

Matériaux composites thermoplastiques pour le stockage de l'hydrogène sous haute pression

Développement de réservoirs d'hydrogène recyclables : les défis scientifiques et technologiques

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Décarbonation : l'hydrogène pour l'énergie

Solutions de stockage d'hydrogène

HYDROGEN ICE

Powering the Transition. Engineering the Future.

AVL & Maruti Suzuki showcase hydrogen-powered Suzuki Swift prototype at the 2026 Vienna Motor Symposium



KEY PERFORMANCE

- 1.4L Hydrogen Direct Injection Engine
- 100 kW (134 hp) Power
- 220 Nm Torque
- Advanced lean-burn + stoichiometric combustion
- Cooled EGR for low NOx emissions
- Refueling in minutes | Range comparable to petrol



HOW IT WORKS

- Intake**
Hydrogen (H_2) + air enter the cylinder
- Compression**
The mixture is compressed
- Ignition**
Spark plug ignites hydrogen
- Power Stroke**
Hydrogen burns rapidly and pushes the piston
- Exhaust**
Exhaust is primarily water vapor with controlled NOx

H_2O Near-zero CO_2

SAFETY CHALLENGES

- Hydrogen burns extremely fast
- High risk of pre-ignition and backfire
- Hydrogen leakage management critical
- High-pressure storage safety
- NOx control essential



BACKFIRE RISK: Due to high flame speed and wide flammability range, hydrogen can cause backfire in intake/exhaust if not properly controlled.

EFFICIENCY CHARACTERISTIC

Hydrogen ICE operates most efficiently in a narrower RPM band.

Efficiency drops significantly outside optimized operating zones.



OPERATING COST COMPARISON*

Battery EV	₹1 – ₹1.5 / km
CNG	₹2 – ₹3 / km
H_2 Hydrogen ICE	₹4 – ₹6 / km

*Indicative values based on current India scenario. Actuals may vary with region, scale and infrastructure.

WHY HYDROGEN WON'T DISRUPT PASSENGER CARS & AUTOS (FOR NOW)

- High hydrogen production cost
- Limited refueling infrastructure
- Compression, storage & transport cost
- Lower overall energy efficiency vs. BEV
- Not ideal for stop-go urban usage
- High system cost for small vehicles

WHERE HYDROGEN ICE MAKES MORE SENSE



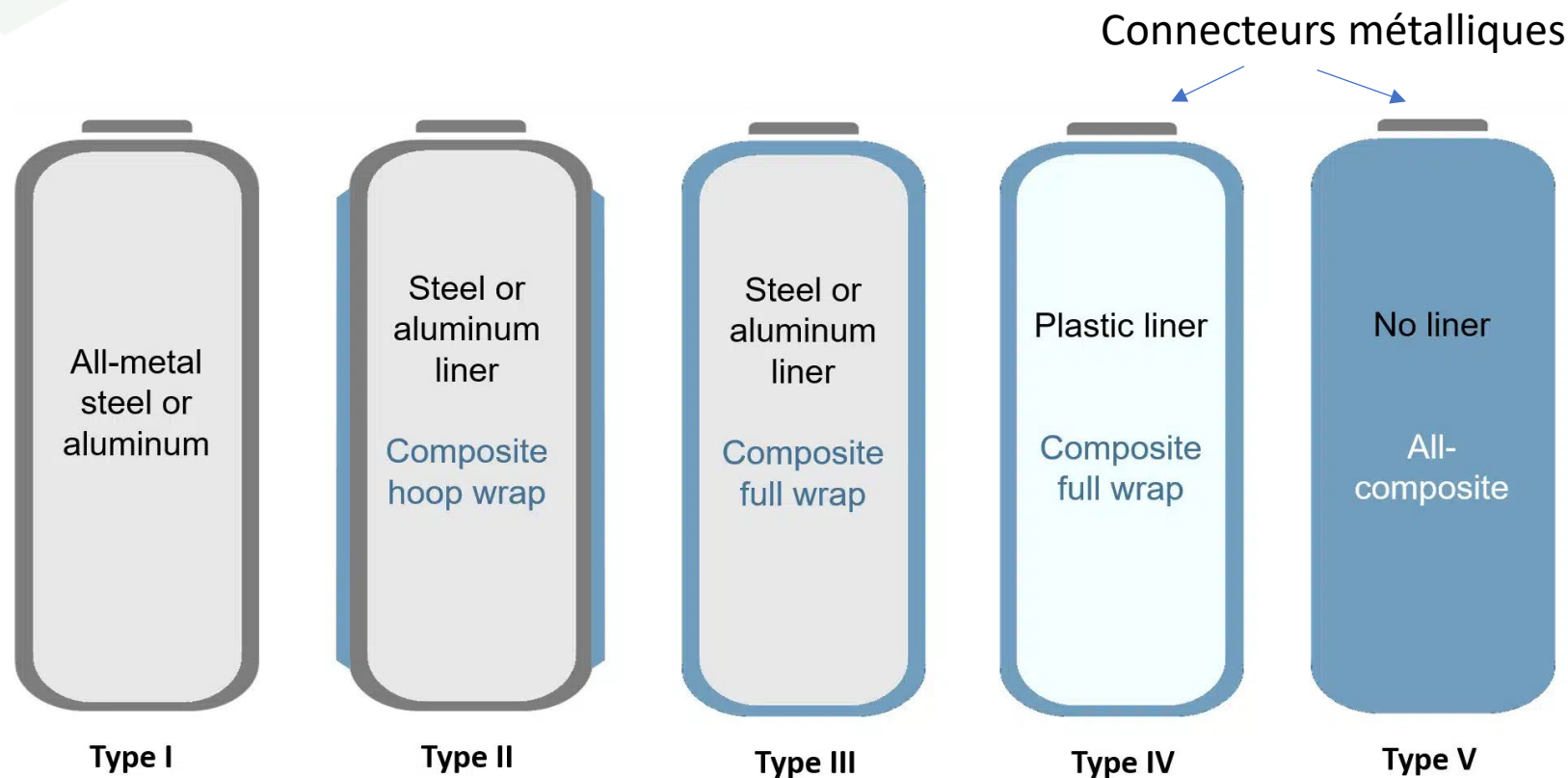
HOW IVRD CAN ADD VALUE WITH HYDROGEN ICE

- Keeps engine in optimal efficiency RPM range
- Reduces RPM fluctuations & improves transient response
- Electric assist for low-speed torque & drivability
- Enables smaller engine with better utilization & lower fuel use
- Smoother power delivery, lower NVH & driveline stress

Hydrogen ICE is not here to replace EVs. | It is here to create more choices for a cleaner, more sustainable future.

MULTI-PATHWAY. MULTI-SOLUTION. ONE GOAL – CLEANER MOBILITY.

Différents types de réservoirs sous pression pour le stockage de l'hydrogène



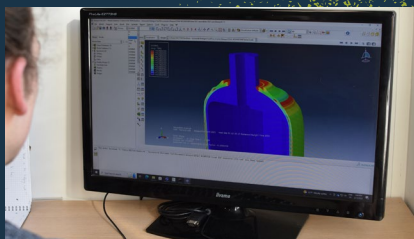
Sans liner, le Type V, est léger de 20 % comparé au type IV

15/07/2026

Défis pour les cuves sous pression à hydrogène

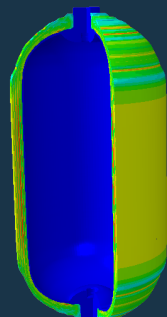
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Exigences pour la conception de réservoirs d'hydrogène



Pre-Design
Exigences pour la conception
de réservoirs d'hydrogène

Qualification
Burst test
Pressure cycling
Other in-house or
outsourced tests



Pre-Design
Exigences pour la
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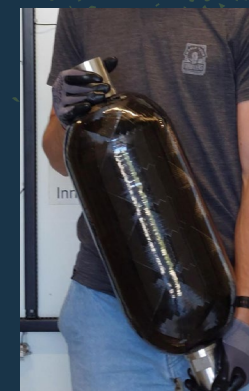
Material
Materials watch
Formulation and
manufacturing
of semi-products
(liner, tape)
Materials
selection and
characterization
-40°C / +85°C



Manufacturing
Tank manufactured by filament
winding or AFP
Thermoset or thermoplastic



**Pre-study
validation**



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Processus et matériaux : sélection et impact

Conception et fabrication de cylindres composites et de réservoir de type IV

Processus :

Enroulement robotisé du filament : pas de pression sur les bandes

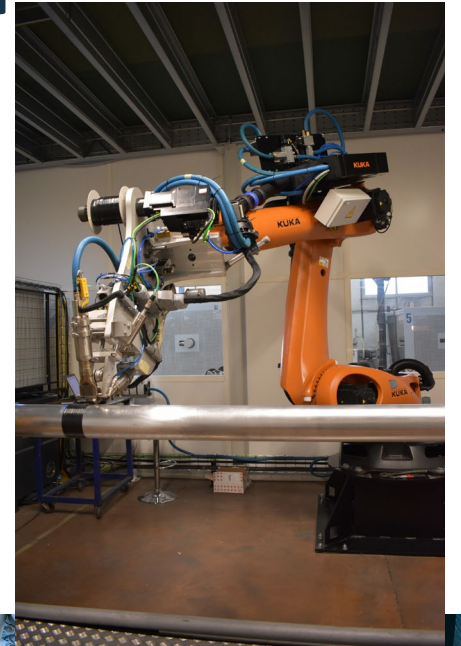
Placement automatisé de la fibre (AFP) : T contrôlée et pression

Matières premières pour composites (bandes de matières premières) :

Fibre : carbone, verre, naturel

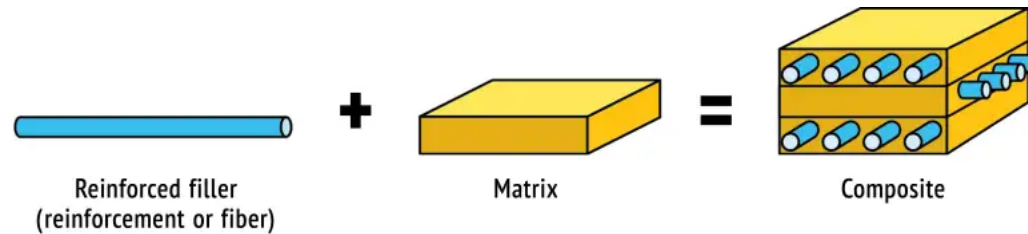
Matrice : thermoplastique (PA, acrylique) & thermodurcissage (époxy)

Matières premières pré-imprégnées (fabrication de ruban)

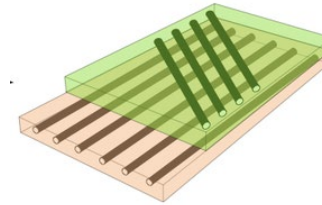
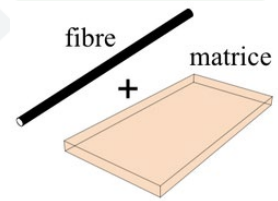


Choix des matières premières et caractérisation

- Des anneaux ou des plaques d'enroulement pour fabriquer des coupons de test (résistance à la traction, test NOL) avec vos propres matériaux.
- Tests standards : résistance à la traction, flexion, cisaillement, K1C, fatigue...
- Analyse morphologique ou physico-chimique sur un vaisseau : tomographie, microscopie...



Origine des variations des propriétés du matériau



Components

Tape

Stacking

Tank

Fiber tension

Polymerization

Material quality
(porosity, fibre
content)

Crossings

Plies Interfaces

Thickness effects

Material quality
(porosity, fibre
content)

Compaction

Defects: resin pockets,
bridging, corrugation

Thickness effects

Polymerization:
exothermy, duration

Residual thermal
stresses

Material quality
(porosity, fibre content)

Chaine numérique et données d'entrée

Modélisation du comportement des reservoirs et comparaison expérimentale

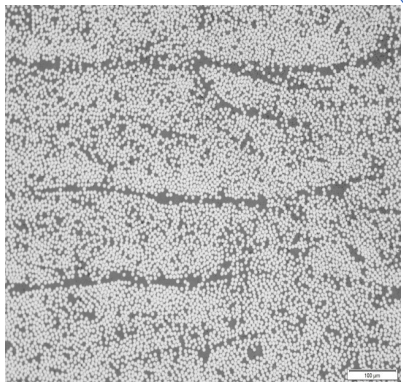
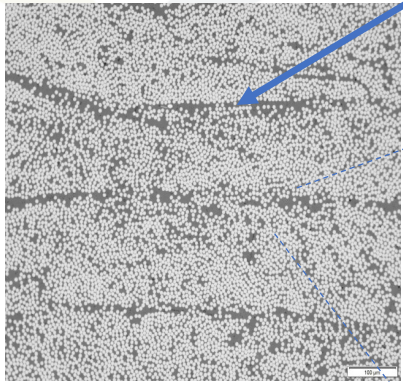
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Origine des défauts entre contreplaqués dus à des espaces

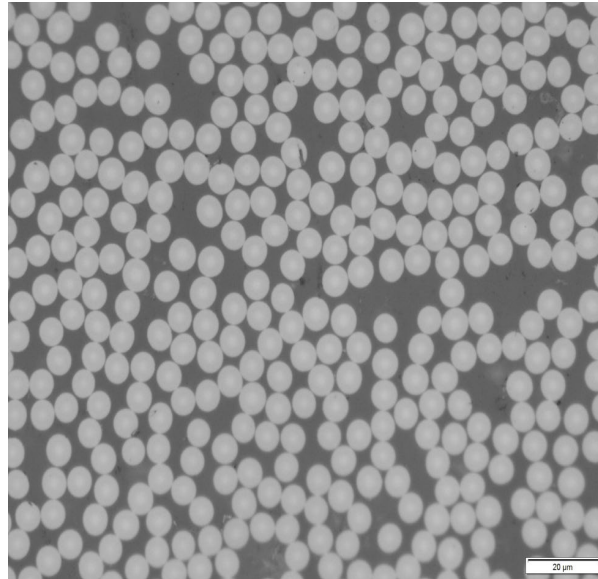
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Observation des défauts locaux dus à la fabrication de thermoplastiques

Uncomplete Interface healing



Plateau
technique



Porosity and gaps

Ressources de qualification– Burst test

Burst test and cycling characterization machine

- Pressurisation from the bottom part
- Maximum internal hydraulic pressure 2000 bar
- Able to program tank cycling

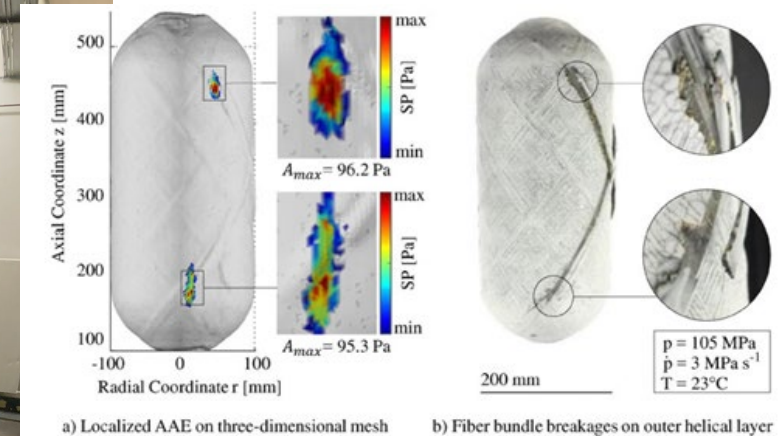
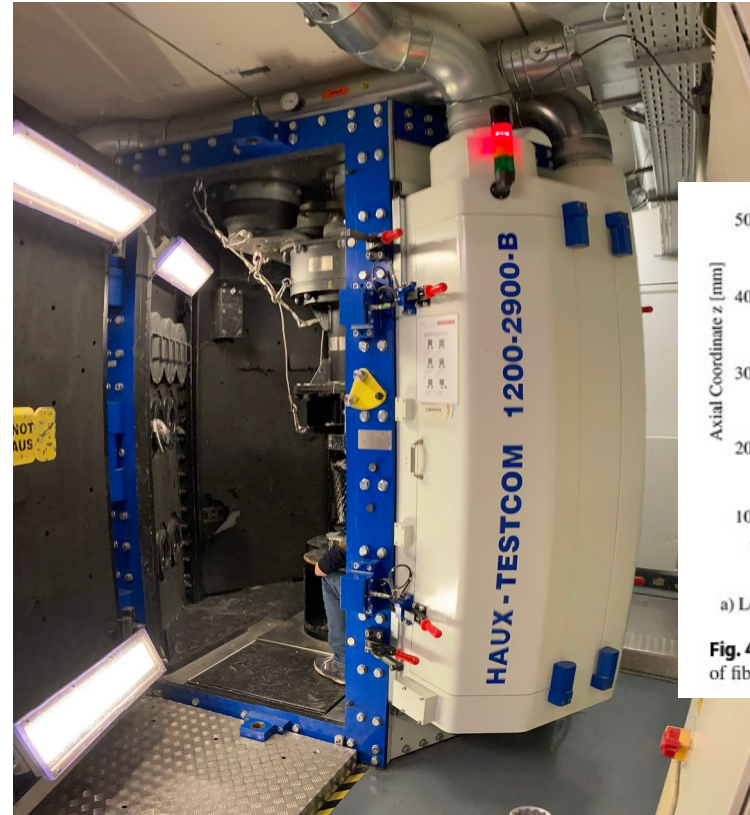
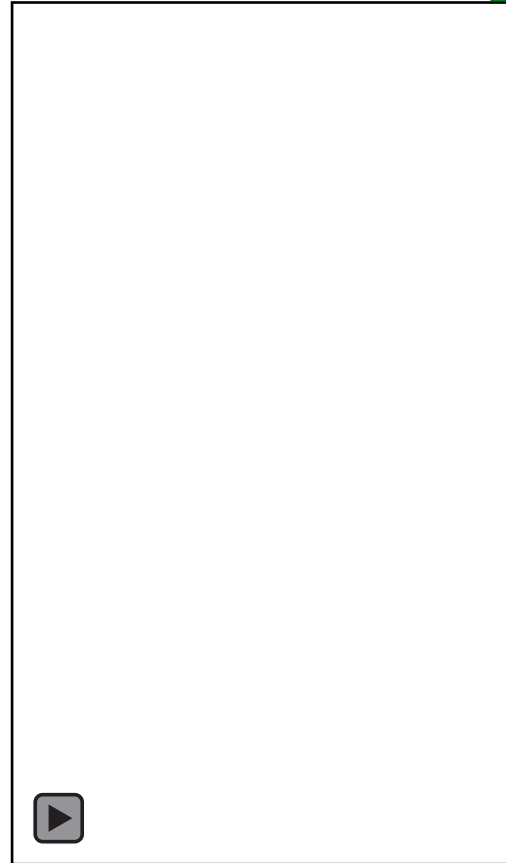
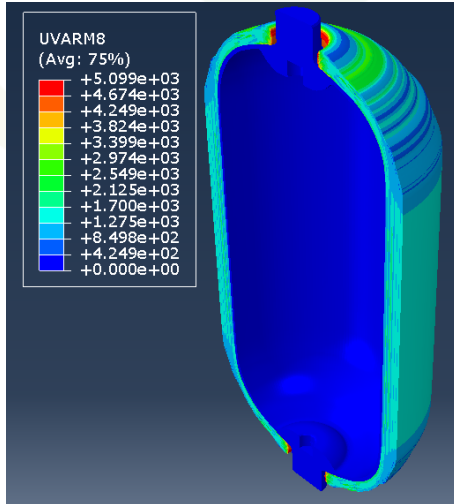


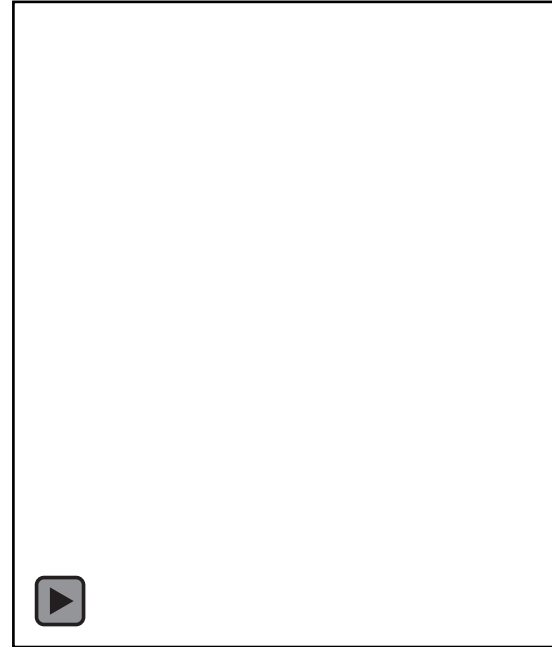
Fig. 4.22 Comparison of emission localization on three-dimensional mesh to the positions of fiber bundle breakages on the outermost helical layer

Essai destructif: Burst test



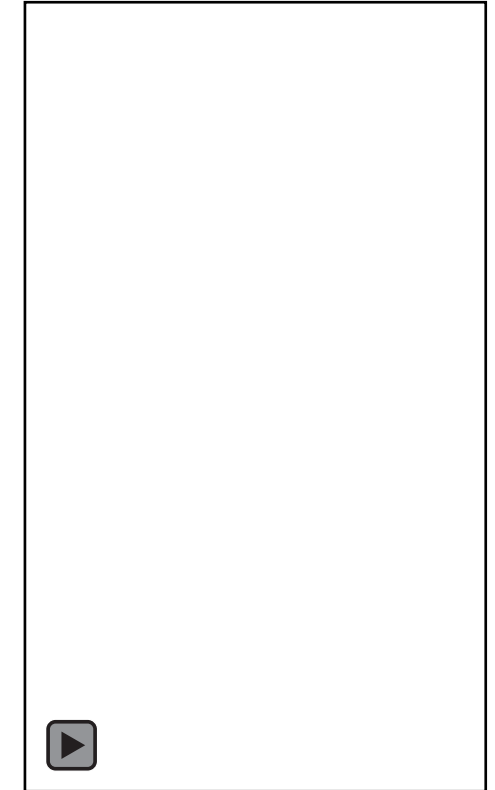
Burst at 1508 bar ✗

Base ejection ✗

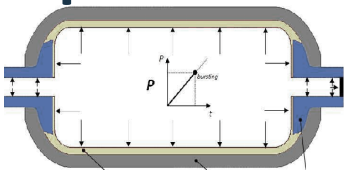


Burst at 1610 bar ✓

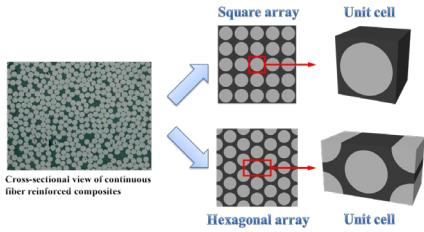
Rupture in the hoop: "safe mode" ✓



Défis scientifiques pour les cuves thermoplastiques

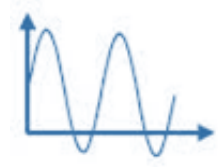


Understand the behaviour of a thick laminate subjected to internal pressure (elasticity, fracture)



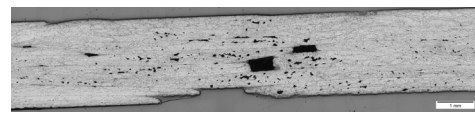
Establish models and homogenisation laws adapted to filament winding

Create semi-structural test devices on a filament-wound composite specimen, to obtain its in-plane and out-of-plane properties



Develop tests to understand material behaviour and interfaces under cycling conditions at extreme temperatures

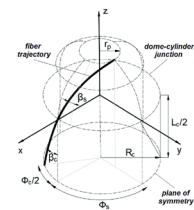
Integrate manufacturing parameters into numerical models (porosity, fibre content, residual thermomechanical stresses)



Optimising fibre trajectories



Assess the environmental impact associated to a material and a process





Merci de votre attention