UNIVERSITY OF DERBY

Liquid hydrogen tank design

MIDLANDS GREEN HYDROGEN WORKSHOP
10th April 2024

UNIVERSITY OF DERBY

Institute for Innovation in Sustainable Engineering (IISE)

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Hydrogen Storage

How hydrogen is stored

Physical based →

Compressed gas

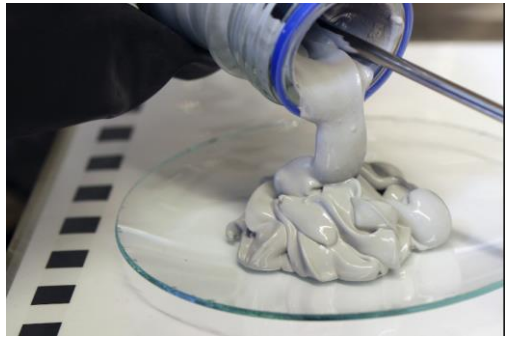
Cold-cryo compressed

Liquid H_2

Material based →

Solid absorption/adsorption

Hydrogen Gel



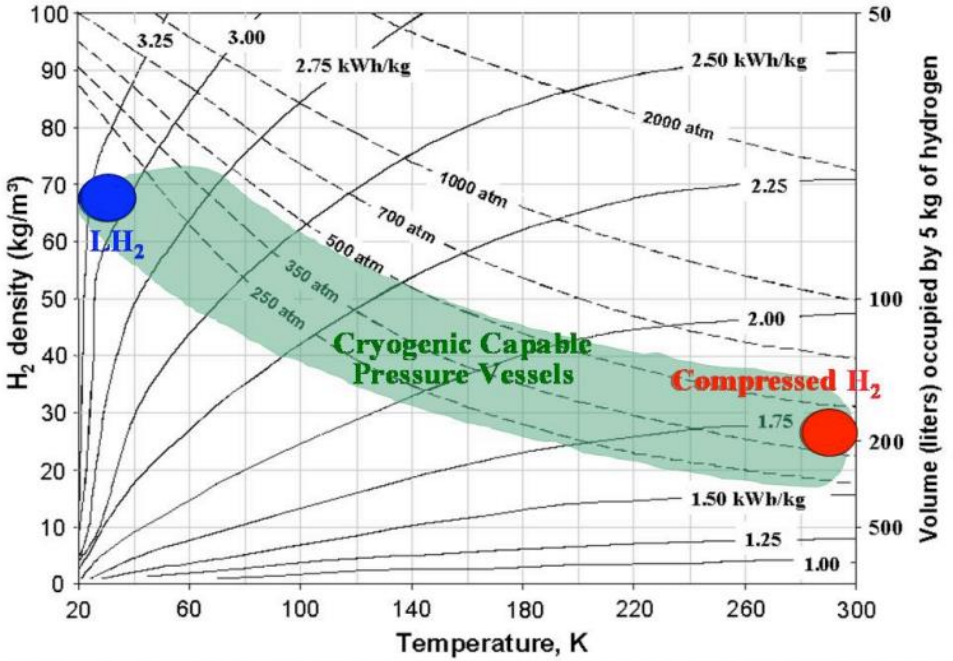


Figure 1. Commercial automotive hydrogen storage technologies occupy the extremes of this phase diagram. Hydrogen is often stored as a compressed gas (red dot) at ambient temperature (horizontal axis), very high pressure (dotted lines), and relatively low density (vertical axis). Hydrogen is much more compact as a cryogenic liquid (blue dot) but with higher energetic cost (solid lines indicate the theoretical minimum work, also known as thermomechanical exergy) to compress and/or liquefy hydrogen. Cryogenic capable pressure vessels have flexibility to operate across a broad region (shaded in green) of the phase diagram, and therefore can be fueled with gaseous H_2 at a low energetic cost when energy or fuel cost savings is important or with LH_2 when long driving range, or low-pressure operation is desired.

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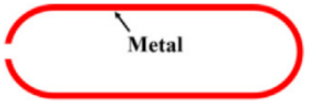
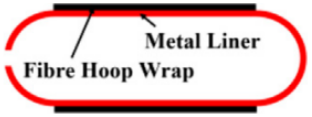
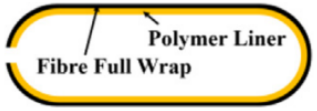
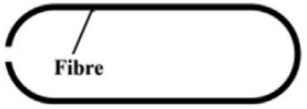
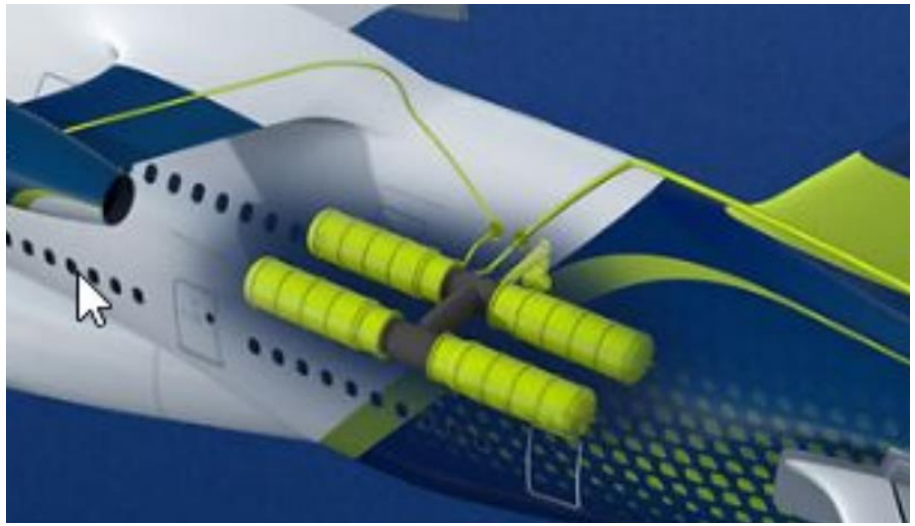
Hydrogen Tank Concept

Hydrogen Tank Type

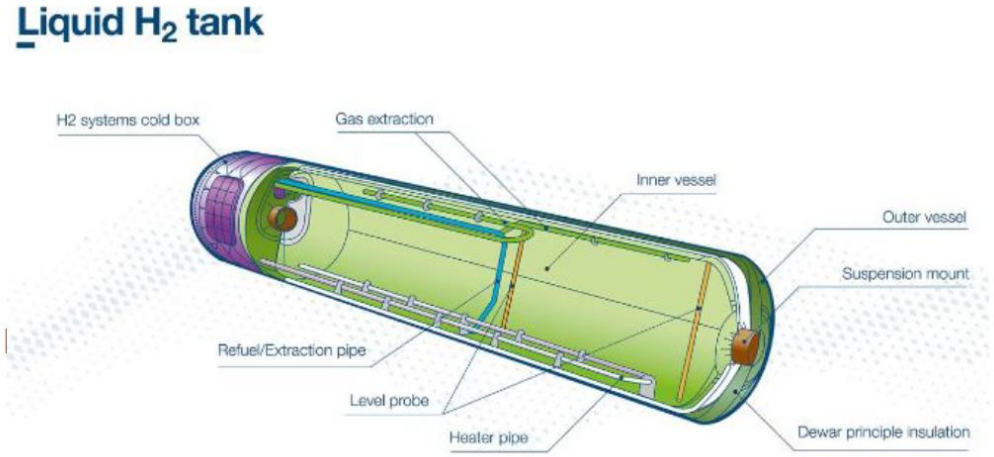
Classification and applications of different hydrogen tanks.

Type	Schematic	Materials		
		Metal	Composite	Polymer
I		Steel/Al	/	/
II		Steel/Al liner	Filament windings around the cylinder part	/
III		Al/Steel liner	Composite over-wrap (fibre glass/aramid or carbon fibre)	/
IV		/	Composite over-wrap (carbon fibre)	Polymer liner
V		/	Composite	/

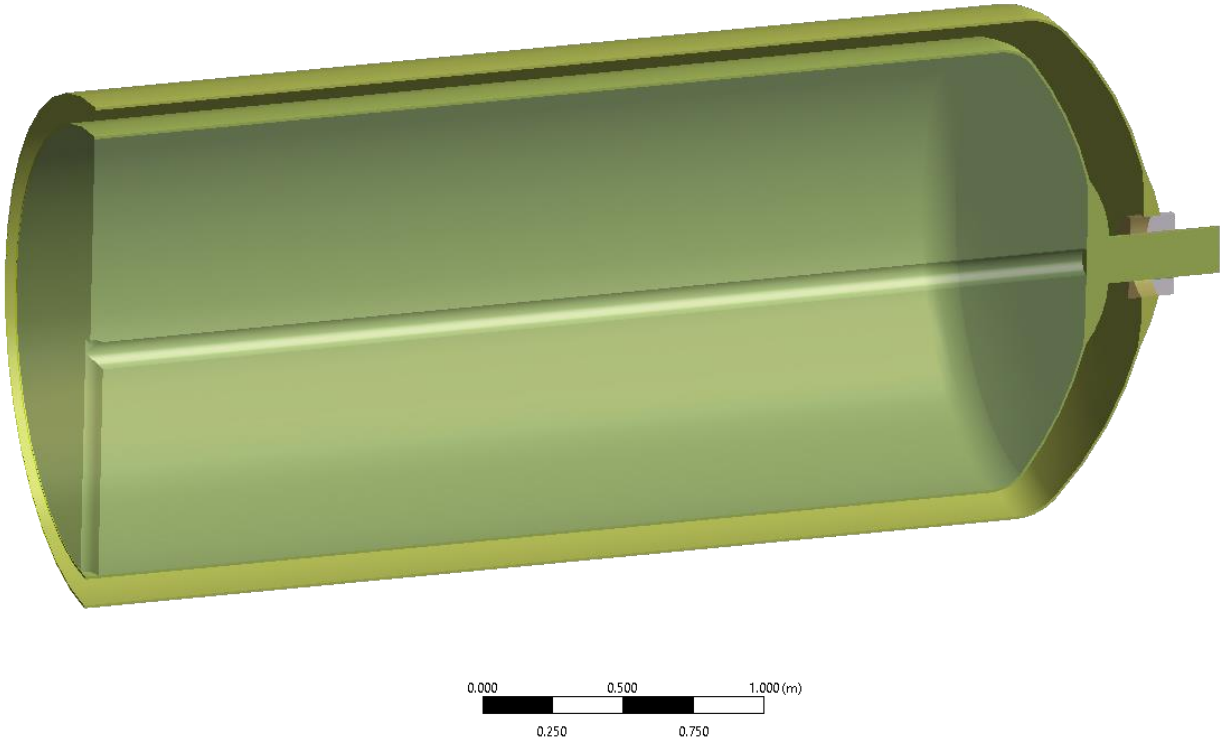
Hydrogen Tank for aviation



Courtesy of Airbus



Hydrogen Tank from concept to design



AETHER project

Advanced Solutions for Hydrogen Zero Emission Fuel

AEROSPACE TECHNOLOGY INSTITUTE

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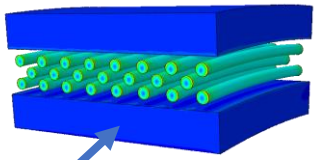
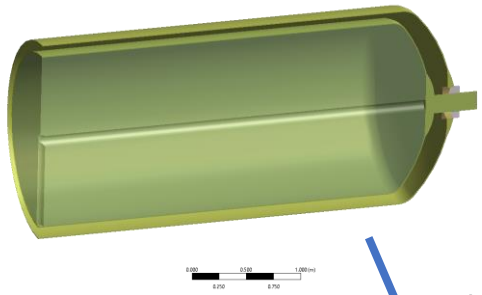
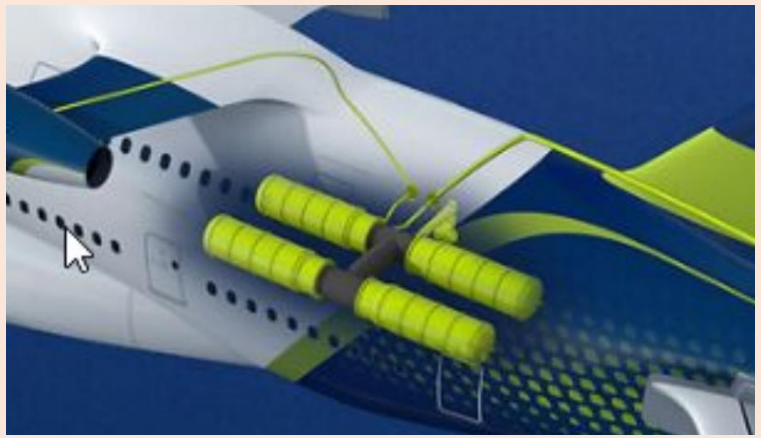
Loop on the material selection and some geometrical design parameters

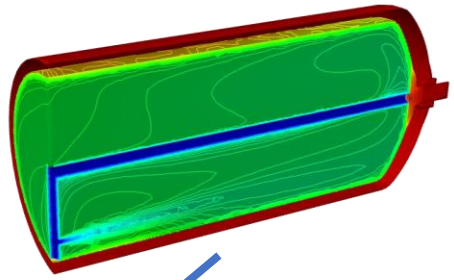




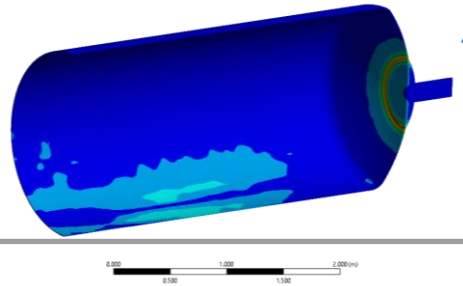
From Concept to Design



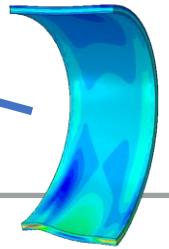
Fluid-dynamics simulations of the filling process at cryogenic temperature.



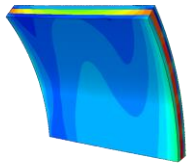
Thermal-stress analysis of the filling process.



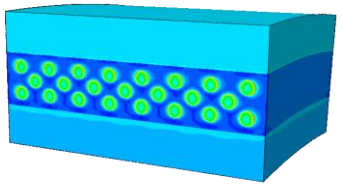
Multiscale stress analysis.



Stacking sequence study and stress optimisation.



Stress analysis and damage tolerance study of multi-component materials.



Meso-scale stress optimisation.

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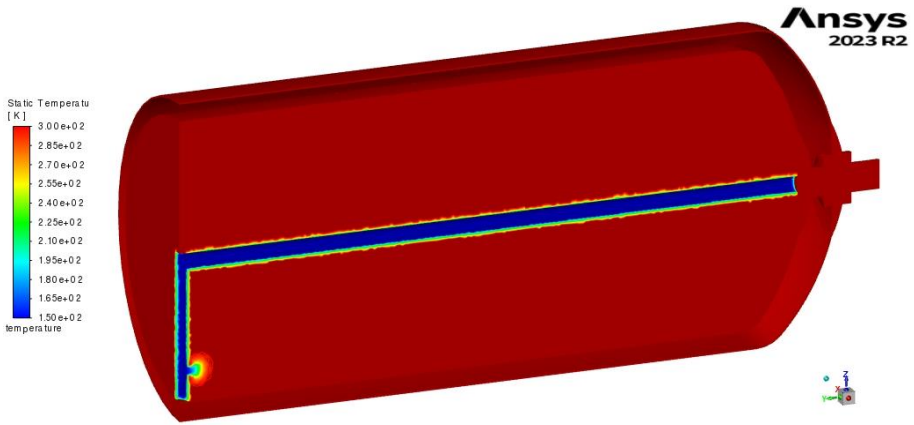
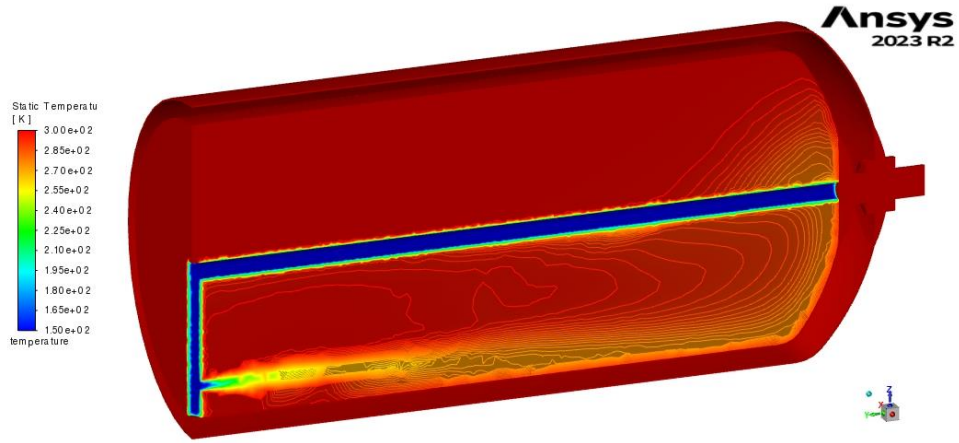
Hydrogen Tank Working Conditions:

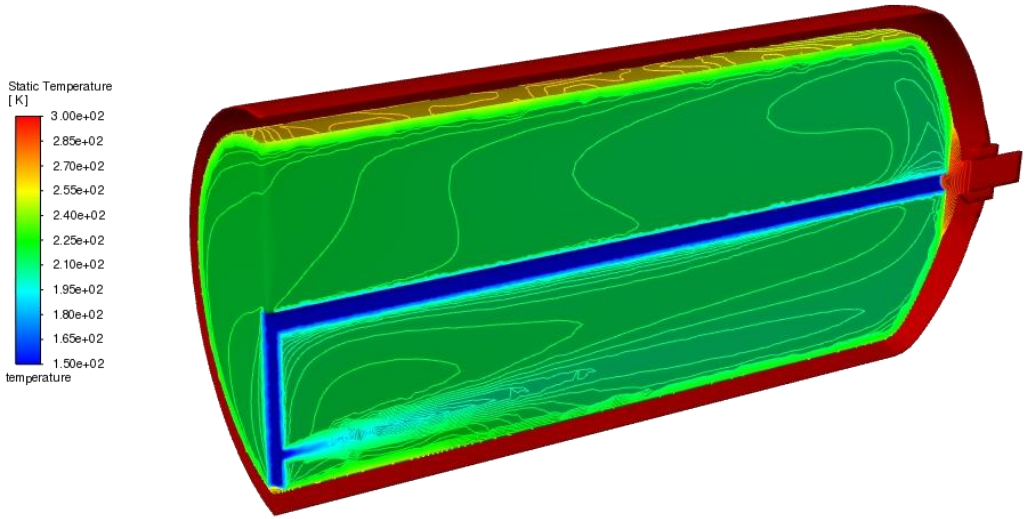
Tank Filling Simulation (Transient Analysis)

Tank Filling CFD Simulation





Gas Inlet
Temp = 150 K



Temperature fluid-structure evolution

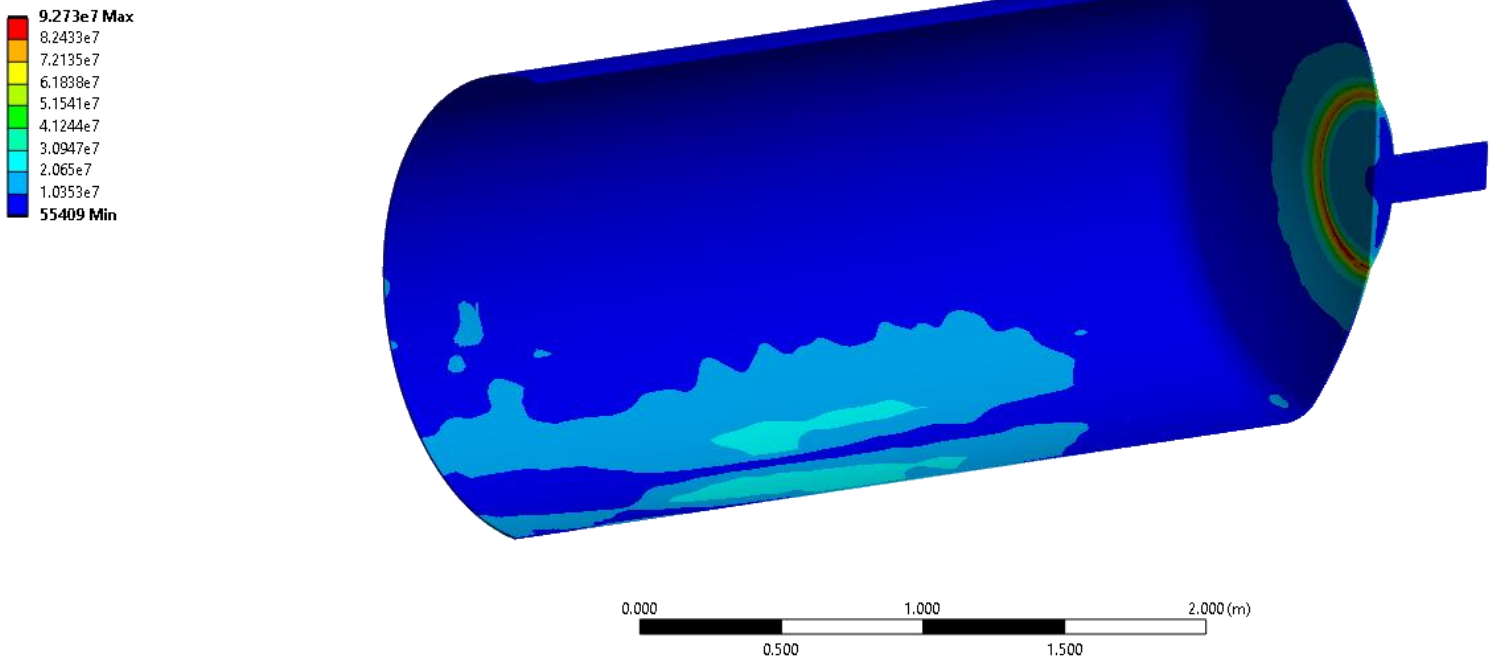
Hydrogen Tank Working Conditions:

Thermal Stress analysis of the filling simulation (Transient Analysis)

Thermo-mechanical transient Stress analysis

Metal liner

Von Mises stress static



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Outcomes

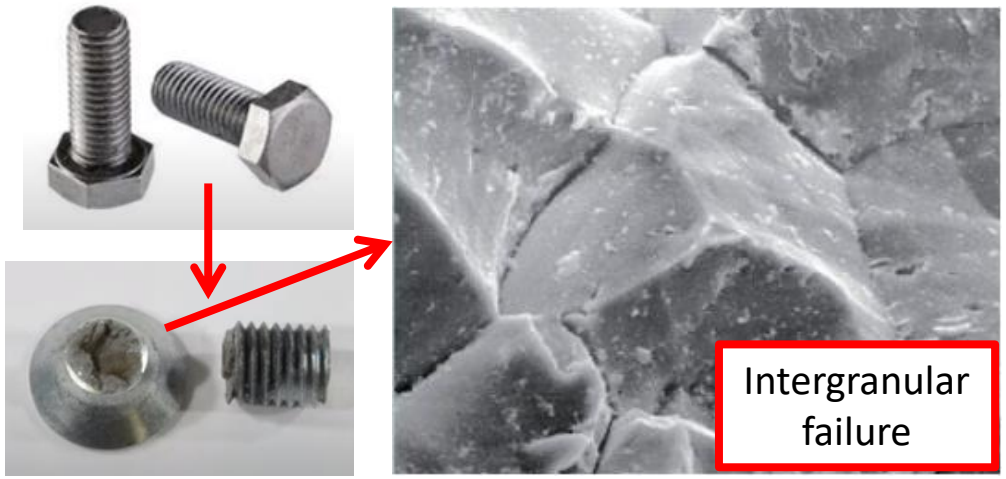
Hydrogen Awards 2024

High Commendation trophy for the "UK Universities' Award for excellence in hydrogen research and innovation"

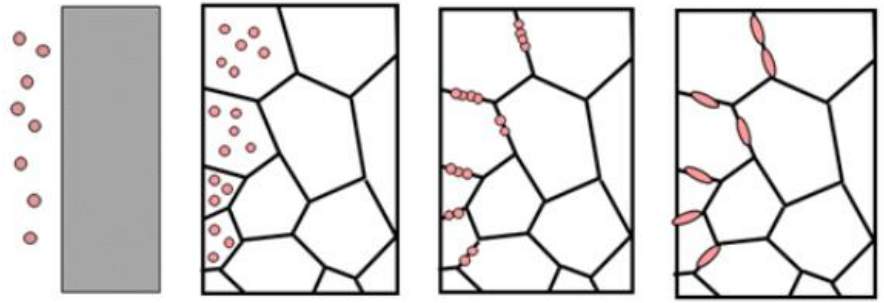
Recent interests for the Hydrogen Tank Failure Analysis：

Hydrogen embrittlement modelling

Background for Hydrogen embrittlement modelling



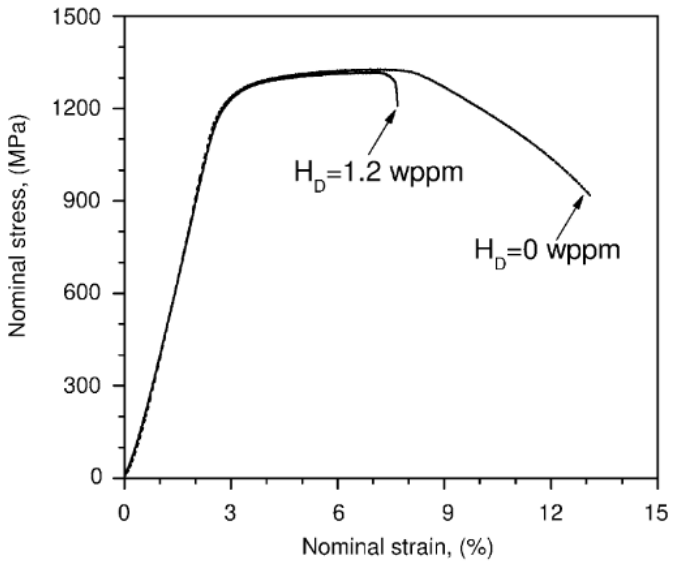
H-enhanced localized plasticity (HELP)
Interface-enhanced decohesion (HEDE)
Other mechanisms (slip bands)

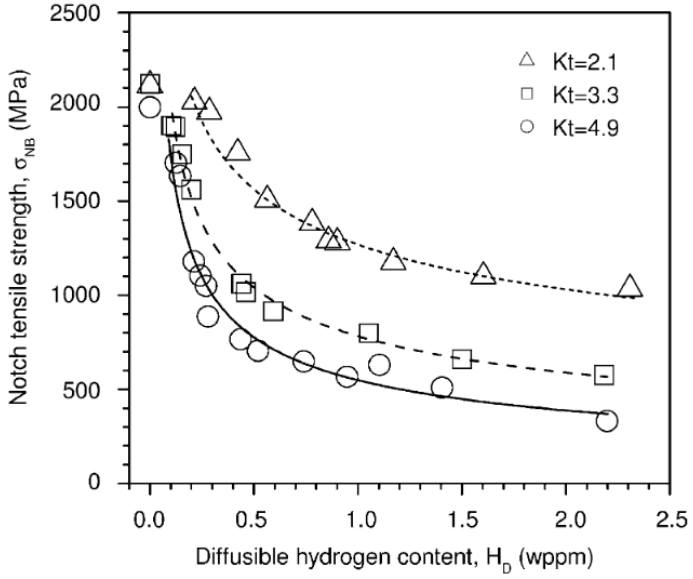


1st: H diffuses into the grains

2nd: H diffuses into the grain boundaries

Change of mechanical properties (due to H) in steels





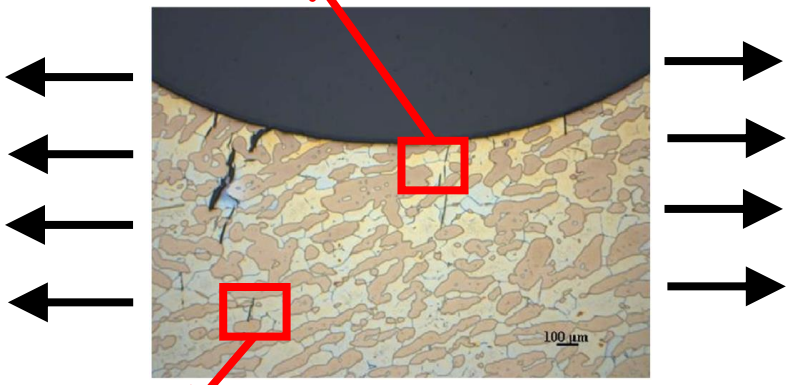
Loss of ductility

Loss of toughness

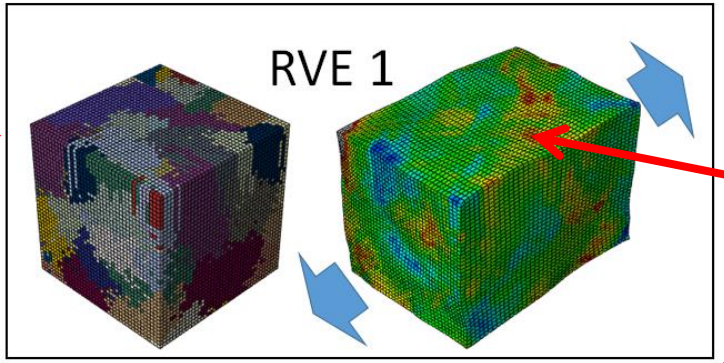
M. Wang et al. / Materials Science and Engineering A 398 (2005) 37–46

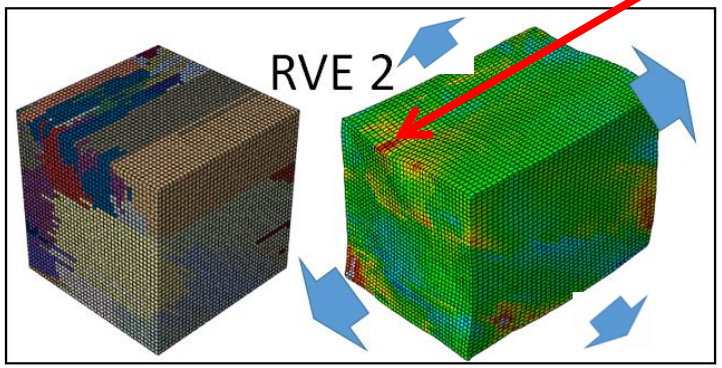
Hydrogen embrittlement Modelling strategy

Failure driven by the maximum principal at the notch route



Failure driven by the build-up of hydrostatic stress (σ_H) subsurface, crack initiations reported subsurface





Strain localisation led to damaged elements.

Elastic modulus lowers with the concentration of H:
E(H)

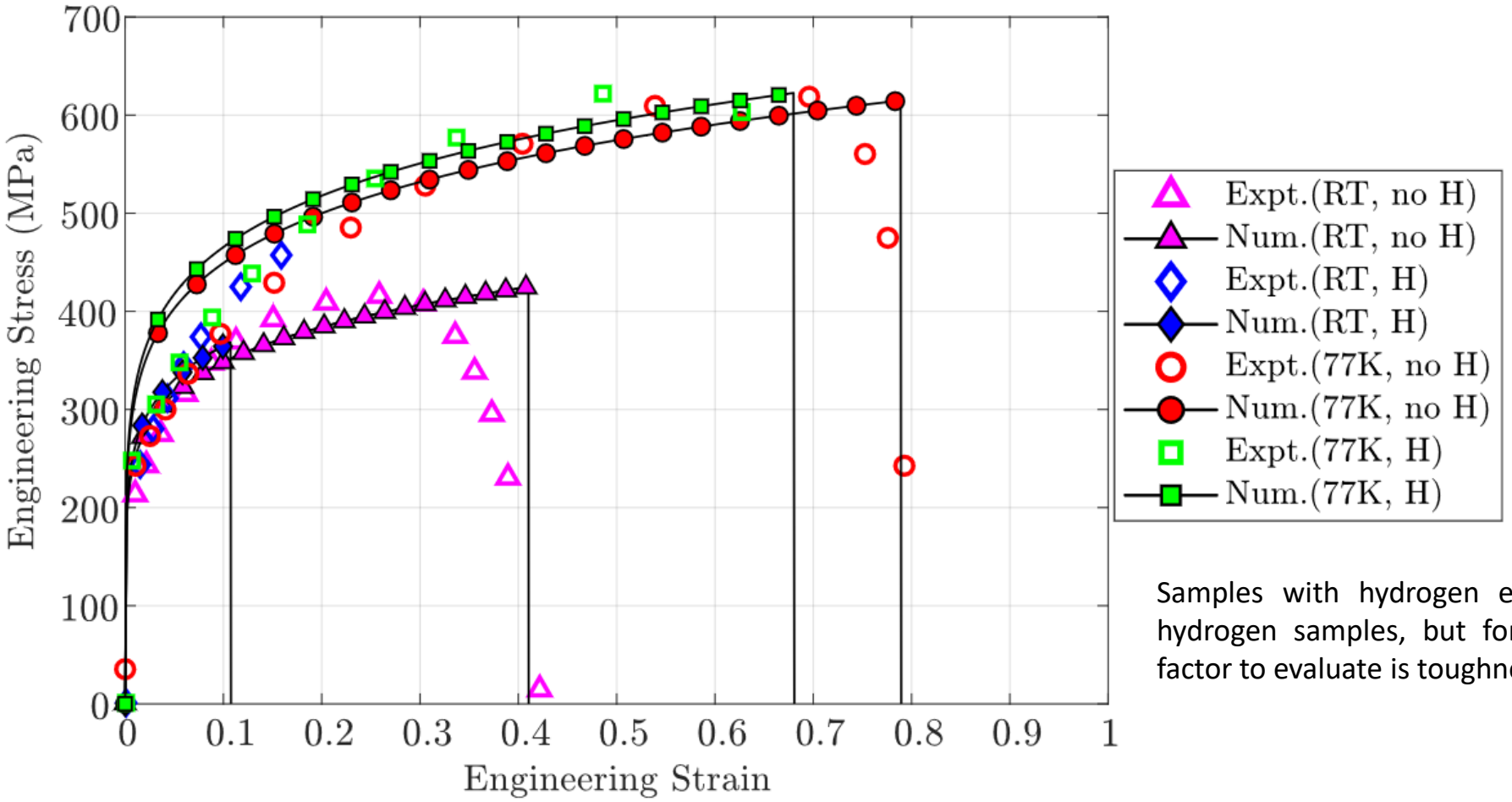
H concentration = f(σ_H)

$$H = H_D \exp\left[\frac{-V_H(\sigma_h - \sigma_{h,min})}{RT}\right]$$

Mass conservation

$$f = \frac{H_D \sum_i V_i}{\sum_i (V_i H_i)}$$

Loss of toughness in H-charged samples



Samples with hydrogen exposure appear harder than non-hydrogen samples, but for hydrogen embrittlement, the key factor to evaluate is toughness, not just hardness.

Valverde-González, A., et al. "Computational modelling of hydrogen assisted fracture in polycrystalline materials." *international journal of hydrogen energy* 47.75 (2022): 32235-32251.

New research projects

HYDRA

Liquid Hydrogen Delivery Systems for Aviation

HYDRA will deliver a high-performance piping solution for gaseous and liquid hydrogen to meet aviation's requirements for weight, impact, fire, damage-tolerance and long service-life. We will be using materials systems to their strengths to create a two-layer composite solution for hydrogen fuel movement within aircraft

HYDRA brings together a UK supply chain with system-design, materials, manufacturing, computational modelling, testing and product safety expertise.

HYDRA will develop digital design tools, materials systems and manufacturing techniques to produce samples for method and materials validation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