Session on applications: HRS - refuelling

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HySafe Research Priorities Workshop,
Washington, 11-12/12/2014

On-board compressed hydrogen: safety aspects

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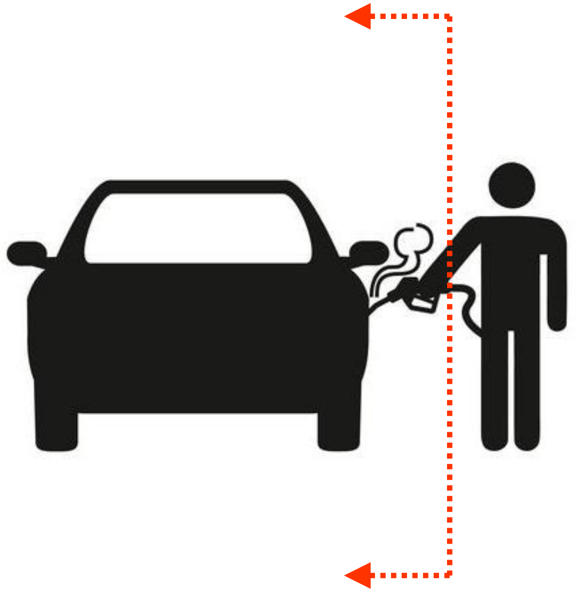
European Commission

Joint Research Centre

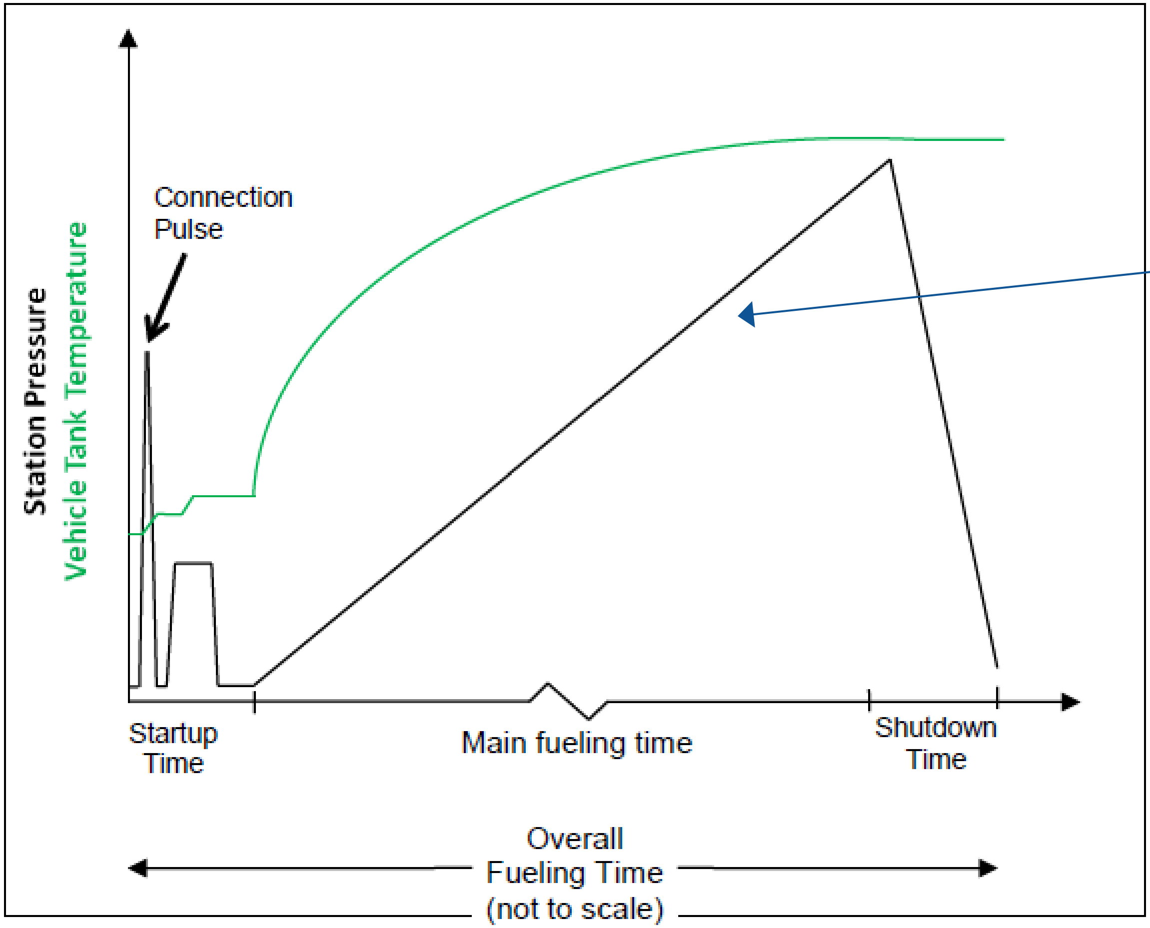
Contents

1. Safety aspects of refuelling. Still research need after SAE J2601?
2. Mechanical resistance of tanks. Do we know how a tank fails?
3. Micro-structural aspects.



The physics of refilling

Safety boundaries:
T(gas) ≤ 85°C
Max Pressure ≤ MAWP



Source SAE J2601:2014

Average Pressure Ramp Rate (APRR)

Different from the real p(t), and from the mass flow rate.

European Commission

The SAE J2601

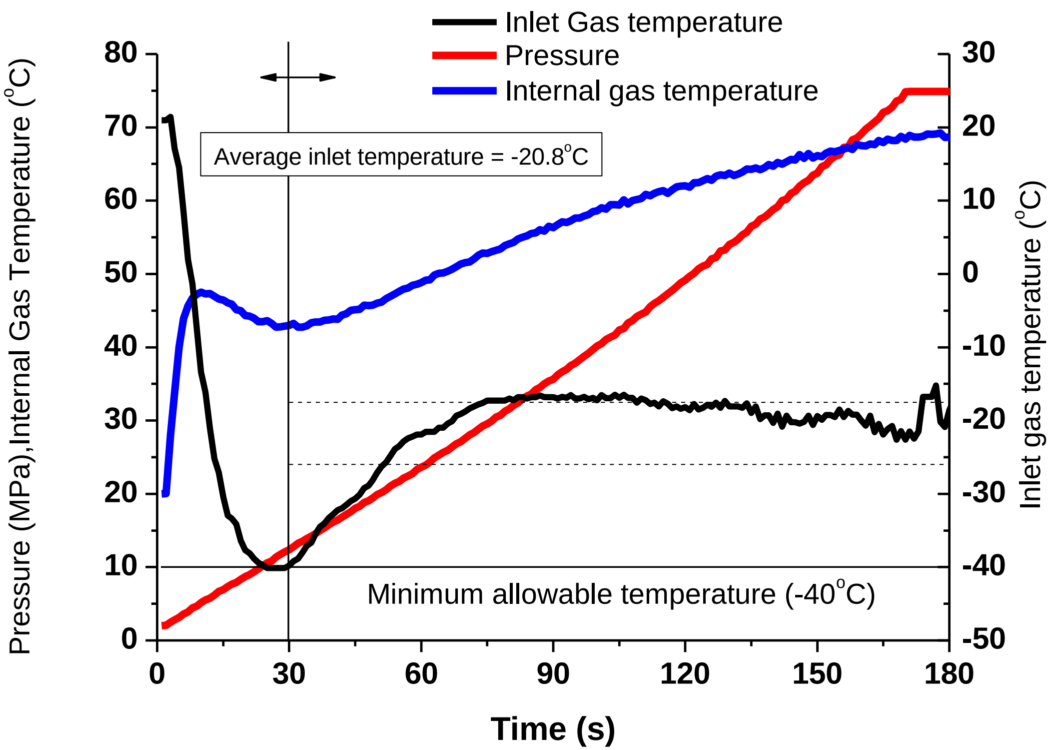
STATUS: update published in 2014 superseding version 2010

Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles

- Tables available for fueling a vehicle in the 50 L to 250 L, 2 Kg to 10 kgH_2
- For environmental conditions between -40 to +50
- For working pressure of 35 and 70 MPa
- For HRS with and without communication with the vehicle
- For gas precooling classes from -40°C, -30°C, -20°C
- Extensively validated

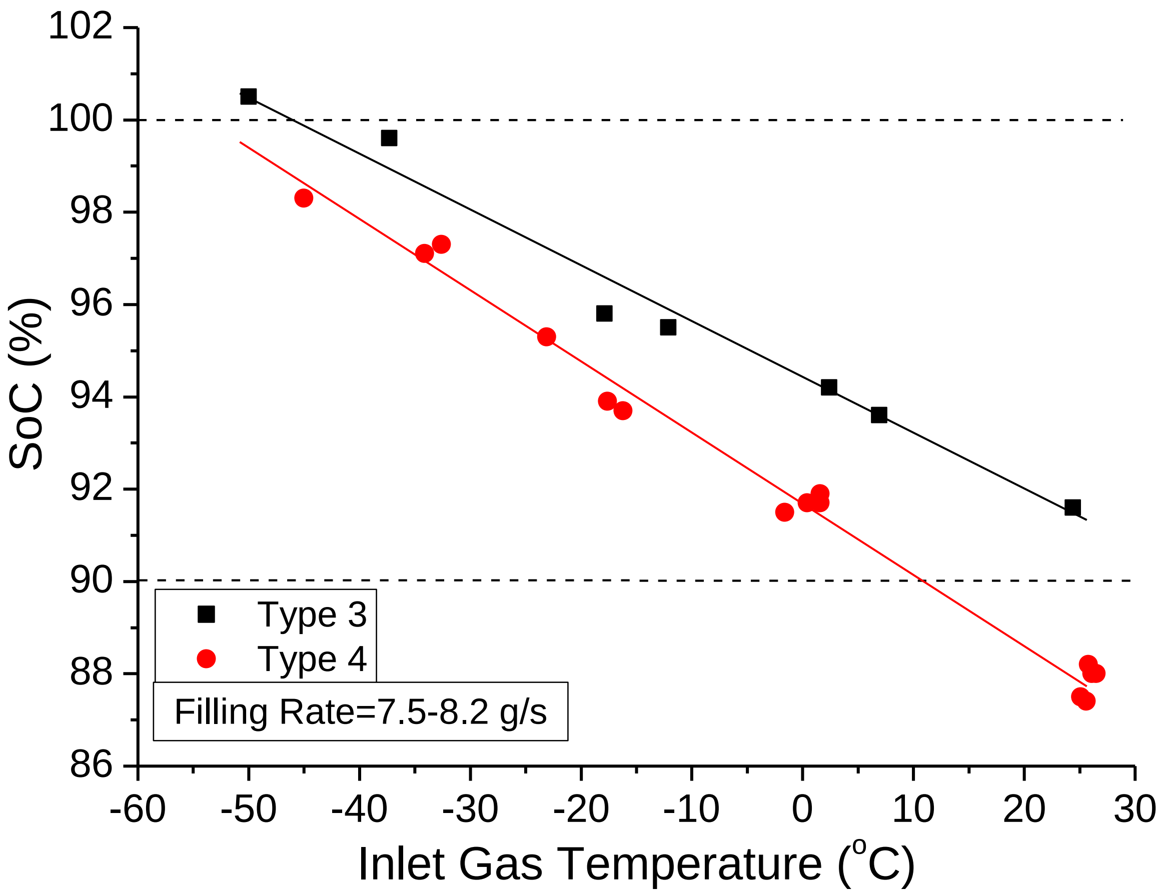
SAE Int. J. Alt. Power. 3(2):2014, doi:10.4271/2014-01-1990.

The physics of refilling – the reality



Source JRC

Influence of the type of tank on the SoC



SoC is higher in a type 3 than in a type 4 tank

This difference increase with inlet gas temperature

Source JRC

Comparison with SAE J2601

	Average inlet gas temperature (°C)	Amb Temp (°C)	APRR (MPa/min)	Initial Pressure (MPa)	Final Pressure (MPa)	SoC (%)	Final Temp (°C)	Type/ Volume
J2601	-40 ≤ T ≤ -33	20	19.3	2	70.9	≥ 90	≤ 85	3-4/50-100 l
JRC	-40.8	22.8	19.2	2.2	71.1	94.7	43.7	3/40 l

SAE tables foresee final gas temperature much higher than that found in JRC experiments.
Which are the reason for this discrepancy?

SAE allow a max pressure at the end of the filling of approximately 71 Mpa.
Next table show what it happens by allowing a slightly higher pressure value (77 Mpa): 100% SOC

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JRC	-40.8	22.8	19.2	2.2	**77.7**	**100.2**	**44.4**	3/40 l

R. Ortiz Cebolla, B. Acosta, N. de Miguel, P. Moretto,
Int. J. of hydrogen Energy 40 (2015) 4698-4706

Comparison with SAE J2601

For those cases where a direct comparison is possible:

- ☞ The maximum temperature reached in JRC experiments results quite far from the 85°C limit ➔ Tentative reasons: i) in a real HRS gas temperature is measured far away from tank inlet, ii) JRC tank is at lower range of SAE volumes.
- ☞ Is there still a high safety margin? If so, would it be possible to increase the mass flow rate (or pressure ramp rate) or reduce pre-cooling requirement?

- ☞ The value adopted for the final pressure in the look-up tables of the SAE J2601 is 71 MPa. ➔ Is there here also a high safety margin?
- ☞ Increasing the final pressure to (for example) 77 MPa does not increase the temperature significantly, while the SoC experiences a non-negligible improvement.

Conclusion on research needs related to refuelling

A standardisation frame is already in place:

- the SAE J2601 contemplate a considerable number of possible and real cases,
- It has been thoroughly validated
- It is consensus based and the results of a joint effort from industries and research community

Thus, nothing to be done? Oh yes, for example:

- Simple refilling points (cheap, no communication, time pressure, three wheelers) are not considered in J2601
- The cooling requirements are felt as excessive
- The refueling physics has still to be understood better for a better modelling
- 1D and 2D modelling improvement still expected

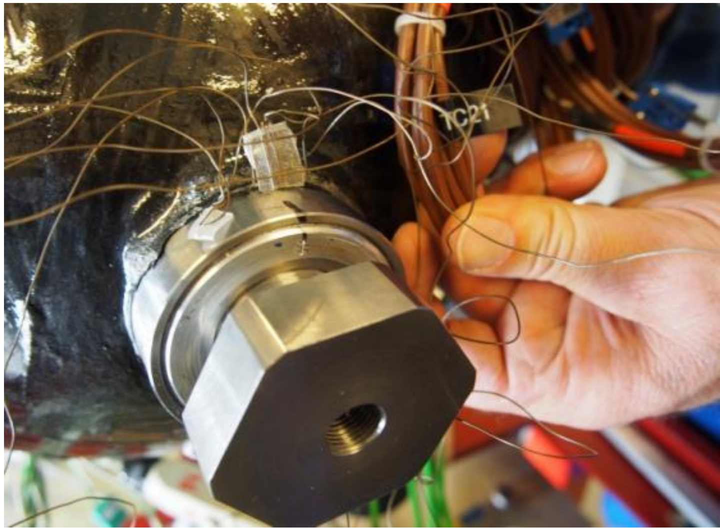
FCH JU project HyTransfer

Pre-Normative Research on Gaseous Hydrogen Transfer

Aim: Converting New Filling Approach into RCS Recommendations

Approach: Tank Wall Temperature is Critical

http://www.hytransfer.eu/



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Mechanical behaviour of tanks

FCH JU project: HyCOMP

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

Final reports and recommendation available at:

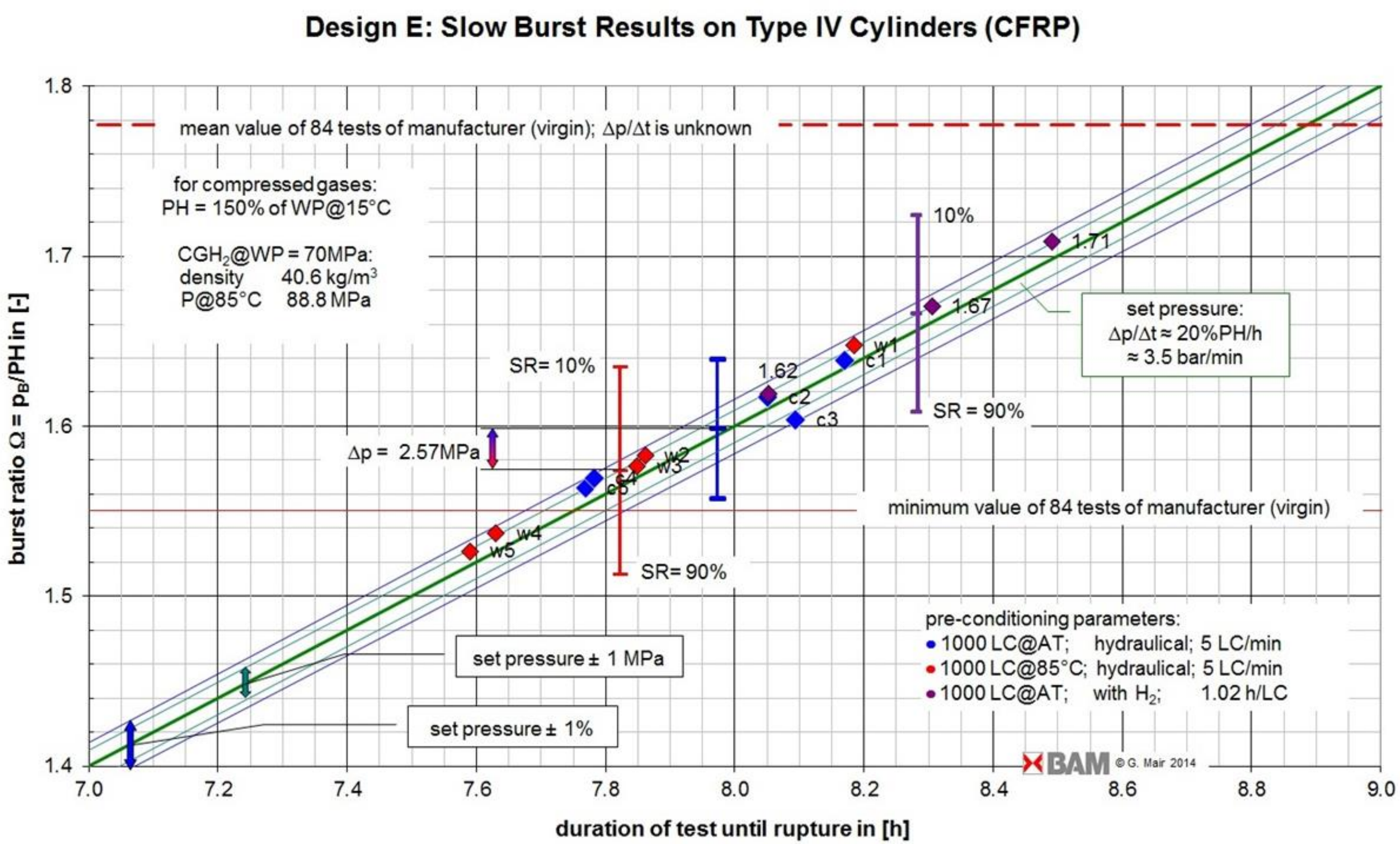
http://www.hycomp.eu/

HYCOMP results

European Commission

HyCOMP

Type 4 model cylinder Slow burst test – Residual burst strength



Source BAM, G. Mair

HyComp conclusions of test results (Type IV)

1. Cycling has a very small effect on the composite wrapping compared to metal liners! Therefore cycling to failure is not efficient, sometimes impossible.

2. A sustained load influences the residual cycle strength: higher slow burst strength with constant or reduced scatter!

3. Gaseous cycle loads result in a lower degradation compared to high or ambient temperature cycling !

Source BAM, G. Mair

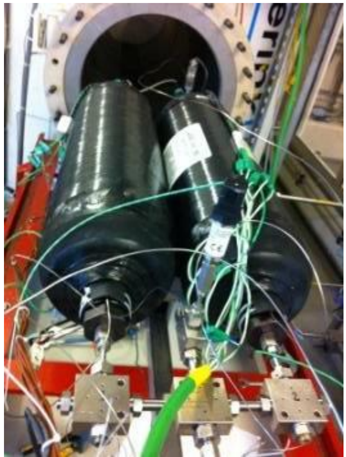
HyCOMP conclusions of test results (Type IV)

Source BAM, G. Mair

The demonstration of minimum values depends very much on the luck of picking up the ONE or TWO required specimens!

This means degradation effects are very often not detectable.

Critical aspects shall be assessed statistically on a sufficient sample size!



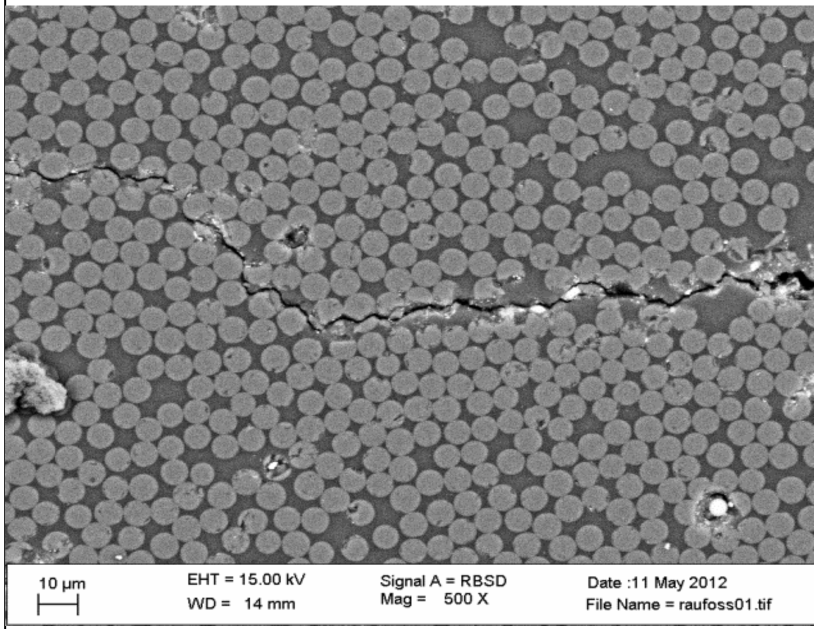
Microstructural damage evolution in a tank

Do we know everything on how a tank fails under purely mechanical conditions?

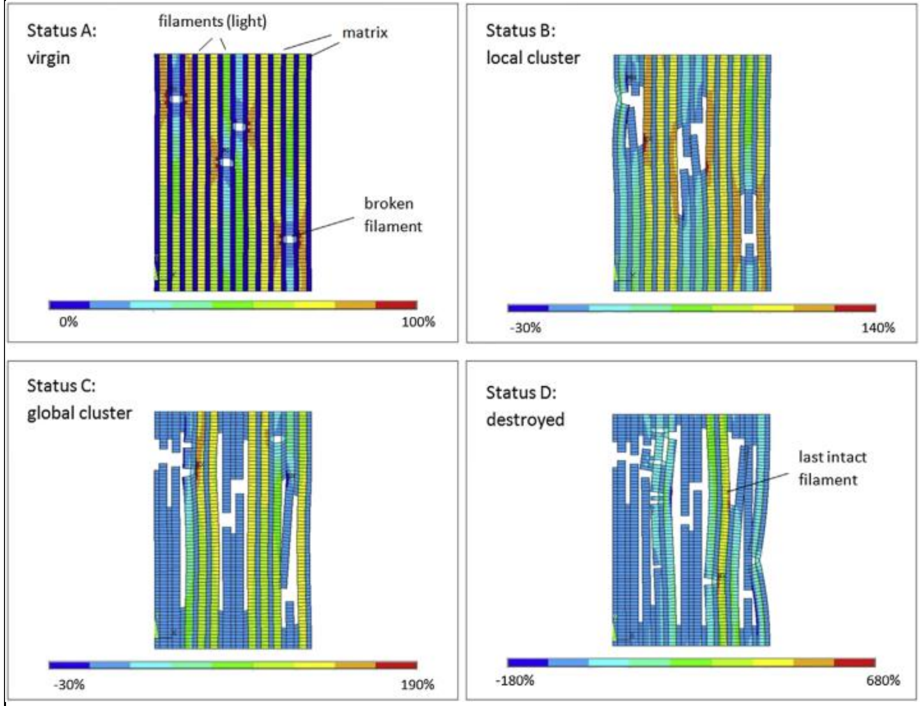
Project H2FC_European_Infrastructure

Micro-structure & Modelling

Porosity, curing defects, fibres distributions, pliers and layers, cracking, etc. are mapped



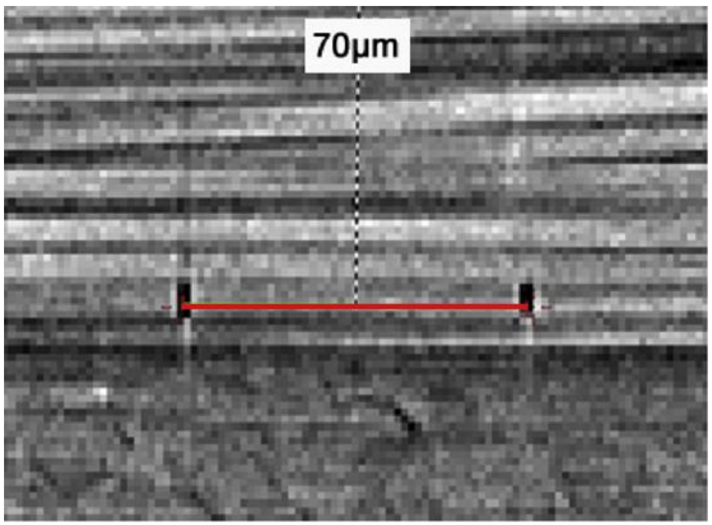
Theoretical models for damage onset, evolution and macroscopic failure also available

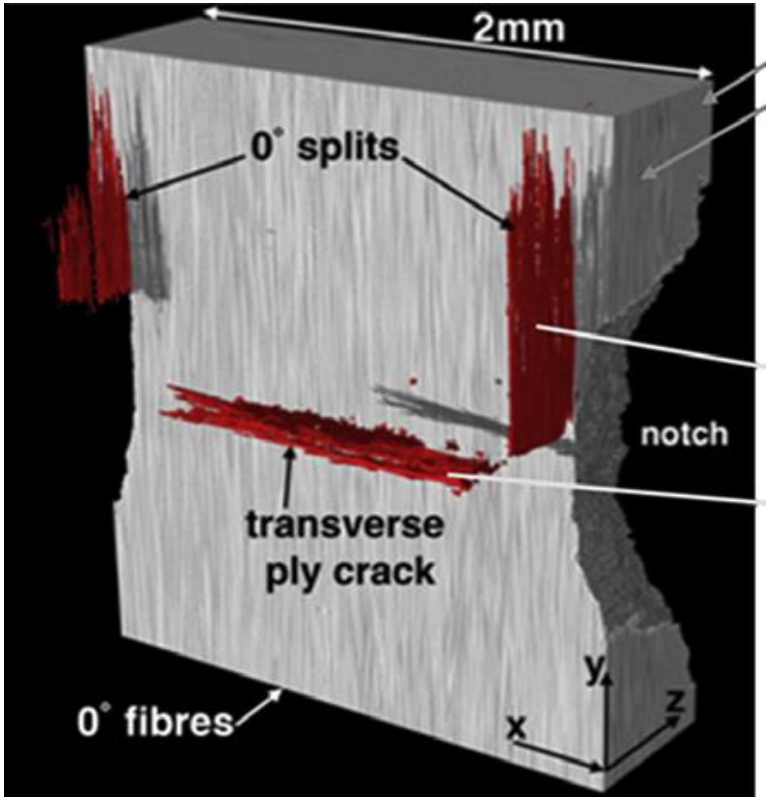


Source JRC

G. Mair, http://dx.doi.org/10.1016/j.ijpvp.2014.05.003

Multi-scale X-Ray Tomography

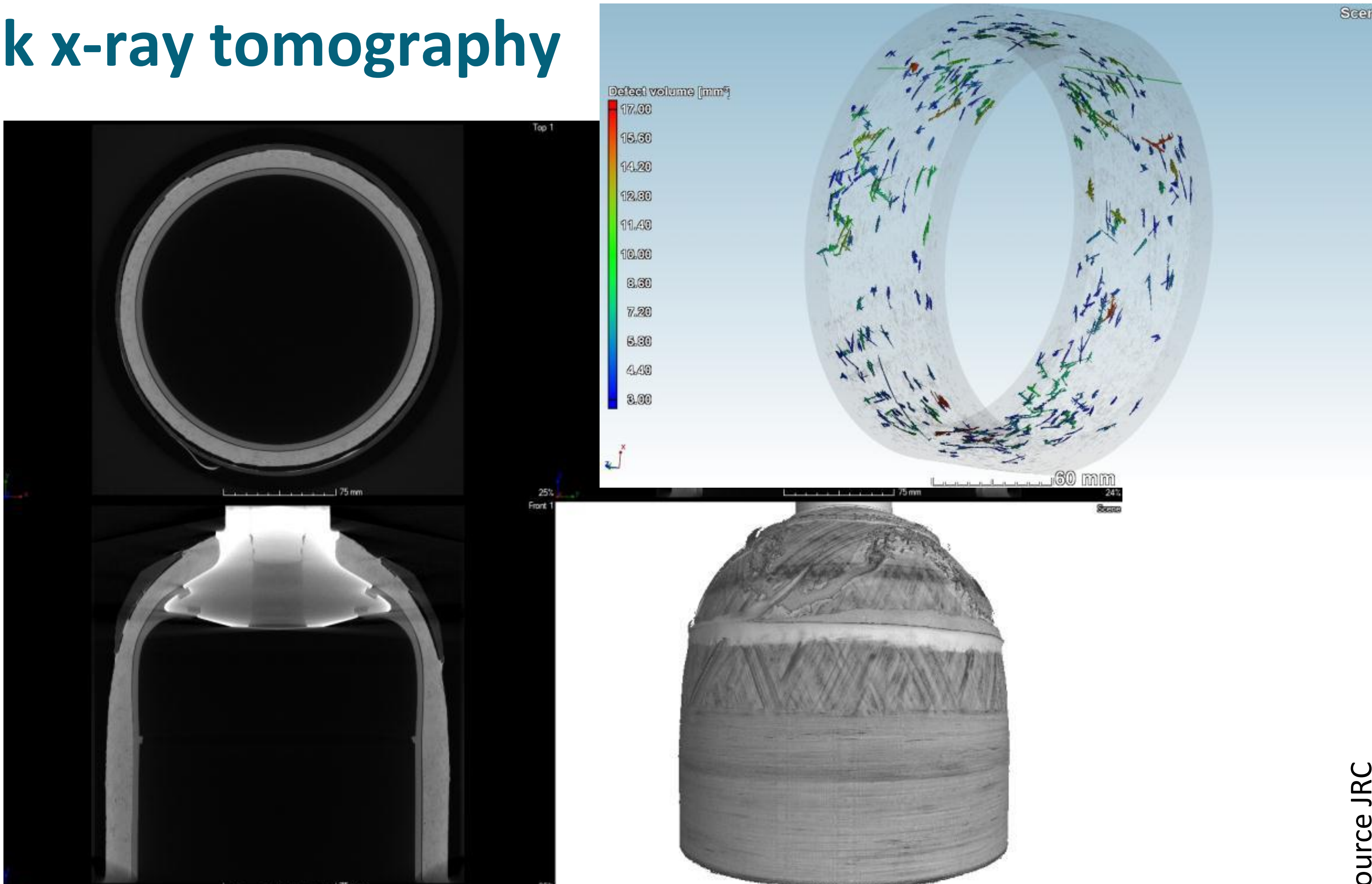




By means of synchrotron tomography and nano- micro- and full scale tomography multi-scale characterisation have been performed, even in situ.

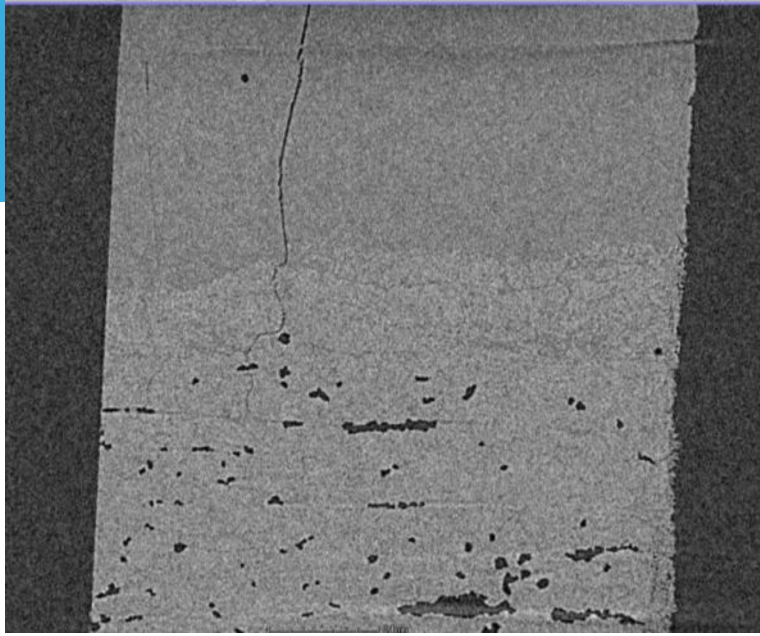
A. E. Scott, doi:10.1016/j.compscitech.2011.06.004

Full tank x-ray tomography



Source JRC

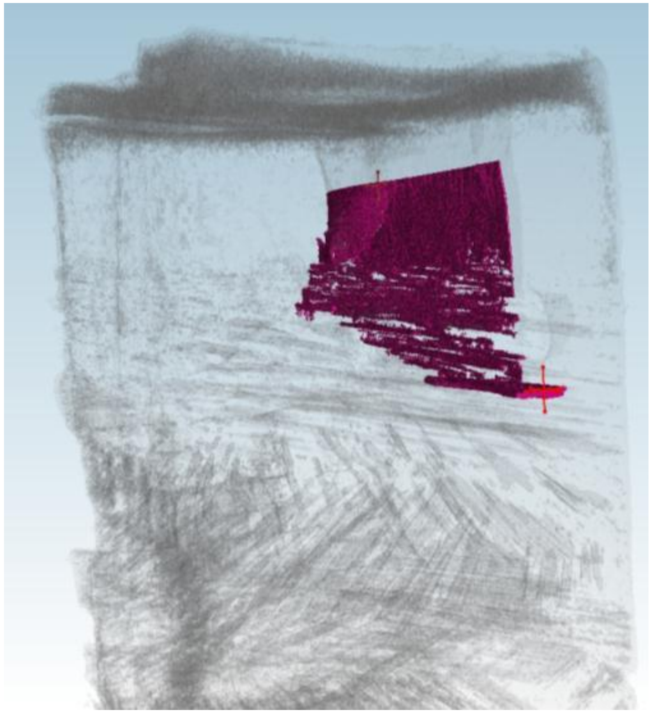
X-ray Tomography and analysis of full as-received tank by GE CT



Damage searching

Plenty of microstructural damage!
Not easy to link it to the stress history of the full components.

O_2 breathing Tank 'almost burst' (hydraulically-tested by BAM, CT- characterised by JRC).



Source JRC

My tentative (and incomplete) research gaps on materials and components damage

Composite behaviour → A clear real time picture of damage growth in the composite shell is not yet achieved.

Characterisation Tools → The (multi-scale) tomography tools have so far been successfully applied only to in situ laboratory experiments

Will AES ever be ready for in-situ monitoring of full tanks?

Liner degradation → Which processes take place in the polymer liner during real cycling? Porosity evolution? Bubble formation? Blistering?

Material behaviour → What does happen if we trespass the mythical 85°C threshold?

Are the above mentioned research topics a priority compared with other technologies?

Standards and/or regulations are already in place for all the above identified safety aspects. Research needs are now triggered by an attempt to reduce costs, by maintaining the same safety margins