off the shelf" :</u>

Tape already in the portfolio of Suprem
Specifications compatible with LA-AFP

- Tank #4: burst @1466b < 1575b
- Tank #5: burst @1477b < 1575b



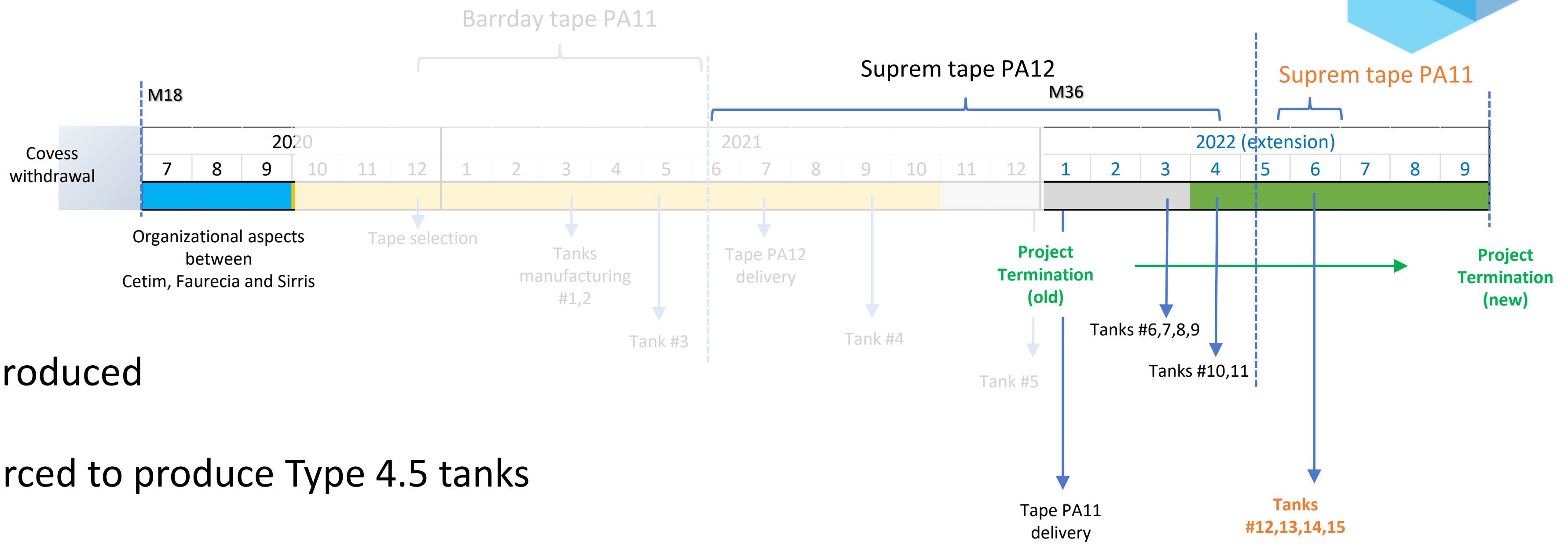
Reasonable burst pressure achieved with Suprem PA12 tape.
Still, some remaining questions:

- Validation plan (hydraulic + gas) not conducted
- Not really a Type 4.5 tank, despite of the chemical compatibility PA12/PA11

Next steps:

- THOR project extension to perform further tests
- Sourcing of "specific" PA11 tape from Suprem

Material selection



Project extension:

9 months extension granted

- Additional 6 tanks in PA12 produced
- Hydraulic tests conducted
- PA11 tape from Suprem sourced to produce Type 4.5 tanks
- 4 tanks in PA11 produced

Step 3 - Suprem tape PA11 “specific” :

Specifications compatible with LA-AFP

Conclusions

Initial objectives not achieved due to several unexpected events:
COVESS withdrawal, COVID pandemic, low quality material…

Material selection not well conducted, due to short remaining time and lower budget.

Main concerns:

- Behaviour of PA11 composite at high temperature 85°C
- Processability of PA11 as matrix for tapes to be used with LA-AFP

Take-aways:

- Best in class TP tanks produced, with a burst pressure close to 1500b
- Better understanding of LA-AFP limitations in CPV manufacturing and improvement directions for future material / Process

Design and modeling strategy

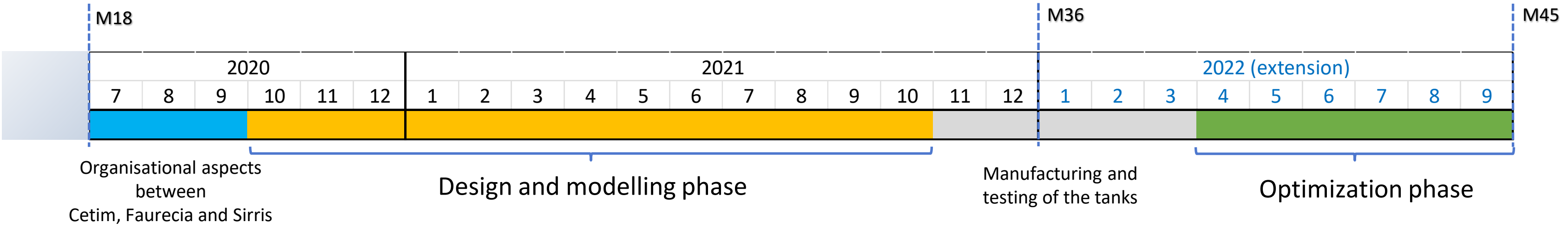
Work Package Leader: Sirris

Participants: CETIM, Faurecia

Introduction – Objectives

THOR

Product :



Type 4,5 63L composite pressure vessel for H_2 storage

Working Pressure : 700 bars

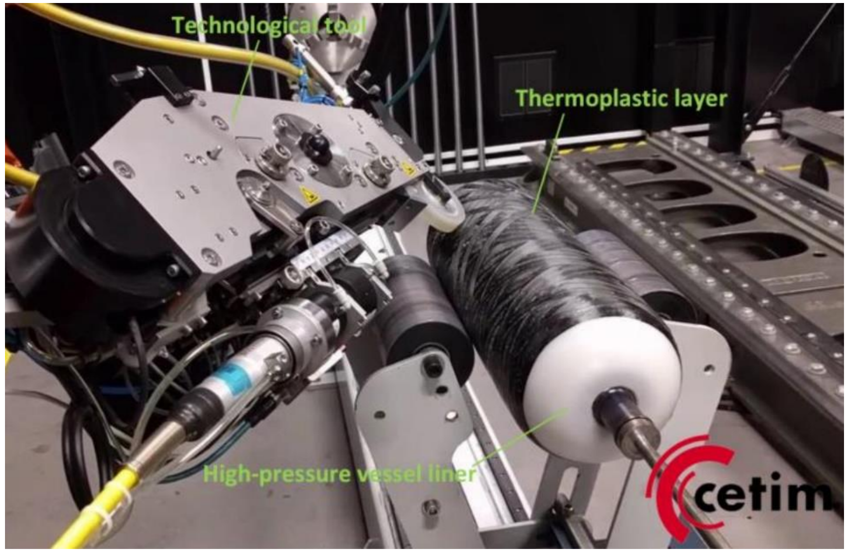
Test Pressure : 1575 bars (2,25 x SP)

Simulation Pressure : 1735 bars (1,10 x TP)

Design and modelling objectives

Provide a laminate sequence that

- Is based on TP composite material
- Can be manufactured with the tape welding technology available at CETIM
- Satisfies with the product requirements in terms of performances and safety aspects (failure mode in cylinder)



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Numerical chain & Inputs for design

WoundSIM

THE integrated intelligence for composite pressure vessels design and simulation

SIMULIA ABAQUS

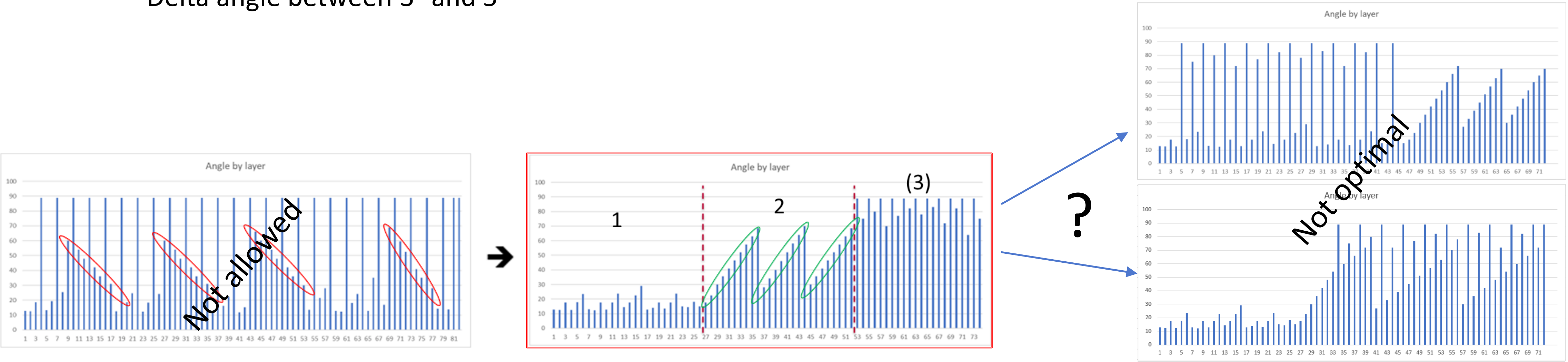
<u>Parameters involving the design phase of the laminate structure</u>

- Boss/Liner geometry (outer surface)
- Tape geometry : width & thickness
- Material properties

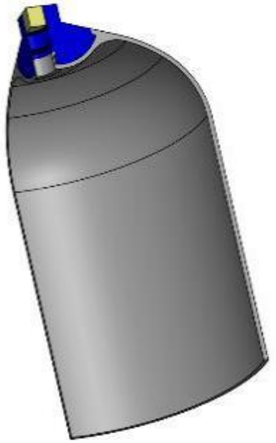
- *Amount of layers + Sequence of angles*

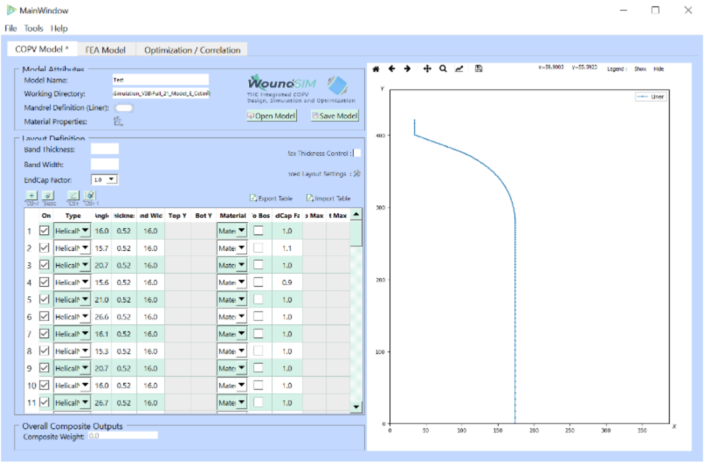
Manufacturing guidelines based on Cetim experience from previous/other projects

- Laminate sequence in blocks
- Increasing angles per sub-blocks
- Delta angle between 3° and 5 °



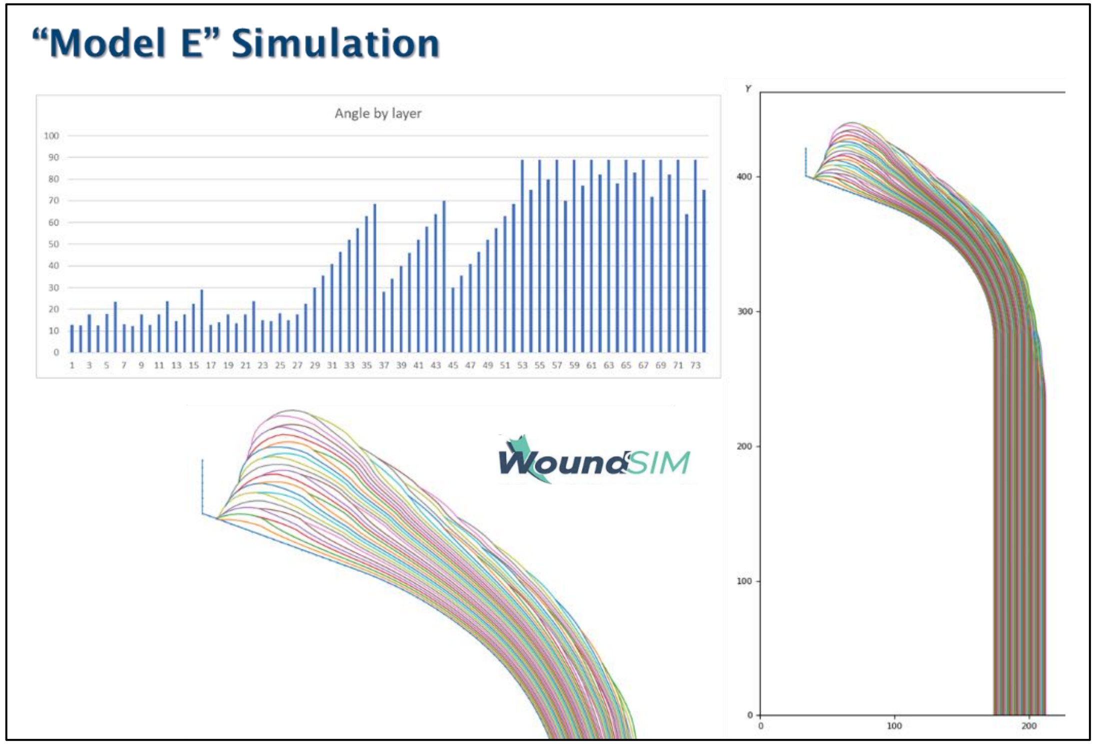
STEP 1 : Hyphone Liner/Boss - Tape PA11/CF





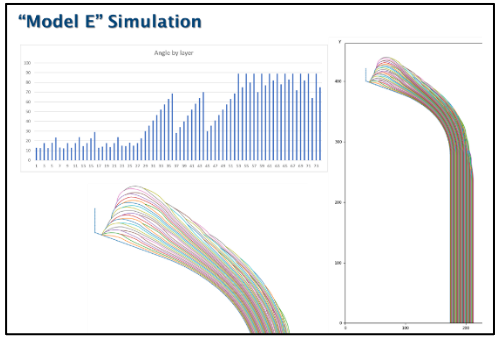
PA11/CF Tape - Datasheet			
Modulus	E1	120000	MPa
	E2	5000	MPa
	E3	5000	MPa
Strength in Fibre Dir	S11	1800	MPa
Interlaminar shear	S13/S23	60	MPa
Width		16,0	mm
Thickness		0,260	mm

After multiple iterations from a sequence proposed by Cetim

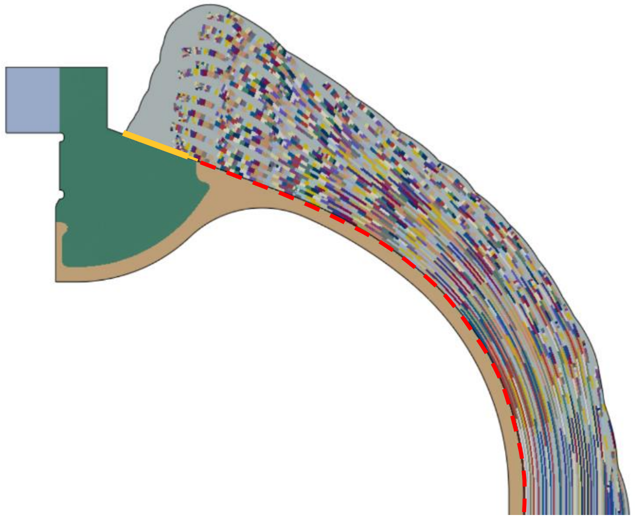


STEP 1 : Hyphone Liner/Boss - Tape PA11/CF

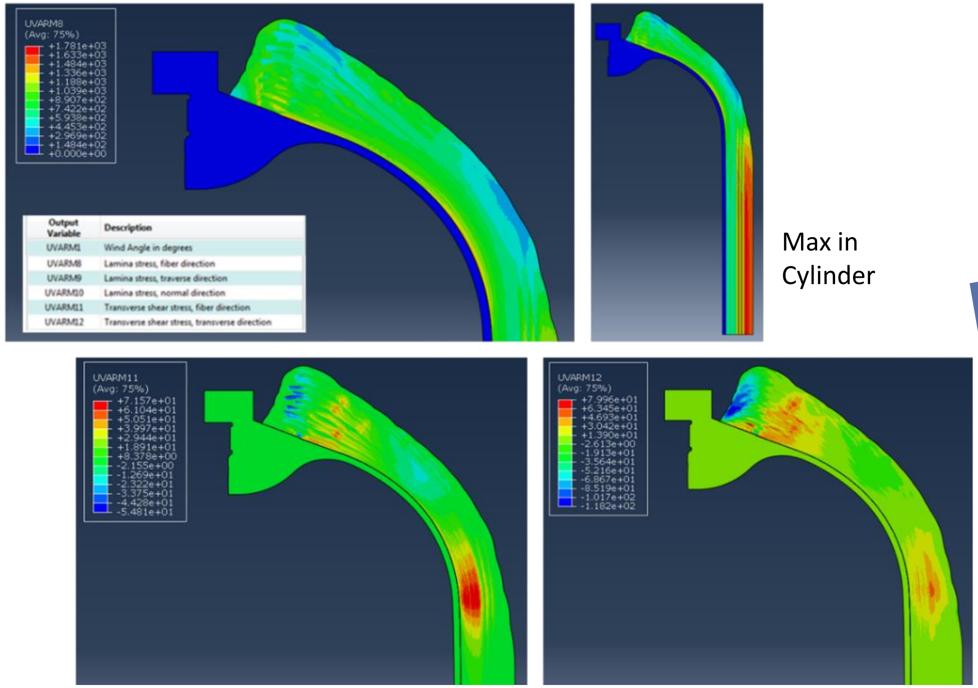
"Model E" Simulation



WoundSIM



SIMULIA ABAQUS



Max in Cylinder

Tank 1 Manufacturing + Burst test

	#layers	Predicted weight	Tensile/ Fibre_Dir UVARM8	Transverse Shear UVARM11	UVARM12
			Mpa	Mpa	Mpa
Model E	74	55,3 kg	1781	71,6	80
		Admissible limits	*1800*	*60*	

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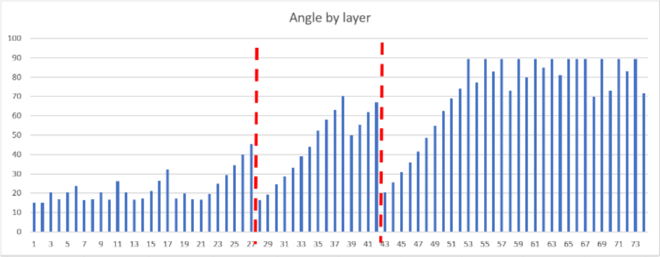
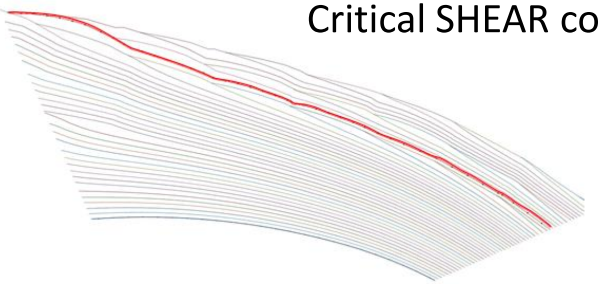
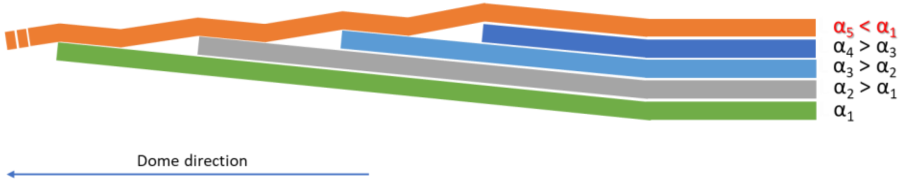
STEP 1 : Hyphone Liner/Boss - Tape PA11/CF

Experimental P_{burst} = 738 bars



Critical SHEAR configuration at block switch





Thermoset "fluid" behaviour vs. Thermoplastic Tape placement

WoundSim supposes full & perfect covering/embedding of the previous layers

Risk of porosity, cavity between layers

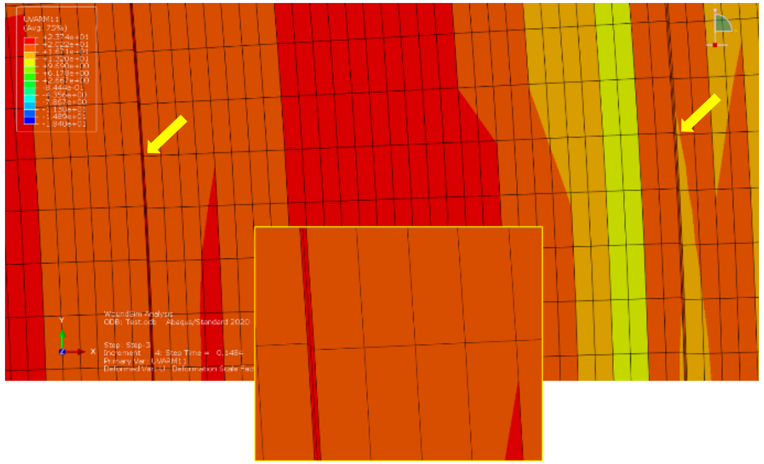
Very sensitive on the

- **process parameters** (temperature/compaction)
- **tape characteristics** (lateral stiffness)

➔ WoundSim not able to predict this critical SHEAR effect of laminates made of TP tapes

STEP 1 : Specific study on the shear behaviour

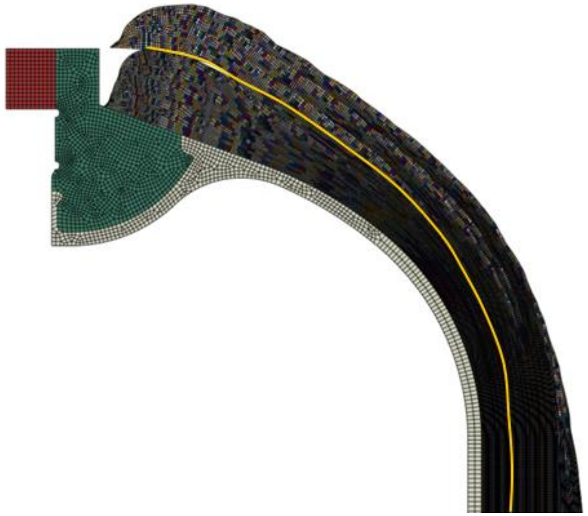
1/ Possible with a thin layer with poor properties ?



Simulations only possible till 700 bars
No significant influence the results in shear

➔ Not possible to predict the low P_{burst} value

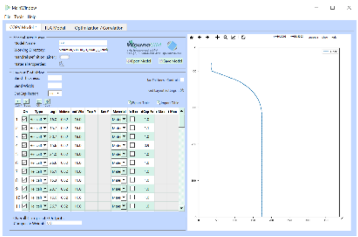
2/ Possible through the split of the laminate and use of contact boundaries ?



No significant influence the results in shear

➔ Not possible to predict the low P_{burst} value

STEP 2 : Hyphone Liner/Boss - Tape PA12/CF

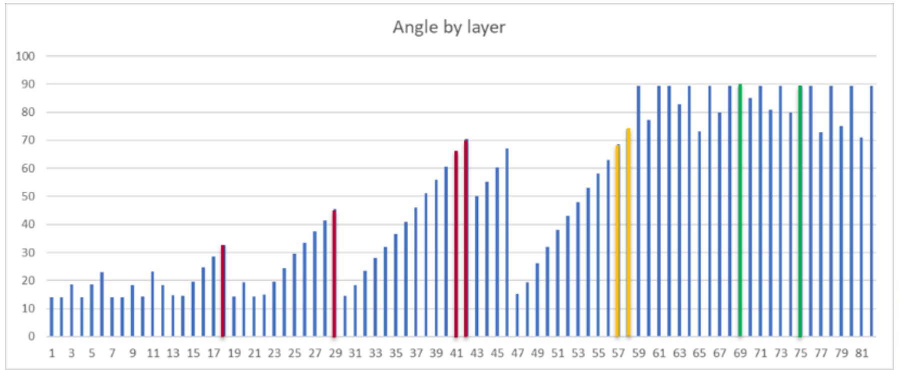


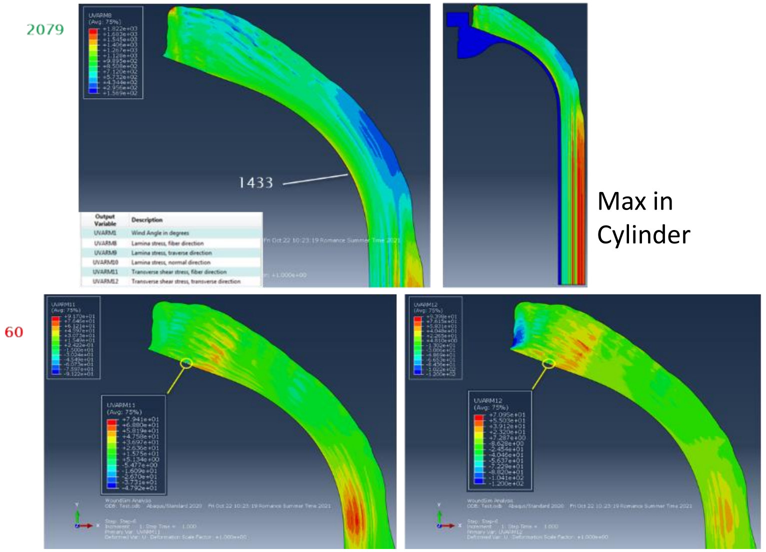
PA12/CF Tape - Datasheet			
Modulus	E1	120000	MPa
	E2	5000	MPa
	E3	5000	MPa
Strength in Fibre Dir	S11	2079	MPa
Interlaminar shear	S13/S23	60	MPa
Width		13,7	mm
Thickness		0,232	mm

PA11/CF
1800 MPa

16,0 mm
0,260 mm

74 ➔ 82 layers





	#layers	Predicted weight	UVARM8	UVARM11	UVARM12
			Mpa	Mpa	Mpa
Model_F_Suprem_06-Prod	82	55,4	1822	79,4	71,0
		Admissible limits	*2079*	*60*	

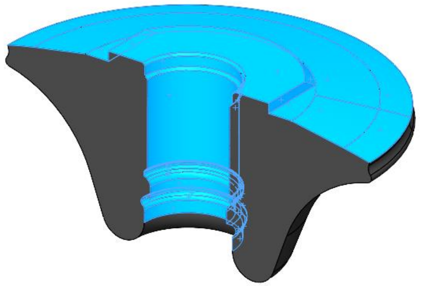
After some "process" adjustments, new tank was manufactured

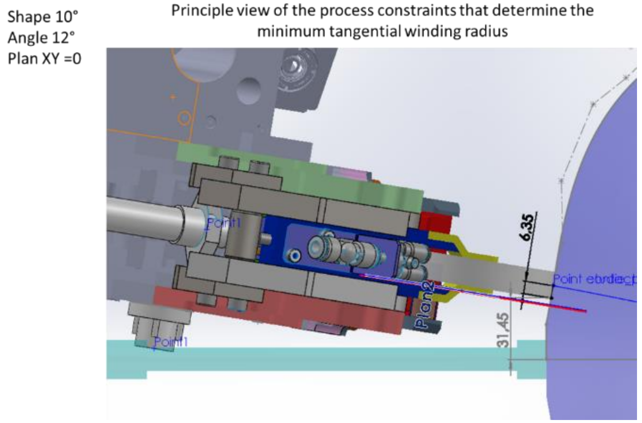
➔ **Second BURST TEST = 1466 bars !! [< 1575 bars]**
With failure mode in the dome !

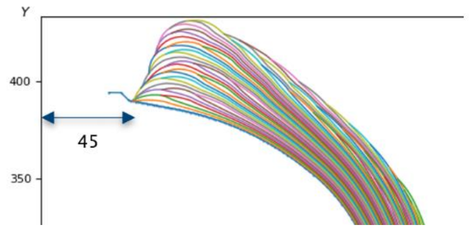
STEP 3 : Boss design optimization – **THOR** specificities

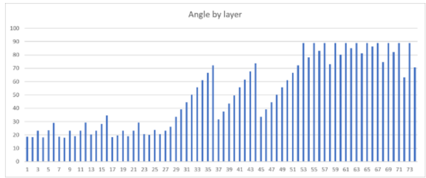
Functional requirements (Boss design) :

Limited space of the tank
Internal connexion with min length
Top surface fixed by liner geometry + process constraints
Diameter fixed by the dimensions of the raw material





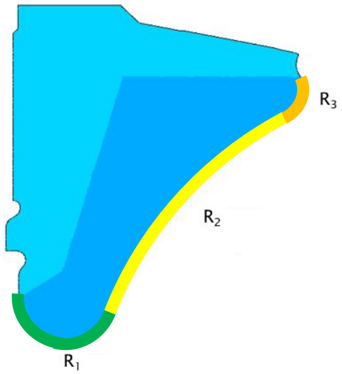




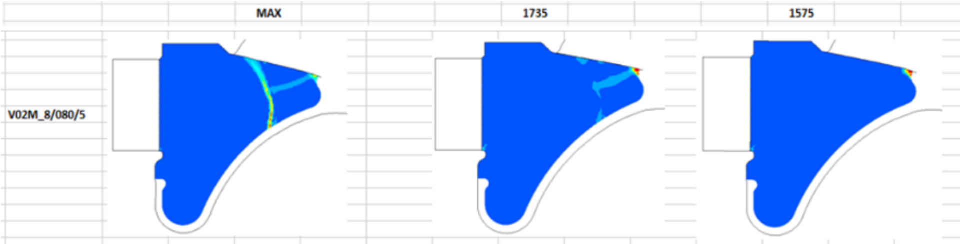
Fixed given laminate design

Al-6082 Material properties		
Young Modulus	70	GPa
Poisson ratio	0,3	
Elastic limit (R02)	310	MPa
Tensile Strength	378	MPa
Ultimate plastic strain	0,06	

Parametric study based on the 3 dimensioning radii R1 – R2 – R3.



	Boss_MASS	MAX values (Num. instability)		1735 bars	1575 bars
	(kg)	PRESmax	PEEQmax_S	PEEQmax_S	PEEQmax_S
V02C	2.104	2075	0.225	0.164	0.145
V02E	1.863	1740	0.150	0.150	0.128
V02_Faurecia	1.601	1523	0.442		
V02G_10/100/5	1.947	1888	0.190	0.161	0.142
V02H_10/100/3	1.862	1811	0.158	0.148	0.129
V02I_10/100/2	1.819	1904	0.334	0.130	0.121
V02J_10/080/5	1.902	1888	0.179	0.156	0.137
V02K_10/060/5	1.829	1791	0.152	0.145	0.127
V02L_10/080/4	1.857	1771	0.156	0.152	0.130
V02M_8/080/5	1.779	1918	0.315	0.149	0.129



Model_V02M

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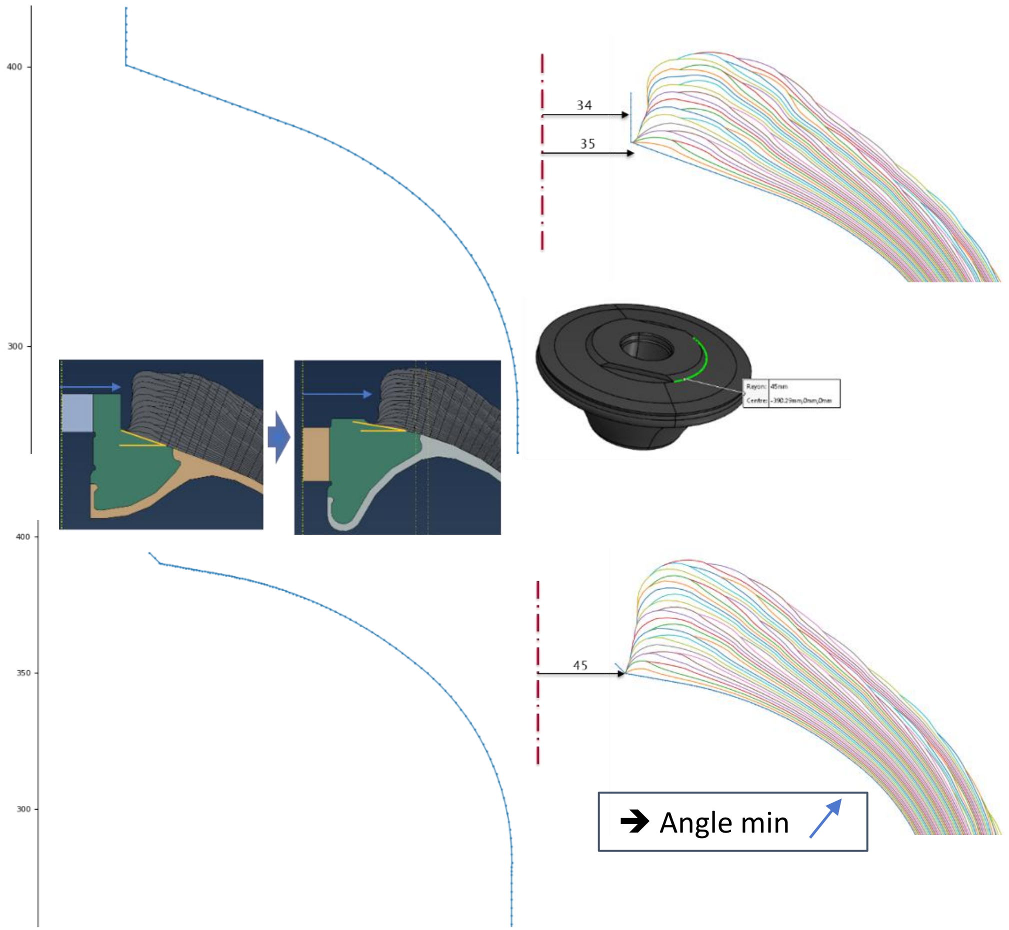
STEP 3 : THOR Liner/Boss - Tape PA12/CF



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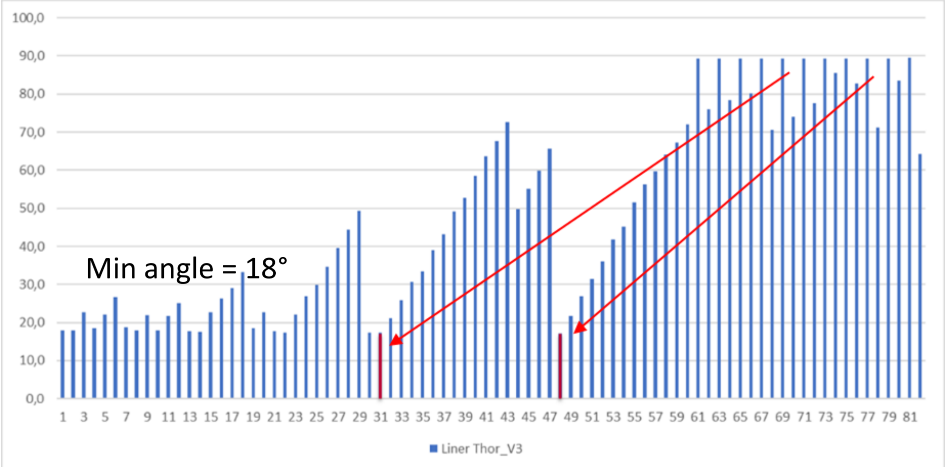
Interlaminar shear	S13/S23	60	MPa
Width		13,7	mm
Thickness		0,232	mm

After measurement :
PA12/CF_2
14,9 mm
0,219 mm



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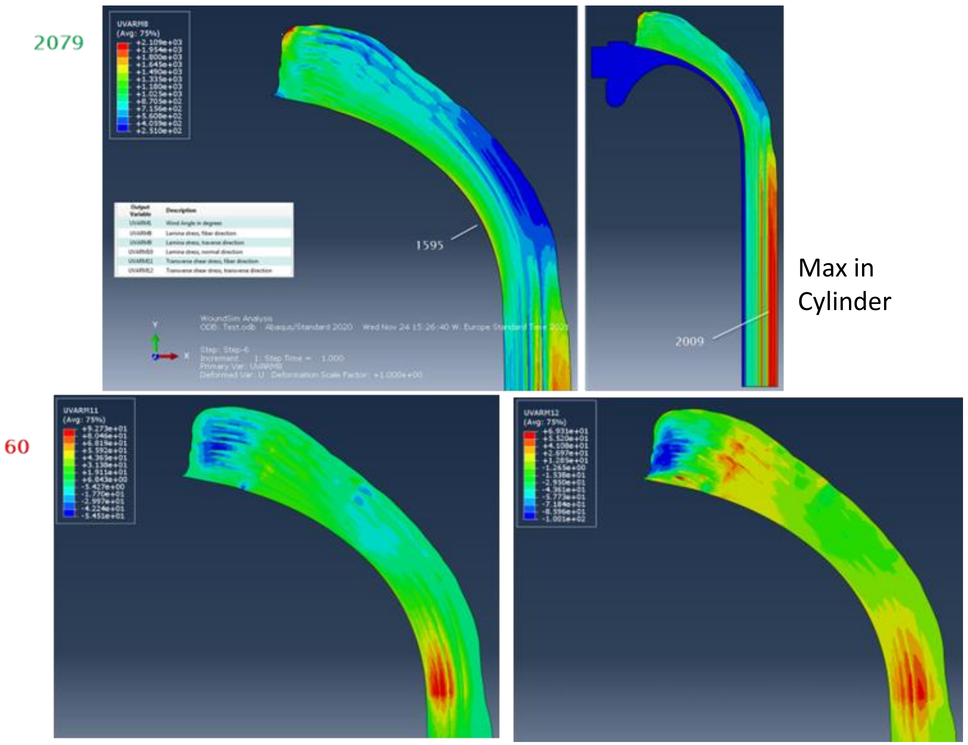
STEP 3 : THOR Liner/Boss - Tape PA12/CF



Liner THOR/Tape Suprem					
	#layers	Predicted weight	UVARM8	UVARM11	UVARM12
			Mpa	Mpa	Mpa
Model_H3	82	52,6	2009	92,7	69,3
		Admissible limits	*2079*	*60*	

P_{burst} = 1476 bars

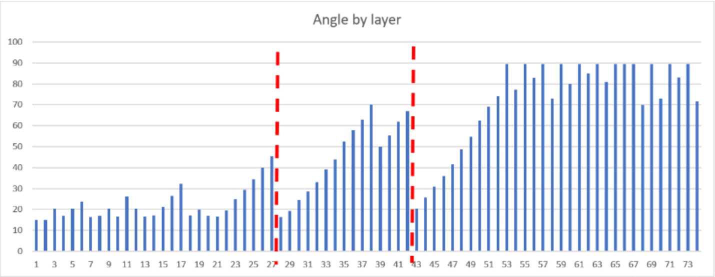
Better experimental result with PA12/CF tape

BUT

Still too low compared to numerical predictions
No relation between Max value, SHEAR performance & failure mode !

➔ Another approach is required for the optimization phase!

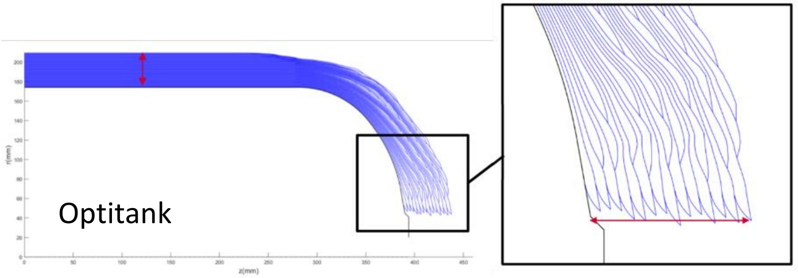
Correlation with experiment - Reduced E3 value

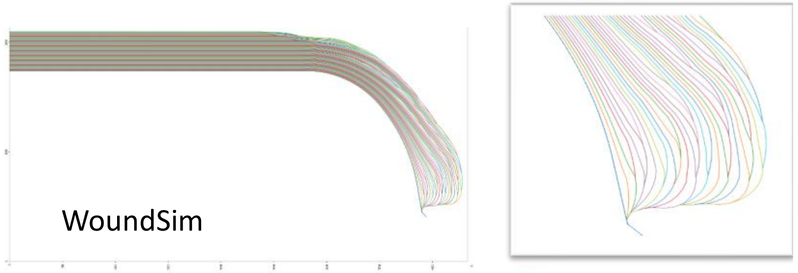


Introduction

Another consequence of poor embedding of TP tapes at a block switch could be a **lower out-of-plane stiffness (E3) value**

It has been shown with **Optitank** (= Cetim development) that this parameter could explain the **move** from the Cylinder to the End/Dome zones of the highest S11 stresses and an **increase** of this value





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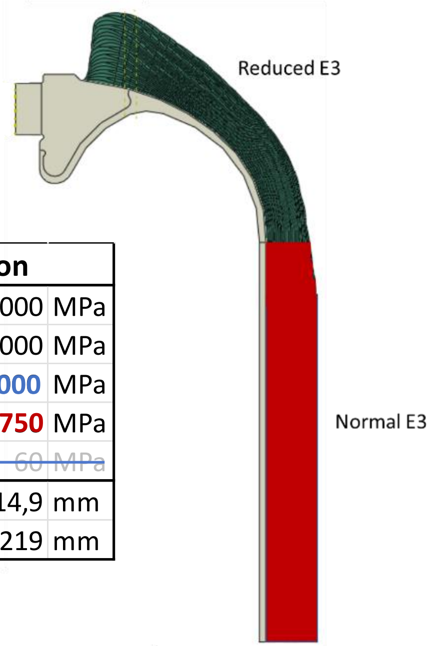
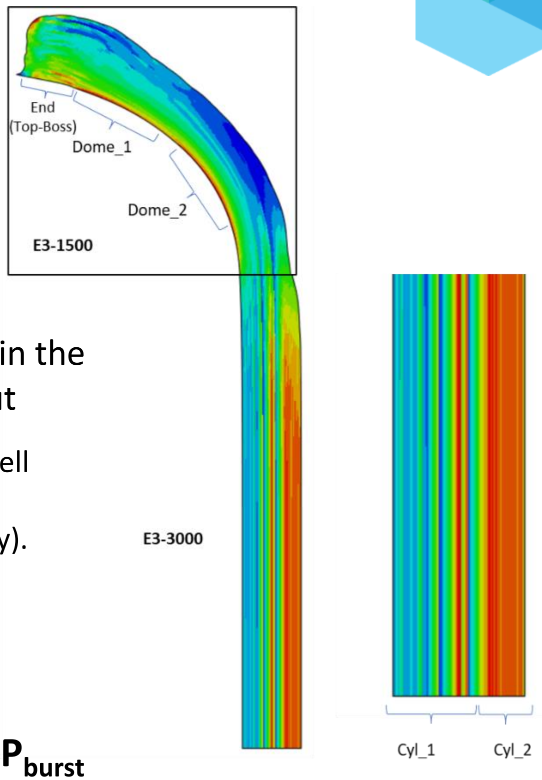
Correlation with experiment - Reduced E3 value



PA12/CF Tape - after correlation			
Modulus	E1	120000	MPa
	E2	3000	MPa
	E3	1500/3000	MPa
Strength in Fibre Dir	S11	1750	MPa
~~Interlaminar shear~~	~~S13/S23~~	~~60~~	~~MPa~~
Width		14,9	mm
Thickness		0,219	mm



5 zones to be checked in the optimization phase, but

End (Top-Boss) zone not well considered by Woundsim approach (wrong geometry).
➔ Indicative values

P_{burst} = 1476 bars

Stresses converted in predicted P_{burst}

	#layers	Weight	Pburst (bar)					
	(-)	(kg)	End (Top-Boss)	Dome_1	Dome_2	Cylinder_1	Cylinder_2	GLOBAL
Model H3	82	52,62	1648	1476	1507	1484	1510	1476

Max in Dome

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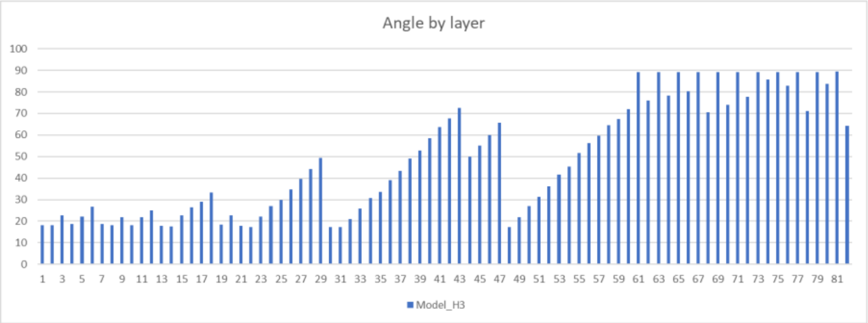
Optimization phase - Low E3

Rules for the optimization phase :

1. **Increasing P_{burst}** till 1575 bars;
2. Value in **Cylinder_2 lower** than in the other zones to promote a **safe failure mode** ;
3. Targeting **similar P_{burst} values for both domes areas**;
4. **Weight** and **amount of layers** as small as possible

To reach this objective, the available parameters are the number of layers and the sequence of angles !

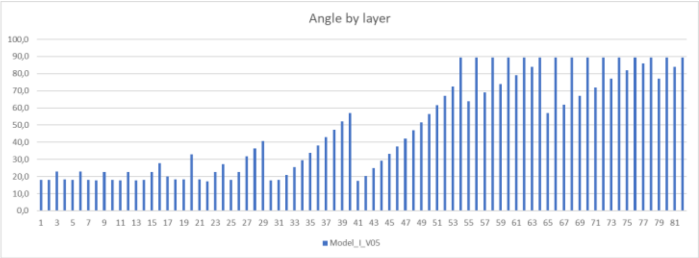
Reference :



	#layers (-)	Weight (kg)	Pburst (bar)					
			End (Top-Boss)	Dome_1	Dome_2	Cylinder_1	Cylinder_2	**GLOBAL**
Model H3	82	52,62	1648	**1476**	**1507**	1484	**1510**	**1476**

Optimization phase - Low E3

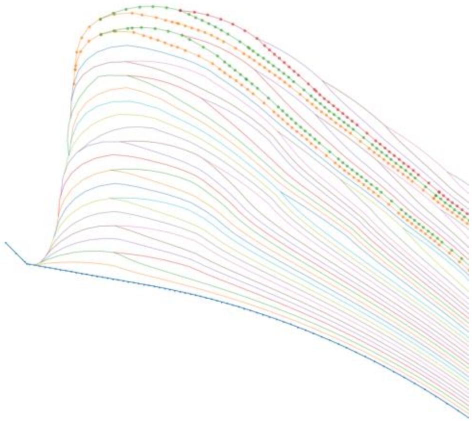
Step 1 Opti : Reorganization of the 82 layers of Model H3 (with new material assumptions)

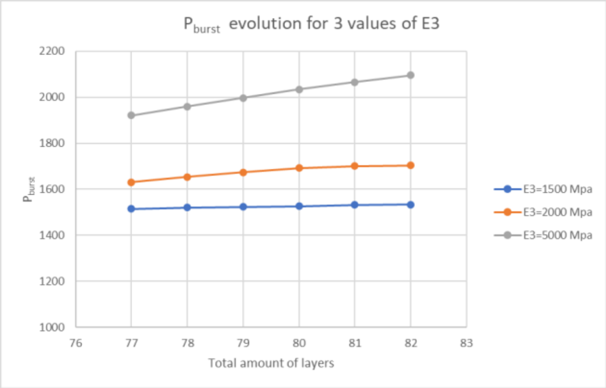


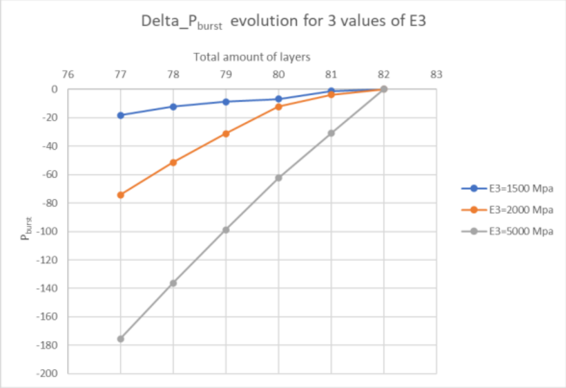
	#layers (-)	Weight (kg)	Pburst (bar) End (Top-Boss)	Dome_1	Dome_2	Cylinder_1	Cylinder_2	GLOBAL
Model H3	82	52,62	1648	**1476**	**1507**	1484	**1510**	**1476**
Model_I_V05	82	52,27	1639	1585	1533	1729	1451	**1451**

Large improvement
in the dome zones

Extra information : outer low-angle layers have poor effect on the Dome values when E3 decreases!







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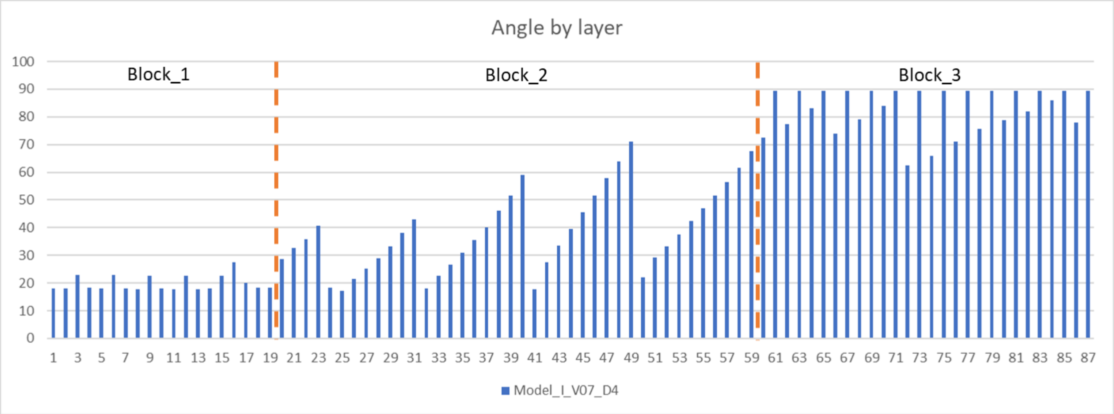
Optimization phase - Low E3

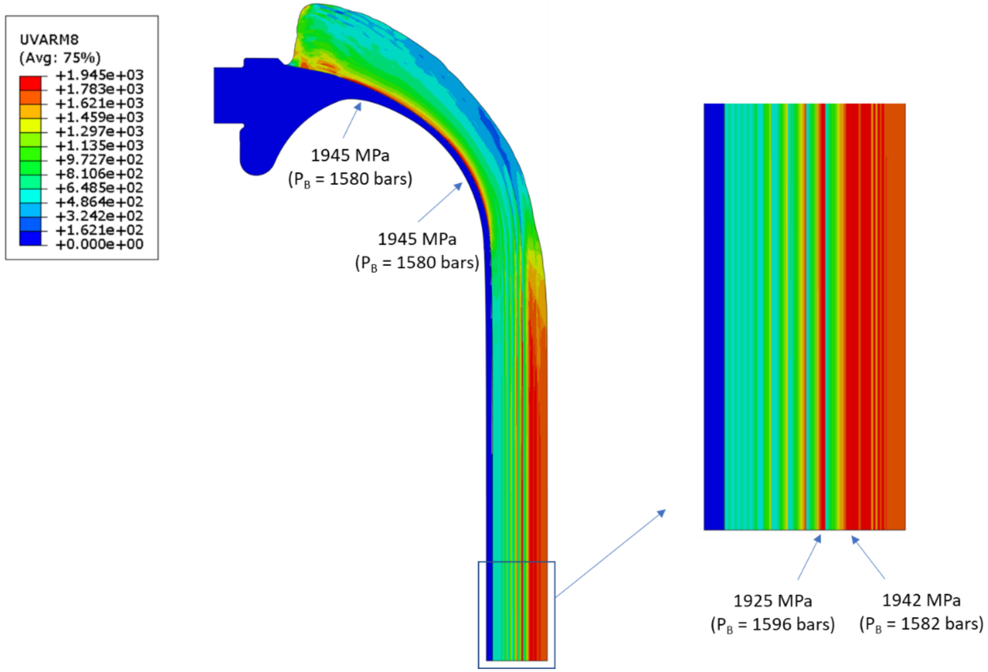
Step 2 Opti : Suppression of the outer low-angle layers and reorganization of the 78 layers

Step 3 Opti : Optimization phase with focus on the weight

Step 4 Opti : Optimization phase with target on P_{burst} = 1575 bars (➔ Model_I_V07_D4).

	#layers (-)	Weight (kg)	Pburst (bar) End (Top-Boss)	Dome_1	Dome_2	Cylinder_1	Cylinder_2	GLOBAL
Model H3	82	52,62	1648	**1476**	**1507**	1454	**1510**	**1476**
Step 1 Opti	82	52,27	1639	1585	1533	1729	1451	**1451**
Step 2 Opti	78	48,40	1614	1517	1517	1504	1508	**1504**
Step 3 Opti	84	53,61	1699	1558	1558	1565	1557	**1557**
Step 4 Opti	***87***	**55,91**	1731	***1580***	***1580***	***1596***	***1582***	**1580**





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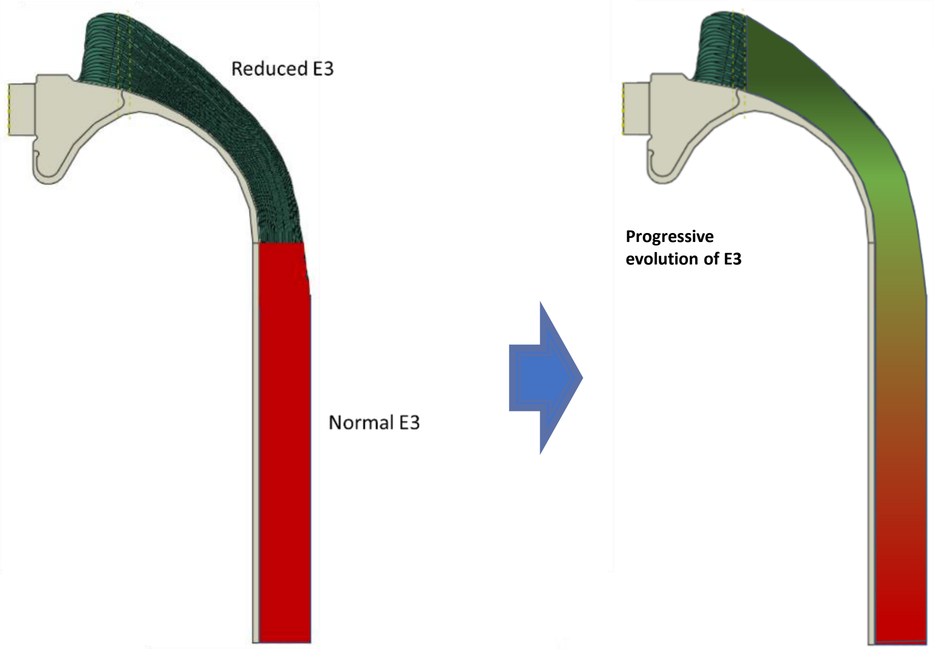
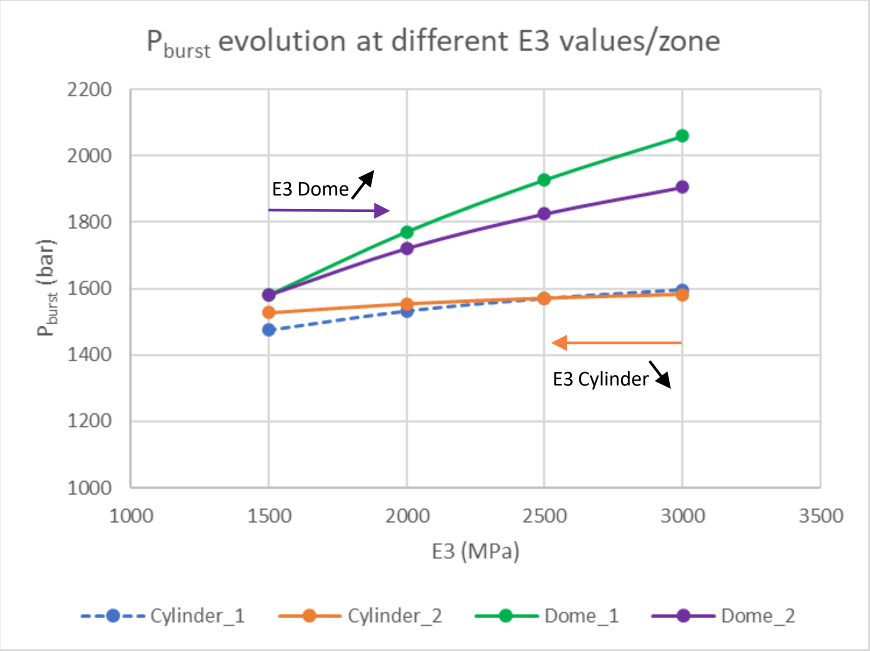
Post analysis of optimal laminate design

1. P_{burst} in End (Top-Boss) zone : +83 bars

	#layers (-)	Weight (kg)	Pburst (bar)					
			End (Top-Boss)	Dome_1	Dome_2	Cylinder_1	Cylinder_2	GLOBAL
Model H3	82	52,62	1648	**1476**	**1507**	1454	**1510**	**1476**
Model_I_V05	82	52,27	1639	1585	1533	1729	1451	**1451**
Model_I_V06_A	78	48,40	1614	1517	1517	1504	1508	**1504**
Model_I_V06_V2	84	53,61	1699	1558	1558	1565	1557	**1557**
Model_I_V07_D4	***87***	**55,91**	1731	***1580***	***1580***	***1596***	***1582***	**1580**

2. Influence of E3 value on Optimized design





Conclusions

Main objective :

Modelling strategy and Design of a laminate structure for a 63L Type 4,5 CoPV considering manufacturing guidelines of TP welding technology and testing needs in … 13 months

Different development phases :

-/ Definition of stackings with Hyphone liner/boss geometries with different tapes characteristics (iterations 1 & 2)

-/ Specific studies on poor **shear behaviour** after first iteration result (Burst at 738 bars)

-/ Optimization of a **boss design** with specific requirements of THOR project

-/ Definition of a new sequence of angles based on THOR inputs – iteration 3

Final optimization phase :

-/ Updated strategy considering **low E3 value** after correlation with experimental results

-/ Optimized laminate structure taking into account this updated strategy

Thanks

Thanks to colleagues (Setareh, Bart, Linde)

Thanks to project partners (Cetim, Faurecia)

Special thanks to M. Abichou from S-Vertical (Woundsim)

Safety of tanks in fire

Benjamin BATIOT – Denis BERTHEAU – Sylvie CASTAGNET
Damien HALM – Eric LAINE – Abel RAPETTI – Séraphin REMY
Thomas ROGAUME

Context

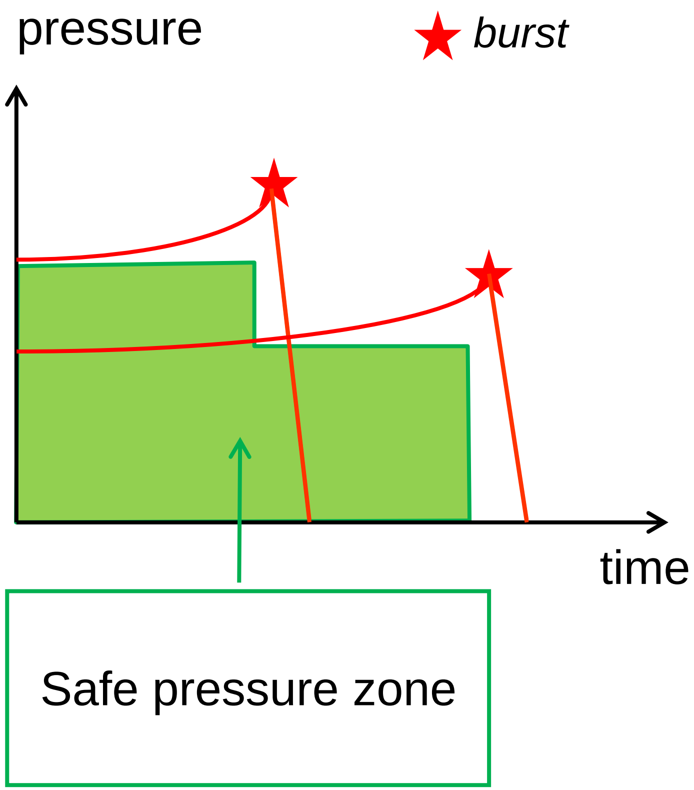
Fire exposure

+

Inner pressure

Coupled thermomechanical loading

Determination of time-to-burst?



Objectives

- Effect of fire exposure at sample scale

  What is the effect of a fire exposure on mechanical behavior?

  - DSC, TGA, cone calorimeter → Tg, pyrolysis onset, combustion kinetics,…
  - Identification of thermophysical properties
  - Radiant panel → residual mechanical strength

- Simulation at tank scale

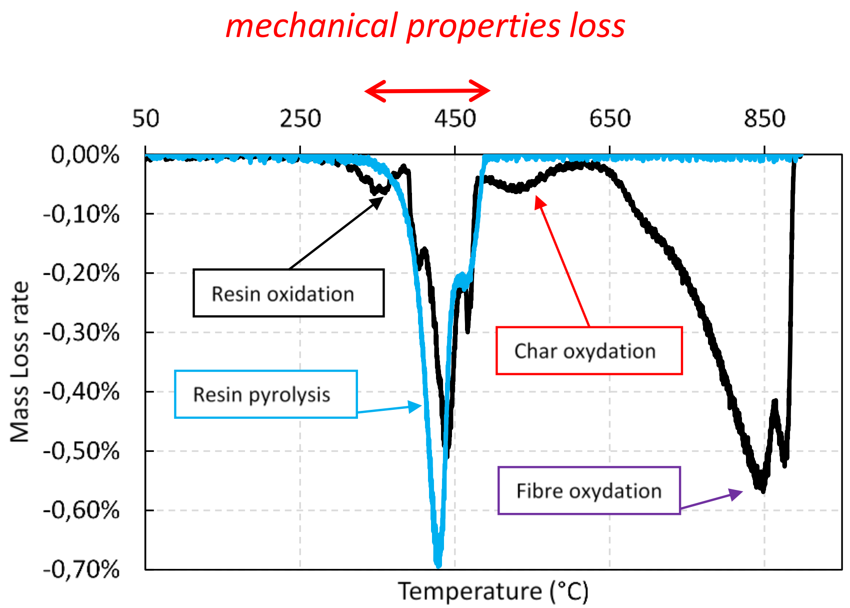
  How to determine time-to-burst / time-to-leak?

  - Thermomechanical Finite Element simulations at tank scale

Effect of fire exposure at sample scale

➢ Thermophysical properties

- TGA tests



- Pyrolysis onset temperature : 380°C
- Pyrolysis end temperature : 500°C

slightly higher wrt. epoxy matrix

- T_g ~50°C

lower than epoxy matrix

- Melting point ~180°C

} DSC tests

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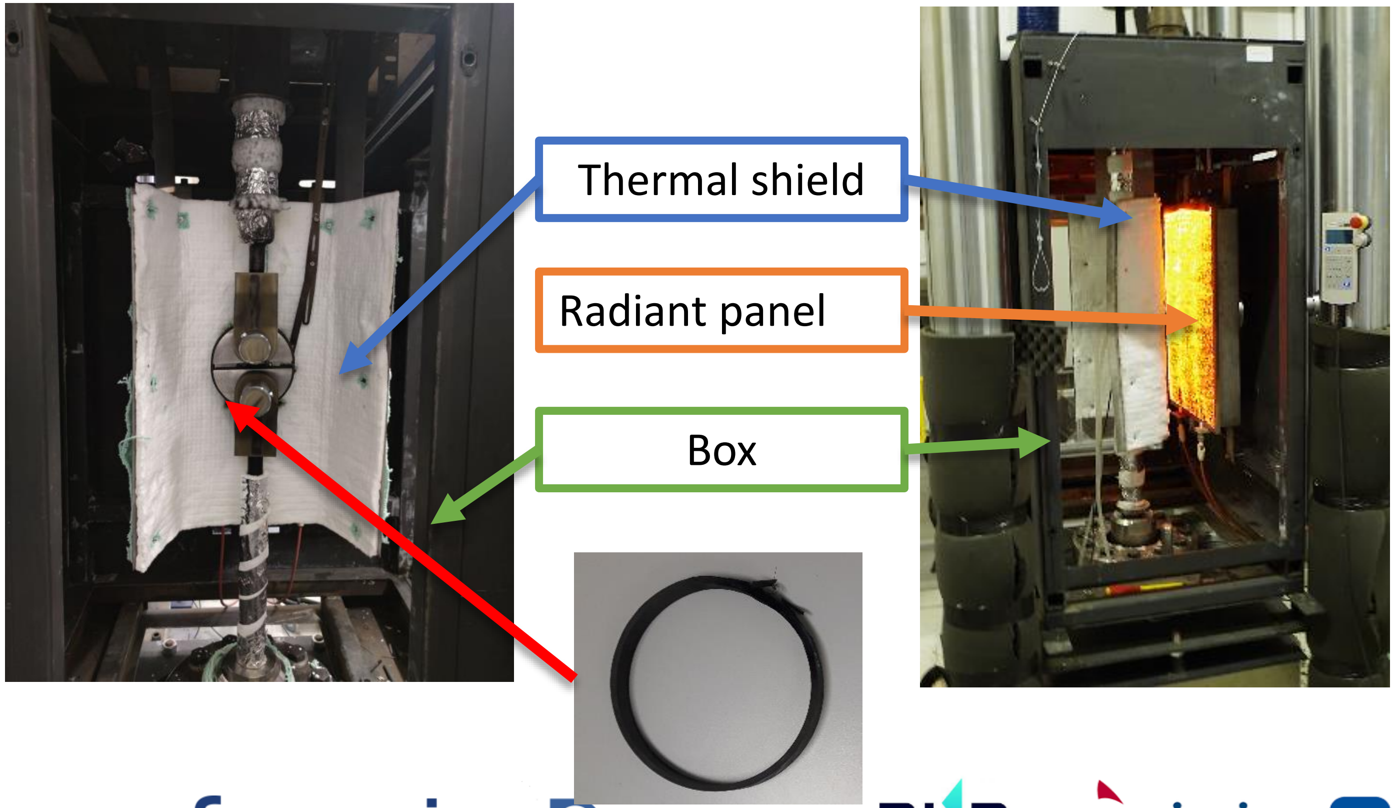
Effect of fire exposure at sample scale

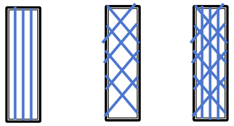
➤ Thermomechanical tests

- Experimental device



Specifications and objectives

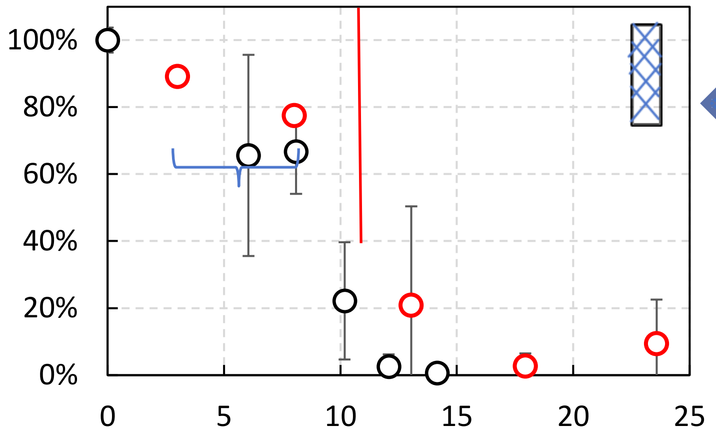
- Maximum flux : 100 kW/m^2
- Tests on rings (more representative of tanks)
- Different fibre orientations



Effect of fire exposure at sample scale

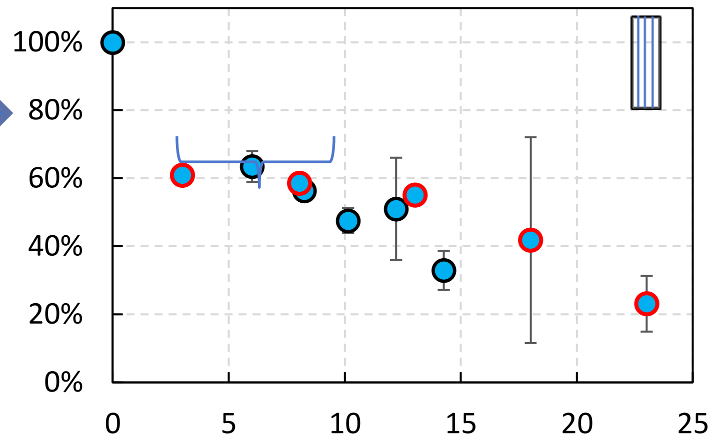
➢ Thermomechanical tests

- Degradation of mechanical properties



Matrix- ⬅ Fiber- ➡

controlled behaviour



- Immediate reduction of mechanical properties
- Matrix properties strongly affected
- Fibers less affected

Simulation at tank scale

➢ Input data

- Thermophysical properties
- Thermomechanical properties

Material ⟵ TGA, panel, cone test

- Tank geometry
- Mechanical loading
- Heat flux

Structure ⟵ Sirris design
usual bonfire conditions

- Burst criterion
- Leak criterion

Failure criteria ⟵ « first ply » failure
melting criterion

Simulation at tank scale

➢ Thermophysical properties

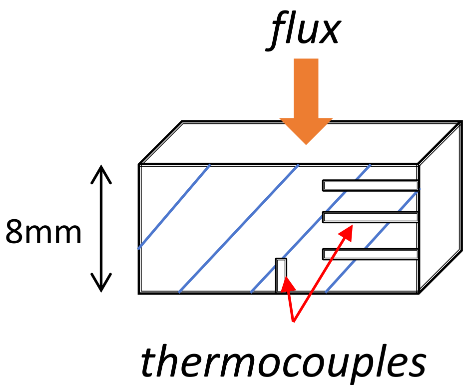
inverse identification

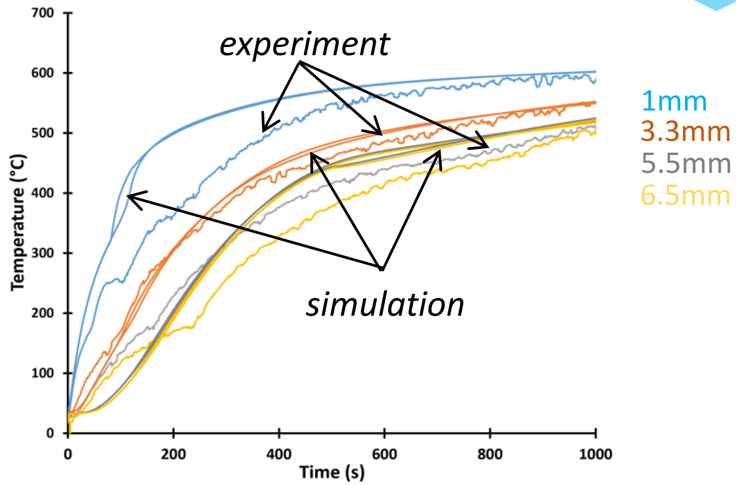
$$\rho(T)\,c(T)\frac{\partial T}{\partial t} = k(T)\frac{\partial^2 T}{\partial^2 x}$$

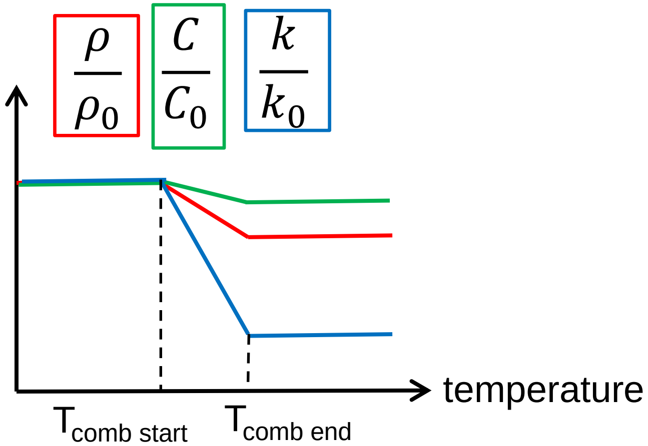
Goal:

accurate temperature profile

cone calorimeter test







Simulation at tank scale

➢ Thermomechanical coupling

Thermal properties

- Conductivity
- Specific heat
- Combustion initiation
- Tg

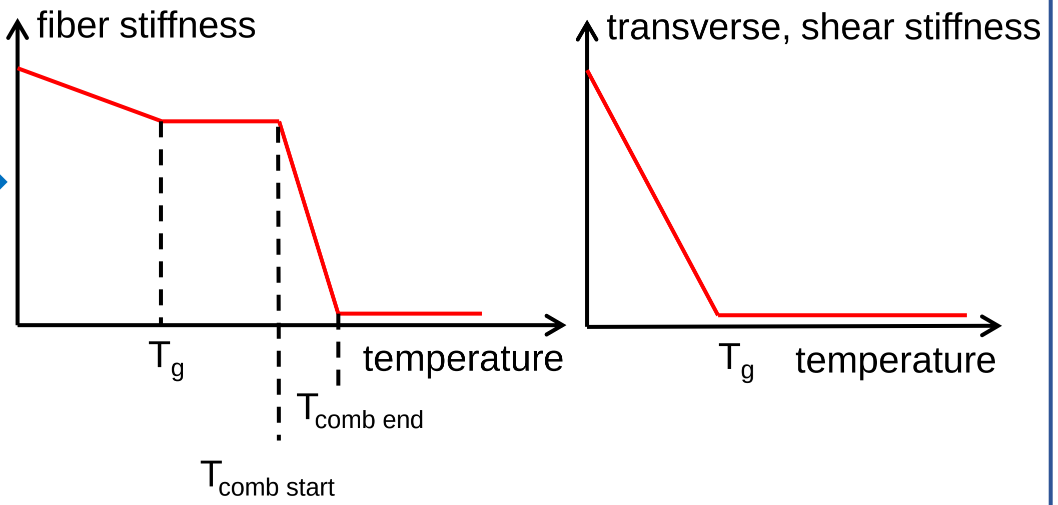
Mechanical properties

- Anisotropic stiffness
- Temperature controlled

Coupling

Heat equation

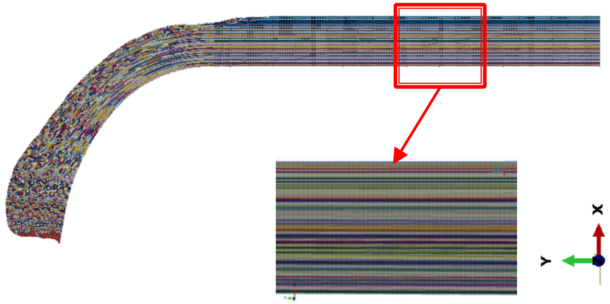
$$\rho(T).c(T)\frac{\partial T}{\partial t} = k(T)\frac{\partial^2 T}{\partial^2 x}$$



Simulation at tank scale

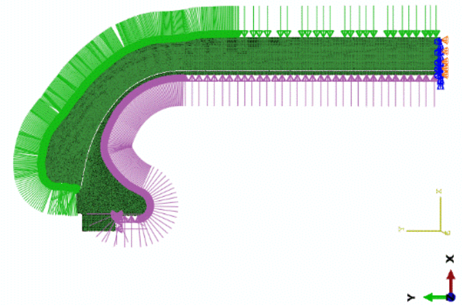
➢ Finite Element input

Geometry + Mesh



- 85,000 elements
- Axisymmetric geometry
- Mirror symmetry

Loading

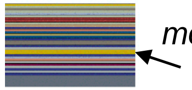


- Heat flux
  100kW/m²
- Pressure
  250 bar – 700 bar

Failure criterion

- Burst criterion

$$\frac{\sigma_{11}}{X} = 1$$



most loaded layer

most loaded layer failure

- Leak criterion

$$T_{liner} = T_{melt}$$

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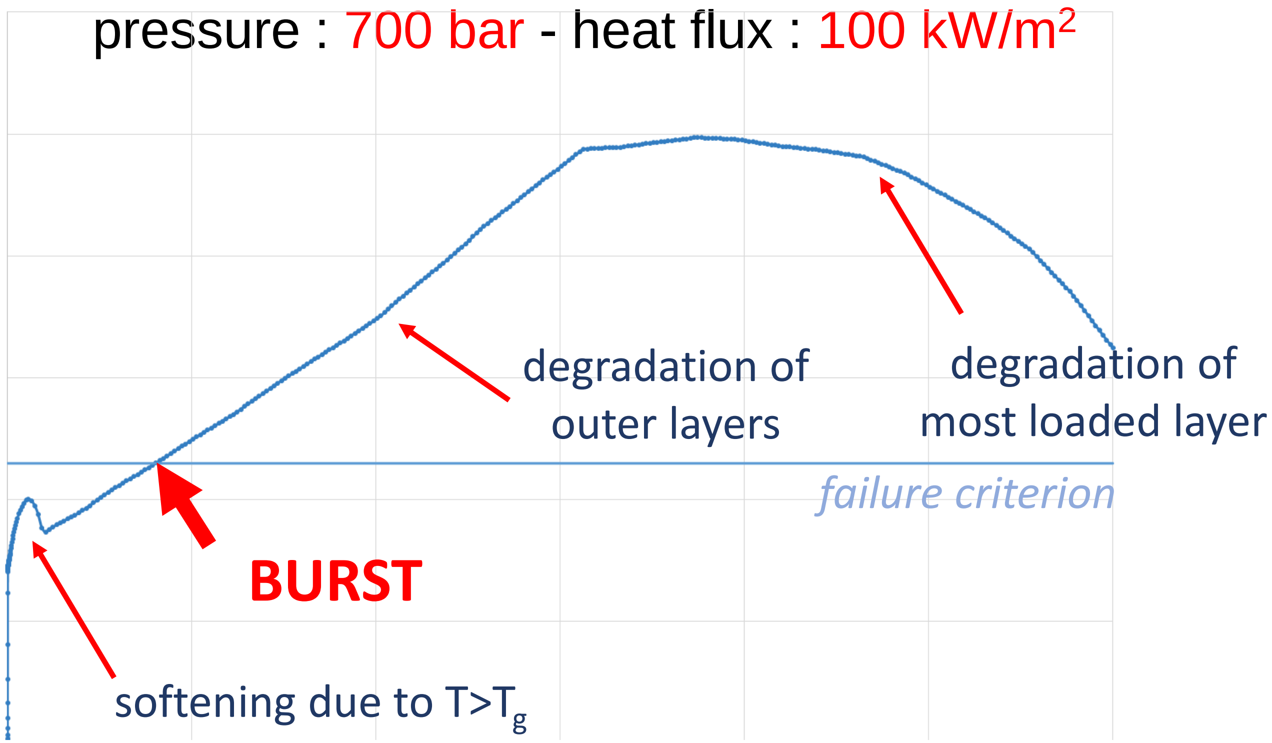
Simulation at tank scale

➢ Results

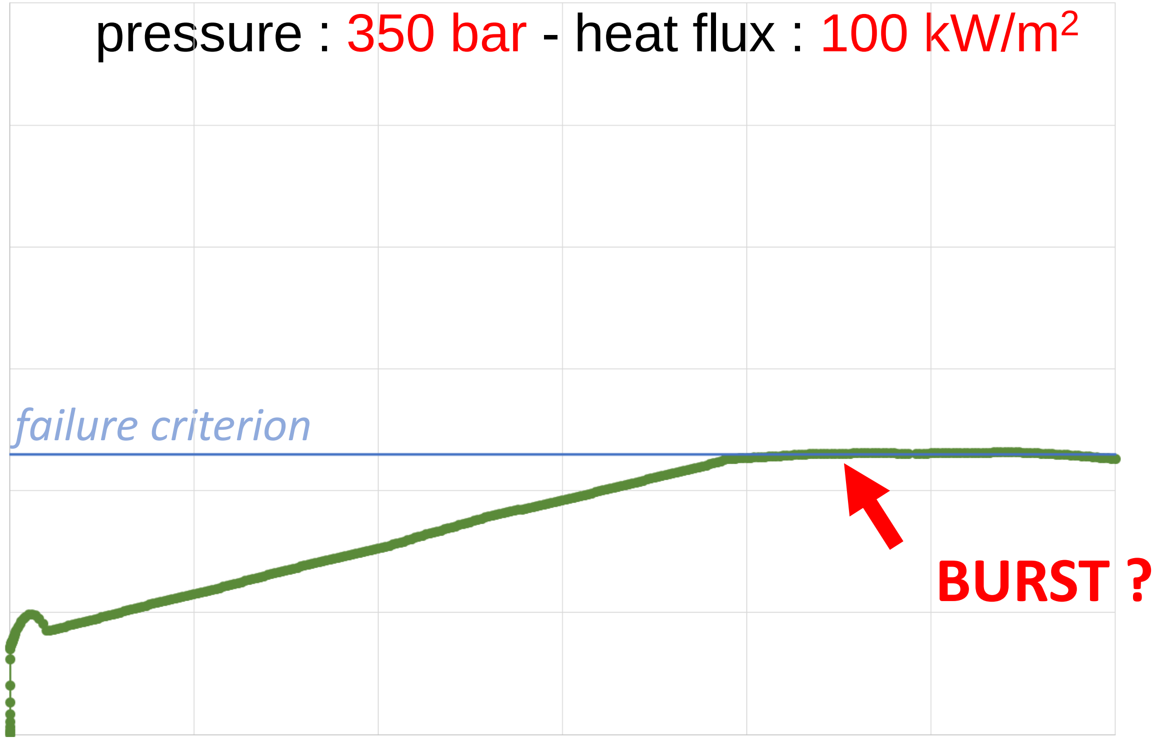


- Complex curve due to competition between degradation and heat transfer
- Rapid increase of maximum stress due to degradation of outer layers and load transfer
- Burst when stress curve crosses failure line (tensile strength)

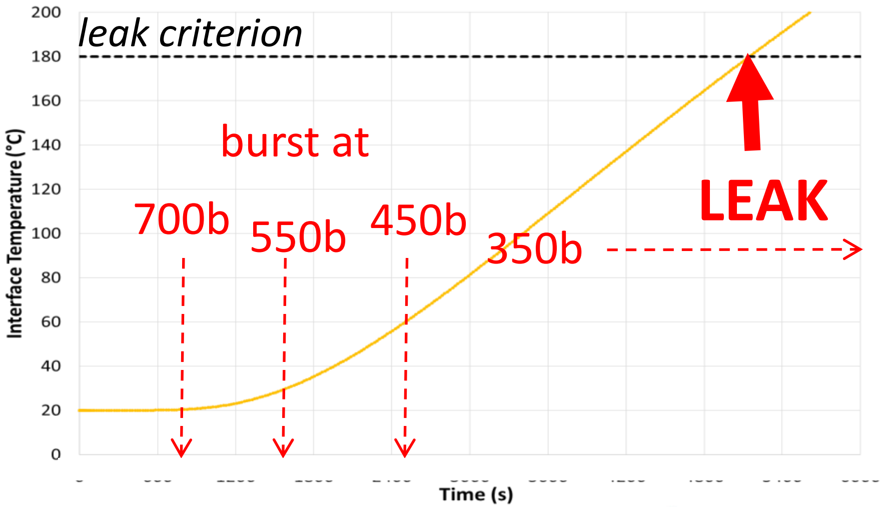
Simulation at tank scale

➢ Results

pressure : 350 bar - heat flux : 100 kW/m^2



- At lower pressure, slower stress increase
- Below a given threshold (300-350 bar), no burst
- Leak when liner reaches melting point



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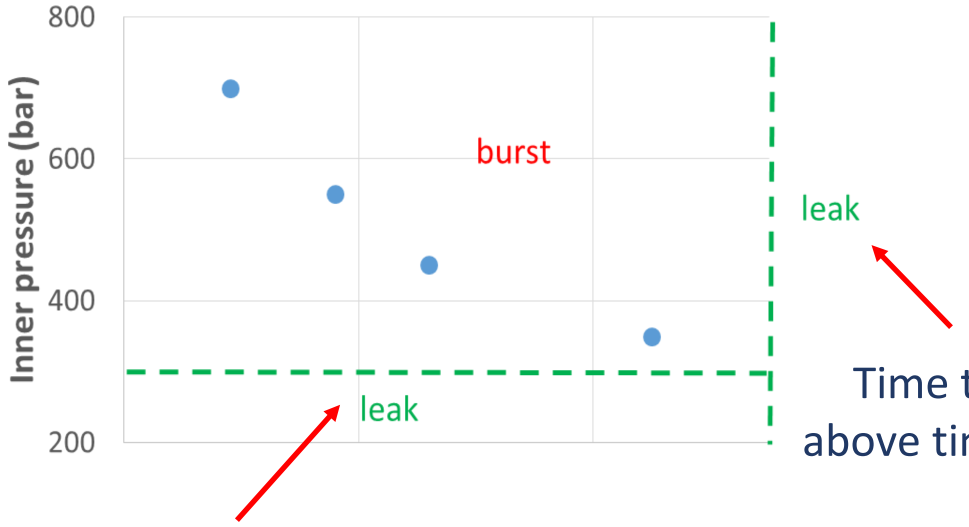
Conclusions

➢ Tool to plot a safety curve “leak / burst”



Time to burst above time to leak

Burst impossible

Conclusions

- Development of a facility to test composite rings in fire conditions

- Numerical approach to simulate rapidly time to burst / leak

- Comparison with thermoset composites:
  - similar degradation mechanisms
  - lower glass transition: early softening
  - higher pyrolysis onset temperature (ΔT_{onset}~50°C): delayed degradation
  - lower diffusivity (ten times lower!): protection against temperature rise

WP5

T5.2

T5.3

M45 THOR Dissemination:

Optical fibres as a fire detection sensory device

Kaspar Lasn, Shaoquan Wang, Lukas Mark, Andreas Echtermeyer

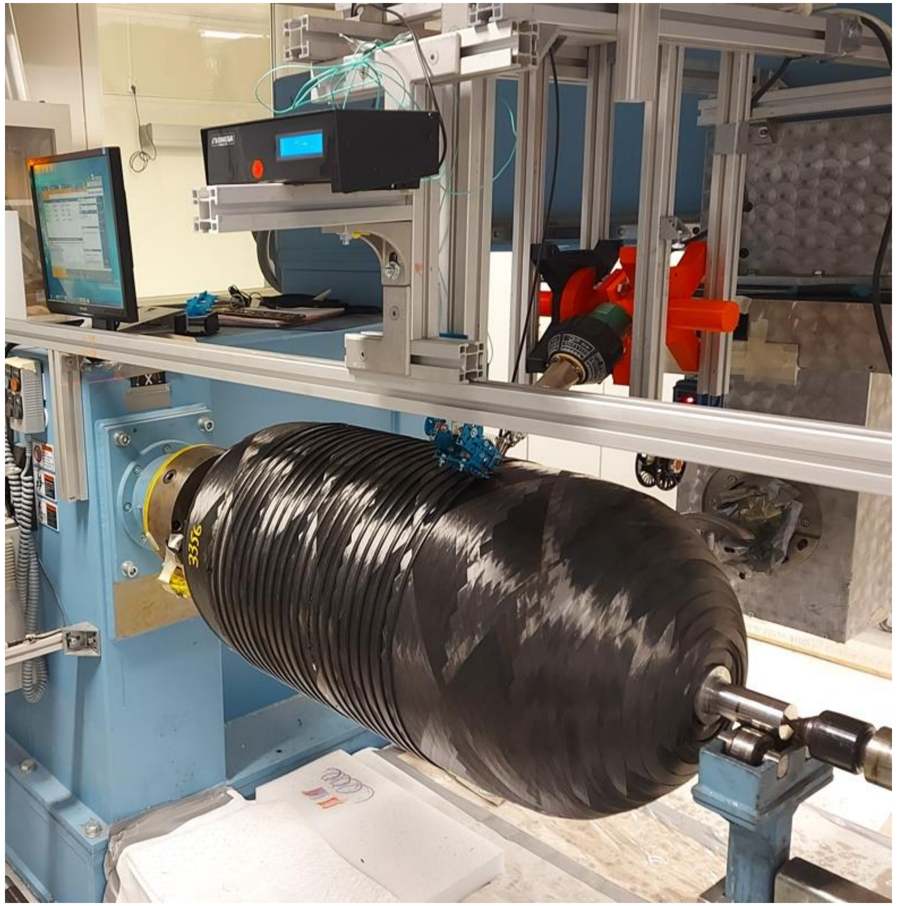
Nantes, France, 21/09/2022

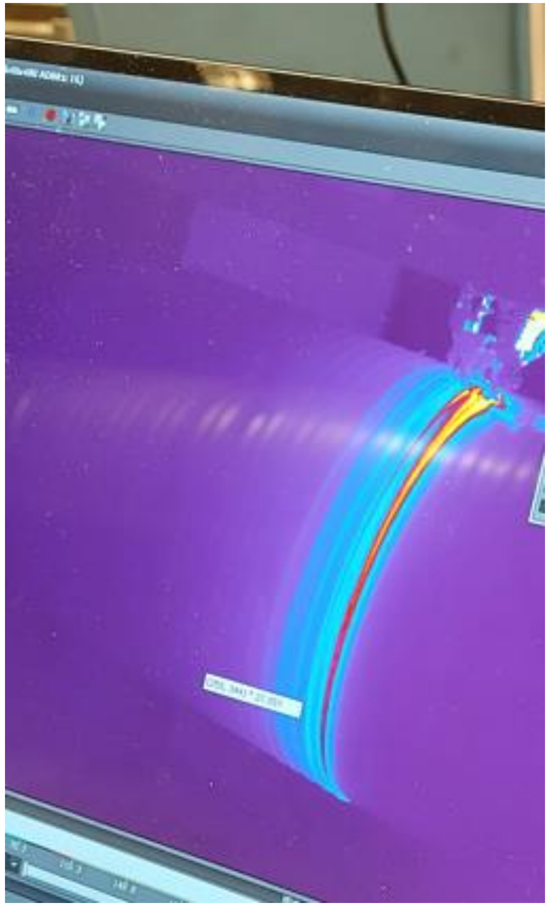
THOR demonstrates the application of **a high-resolution optical fibre grid as a sensory safety device** for the monitoring of fire aggression

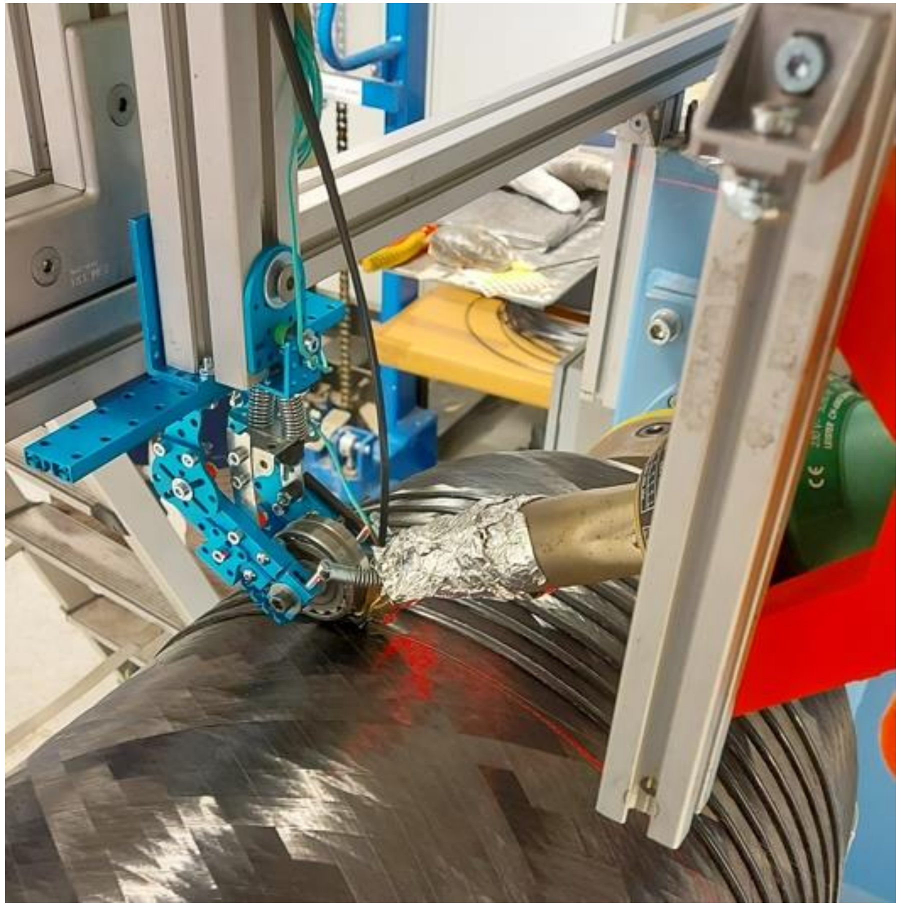
Full-scale Experiments

Thermoplastic Pressure Vessel

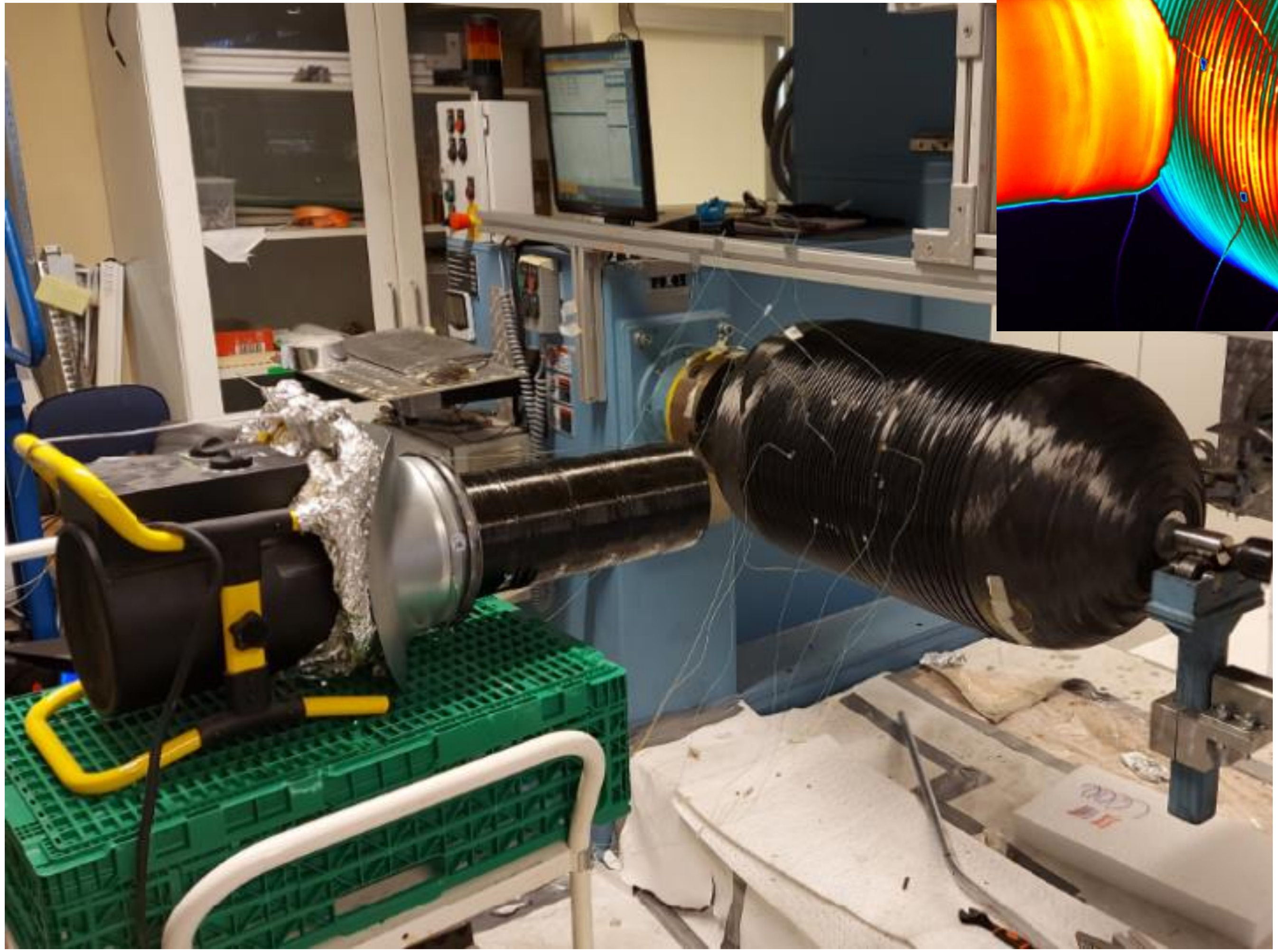
Instrumentation

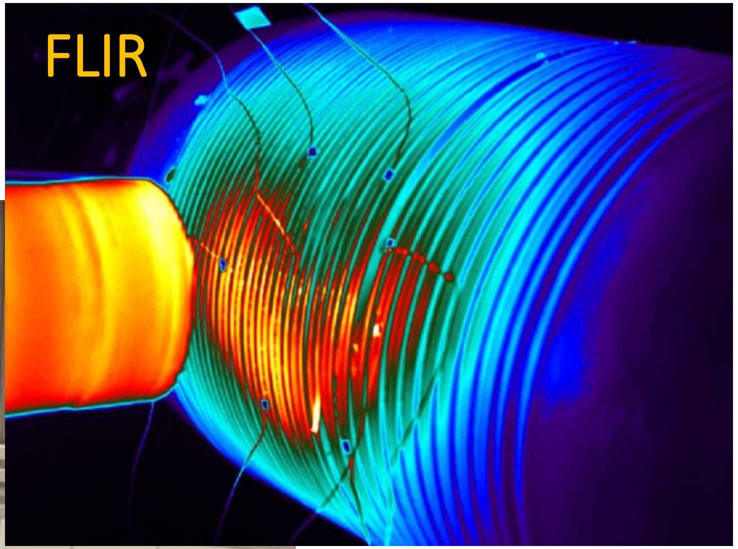






Hot air cannon





Ambient room

T: 19 °C

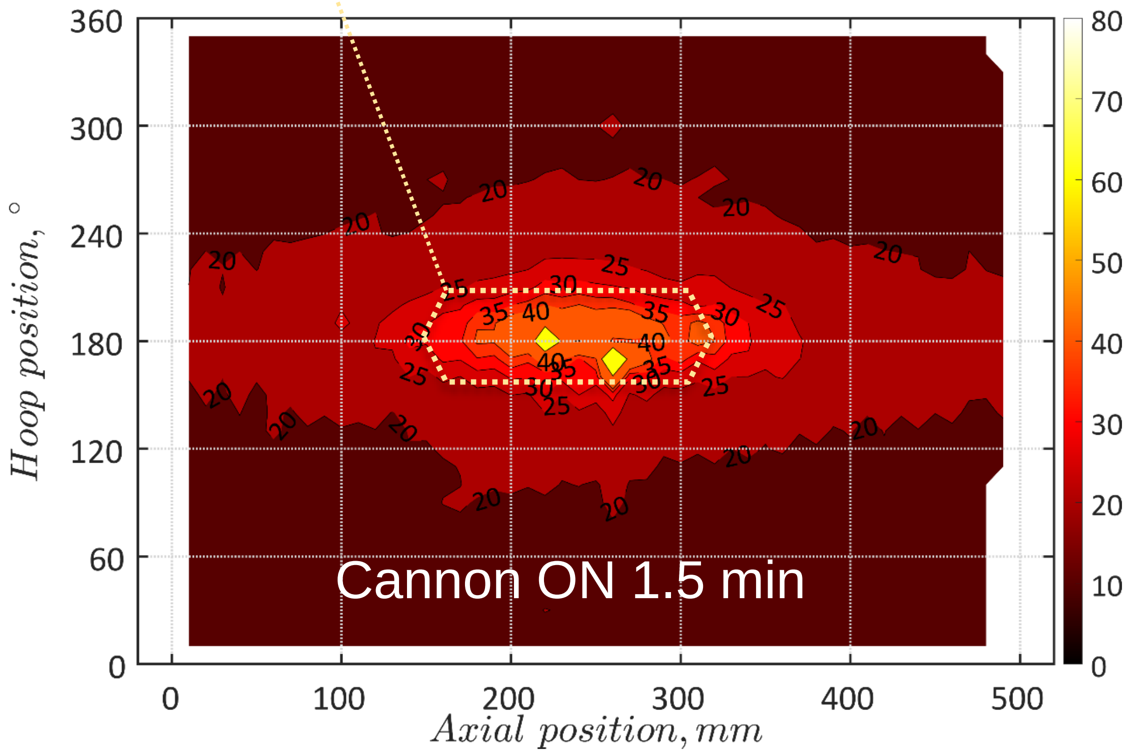
Hot air cannon

Thermocouples, °C

Circle: avg 36.8 °C

Center: 75.8 °C

OBR, °C

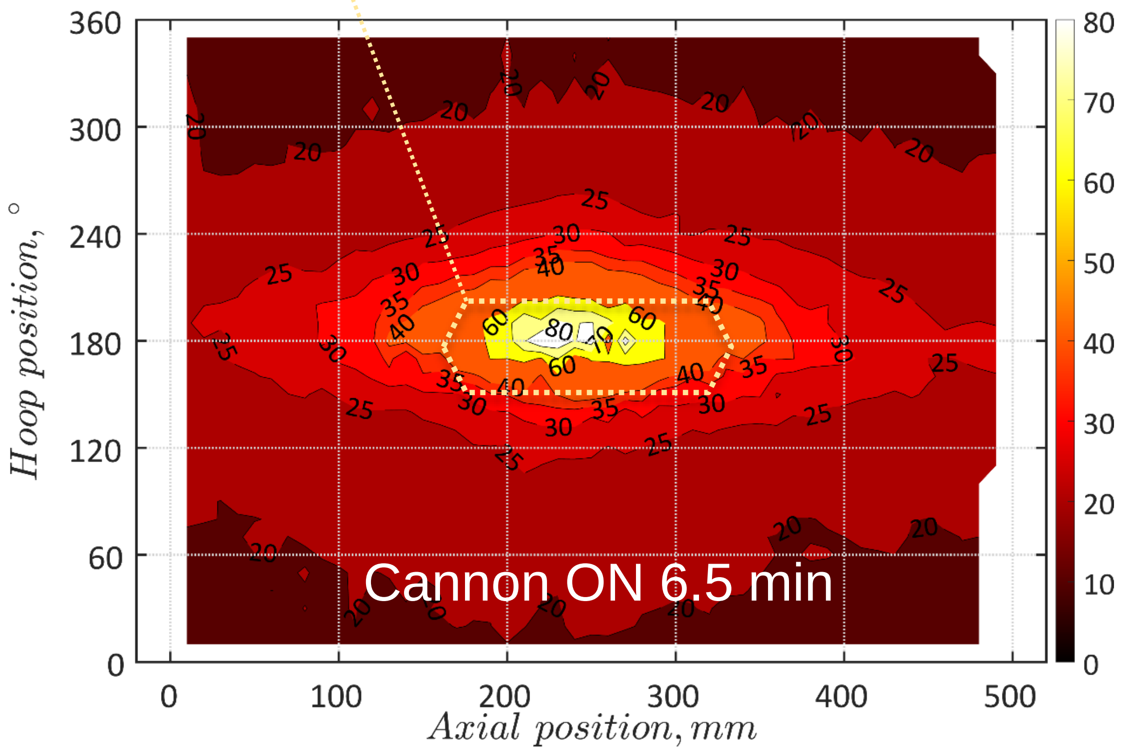


Thermocouples, °C

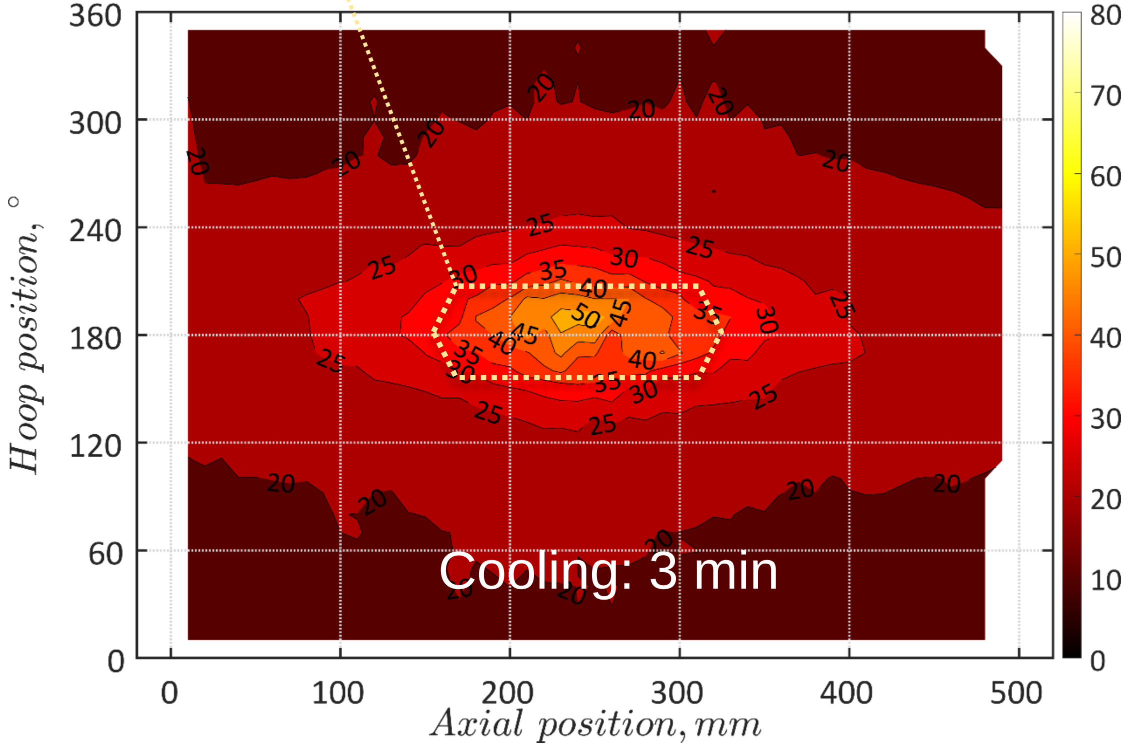
Circle: avg 40.4 °C

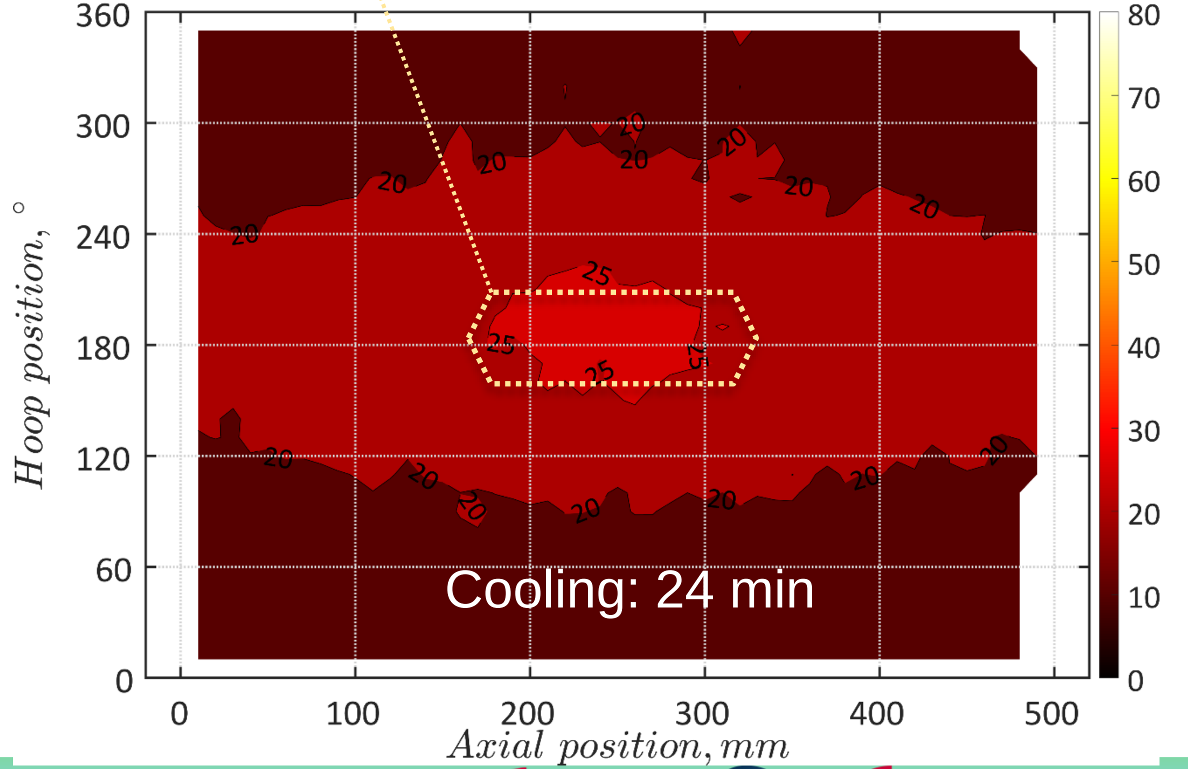
Center: 69.7 °C

OBR, °C



Cooling down

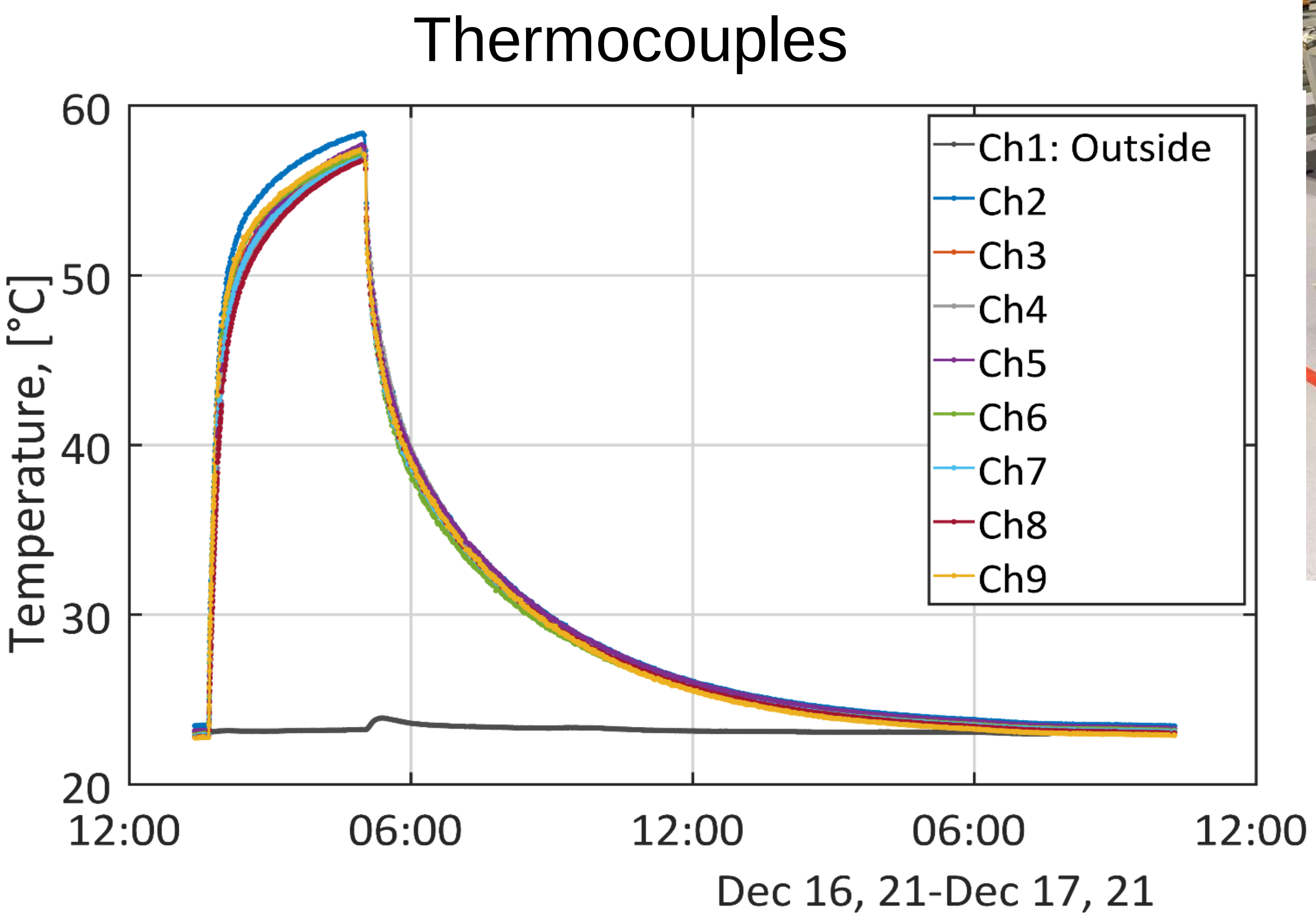




Air cannon takeaways

- Initial transient $T_{OBR} < T_{Thermocouple}$ (expected)
- After initial period $T_{OBR} > T_{Thermocouple}$
  i.e OBR overshoots (reasons)

Uniform heating



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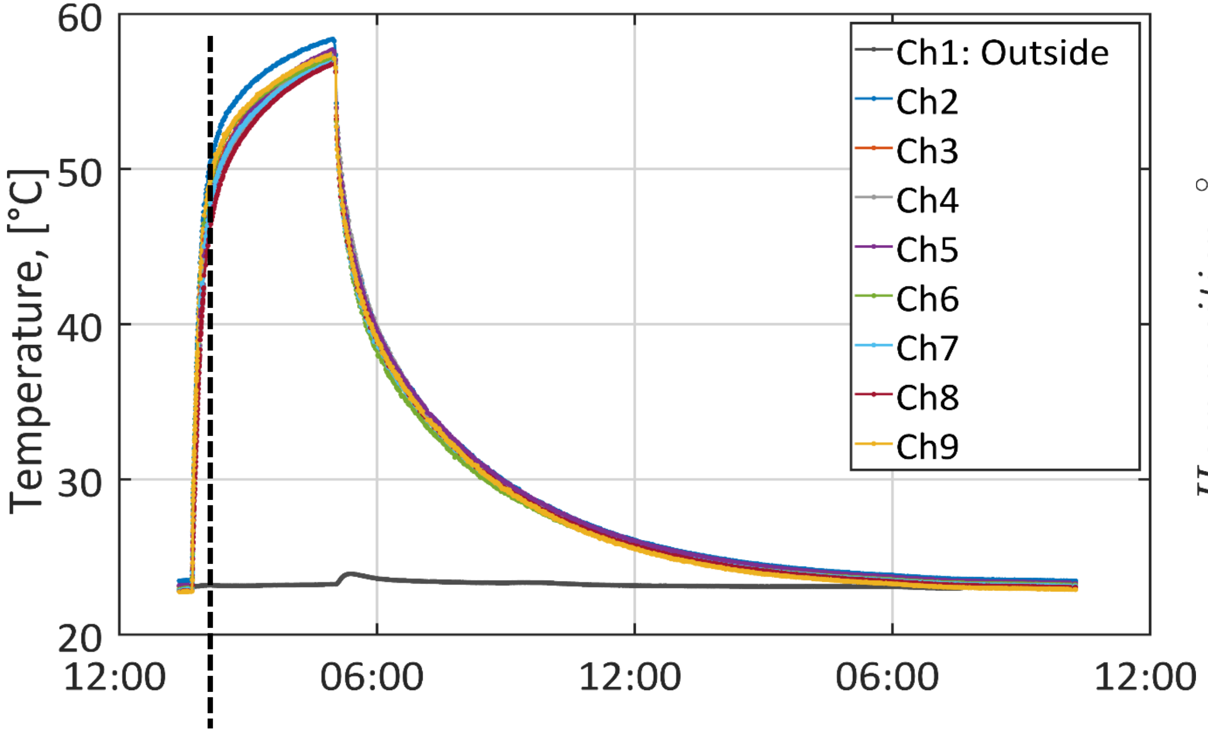
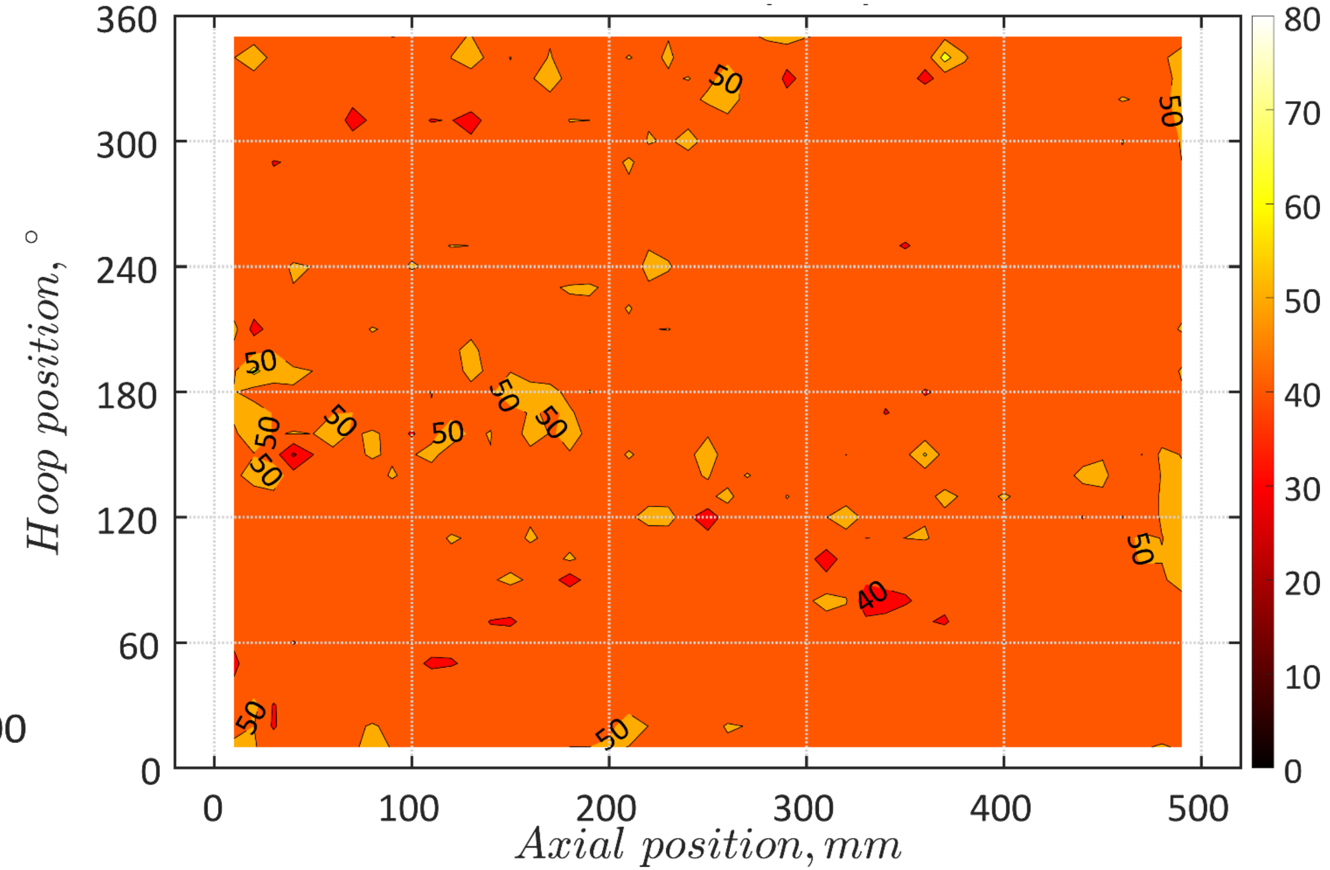
Heat ON

Thermocouples



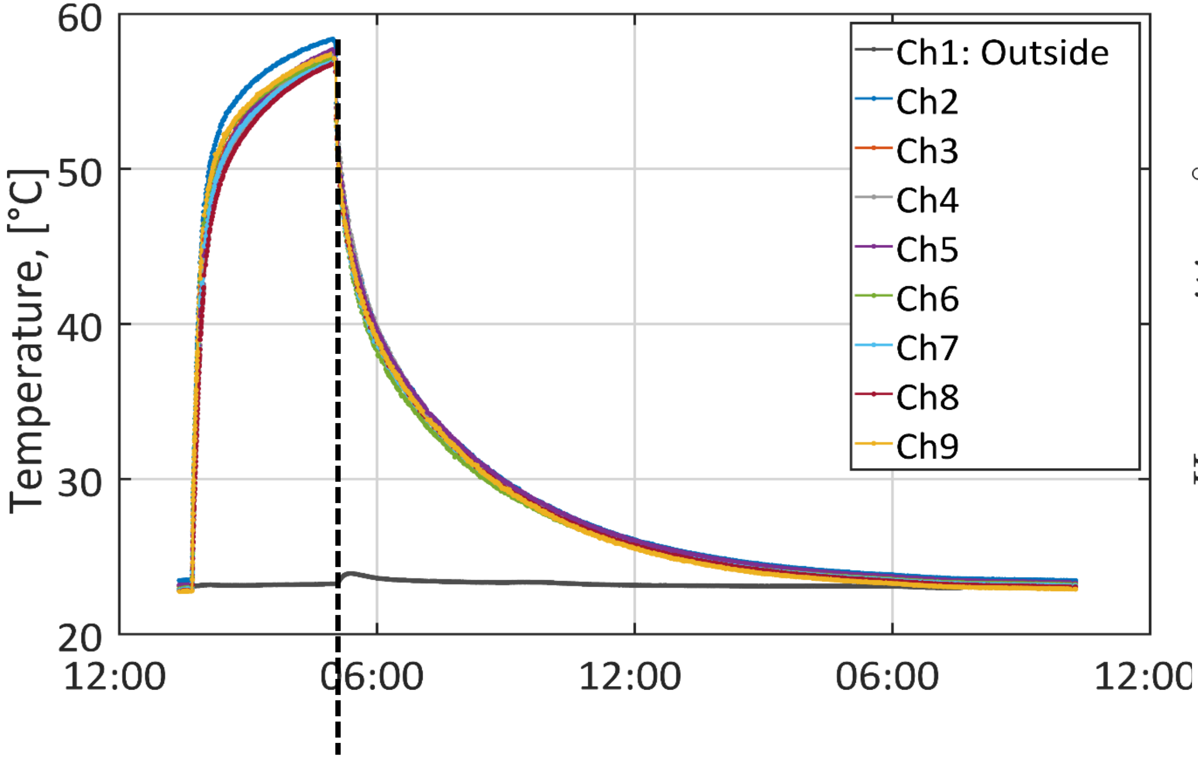
at 14:00
T = [44, 48] °C

OBR: [40, 50] °C



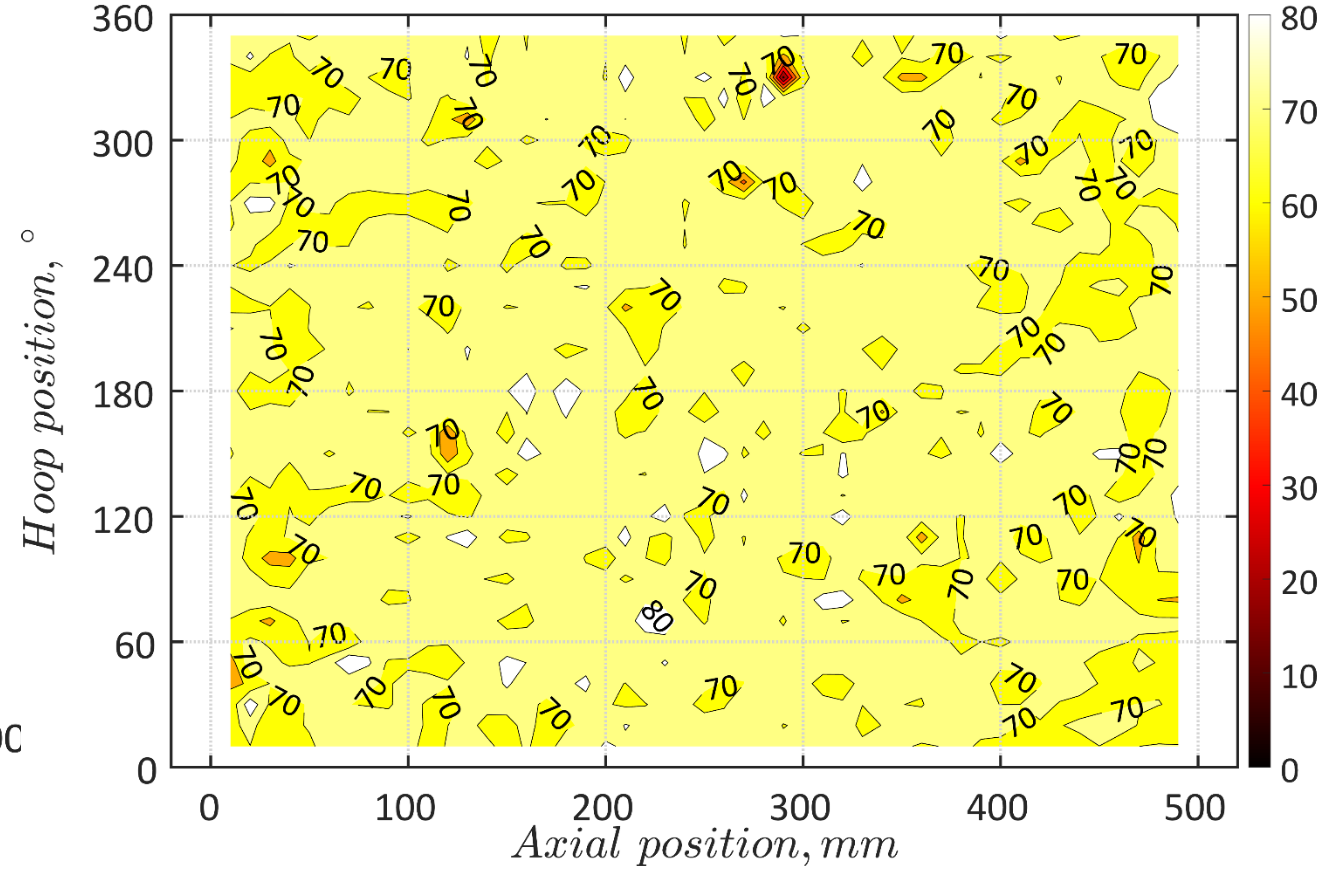
Heat ON

Thermocouples



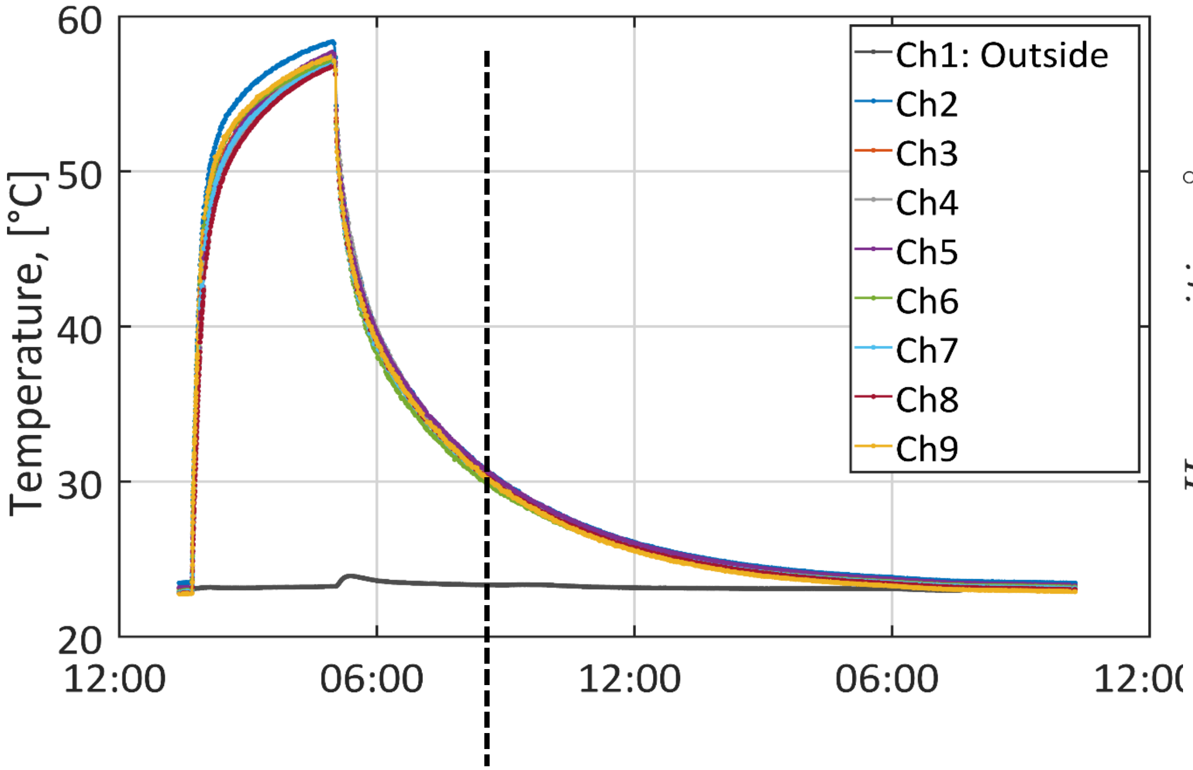
at 17:00
T = [57, 58] °C

OBR: [70, 80] °C



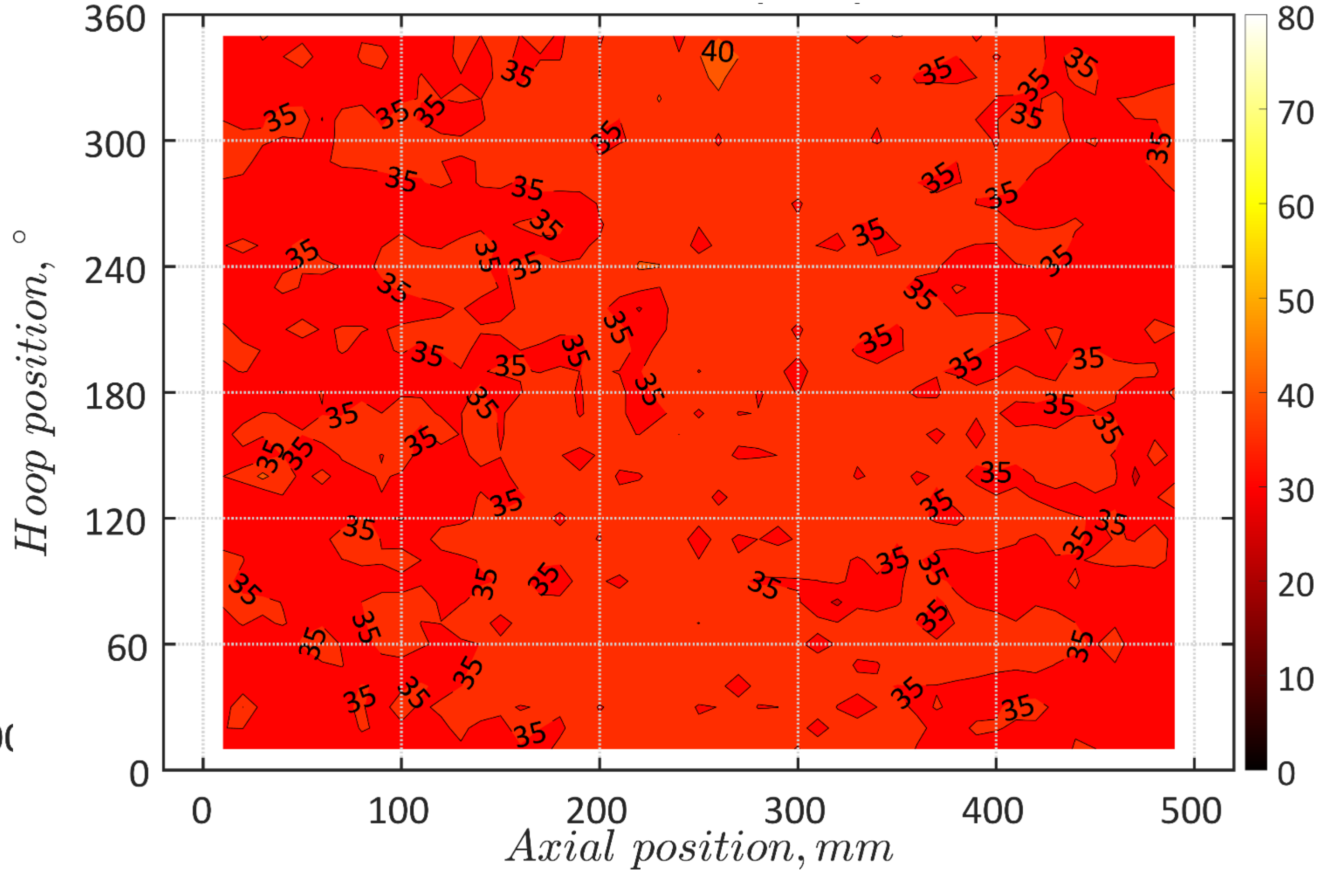
Cooling down

Thermocouples



at 20:00
T = [31, 32] °C

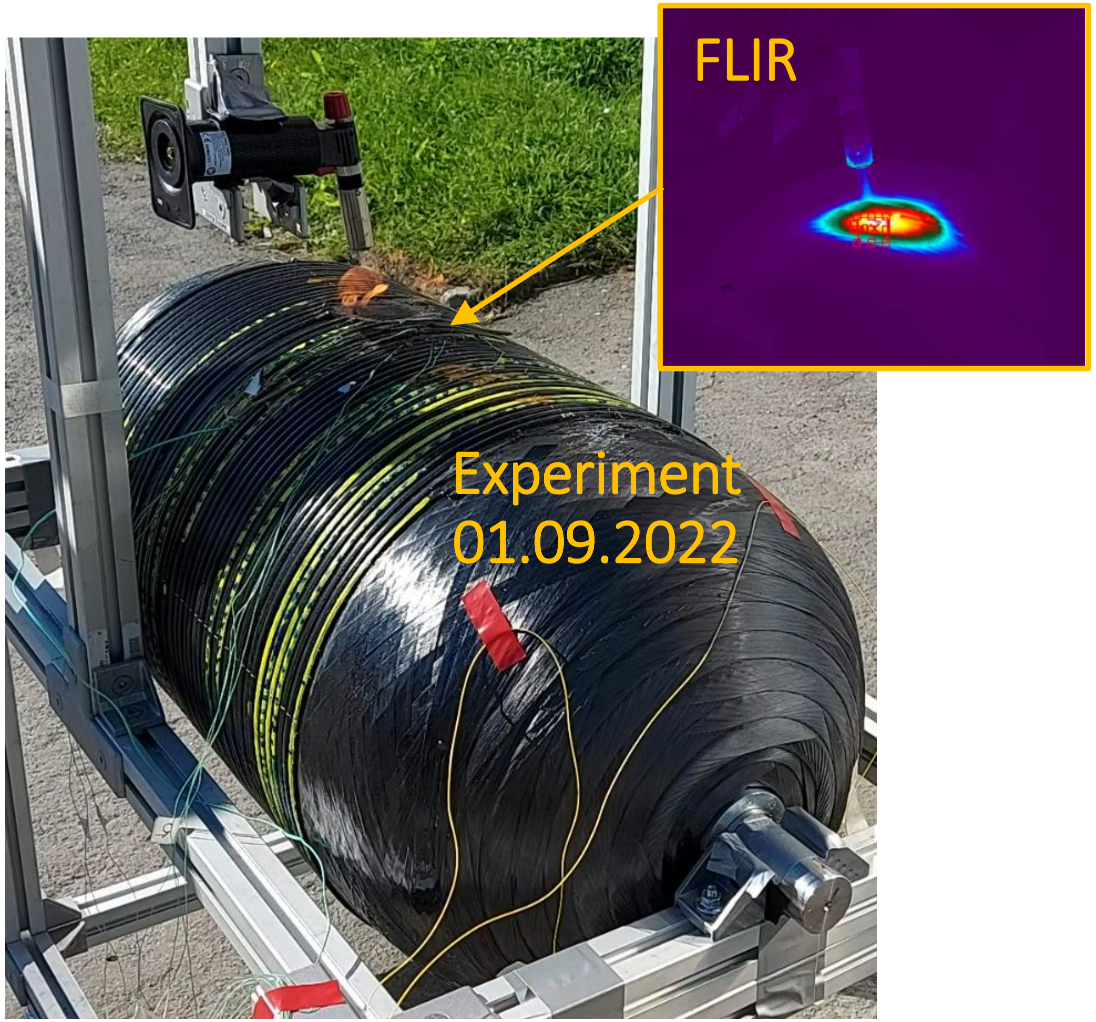
OBR: [35, 40] °C

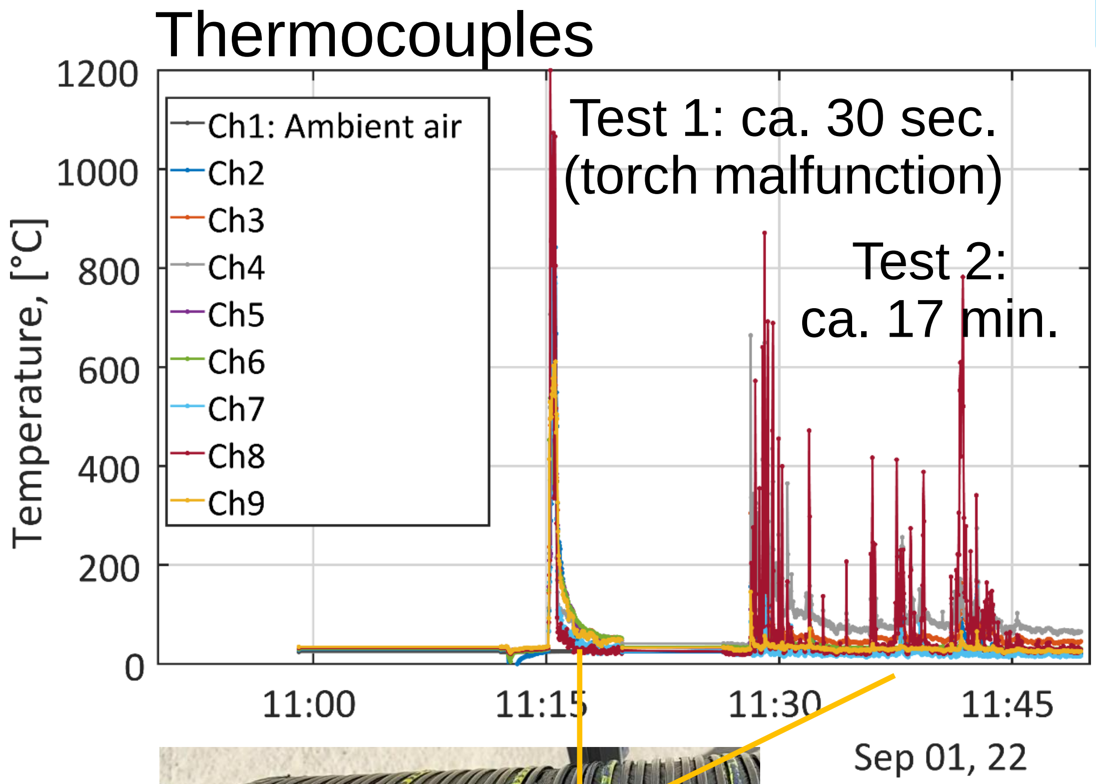


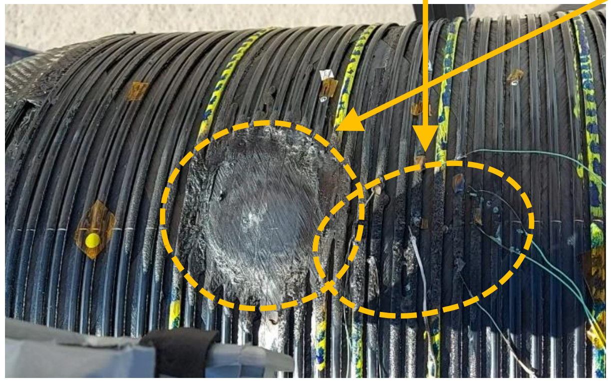
Oven testing takeaways

- OBR gives uniform temperature (expected)
- Throughout experiment $T_{OBR} > T_{Thermocouple}$
  i.e OBR consistently overshoots (reasons)

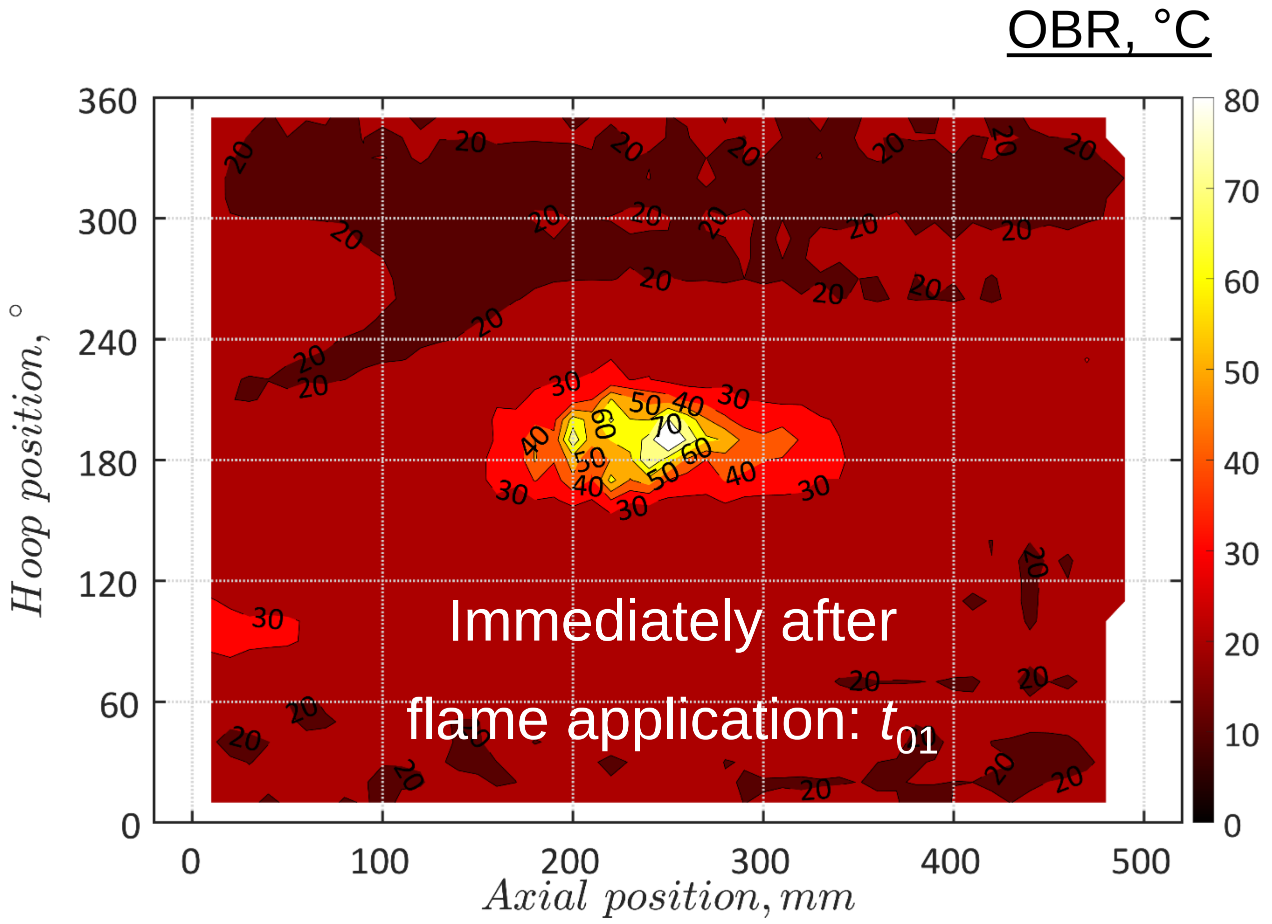
Direct flame: Test 1 and Test 2

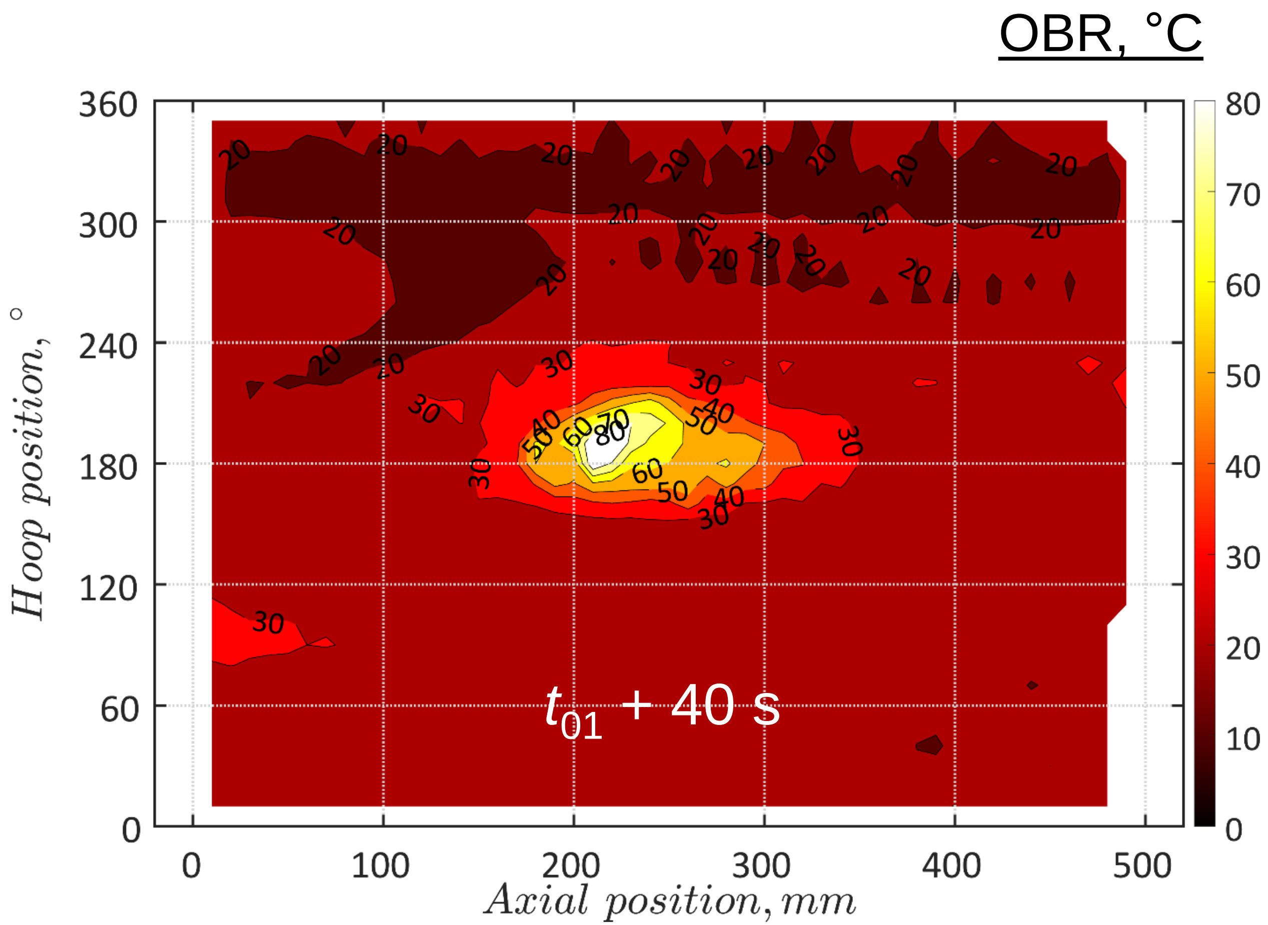




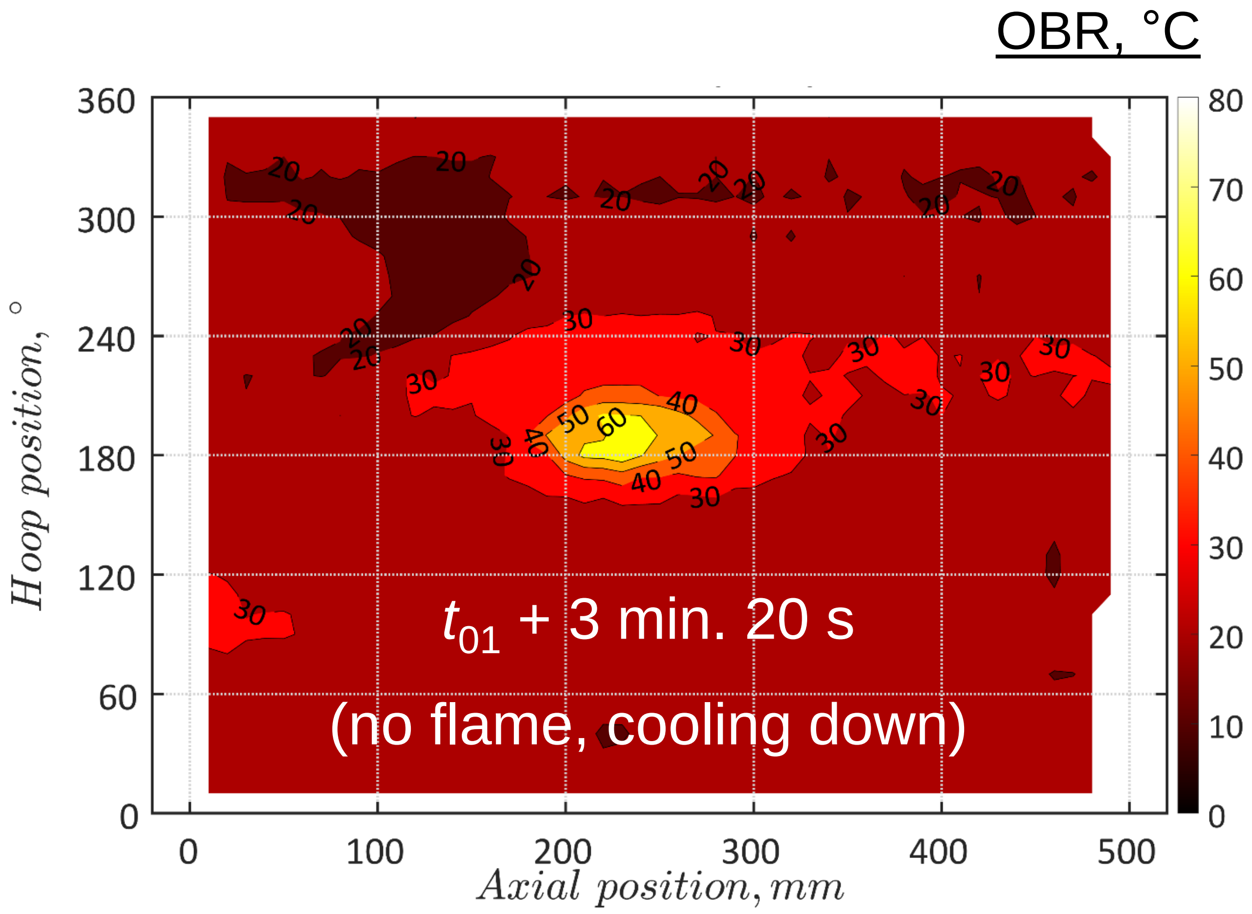


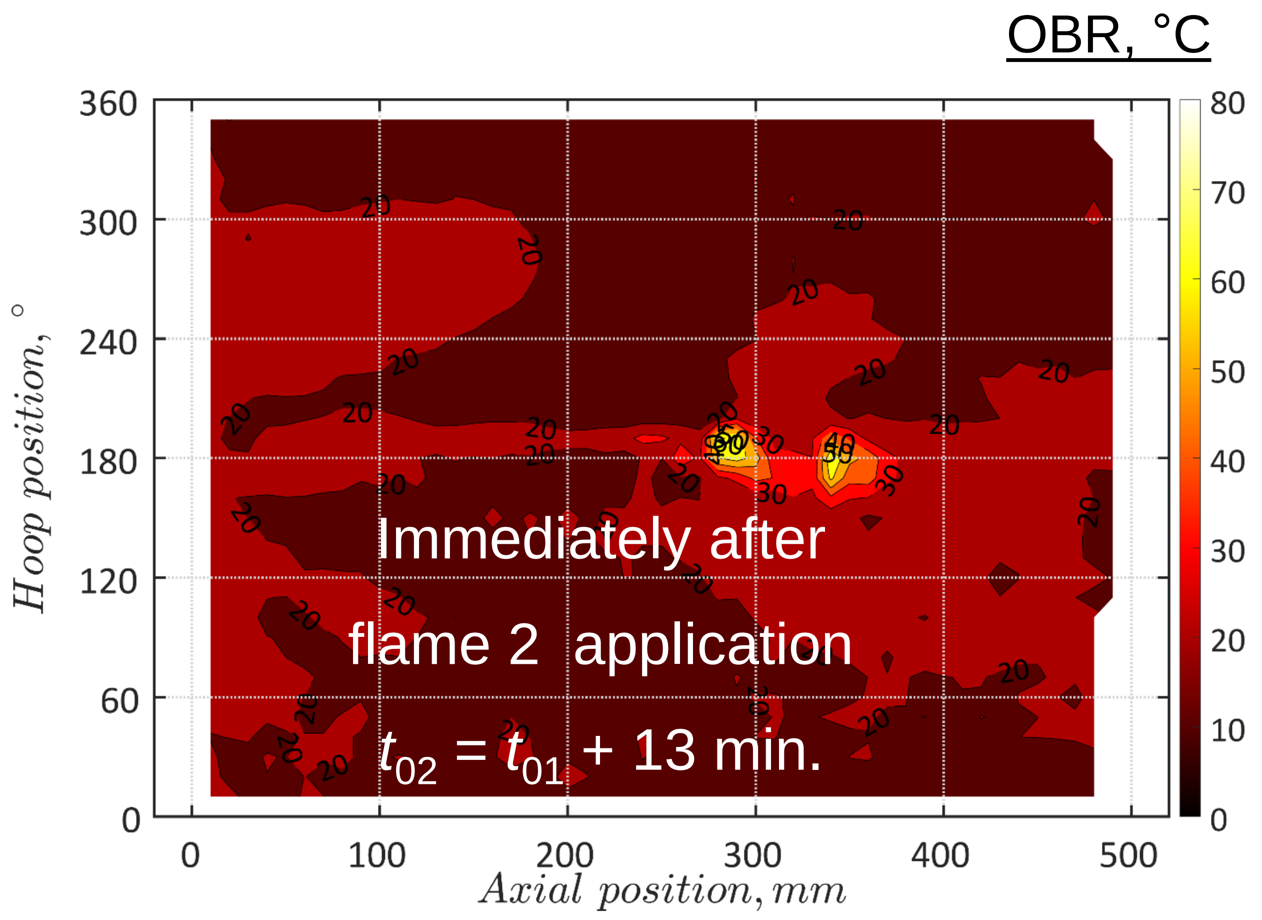
Fire Test 1


OBR, °C
Hoop position, °
Axial position, mm
Immediately after
flame application: t_{01}

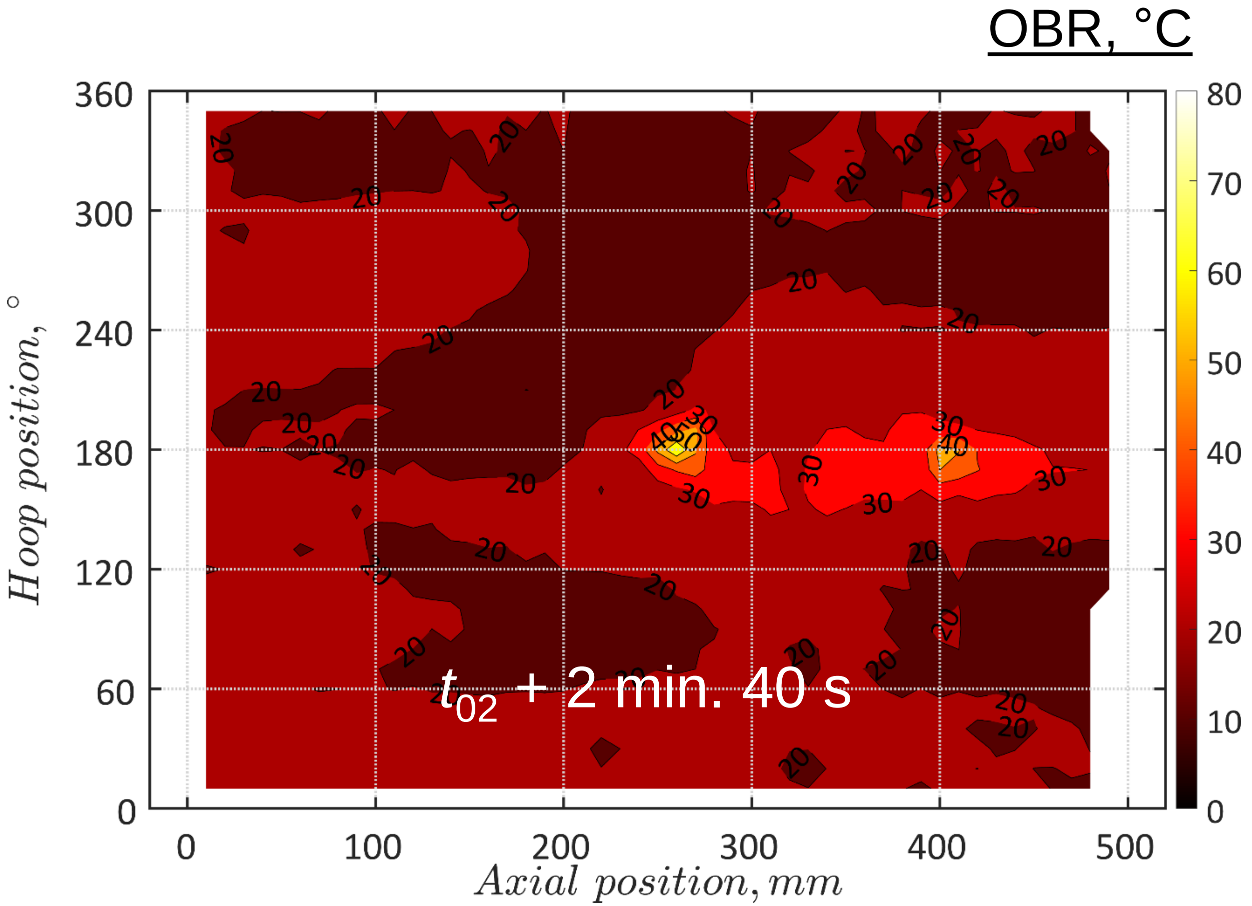

OBR, °C
Hoop position, °
Axial position, mm
t_{01} + 40 s

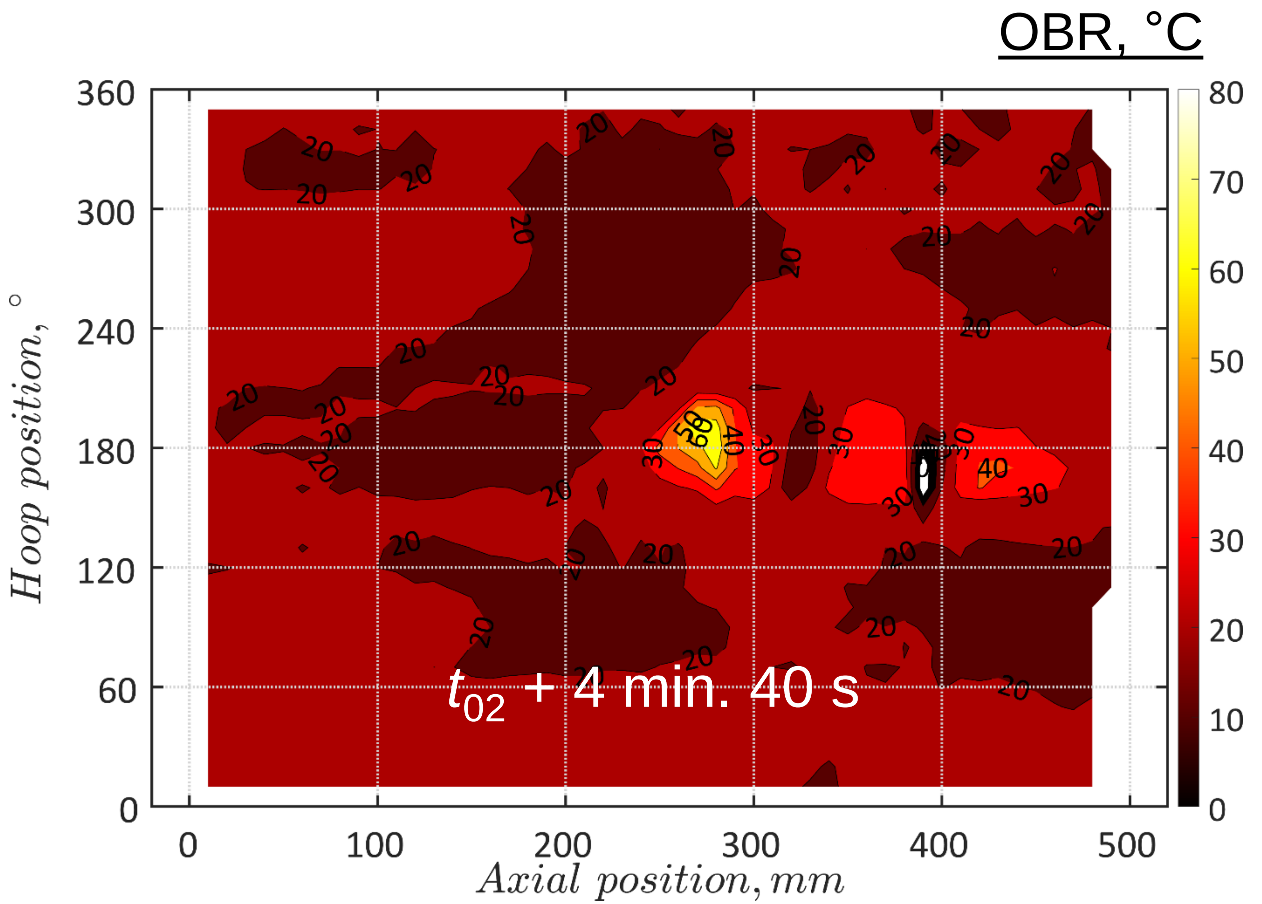
Fire Test 1 and Fire Test 2



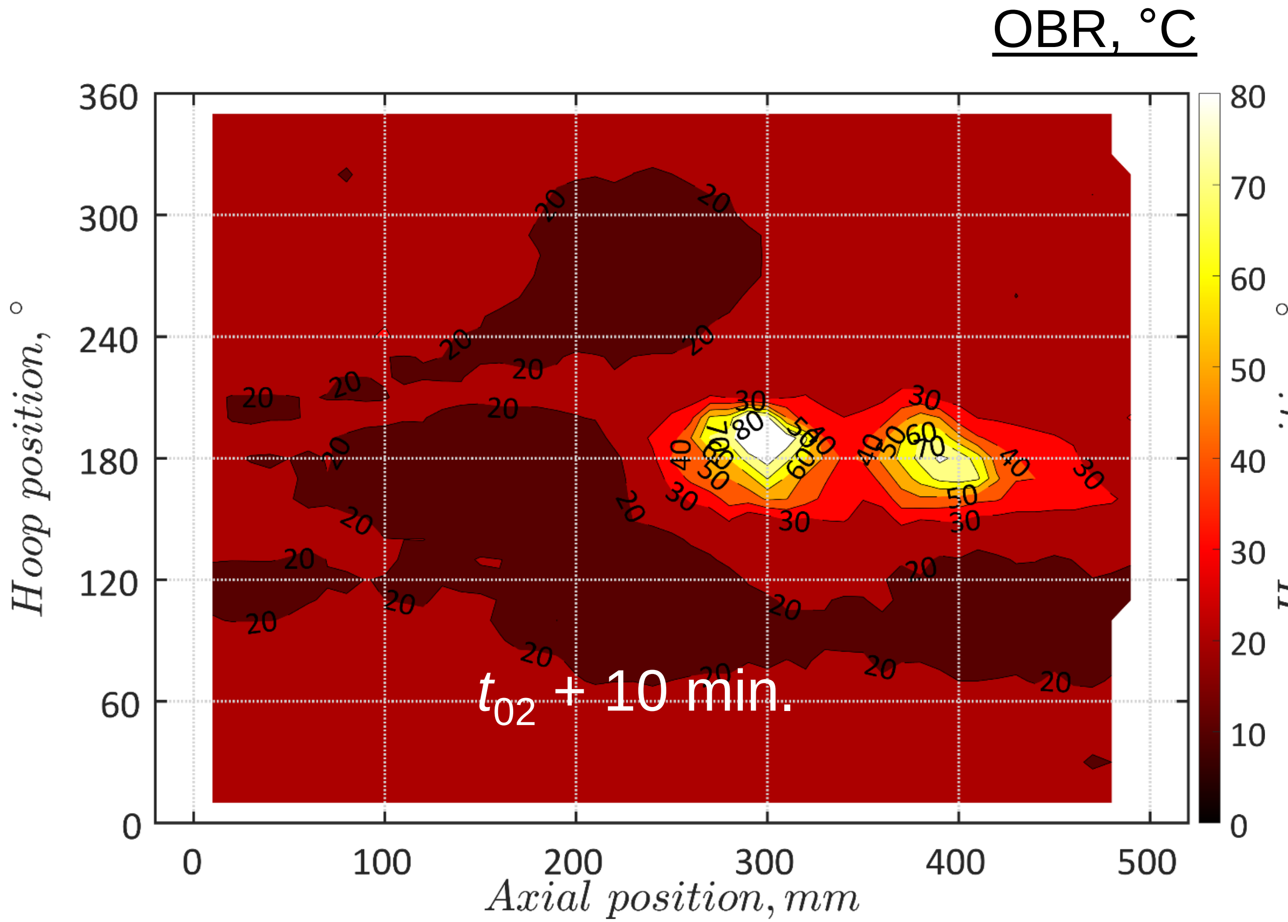


Fire Test 2

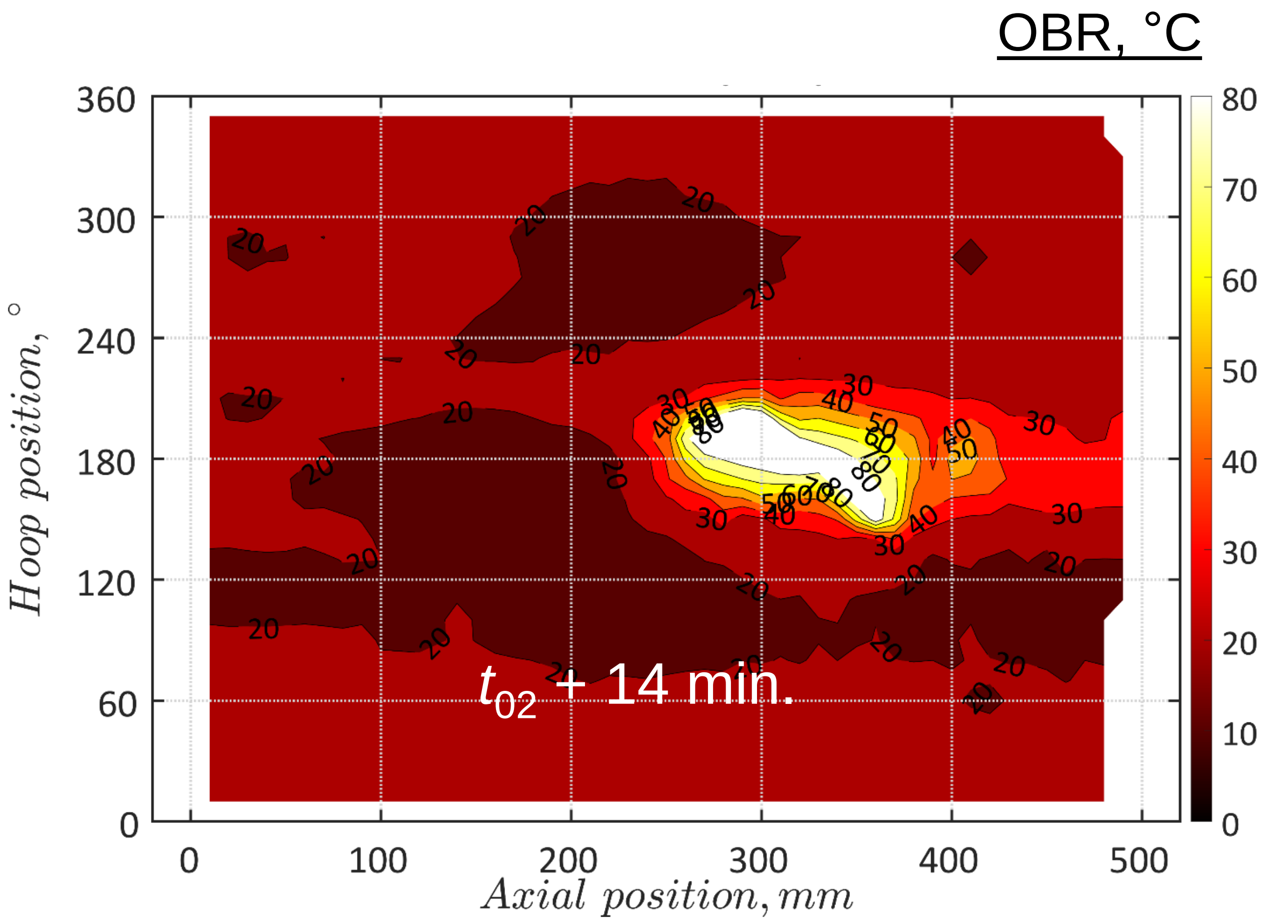

OBR, °C
Hoop position, °
Axial position, mm
t_{02} + 2 min. 40 s


OBR, °C
Hoop position, °
Axial position, mm
t_{02} + 4 min. 40 s

Fire Test 2

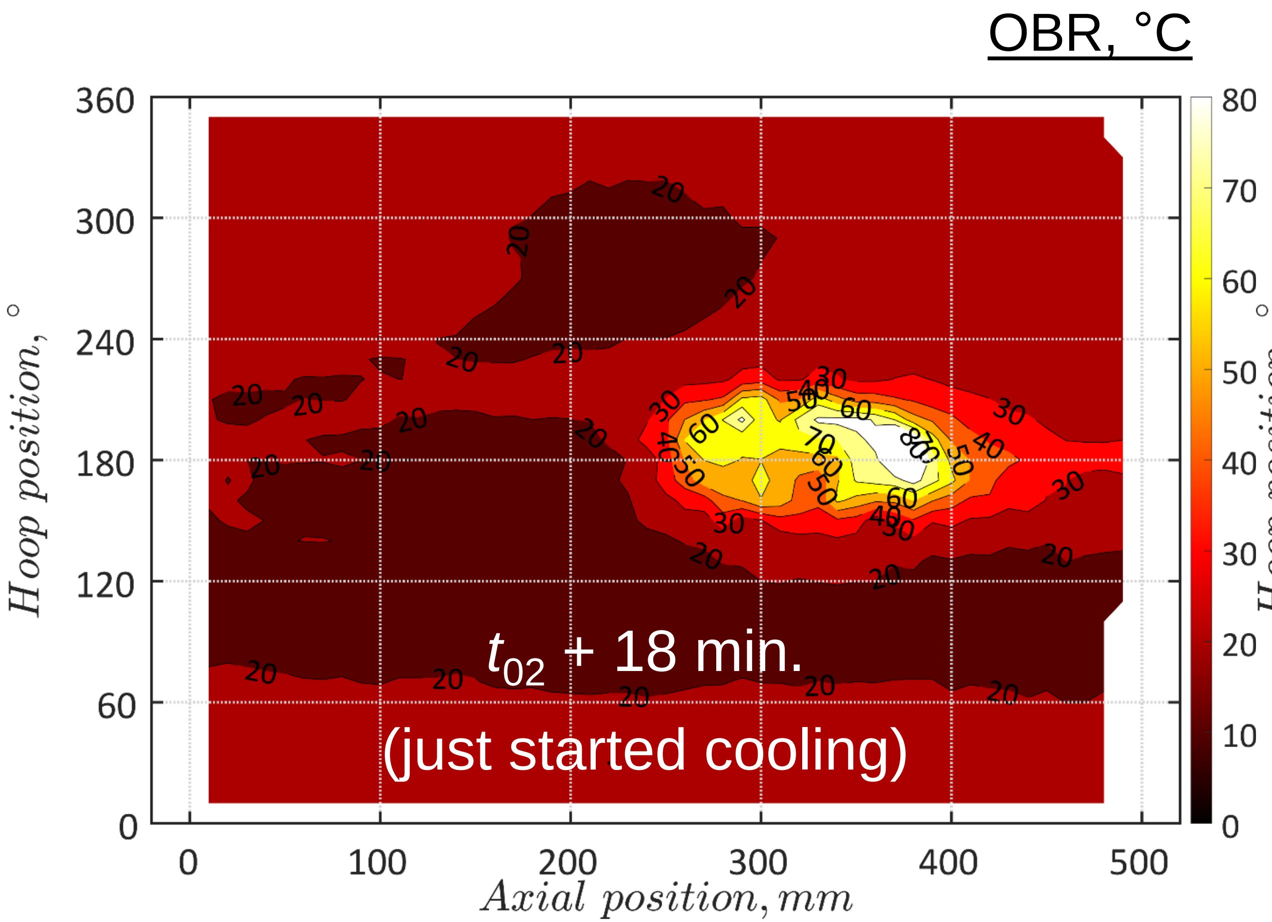


OBR, °C
Hoop position, °
Axial position, mm
t_{02} + 10 min.
0
60
120
180
240
300
360
0
100
200
300
400
500
0
10
20
30
40
50
60
70
80

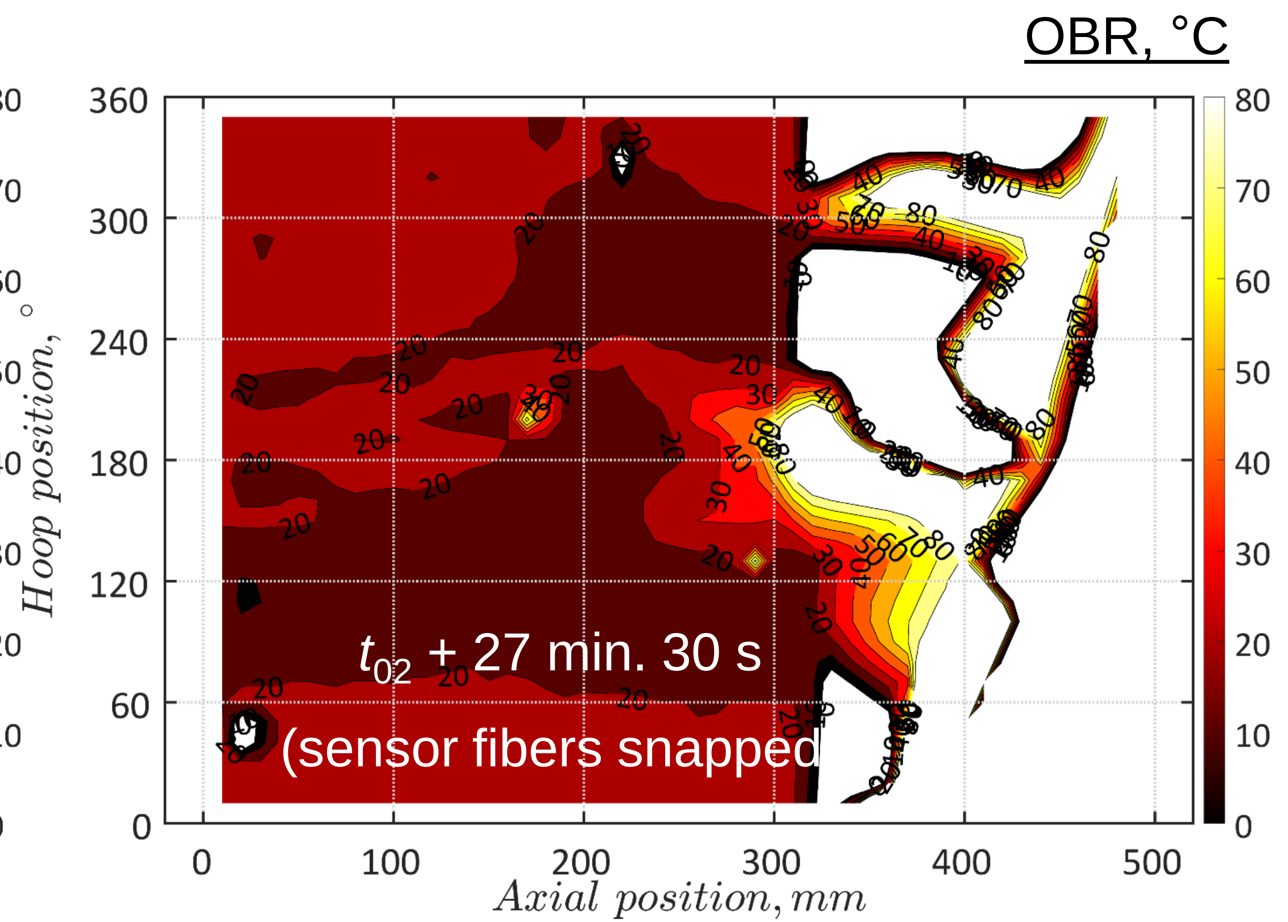


OBR, °C
Hoop position, °
Axial position, mm
t_{02} + 14 min.
0
60
120
180
240
300
360
0
100
200
300
400
500
0
10
20
30
40
50
60
70
80

Fire Test 2

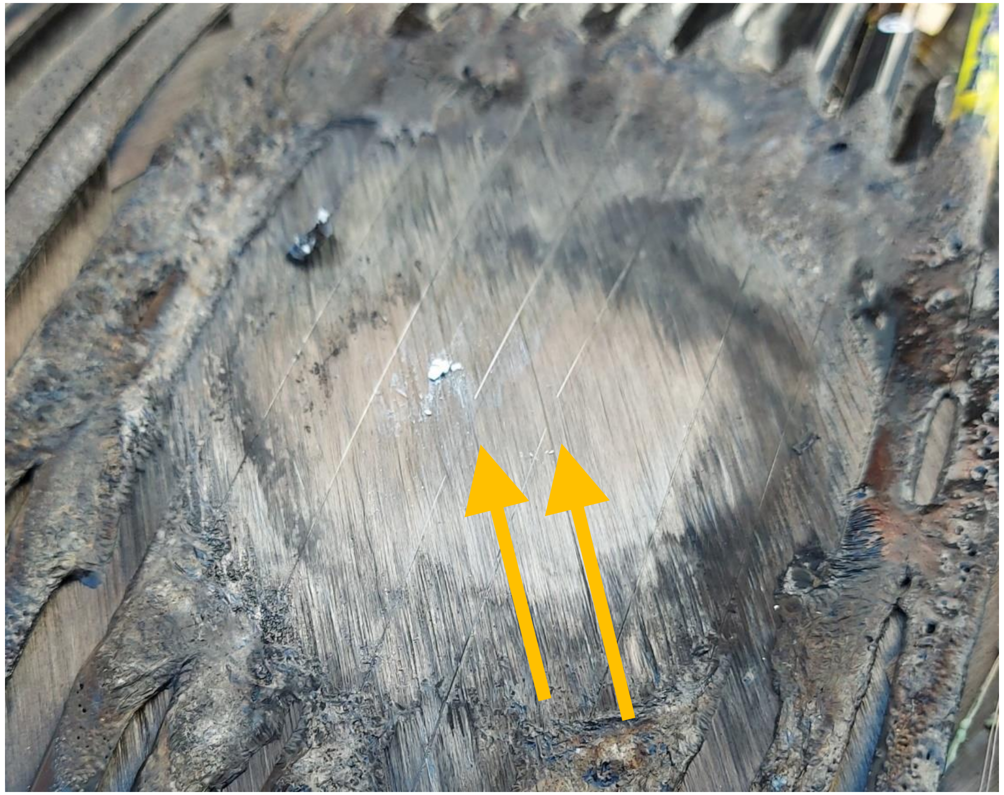


OBR, °C
Hoop position, °
Axial position, mm
t_{02} + 18 min.
(just started cooling)



OBR, °C
Hoop position, °
Axial position, mm
t_{02} + 27 min. 30 s
(sensor fibers snapped)

Aftermath



- Scene of the flame
- Both sensor fibers snapped when the cylinder was cooling down

Flame testing takeaways

- Optical fiber sensors survived for 17+ min. under localized direct flames
- Flame location can be identified throughout the process, specific temperature values with used sensor fibers not
- Fibers snapped during vessel cooldown
- Measurement noise is elevated

Conclusions

- Optical fiber integration into Type V cylinders is challenging

- Optical fiber grid on Type V cylinder was demonstrated as a high-resolution sensory device for monitoring fire aggression

Thank you to partners for good cooperation!

Questions?

Tank Manufacturing

Pablo NODENOT

Configuration Reminder

① Setting tanks
CETIM
03/2021
04/2021

② Validation tanks
CETIM
09/2021
12/2021

③ Production tanks PA12
AFPT
03/2022
04/2022

④ Production tanks PA11
AFPT
06/2022

	Production	Liner	Stacking	Material		Test done		
				Supplier	Matrix	Test name	Results	Objectives
Tank 1	CETIM	Hyphone PA11	Model F : 74 plis	A	PA11	Burst test	738 Bar	1575 Bar
Tank 2		Hyphone PA11	Model F : 74 plis			Burst after ASR	350 Bar	
Tank 3		Hyphone PA11	Model F : 74 plis			Optical fibres placement trials		
Tank 4	CETIM	Hyphone PA11	Hyphone G : 82 plis			Burst test	1466,3 Bar	1575 Bar
Tank 5		THOR PA11	Hyphone G : 82 plis				1476,2 Bar	1575 Bar
Tank 6	AFPT	THOR PA11	Hyphone G : 82 plis	B	PA12	Burst test	1250 Bar	1575 Bar
Tank 7		THOR PA11	Hyphone G : 82 plis			Ambient Temperature Pressure Cycle	1800 cycles	22000 cycles
Tank 8		THOR PA11	Hyphone G : 82 plis			Extreme Temperature Pressure Cycle		22000 cycles
Tank 9		THOR PA11	Hyphone G : 82 plis			Assembly, leak & bonfire - Burst test	1198 Bar	1575 Bar
Tank 10		THOR PA11	Hyphone G : 82 plis			Assembly, leak & bonfire		
Tank 11		THOR PA11	Hyphone G : 82 plis			Assembly, leak & bonfire		
Tank 12	AFPT	THOR PA11	Hyphone G : 82 plis	B	PA11	Burst test	1370 Bar	1575 Bar
Tank 13		THOR PA11	Hyphone G : 82 plis					1575 Bar
Tank 14		THOR PA11	Hyphone G : 82 plis			Ambient Temperature Pressure Cycle		22000 cycles
Tank 15		THOR PA11	Hyphone G : 82 plis			Extreme Temperature Pressure Cycle		22000 cycles

CETIM Machine Specification

First version of AFPT tape winding machine

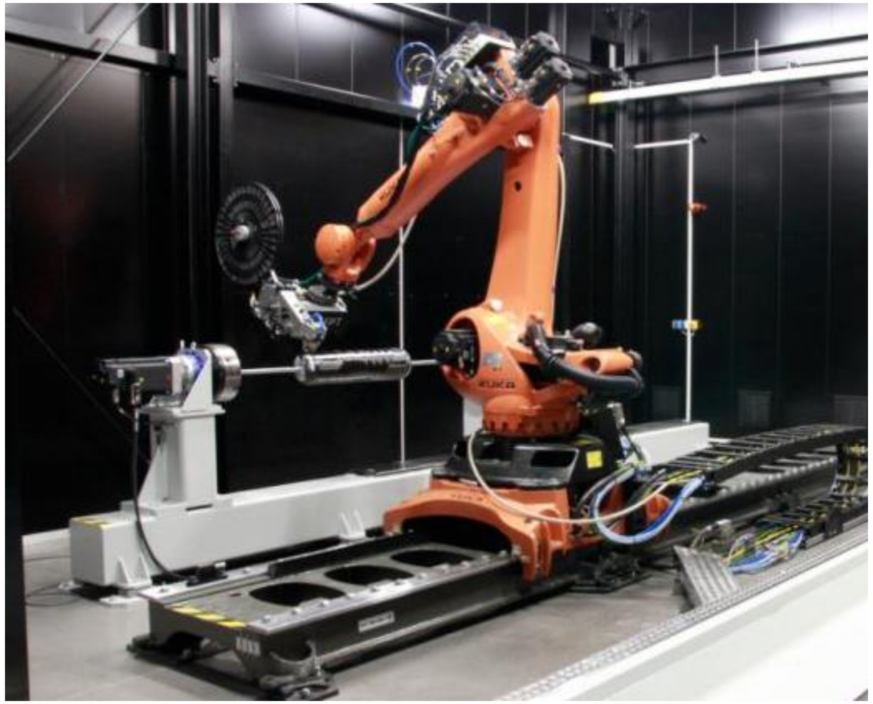
➢ Optimized by CETIM according to our experiences

2 external axis

- Largest : Ø0,25m – 2,5m ; up to 6m long
- Smallest : Ø25mm – 500mm ; up to 3,5m long

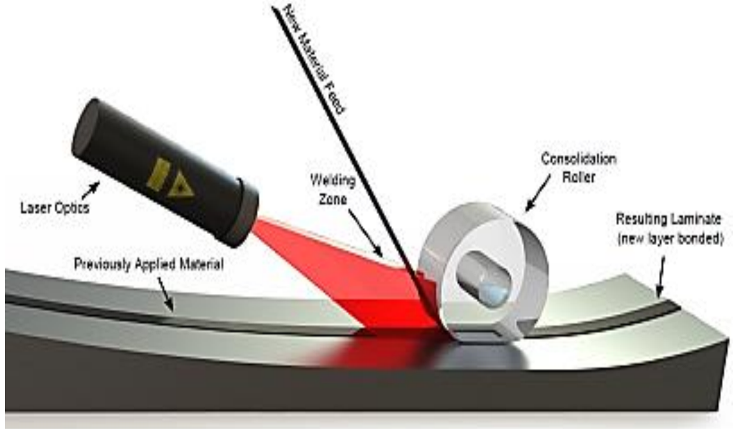
Material

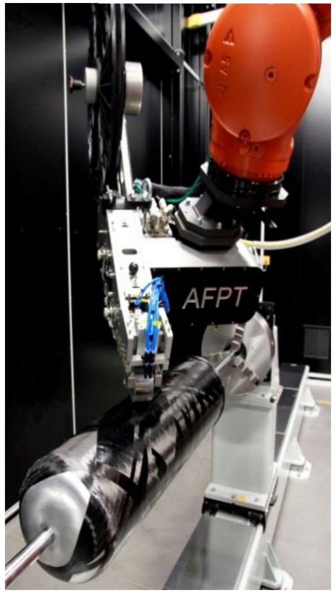
- Up to 1 inch (25,4mm)

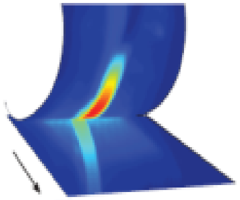


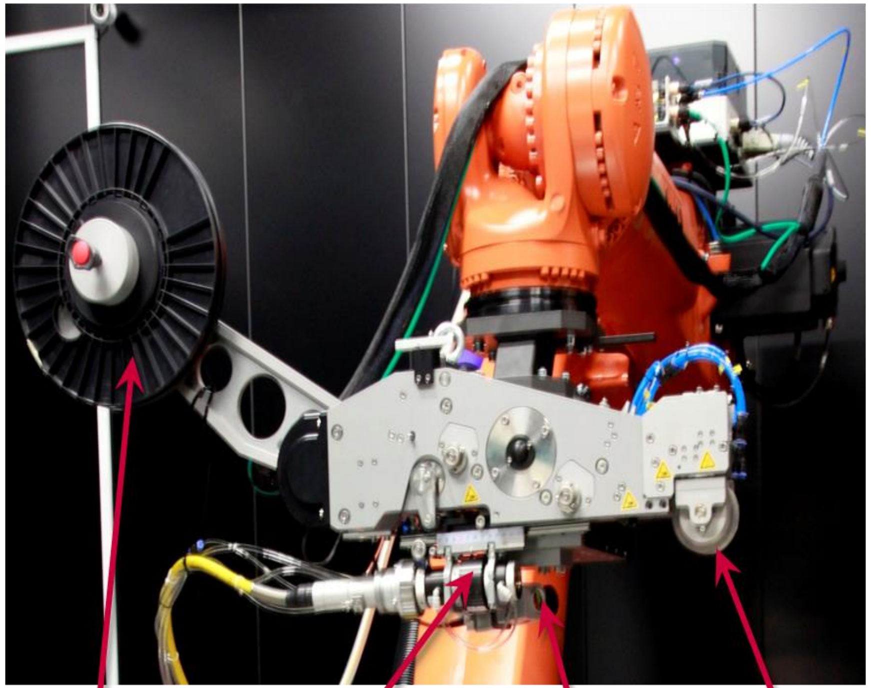
The tape winding equipment from CETIM

CETIM Machine Specification





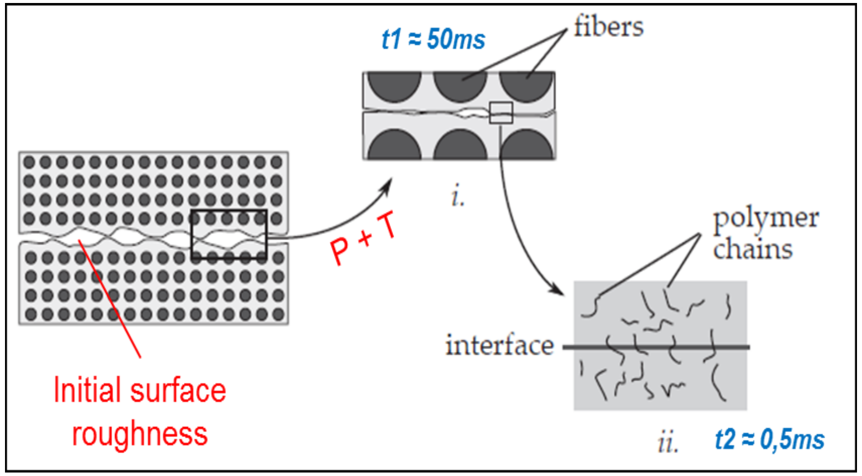


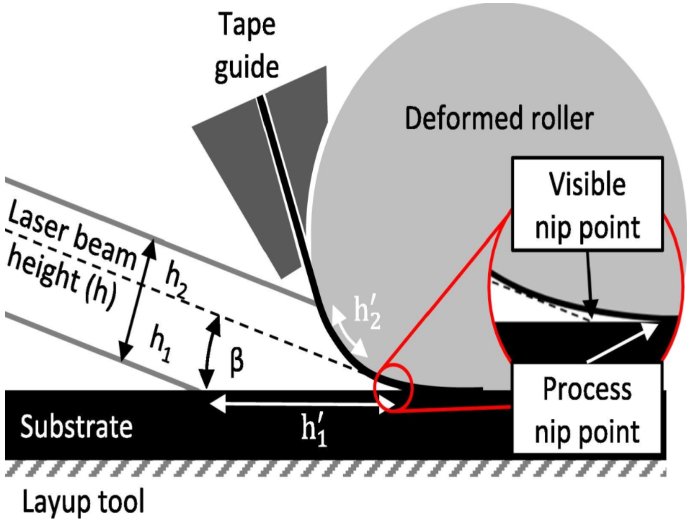


CETIM Machine Specification

Influencing parameters

- *Laser power (T°C)*
- *Compaction force*
- *Layup speed*
- *Laser beam incidence*
- *Etc…*





- ***Expectations***
  - *Optimized material health (porosity, crystallinity,...)*
  - *Limitation of internal stresses*

CETIM & AFPT Quality Results

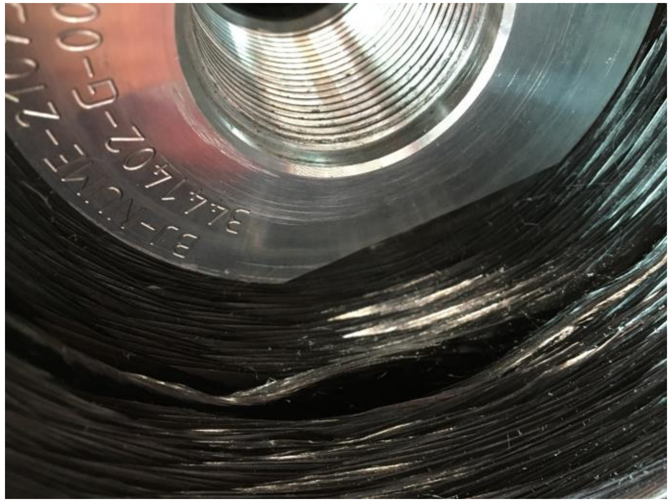
cetim Quality results in domes

Tank #4 CETIM

Tank #4 CETIM

AFPT Quality results in domes

Tank #6 AFPT



Tank #6 AFPT

faurecia Air Liquide creative oxygen RINA sirris NTNU cetim Grand Est cnrs cetim

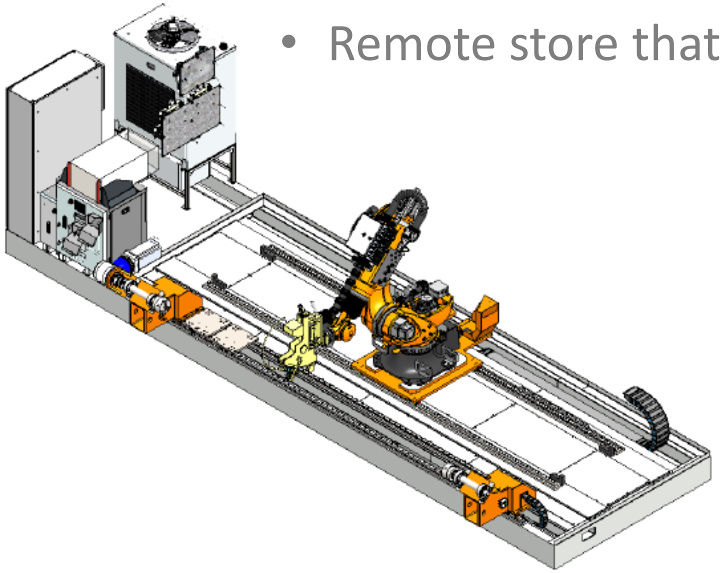
CETIM & AFPT Machine Specification

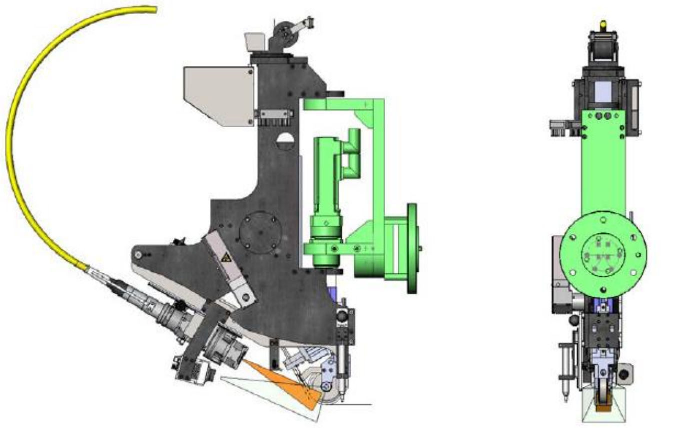
AFPT

New thermoplastic winding machine – Speedhy

Last version of AFPT tape winding machine : dedicated for tank manufacturing

- Optimized head
- Speed : 3 to 100m/min
- Remote store that can hold 8000m winding coils





View from right

View from front

- Robot (KR 150-2700-2) on track
- Track movement 4100 mm
- Tilted winding axis for better access to the vessels
- Maximum length of the winding mandrel 4100 mm
- Maximum diameter of the winding mandrel 500 mm
- Maximum mass of the winding mandrel (clamping on both sides) 500 kg
- Maximum mass of the winding mandrel (one-sided clamping, distance center of gravity to the mounting 1 m) 50 kg
- Two slides to accommodate a mandrel support

CONCLUSION

- Strong deadline constraints leads to few iterations
  - Burst result close to the target (-6%)

- Tank settings can be optimized
  - By understanding key parameter influence
  - With appropriate tools : dedicated machine and development of software for digital chaining (finite element simulation, programming, robotics simulation)

- All tools are available to continue and reach the objectives