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

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PROJECT OVERVIEW

- HyCOMP is a Pre-Normative Research (PNR) project on composite tank storage
  - Call topic : SP2-JTI-FCH.1.5 – Pre-normative Research on Composite Storage
- Launched in January 2011 and finished in March 2014 (39 months)
- Budget: 3 802 542 € of which 1 380 728 € (36 %) is funded by FCH-JU
- Partnership:

  3 tank manufacturers

- Stage of implementation: 100% of project duration

PROJECT PRESENTATION

- Need to improve the performance of storage vessels
  - Performance objectives in terms of cost efficiency, safety and improved logistics (high quantity transported and low compacity)
    - Gravimetric storage capacity = m_{H2} / (m_{system}+m_{H2}) (in wt.% hydrogen) **≥ 4,8 %**
    - Volumetric storage capacity = m_{H2} / V_{system} (in gH2/L) **≥ 23 g_{H2}/L**

Targets fixed by the FCH-JU by 2015-2016

  - Strong need to have composite pressure vessels that are:
    - **Reliable & safe** (in any circumstances in normal service conditions) <u>AND</u> **cost competitive**

$\nearrow$ m_{H2}
$\searrow$ m_{system}
$\searrow$ V_{system}

→ $\nearrow$ NWP (Nominal Working Pressure) → $\nearrow$ Composite thickness (i.e. carbon fiber quantity) → $\nearrow$ Cylinder price

Safety factor SF

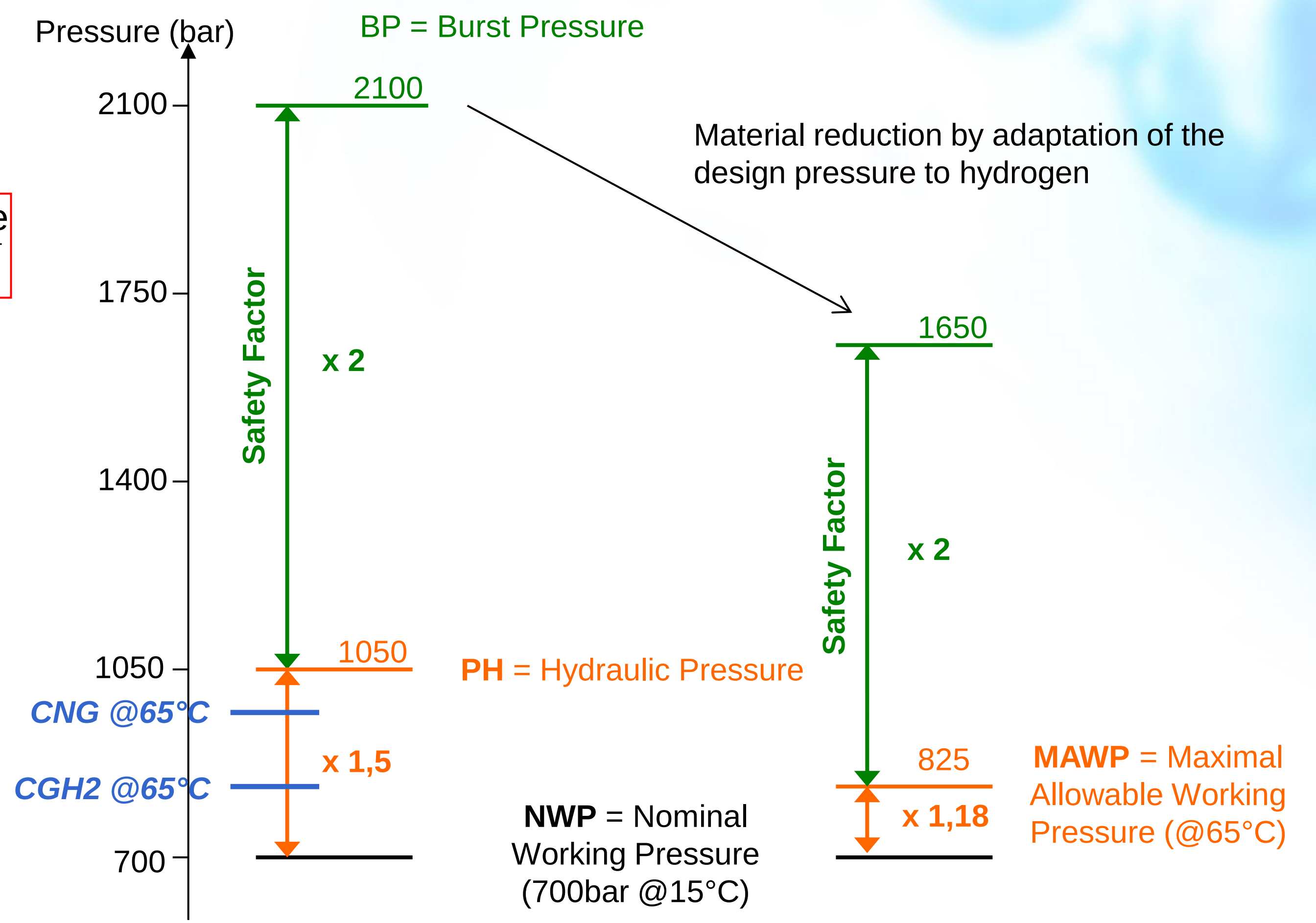
PROJECT PRESENTATION

- Example of transportable cylinders @ 700 bar (ALL gases /EN12245)

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

1- NWP defined @ 15°C
2- MAWP ∝ gas type
3- PH defined to be ≥MAWP
4- SF= min(BP)/PH

➔ Opportunities of SF reduction for H2



For general service (all gases):
Design Pressure = PH

For dedicated service (specific gas):
Design Pressure = MAWP

HyCOMP

PROJECT PRESENTATION

- Target #2 : Need to **improve standards** to better address structural integrity of composite cylinders throughout their service life

- Goals & expected outcomes:
  - Quantify the damage accumulation rate in composite materials, in order to preserve structural integrity of CPV
  - **Improve design requirements** (including acceptable stress ratios for carbon fibres) and testing procedures for type approval, manufacturing quality assurance and in-service inspection
  - Disseminate project recommendations through RCS and industrials (cylinder manufacturer, OEMs, etc.).

PROJECT TARGETS AND ACHIEVEMENTS

HyCOMP is a Pre-normative Research Project ➔ No quantified targets

AIP target	Project Target	Status/achievements	Perspectives
"Pre-Normative Research on composite storage to address design criteria like ageing, pressure levels, shock resistance, failure modes. The goal is to establish production and performance standards and define safety factors" - *No figured target*	**Improve the full set of requirements** to ensure the structural integrity of the cylinders throughout their service life, for different type of testing: ▪ Design type approval, ▪ Manufacturing quality assurance, ▪ In-service inspection.	80 % : Improvements of qualification test conditions and criteria have been proposed, except for in-service inspection	Development of in-service inspection is a project in itself and has not been covered by HyCOMP → *Launch of HyPactor in April 2014*

PROJECT TARGETS AND ACHIEVEMENTS

HyCOMP is a Pre-normative Research Project ➔ No quantified targets

MAIP target	Project Target	Status/achievements	Perspectives
"Design and test criteria for high pressure composite storage tank" - *No figured target* (Transport & Refueling Infrastructure application area)	Enhance design requirements for Composite Pressure Vessels (CPV) for storage or transport of compressed hydrogen, by **redefining a safety factor (SF) value based on anticipated degradation in service**	90 % : A value of SF has been proposed based on a scientific justification at a material scale.	Justify the concept of Safety Factor, and the contribution of different parameters to this SF Demonstration of a possible SF on cylinders from various manufacturers, various designs, etc.
"Safe, efficient and reliable hydrogen distribution and refueling infrastructure" - *No figured target* (Hydrogen Production & Distribution application area)			

PROJECT TARGETS AND ACHIEVEMENTS

Determination of damage kinetics at a material scale in order to predict durability

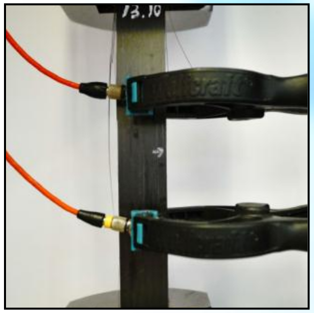
- Assess the effect of operational loads (pressure loads, environmental conditions)
- Develop a **predictive model** able to account for the composite damage kinetics
- Definition of an **intrinsic Safety Factor (iSF)** covering intrinsic material properties only

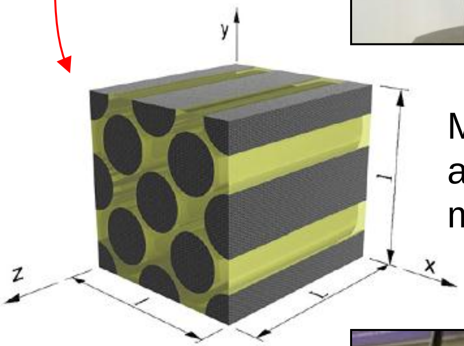
-Based on specimen results ONLY-
A "science based" minimum SF has been defined
(hypothesis = Under a constant load and 10^{-6} probability of failure)
A min **iSF value of 1.4** must be applied to
guarantee specimen lifetime ≥ 20 years
under a constant load, with a probability of failure (10^{-6})

→ Must be taken with an extreme caution (determined on UD specimens with specific materials)

→ Need to consider other parameters: full-scale cylinder structure, type of materials, effect of temperature, process parameters variability…

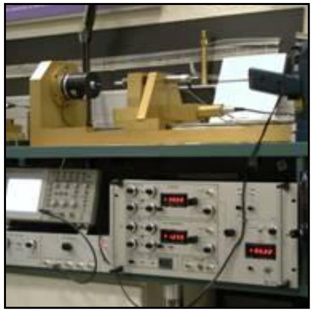
Acoustic **E**mission





Multi-scale approach and modeling

Probabilistic description of the failure mechanisms at the material scale



PROJECT TARGETS AND ACHIEVEMENTS

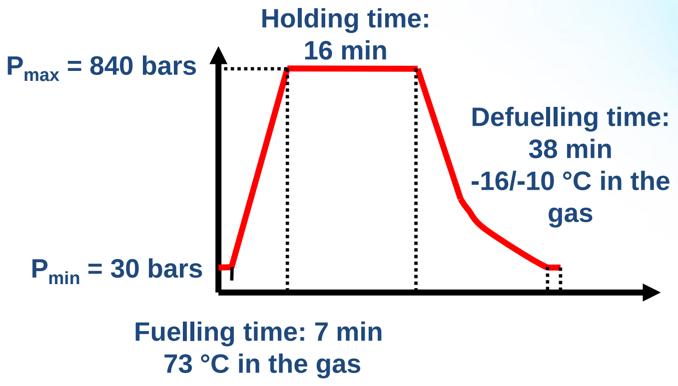
Determination of damage kinetics at a <u>cylinder</u> scale (type 3 & type 4 cylinders)

- *<u>T3 cylinders</u>*:
  - Identification of parameters leading to premature liner failure (autofrettage, service conditions…)
  - Development of new test procedures / methodologies based on a **probabilistic assessment of test results** to evaluate the current state of damage of pressure cylinders

- *<u>T4 cylinders</u>*: State of damage after cycling test (effect of mean cycle pressure, effect of amplitude, etc.) by Acoustic Emission

- *<u>T3 & T4 cylinders</u>*: Effect of gaseous load cycle on the mechanical behavior of the cylinder wrapping

⇨ Approximately 80 cylinders tested

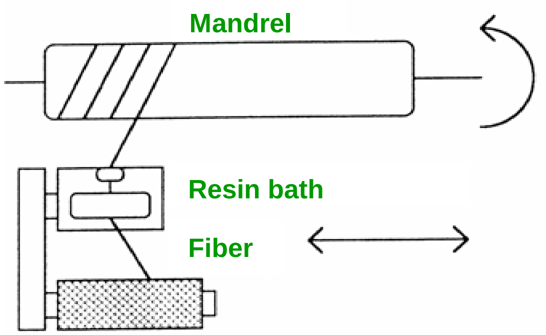


Highly instrumented H2 cycling test at the **JRC-IET reference laboratory** on own funding

PROJECT TARGETS AND ACHIEVEMENTS

Target #2 : Improved requirements / Manufacturing Quality Assurance

- Objective: Define requirements for ensuring that manufactured cylinders will behave as observed under type approval
- Characterization of cylinder performance due to variations in manufacturing parameters



Parameters studied:

Pattern and placement of the fibres	Modify the offset during winding by 1 bandwidth
Resin mix	Increase the quantity of hardener by 20%
Resin curing	Curing at room temperature
Fibre type	Use T300 instead of T700 to simulate a picking error *(same linear mass, same Young modulus, but lower UTS)*

⇨ 120 cylinders tested

- Characterization of initial strength (burst) and long term properties (pre-conditioning + cycling)
- **Curing of the matrix** has shown to have the greater influence on cylinder performance
  - ➔ Requires then a specific attention (included in recommendations)

PROJECT TARGETS AND ACHIEVEMENTS

- 9 recommendations have been extracted from HyCOMP results

- Main recommendations:

1. Reduce the Design Pressure to the Maximum Developed Pressure at the maximum temperature for dedicated service (especially Hydrogen – 70 MPa).
2. Reduce Safety Factor to a fixed value in between 1,4 and 2 (to be decided), e.g. 1,8
3. Make statistical assessment

4. Add specifications on T_g
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, i.e. by using Acoustic Emission
9. Continue to **develop Non-Destructive Techniques** to carry out periodic inspection of composites pressure vessels

RISKS AND MITIGATION *(analysis after project)*

- MAIN RISK: Recommendations not implemented into standards
  - Action taken: dissemination workshop organized in junction to ISO meetings in order to convince experts with HyCOMP results.
  - Strengthening the involvement of partners into normative working groups

- <u>Reduction of SF</u>: Fail to win unanimous support
  - Why?
    - Touchy topic: safety, intercomparison of competitive products…
    - No real « meaning » given to the Safety Factor (pure margins). How to quantify margins?

- <u>Design type approval</u>: Difficulty to propose new testing (or improve existing testing) representative of all types of loads encountered in service
  - Small improvement of existing testing have been proposed: adjustment of testing pressure mainly,
  - Modernization of current standards by **statistical assessment**

SYNERGIES WITH OTHER PROJECTS AND INITIATIVES

- Earlier projects:
  - **StorHy** (European project, finalized in 2008): similar intention as HyCOMP on the way to design cheaper cylinders by a more intelligent approval approach.
  - **HyCube** (KIC, 2011-2013): dedicated exchanges of test results and its statistical assessment
  - **DeliverHy** (FCH-JU, 2012-2013): strong collaboration with DeliverHy project whose objective is to optimize transport solutions for compressed hydrogen, because:
    - SF decrease is an option to improve the capacity of transport solutions;
    - Adapted testing procedures for the approval of large cylinders are required.

DISSEMINATION ACTIVITIES

- Dissemination workshop organized in Paris (AFNOR facilities) at the end of HyCOMP (05/03/2014)
  - Objectives:
    - Present HyCOMP experimental results and recommendations, in order to **convince experts in the field of composite pressure vessels** for the storage of hydrogen (manufacturers, end users, test laboratories, OEMs, etc).
    - Obtain feedbacks on the work carried out in HyCOMP and the recommendations coming from the project.
  - Two ISO Technical Committees have been targeted:
    - **TC58 Gas cylinders** (all gases, not only hydrogen),
    - **TC197 Hydrogen technologies** (all technologies in the Hydrogen Energy field, not only composite pressure vessels).
  - Invitation :
    - Sent to registered members of TC58 and TC197, and largely diffused by partners to relevant people
    - Personal invitation sent to OEMs : Volkswagen, Opel/GM, Honda …
    - **40 people** attended the workshop, among which 22 from external audience (4 by teleconference).

DISSEMINATION ACTIVITIES

- Around 15 dissemination activities attended by the project:
  - Several conferences with oral presentation (and papers for conference proceedings):
    - Industry audience: WHEC 2012, 4th International Carbon Composites Conference
    - Scientific audience: ICCM 2013 (International Conference on Composites Materials), German congress on acoustic emission, ASME 2013 Pressure Vessels & Piping Conference...
  - Oral presentation at PRD each year since the beginning of the project
  - Several publications written by academic partners mainly, to be submitted in peer-reviewed scientific journals
    - International Journal of Pressure Vessels and Piping
- No application for patents, trademarks, registered designs, etc… during the project

EXPLOITATION PLAN / EXPECTED IMPACT

- How will the project's results be exploited? When? By whom?
  - Some HyCOMP partners are member of standardization working groups (*Air Liquide, Faber, Hexagon, CCS, CEA*)
    - Must support HyCOMP recommendations in these WG after project termination…
  - No control of the timing for a revision of current standards
    - A non-compressible time is needed to get a revised standard (around 2 years)

- What are the achievements that will allow progressing one step further to cost reductions and enhanced performance (efficiency, durability)?
  - It would be of interest to perform a full approval test program on different commercial cylinders with a reduced safety factor (demonstration step)

- How can the results from your project be taken on-board by industry?
  - Having a cylinder with a reduced safety factor on the market will probably take few years (2-3 years), after standards have changed…

END OF PRESENTATION

Thank you for your attention

Any questions?

http://hycomp.eu