HyPactor

Residual performance of composite pressure vessels submitted to mechanical impact

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cea · Air Liquide creative oxygen · IS Institut de Soudure Groupe · Hexagon Composites · NTNU Norwegian University of Science and Technology · Wrocław University of Technology · ayming

A European Project supported through the Seventh Framework Programme for the Fuel Cells and Hydrogen Joint Technology Initiative (grant agreement n°621194).

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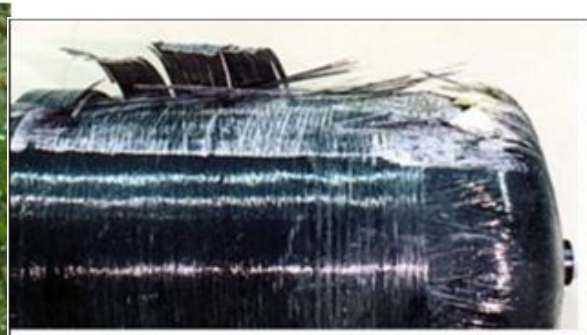
Context and overview of the project

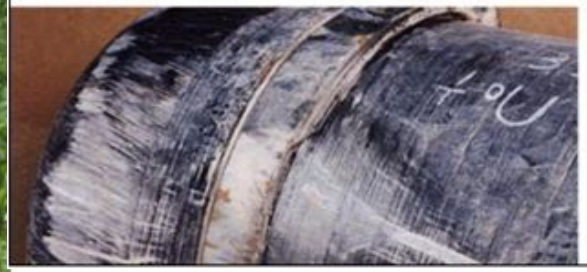
A European Project supported through the Seventh Framework Programme for the Fuel Cells and Hydrogen Joint Technology Initiative (grant agreement n°621194).

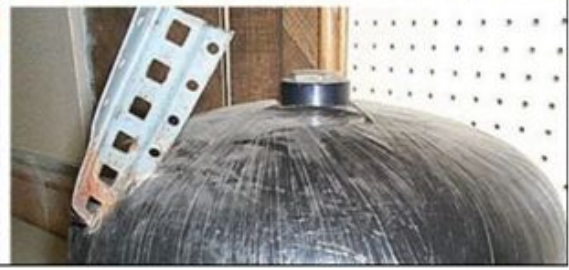
Today's challenges

- **H_2 : a highly valuable energy carrier for the 21st century**
- **Demonstrating optimum safety in use** will contribute to help its social acceptance and its extensive use as an energy vector.
- Feedback gathered on cylinders currently in service (mostly metallic), **=> Resistance to mechanical impact is of main concern!**
- HyPactor aims at **strengthening the knowledge on influence of mechanical impact with respect to (type-IV) COPV integrity**

Real life examples...







The past performance of Hexagon Lincoln's products in an accident does not guarantee a similar result in the future. All accidents involve different circumstances and therefore may result in different outcomes with respect to a CPV. Any CPV, which has been involved in an accident or has otherwise been misused must be inspected at a qualified service facility before the cylinder is returned to service to ensure it is safe for further use.

FCH JU Hypactor consortium

CPV Testing
CEA, WRUT

CPV Operation
Air Liquide, Hexagon

CPV Manufacturing
Hexagon

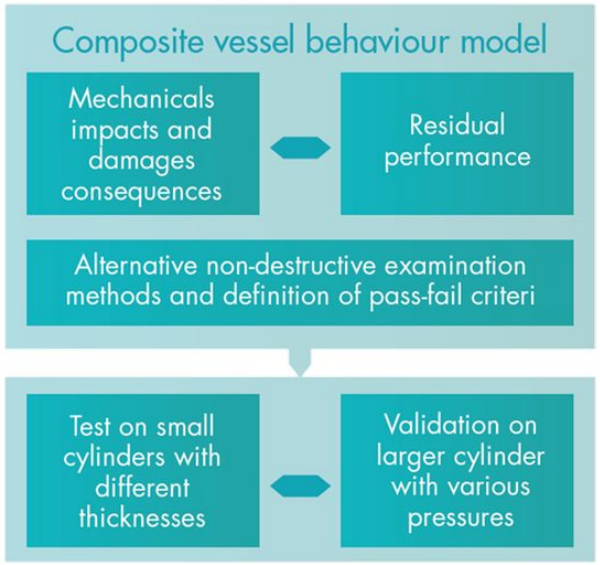
Non destructive testing
IS, WRUT, CEA

Modelling
NTNU

RCS Development
Hexagon, Air Liquide, IS, CEA

Project coordination support
Ayming (Alma)

Main goals



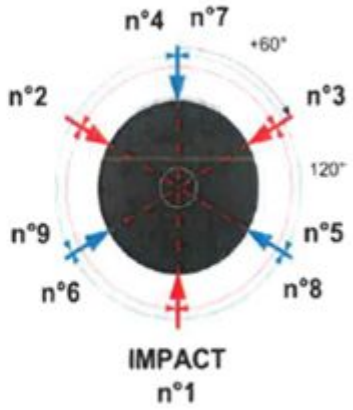
Goals:

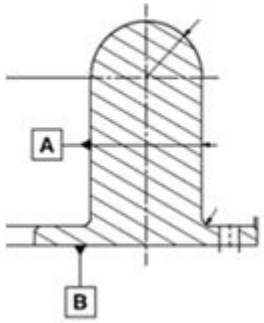
- **Build an extensive experimental database** (impacts ↔ damages)
- **Understand/characterize relationship** between impact, damage and loss of performance (short term and long-term)
- **Develop models** to simulate mechanical impacts on CPVs
- **Assess / develop relevant non-destructive inspection procedures** and define pass-fail criteria for CPV inspection in service

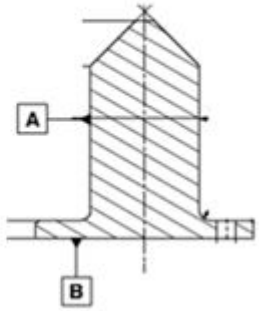
Main objective:

- **Provide recommendations for Regulation Codes & Standards (RCS)**
  - Qualification requirements and acceptance criteria for new designs
  - impact testing set-up
  - Periodic inspection

Hypactor in a few figures







Tank tested # **100**

CPV Working Pressures from **250** to **950 bar**

CPV Water Volumes from **36 to 513 L**

Impact Energies (**0,3 to 10 kJ**), Weights (**1-100kg**), Speeds (**3-120m/s**),Multi-impacts, Pressure state (**0 to 875 bar**), composite thicknesses (**16 to 63mm**)

Test to Failure or further NDT testing

Short-term (Burst) and Long-term (hydraulic cycling, hold) evaluations

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Impact tests performed

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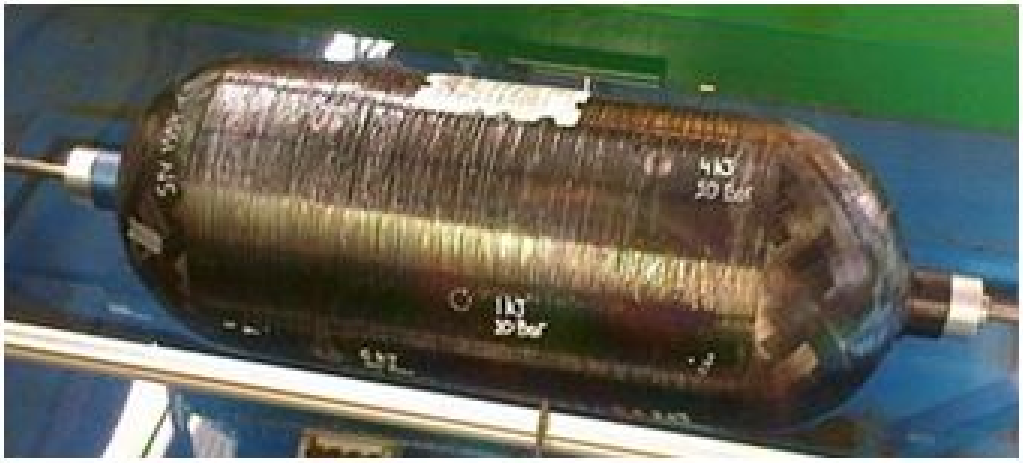
Cylinders used

Hexagon ID	Volume (Liter)	Working pressure (MPa)	Nominal length (mm)	Nominal Diameter (mm)	Composite wall thickness (mm)	Weight (kg)
A	36	70	906	319	23	32
B	255	95	2783	515	63	369
C	513	25	2032	675	16	128

All cylinders presented here are **Type 4 cylinders** of water volume 36L (model #A) produced by Hexagon Composites. They are all made of **HDPE-liner, metallic boss, and carbon fibre reinforcement.**

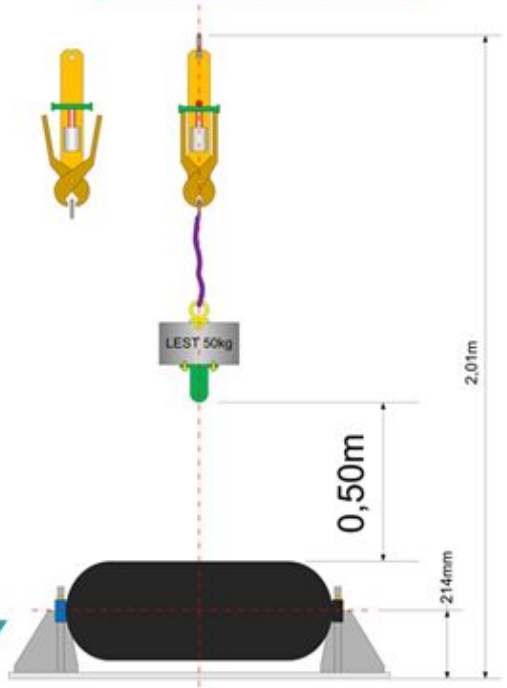


Impact test setup (1)

Fast camera

Impactor

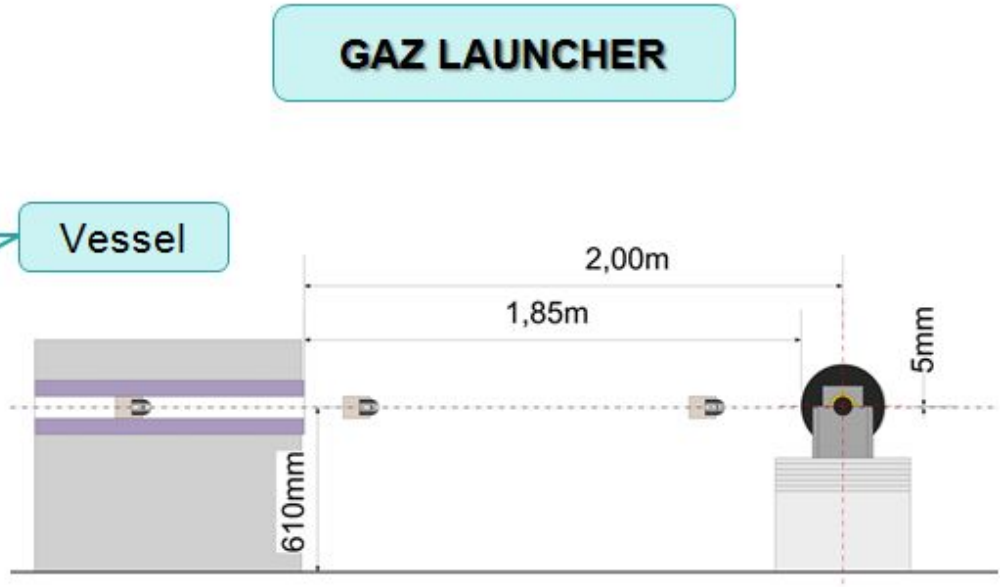
DROP TOWER



Vessel

Sandbags for impactor protection

Impact test setup (2)



Scope of the presentation

The conditions below were common to all cylinders in this presentation :

- Only one **single impact** is performed on each cylinder Cylinder is **neck-mounted**
- Impactor is **hemispherical**, diameter 60 mm
- All **cylinders are empty** at the moment of impact
- Cylinders are type 4 with **plastic liner**
- Cylinders are model A (**36 L for on-board** H2 vehicles)
- **Residual performance is assessed as residual burst pressure** only in this presentation.
    - *Reduction of fatigue performance due to impact has not been observed on Hypactor cylinders, but could occur with others (especially metallic liners)*

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Short term residual performance (burst pressure) of impacted cylinders

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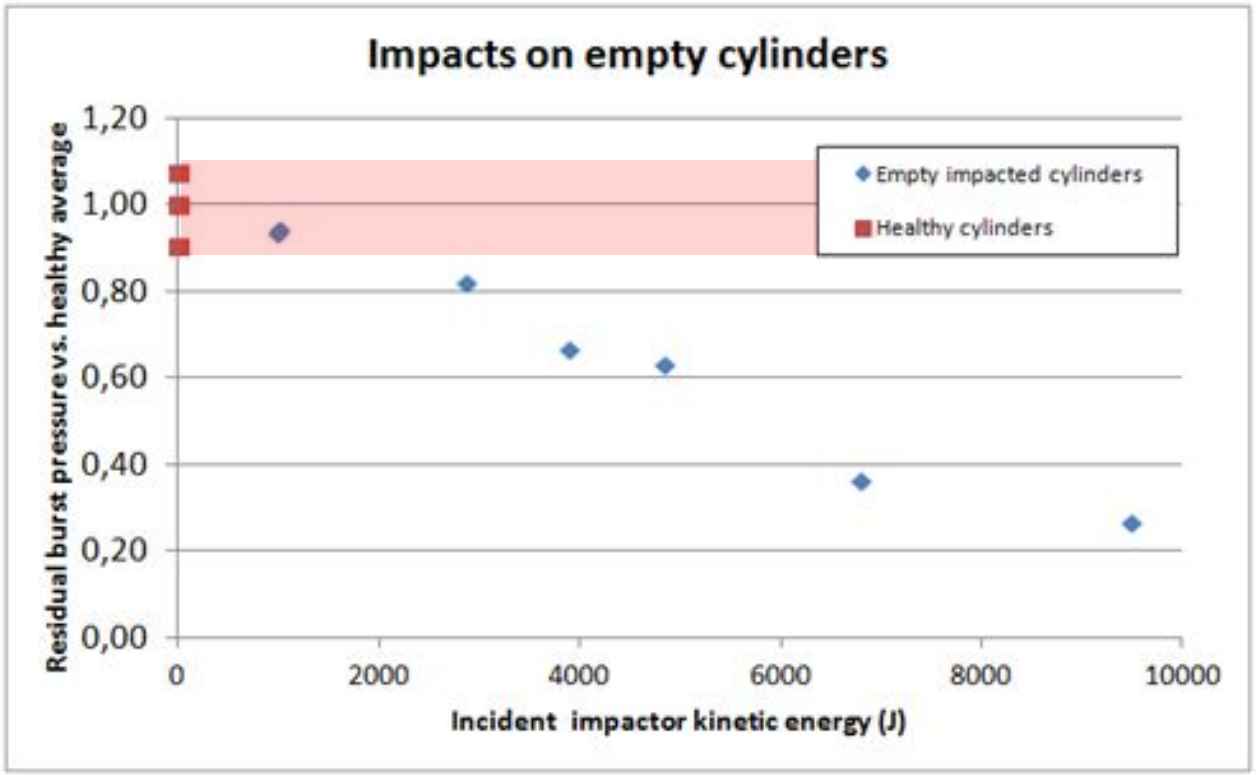
Impacts on empty cylinders



There seems to be an **energy threshold** below which **burst pressure becomes reduced**.
Such behaviour has also been **observed on other models** of cylinders from [1].

For these Hexagon 36L cylinders impacted empty, the threshold seems to be between 1kJ and 3kJ

[1] P. Blanc-Vannet, *Burst pressure reduction of various thermoset composite pressure vessels after impact on the cylindrical part*, Composite Structures, vol. 160, pp. 706-711, 2017.

A potential explanation

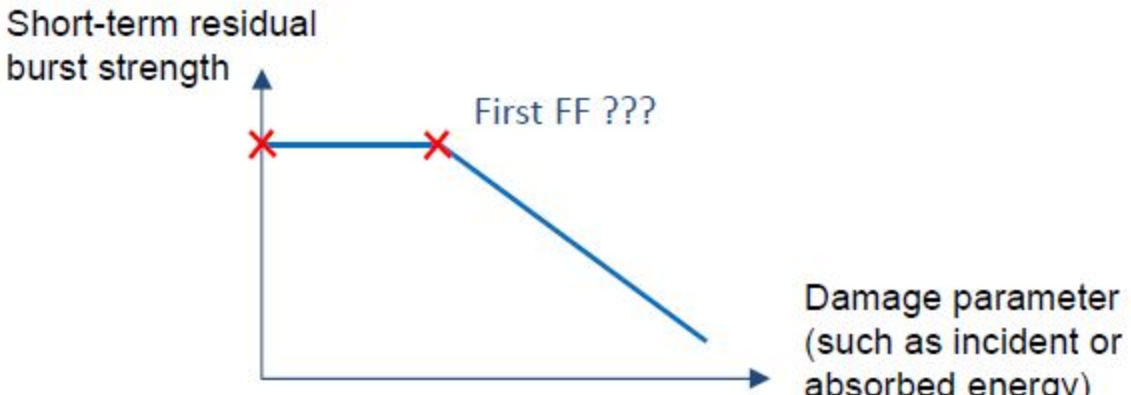
K. Lasn et al., Artificial impact damage for estimating the short-term residual burst pressure of COPVs, 21st International Conference on Composite Materials, Xi'an, China, 22/08/2017

The effect of delaminations

Configurations	Range of burst pressures, [bar]
Healthy reference	1842...1865
A large delamination (as in 0 bar impact)	1842...1863
A small delamination (as in 700 bar impact)	1842...1866

Artificial delaminations, when modelled separately from fibre failures:

- Do not significantly alter stress fields
- Do not affect burst pressures



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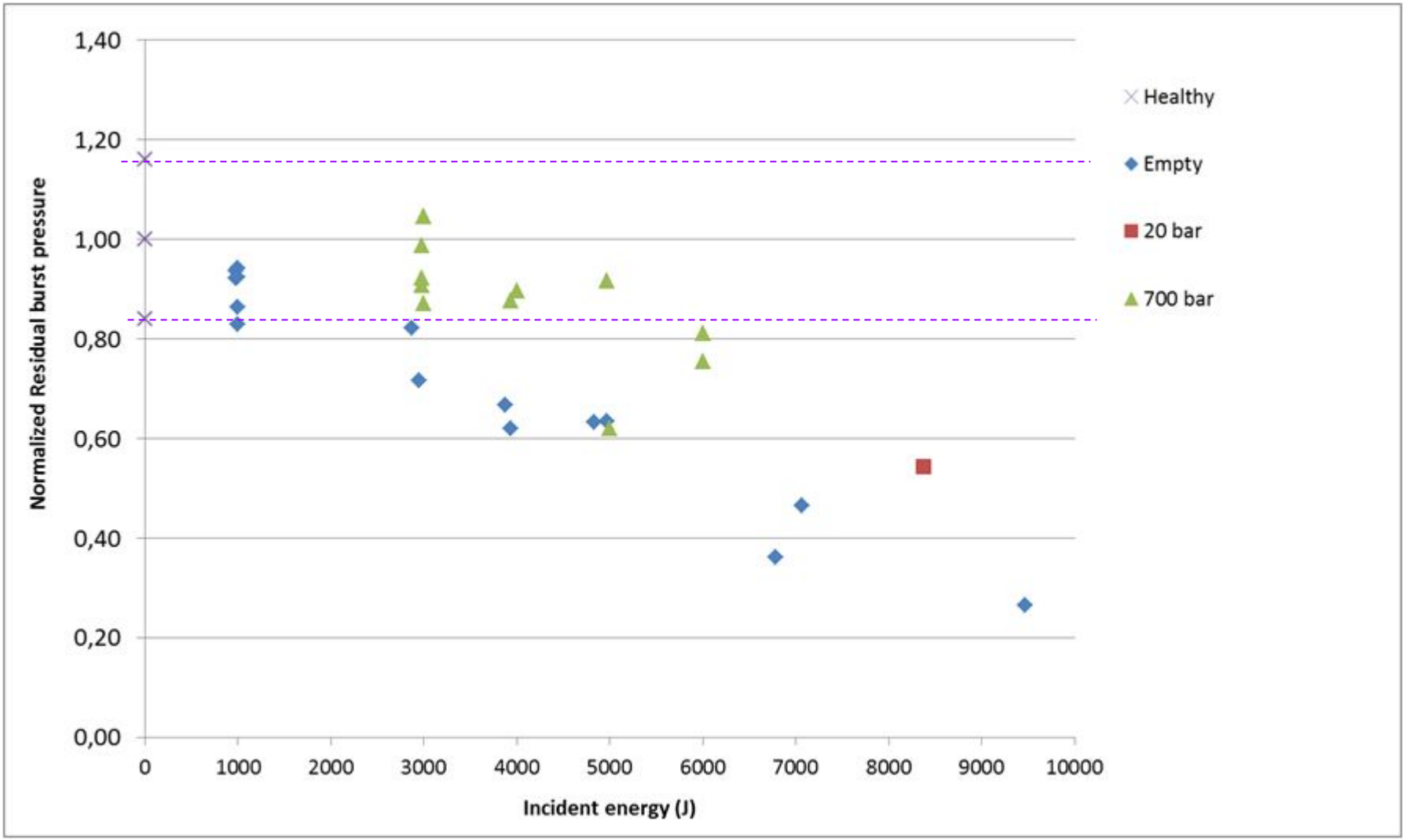
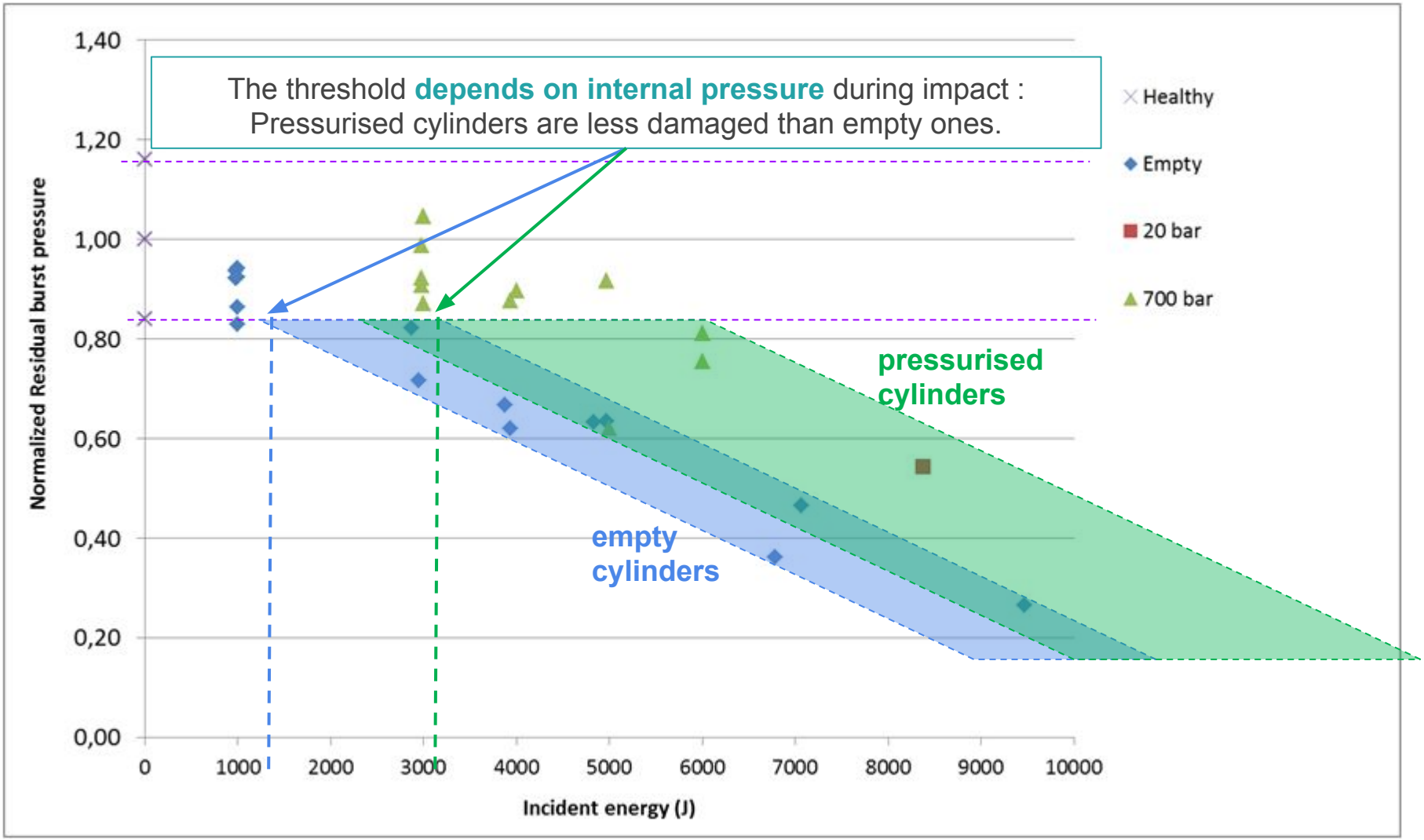
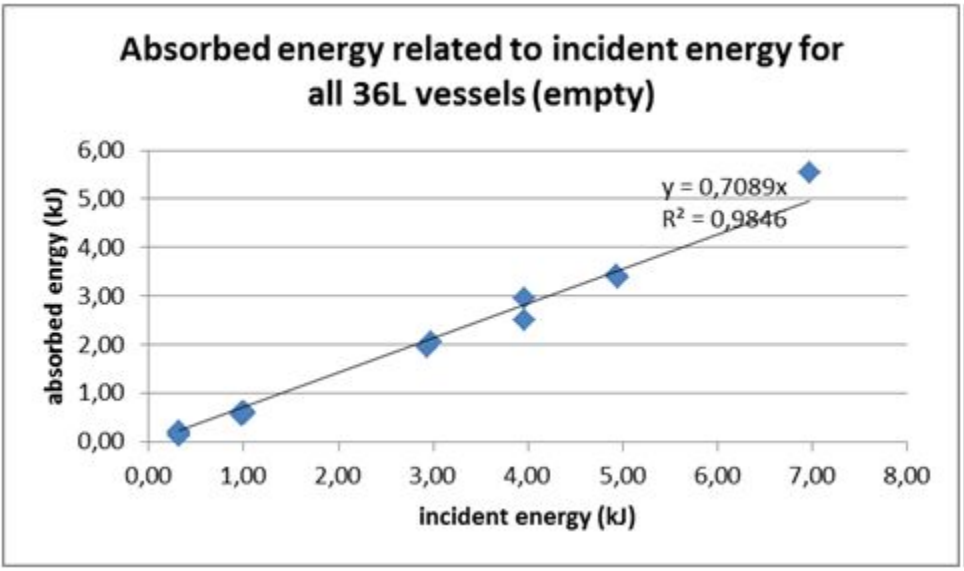
Empty and pressurised cylinders

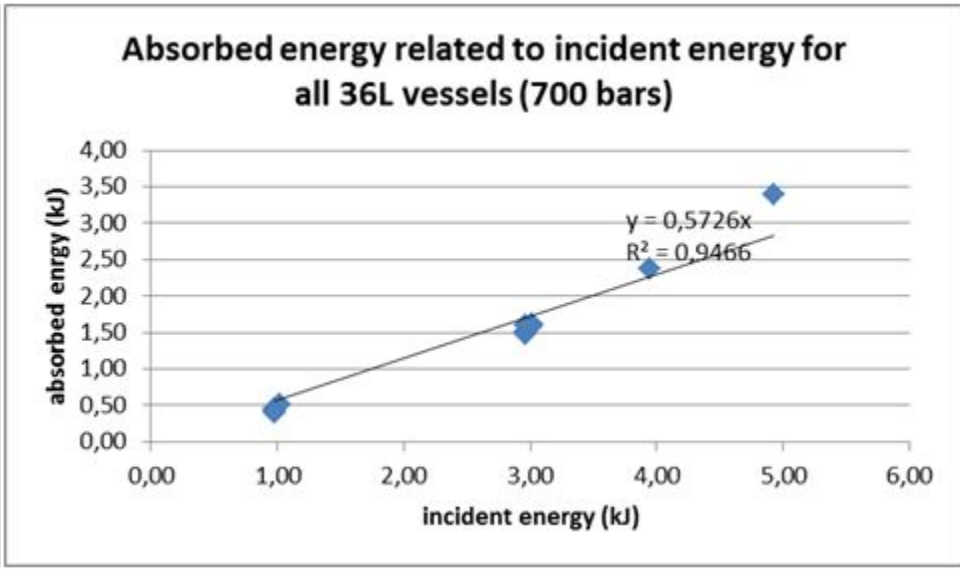


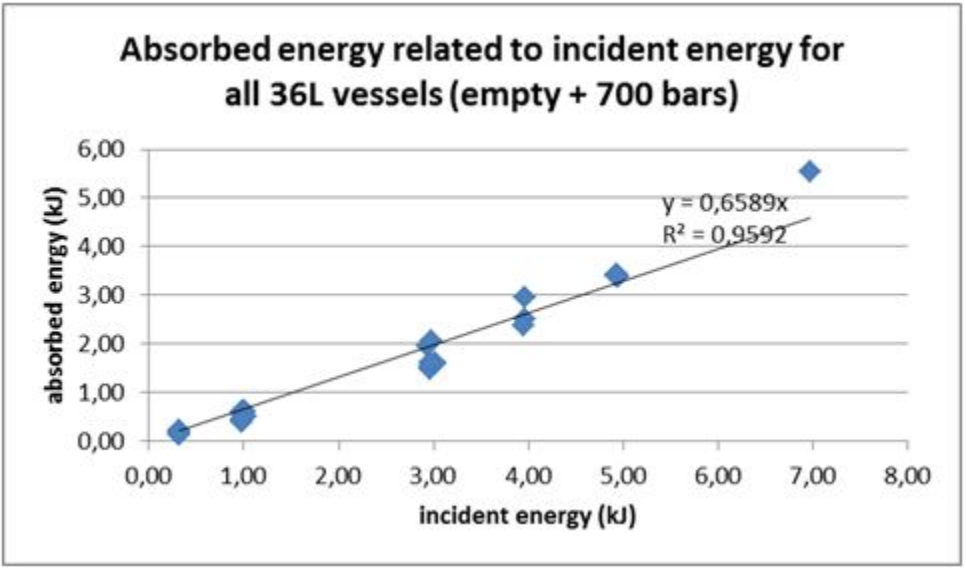
Empty and pressurised cylinders



Energy transferred to the cylinder



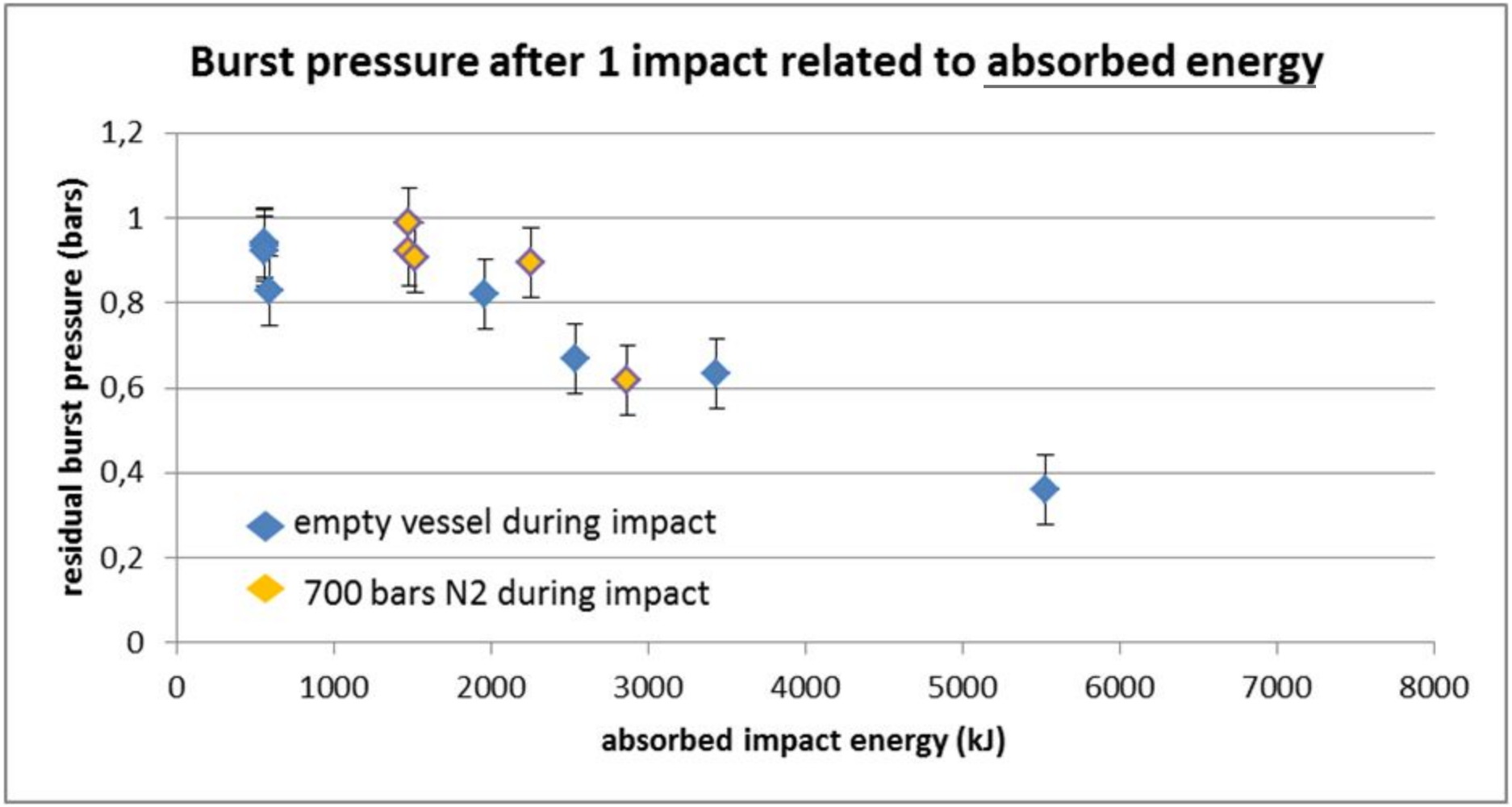




- Empty 36L vessel : **71%** absorbed
  (28 vessels)
- 700 bars 36L vessel : **57%** absorbed
  (15 vessels)
- "Mean" value : 66% absorbed
  (43 vessels)

/!\ Specific to the cylinder and test setup used !

Residual burst pressure



Considering **absorbed energy** leads to a **common trend for empty and pressurised** cylinders.

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Conclusion:
Calibration of visual inspection

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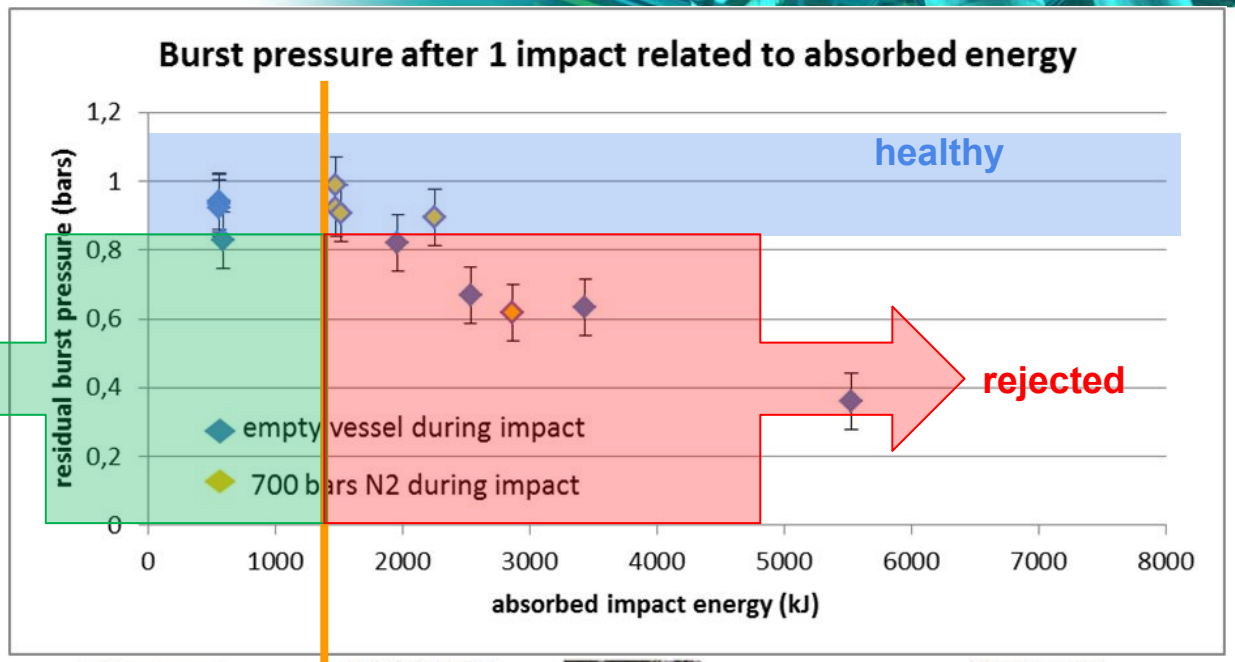
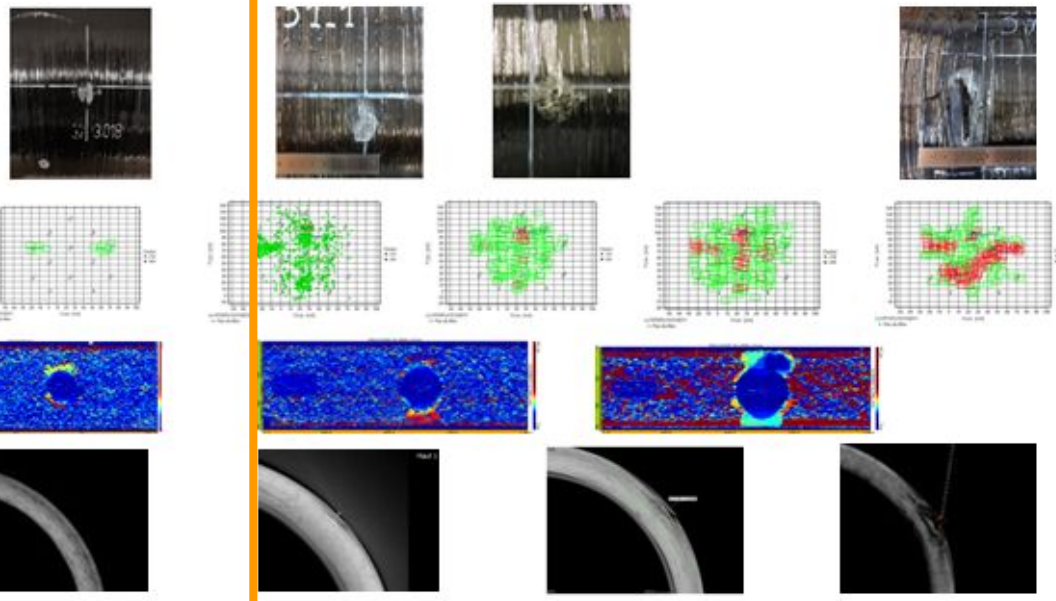
Conclusions

- For Hypactor cylinders, **empty and pressurised cylinders look the same** after an impact of same energy
  - *this may depends on cylinder design*
- For a same impact energy, **empty cylinders are more damaged** than pressurised ones
  - *impacts should be performed on empty cylinders...*
  - *...if the first point is still true for the new design*
- Using the threshold, visual inspection **can be calibrated** in order to reject cylinders with decreased burst pressure and **eliminate the risk of burst**
  - Hypactor recommends that some pictures are taken during approval process, and included in user manual
- The calibration is **specific to the cylinder design**
- **Other non destructive testing** methods can also be calibrated to improve the reliability of inspection

The inspector's dream



- Visual criteria
- AE criteria
- UT criteria
- CT scan criteria



Thank you for your attention