DE LA RECHERCHE À L'INDUSTRIE

H_2 Composite Pressure Vessel

GTR 13 meeting

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5-7/03/2019, PowerTech Lab., Surrey, Canada

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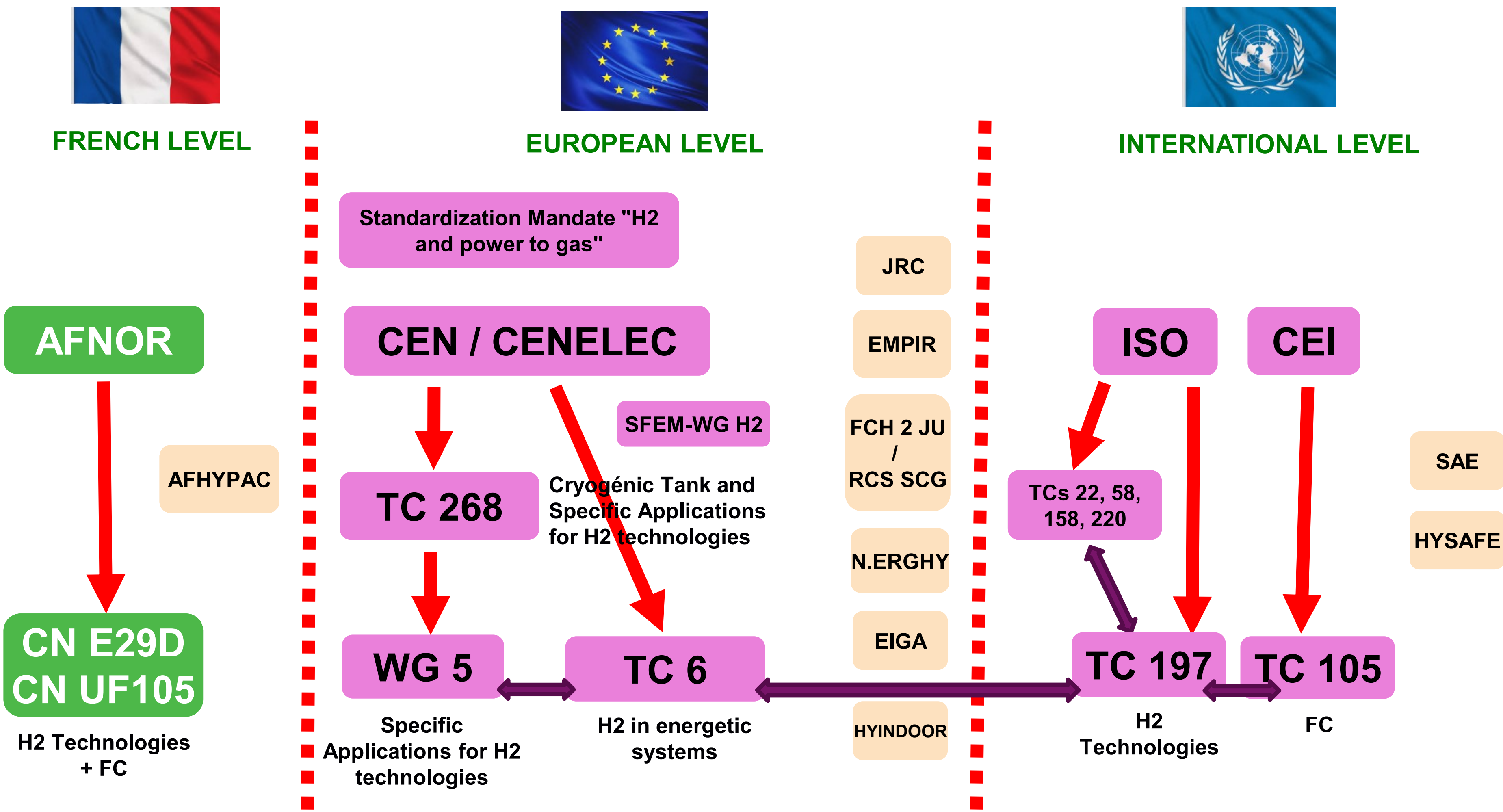
PLAN

- French Hydrogen Plan
- H2 Composite Pressure Vessel at CEA
- Burst ratio / HYCOMP project

PLAN

- French Hydrogen Plan

French H_2 Tech. Standard Organization



1st June 2018: French deployment Hydrogen Plan

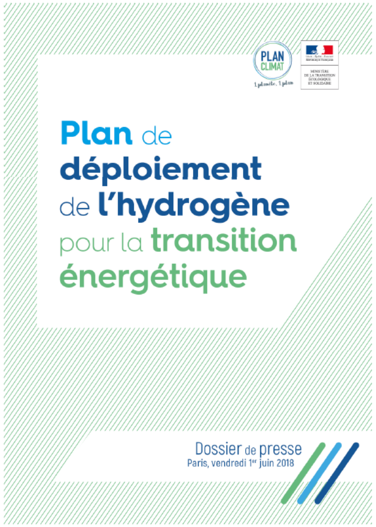
Nicola Hulot

French Minister of Ecological and Solidarity Transition

"…It is in this spirit that I present a plan for hydrogen that will aim to make our country a world leader in this technology.

To do this, I proposed to set a 10% share of hydrogen produced from renewable sources by 2023.

Moreover, because we need innovations, demonstrators and economic champions of storage Electrolysis, I decided to mobilize 100 million euros to support the first deployments of these technologies of production and transport in the territories."



PLAN

- H2 Composite Pressure Vessel at CEA

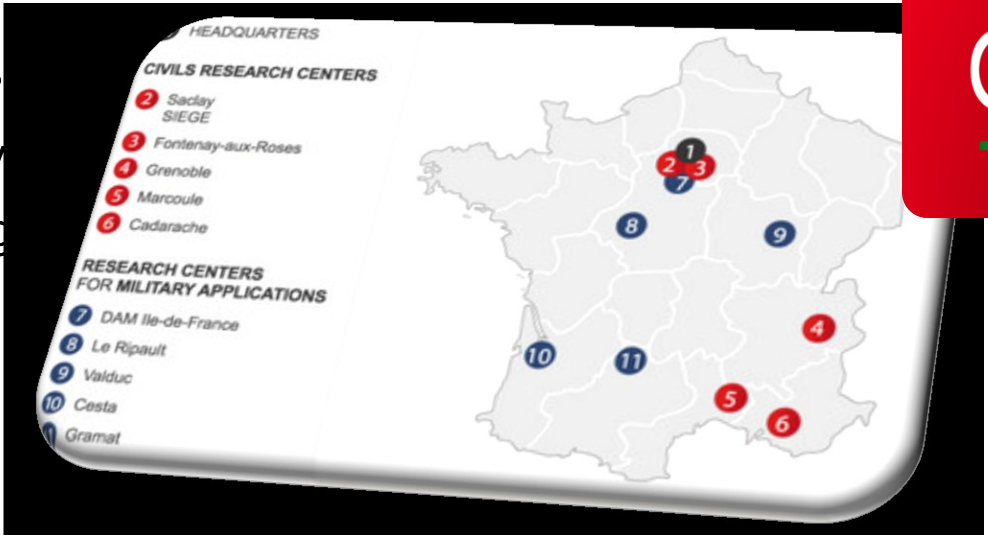
CEA is active in 4 main areas

Low-carbon energies

Defense and security

Information technolog

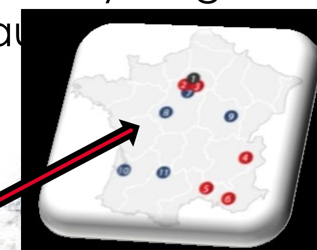
Health technologies



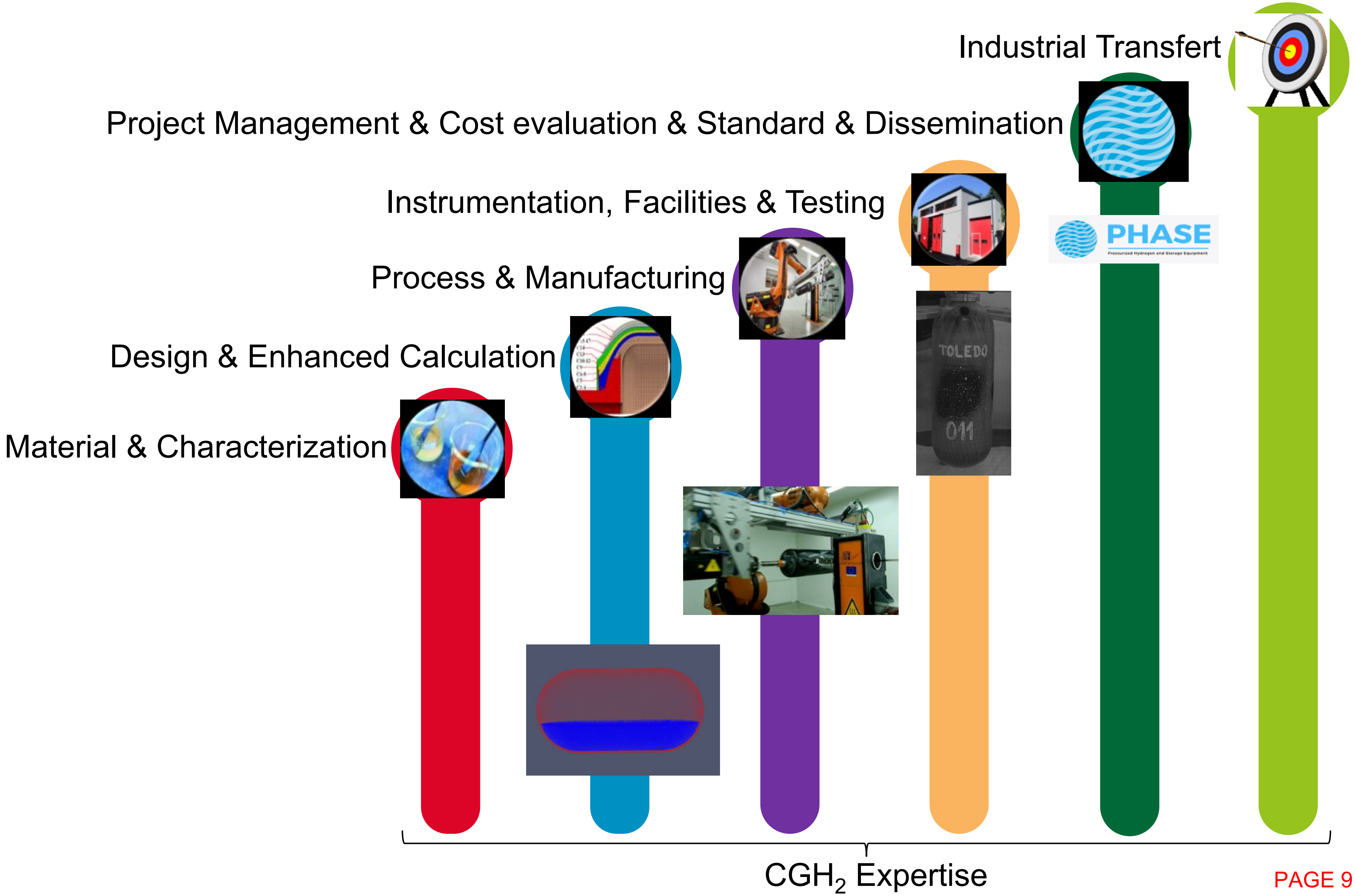
CEA is “The World's Most Innovative Research Institution”
(ranked n°1 by Reuters, 8th of March, 2016)

CEA CPV plateform = Lavoisier Plateform

- CEA Le Ripault: Lavoisier Facility (Tours): dedicated to H_2 application (storage, EMA, Bipolar plates) and batteries (1000 m^2 lab + Cycling Facility + TER experimental testing center + CEA CESTA Bordeau



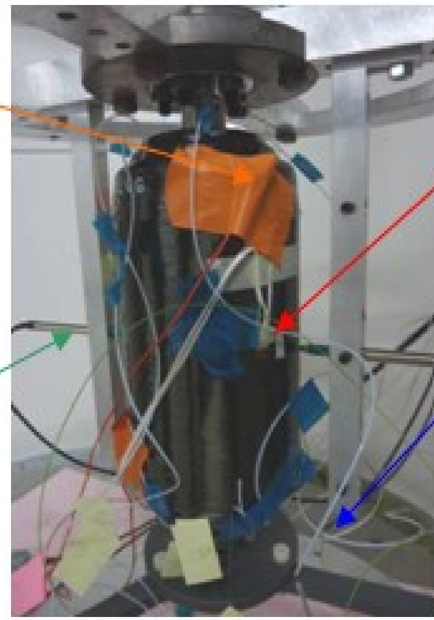
CEA CGH_2 storage Value Chain



Multi-instrumented test (pressure, temperature, optical fibers, strain gauges, acoustic emission, LVDT, fast camera, 3D digital image correlation)

Acoustic emission

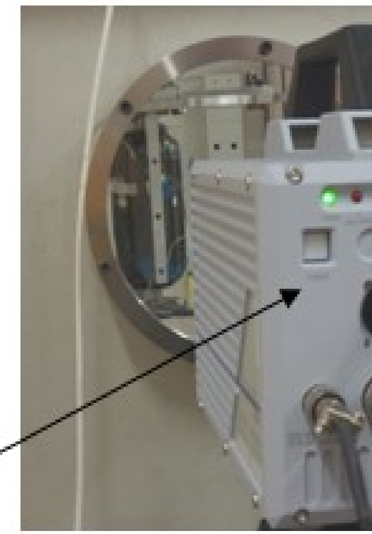
LVDT



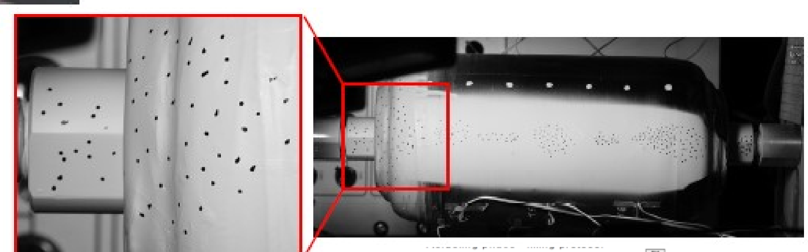
Strain gauges

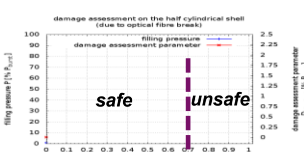
Optical fibers

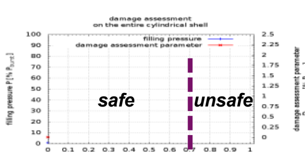
Fast camera

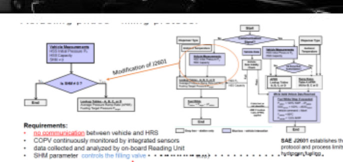


3D DIC

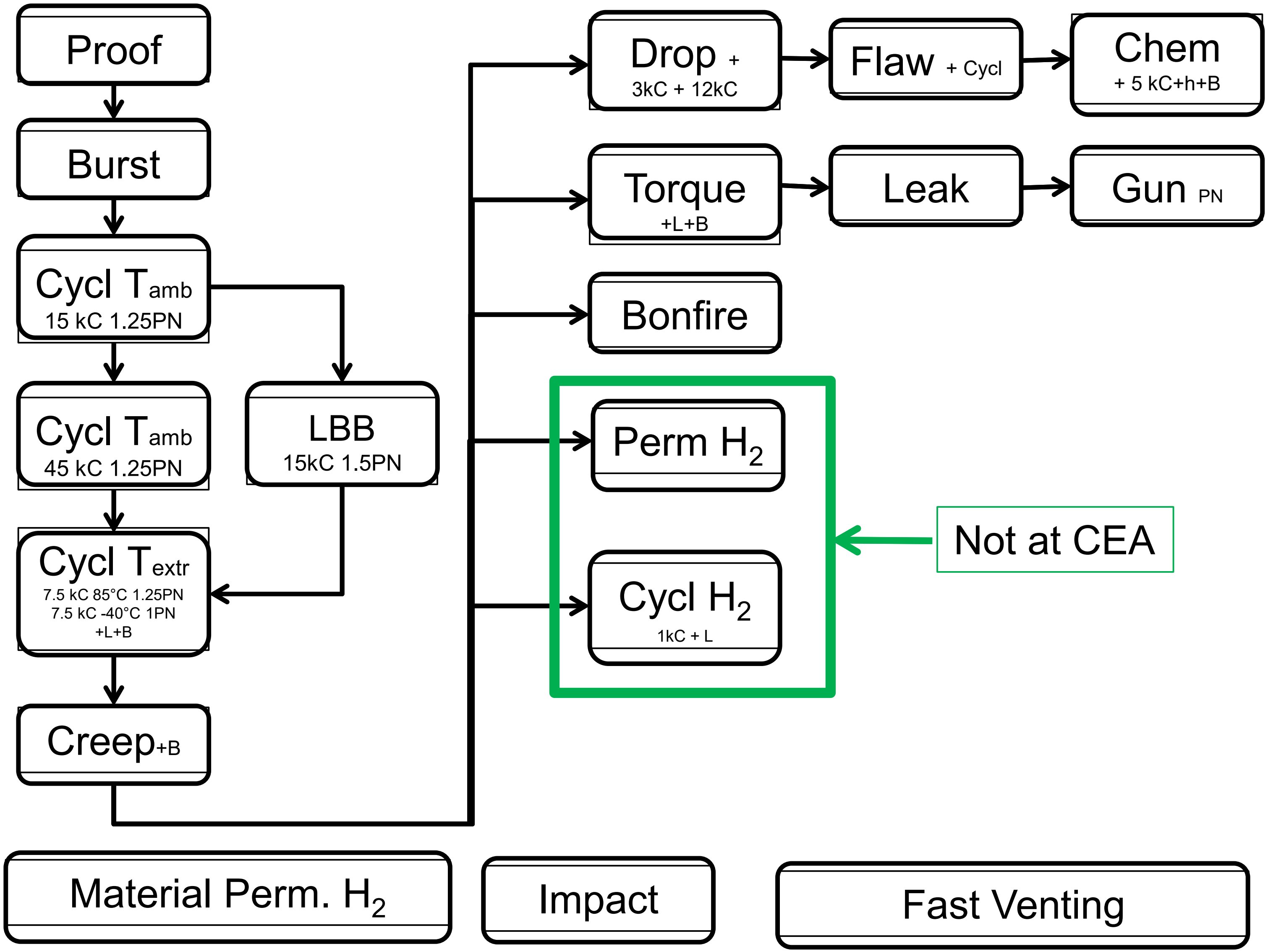








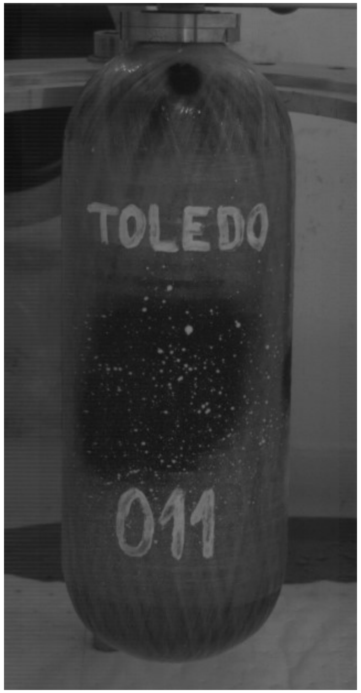
CEA Testing: EC79 + other tests (R134…)

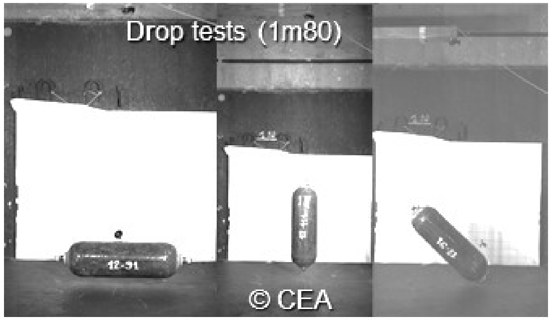


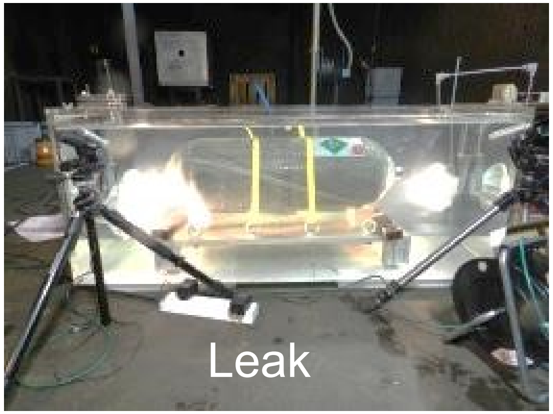
CEA Testing Facilities

- Performances & safety assesment

Compliance to standard testing (EC79, R134)





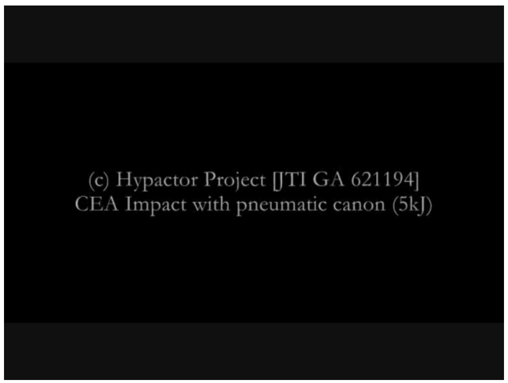


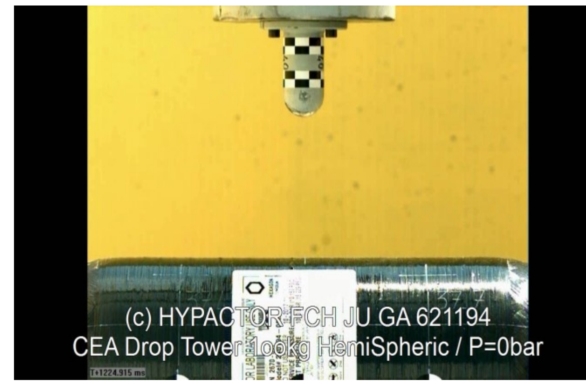
CEA Impact Test Facilities

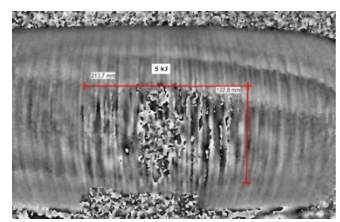
- **Performances & safety assessment**

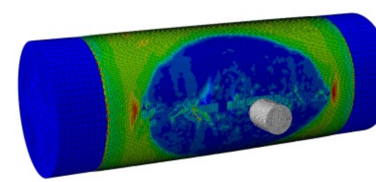
HyPactor

- with Hexagon and Air Liquide
- Resistance to abusive testing (e.g. impact, pressure overload/creep…)
- Provide recommendations for Regulation Codes + Standards (RCS)









CEA CPV Cycling Facility

Main characteristics:

- at Ambient Temperature
- for vessels with damage (flaws, impacts, chemical exposure…)
- at **Extreme Temperatures** (-40°C, +85°C) extended to (-60°C to +100°C)
- for Leak before burst
- for Accelerated stress rupture test : Pressure Constant Load at given extreme temperature and hygrometry
- Cycles from **5 bar to 1100 bar**
- Max Volume Expansion at 1050 bar : 46L
- Frequence: 5 cycle/min for 300L
- Maximal Vessel Volume : **300L**
- Hygrometry: 0<RHH<100%
- 2 cells compatible with 300L/1100 bar

PLAN

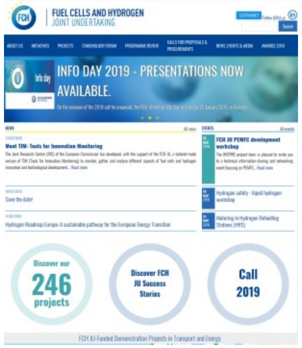
- Burst ratio / HYCOMP project

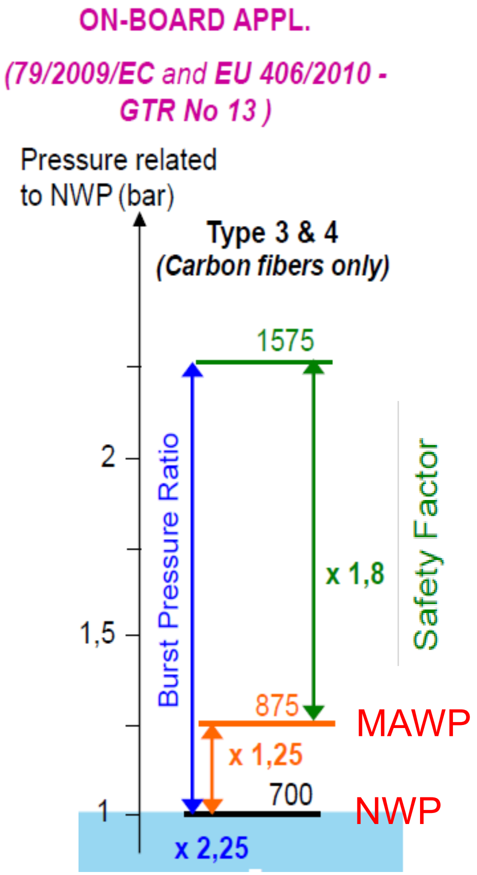
HYCOMP project: Safety Factor definition

HYCOMP : European FCH-JU project

"Enhanced Design Requirements and Testing Procedures for Composite Cylinders intended for the Safe Storage of Hydrogen"

HyCOMP is a Pre-Normative Research
January 2011 to March 2014 (39 months)
Budget: 3 802 542 €





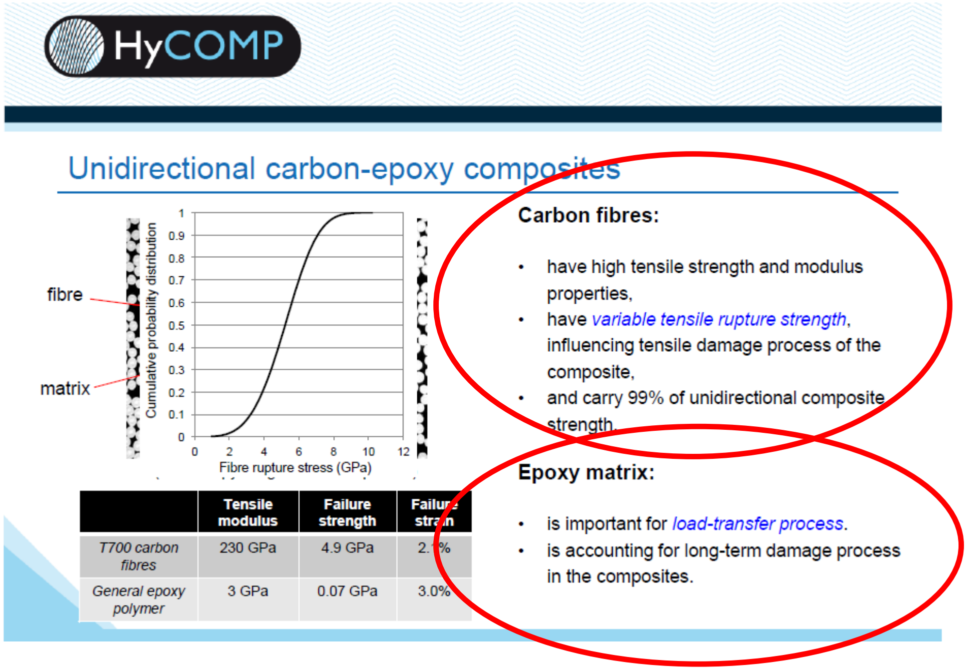
www.hycomp.eu
https://fch.europa.eu/

public information available

$$SF = \frac{MinimalBurstPressure}{DesignPressure}$$

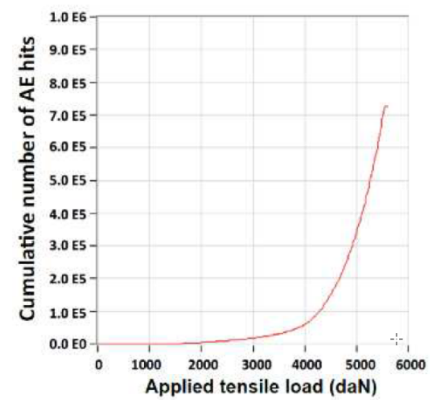
NWP=Nominal Working Pressure, NAWP=Maximum Allowable Working Pressure, Design Pressure=MAWP

Carbon Epoxy Composite Damage Process



	Tensile modulus	Failure strength	Failure strain
T700 carbon fibres	230 GPa	4.9 GPa	2.1%
General epoxy polymer	3 GPa	0.07 GPa	3.0%

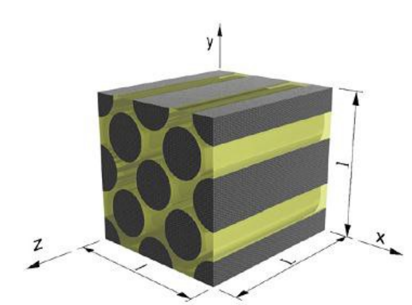
Figure shows that a rapid increase in volumetric density of fibre breaks was found as the applied tensile stress increased beyond 80% of its tensile failure strength.



The failure of UD composites are dependent on clustering process of fibre breaks.

- Two different fiber/matrix systems studied:

		Plate specimens CAQ's & Faber's cylinders (Reference system)	*Hexagon's cylinders (Specific system)*
Carbon fiber		**T700** (E = 230 GPa, ε = 2,1%, UTS = 4,9 GPa)	
Epoxy resin	Commercial reference	Huntsman resin	Hexagon proprietary
	Glass transition temperature T_g	Measured around 115°C	**110°C**



Effect of applied loading rate on fibre damage process

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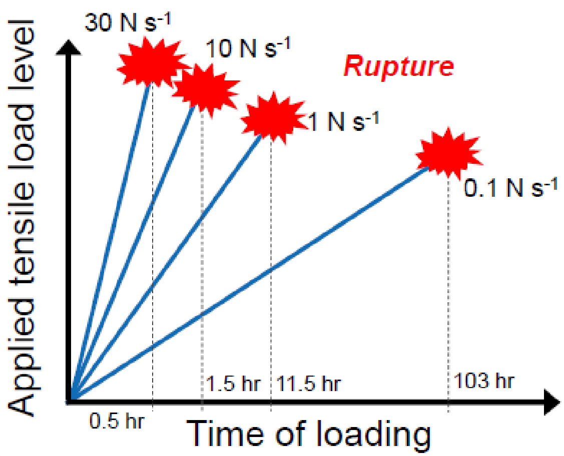
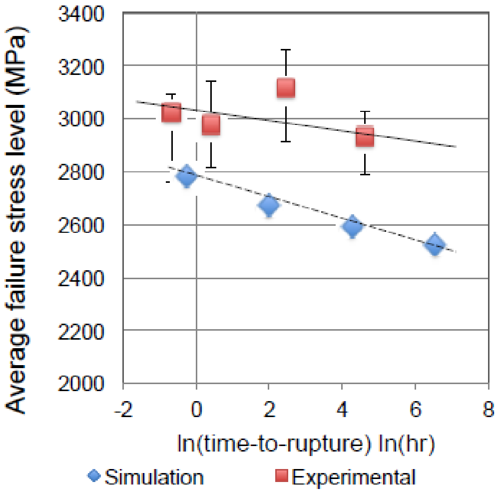
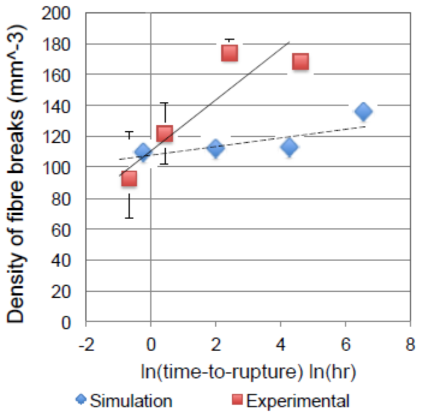
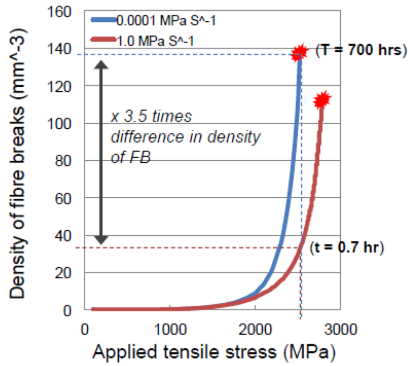
Effect of the applied loading rate on fibre damage process









Methodology for Intrinsic Safety Factor analysis: iSF

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General methods for *iSF* analysis

Step 1: Determine the average failure stress of the UD composites.

Step 2: Determine time-to-rupture properties of UD composites.

Steps 3 - 5: Statistically analyze the obtained time-to-rupture results and determine the time-to-rupture as a function of the applied creep stress level for the failure probability of *p*.

Step 6 - 7: Calculate *iSF* for the composites.

$$iSF = \frac{Average\ material\ strength}{Design\ load\ level}$$

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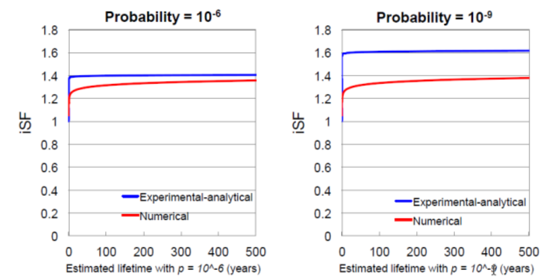
Results of *iSF* analysis

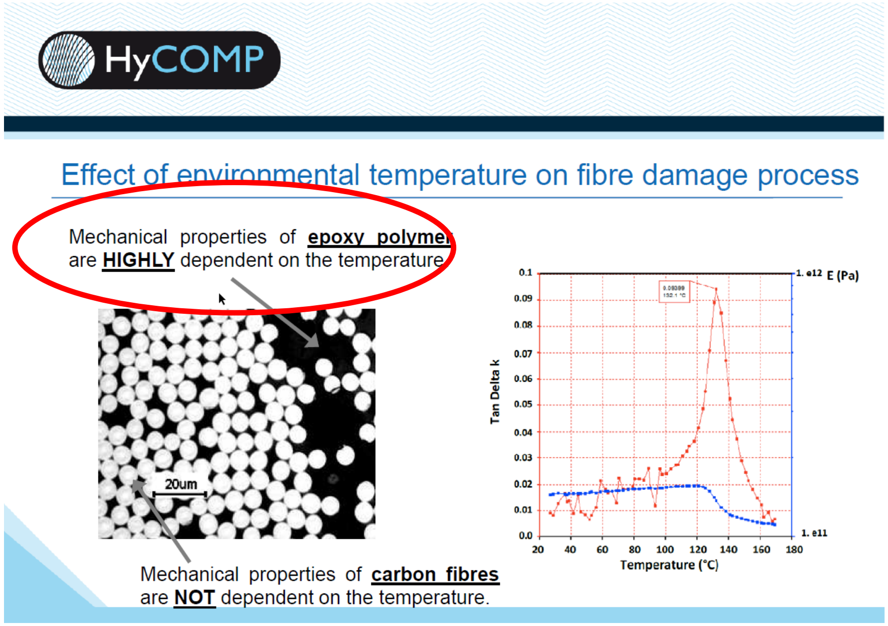
The *iSF* values were calculated for various lifetime and failure probability:

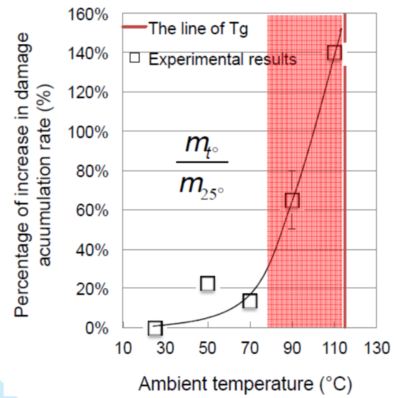


	Numerical		Experimental-Analytical	
	15 years	150 years	15 years	150 years
P $=10^{-6}$	1.28	1.32	1.39	1.40
P $=10^{-9}$	1.29	1.34	1.60	1.61

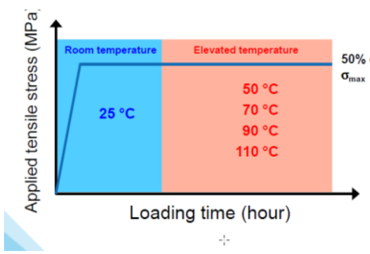
- A quasi-asymptotic behavior of *iSF* value with respect to the lifetime was observed.
- Based on specimen results ONLY, A “science based” minimum SF has been defined (hypothesis = Under a constant load and 10^{-6} probability of failure or 10^{-9}) a minimum iSF value of 1.4 or 1,6 must be applied to guarantee specimen lifetime ≥ 15 years under a constant load, with a probability of failure (10^{-6} or 10^{-9})

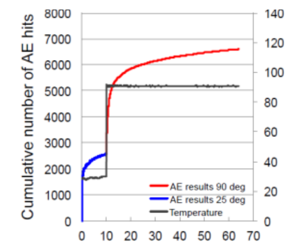
Effect of environnemental temperature on fibre damage process





- Increase in damage accumulation rate was found as the temperature increased, in particular when approaching to the T_g.
- These behavior are due to thermal expansion of the material and augmentation of stress relaxation process of the composites.
- The rise in damage rate could further increase when the composites are subjected to higher creep stress level (now is 50% of σ_{max}).
- The T_g of the composites could vary depending on the type of polymer used and composite curing condition.





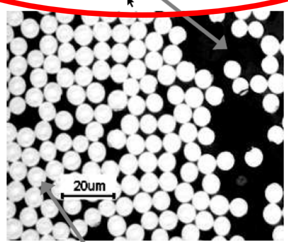
- The long-term damage processes of composites, which are time-dependent, are governed by the viscoelasticity properties of epoxy polymer.
- The effect of the temperature on damage process of the composites is relatively small when the increase in ambient temperature is 30 ° C below the T_g.
- The efficiency of load transfer mechanism at the interface of fibre and matrix declined and the effect of the existing fibre breakage on the neighbouring fibres was enlarged.

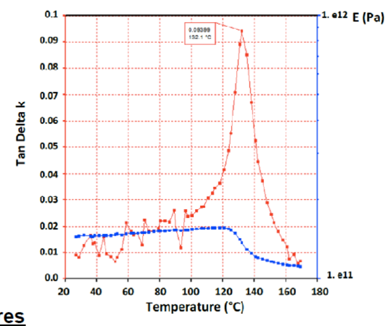
Effect of environnemental temperature on fibre damage process

HyCOMP

Effect of environmental temperature on fibre damage process

Mechanical properties of **epoxy polymer** are **HIGHLY** dependent on the temperature





Mechanical properties of **carbon fibres** are **NOT** dependent on the temperature.

HyCOMP

WP4 - Task 4.2 / Conclusions

- Improper curing has shown important effects on cyclic test with Type 3 cylinders and on the scatter of the test results for Type 4 cylinders. It has been confirmed that the curing quality is of high importance to ensure good properties of the composite structure, as indicated also by the WP2 investigations. This suggests the need to introduce a control of this characteristic by additional tests (such as a Barcol test on each cylinder) to verify the optimum curing of the resin mix.

- It was calculated that the lifetime for the composites subjected to creep test at 70% of the average failure stress decreased from 2E27 years to 0.2 year when the ambient temperature changed from the room temperature to 90 °C.

- Since the rise in the temperature level could influence the lifetime of the composites, the temperature effect must be taken into account in the safety factor analysis, which can be determined in the future analysis.

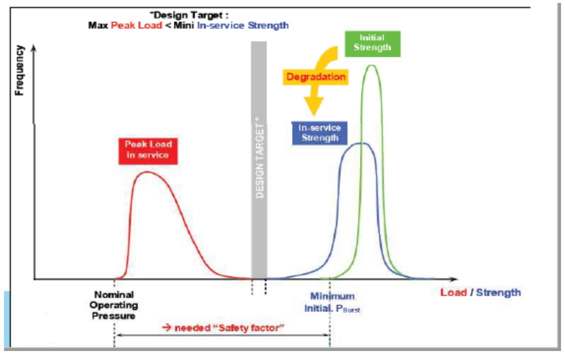
HYCOMP recommendations

HyCOMP

WP conclusions

- Synthesis of recommendations:
  1. Reduce the Design Pressure to the **Maximum Developed Pressure** at the maximum temperature
  2. Reduce Safety Factor to a **fixed value in between 1,4 and 2** (to be decided), e.g. 1,8
  3. Add specifications on T_g
  4. Make statistical assessment
  5. Perform tests at the new Design Pressure
  6. Tests at elevated temperature should be performed at **5°C above T_{max}** defined for the application
  7. Add test to verify the good curing of the resin (e.g. Barcol test)
  8. Control each manufactured cylinders to detect any deviation from a reference batch, for example by using Acoustic Emission
  9. Continue to **develop Non-Destructive Techniques** to carry out periodic inspection of composites pressure vessels.

Decreasing Burst Ratio!



- Burst ratio

Decreasing burst ratio from 2,25 to 2
=> Decreasing Hycomp safety factor from 1,8 to 1,6
=> No margin with the Intrinsic Safety Factor (1,6) without taking into account temperature and humidity effects

nominal pressure	filling pressure	burst ratio	burst pressure	Hycomp safety Factor
700	875	2,25	1575	1,8
700	875	2	1400	1,6

- Specification on Composite Tg

Example of ISO 19881 where a new specification on Tg has been added (chapter 6.6: Tg > Tmax+20°C=105°C; Tmax=85°C)

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Thank you

for your attention