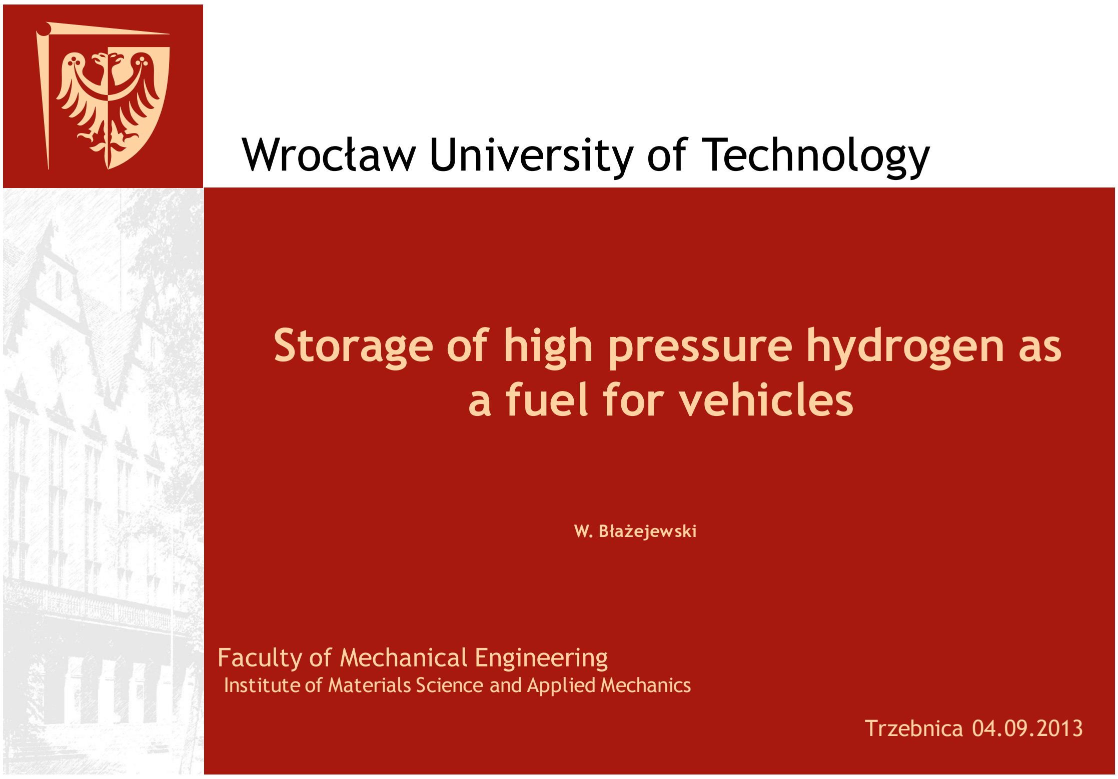
Storage of high pressure hydrogen as a fuel for vehicles

Wojciech Błażejewski*

Trzebnica, 3–6 th September 2013



*Wrocław University of Technology, Institute of Materials Science and Applied Mechanics

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The team of the High Pressure Vessels and Composites Laboratory

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Our research and technology interests

Testing methods:

- Universal testing machines (static, dynamic and fatigue)
- Creep
- Pressure test up to 2400 bar
- Climatic chamber (high and low temperatures)
- Microscopic analysis
- Acoustic emission
- Thermography
- Non-standard tests

Technologies:

- Filament winding
- Pultrusion
- Hand lay-up
- Vacuum Infusion (VI)
- Resin Transfer Moulding

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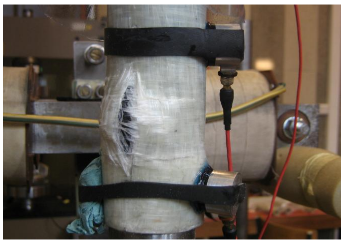
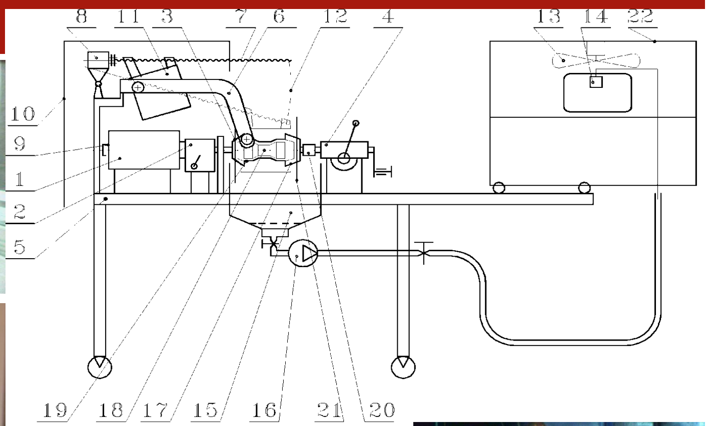
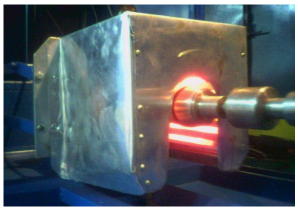
Centrifugal moulding

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Military pontoon (floating) bridge concept


kompozyty Sp. z o.o.
www.kompozyty.pl
zapraszają na
WIOSENNY KONCERT
WOKALNO - INSTRUMENTALNY
na studyjnych modelach skrzypiec i wiolonczeli
wykonanych z kompozytów karbonowych
Sala Oratorium Marianum
1 czerwca 2008 r., godzina 18.00
WYSTĄPIĄ:
Maria Zygmaniak -Lesiak - sopran, skrzypce
Anna Korecka - wiolonczela
prof. Andrzej Janusz - fortepian
Edyta Piaczyńska - prowadzenie koncertu
W PROGRAMIE
J. Sebastian Bach L. van Beethoven
L. Boccherini J. Brahms A. Dworzak
Z. Fibich G. Gershwin J. Haydn
I. Kalman F. Lehar V. Monti
W. A. Mozart R. Schuman C. Seant-Seans
WSTĘP WOLNY


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Instytut Materiałoznawstwa i Mechaniki Technicznej
PZL W-3RM Anakonda (PZL W-3 Sokół) 1992
POLISH NAVY
RESCUE
0813

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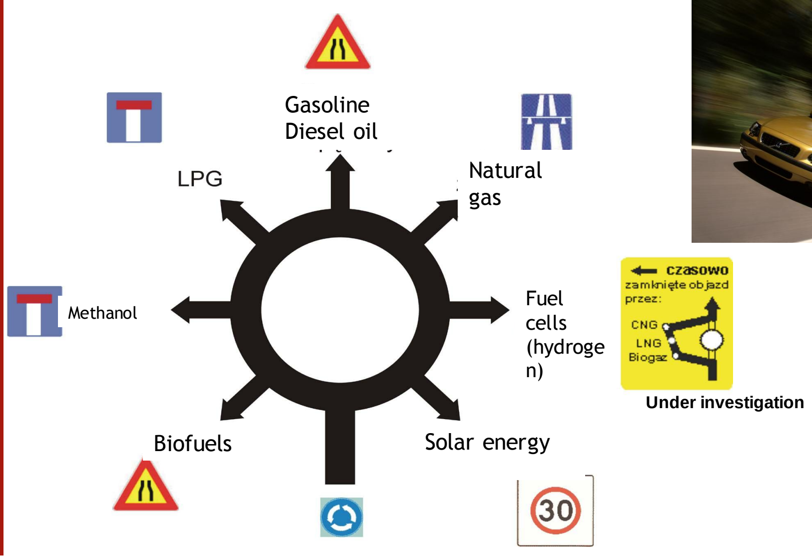
Which way to choose?



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Wood gas vehicles

Gasifier is visible in the rear, the fuel storage on the roof. Along the roof and pillars, hot wood gas runs to the cooler mounted in the front of the vehicle.

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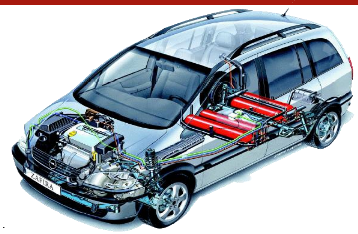
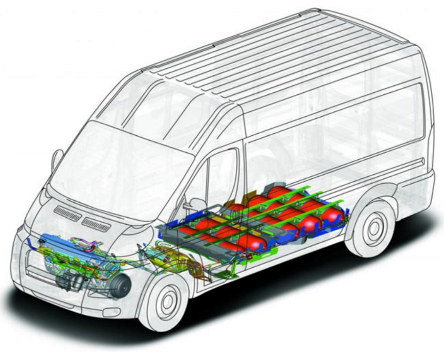
CNG-fuelled passenger and utility cars

All of the automotive producers offer CNG car models





Fiat Ducato 140 Natural Power

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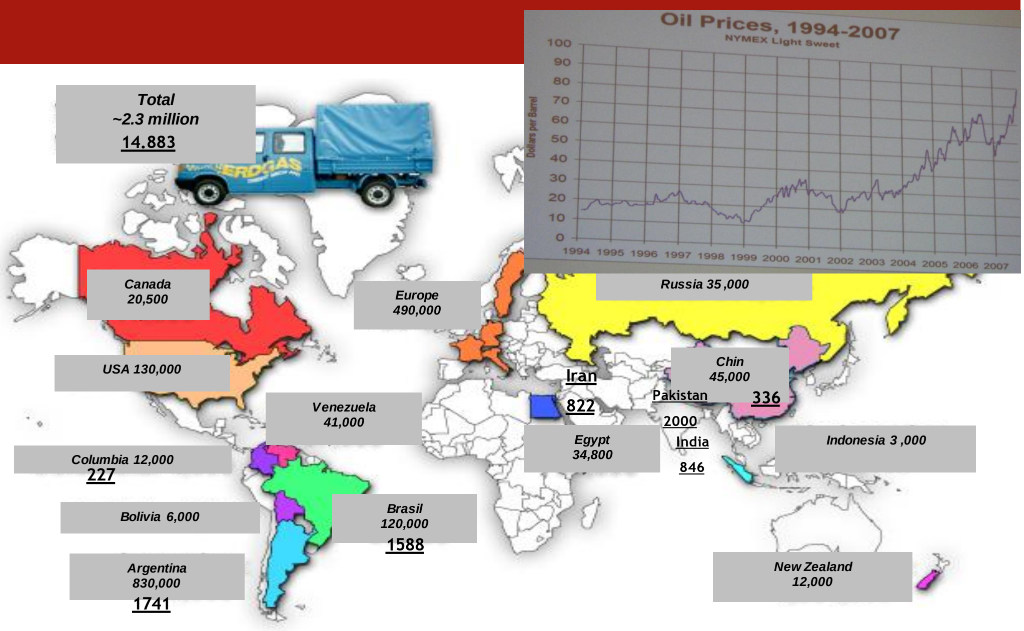
Number of CNG-fuelled vehicles in the world



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INTERVIEW: III Industrial Revolution a solution for crysis

Jeremy Rifkin: To defend European quality of life and European social model a vision of a new European project is needed.

The Third Industrial Revolution is the plenitude of small energy sources from:

wind,

sun,

water,

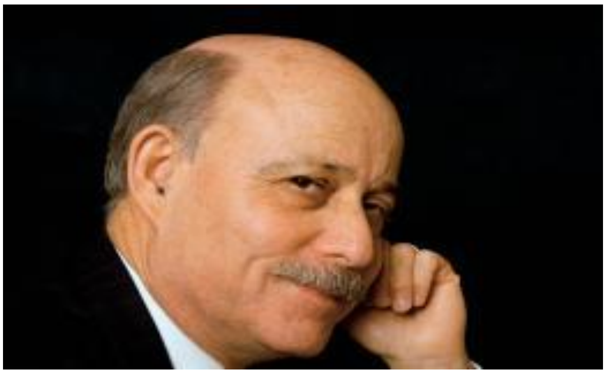
geothermal,

heat pumps,

biomass

etc.

POLITYKA.PL



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Hydrogen-fuelled vehicles - Berlin

Hydrogen-fuelled forklift trucks

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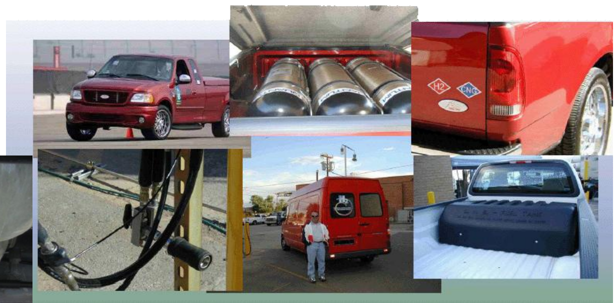
Hydrogen-fuelled vehicles (CNG and CH2)

Hydrogen Test Vehicles



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Hydrogen-fuelled vehicle

(fuels with water while driving to fire)

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Future car equipped with hydrogen fuel cells

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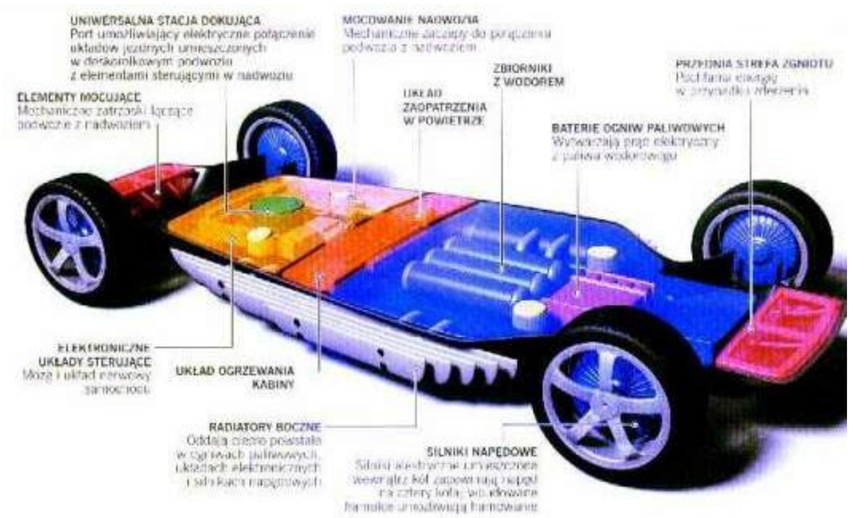
Concept of placement of components of a hydrogen-fuelled vehicle (AUTOnomy) - fuel cells in the chassis



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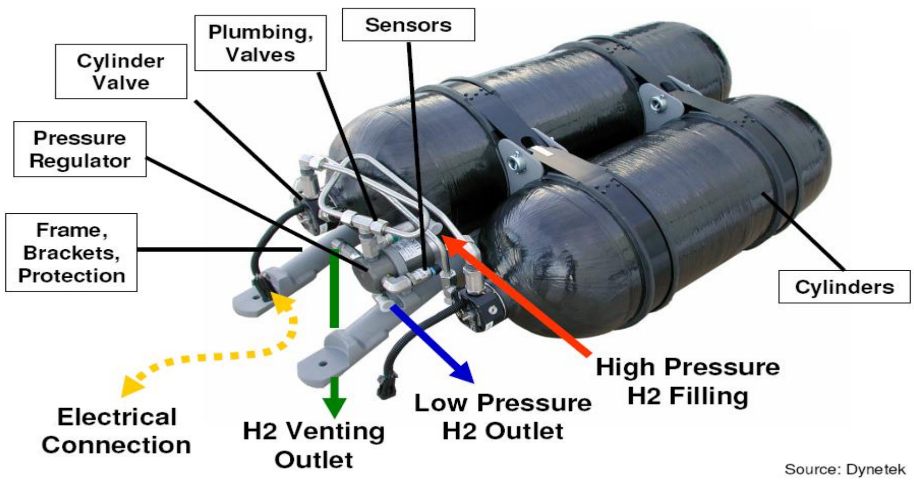
Pressure Vessel Components



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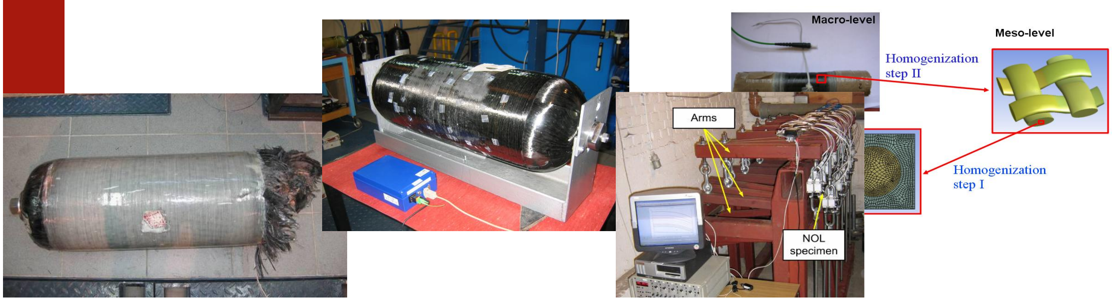
StorHy Consortium

Wrocław University of Technology Instytut Materiałoznawstwa i Mechaniki Technicznej

Co-operation in StorHy project:

- testing of high pressure vessels
  - Cyclic tests at ambient and extreme temperatures
  - Burst tests
- concept of „on-line" monitoring sensor system for high pressure vessels (optical fiber sensor based)
- creep test of NOL-type composite specimens
- modelling of running damage process and current damage level



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StorHy Vision

... introduce and
for cars, busses

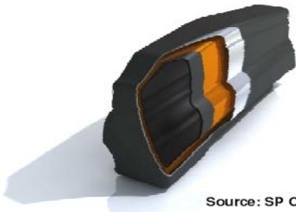
and trucks as quickly as possible

STORHY

Gas

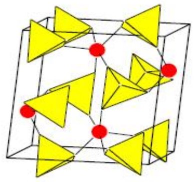
Source: Dynetek

Liquid



Source: SP Cryo

Solid



Source: FZK

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Transport of hydrogen

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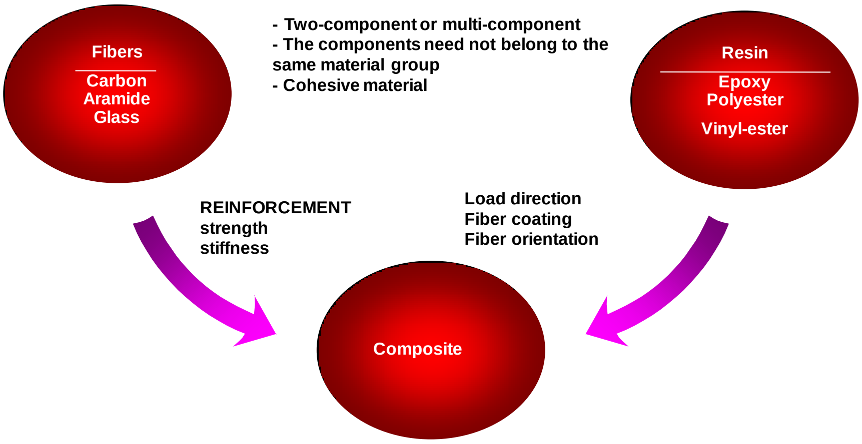
Definition of composite materials



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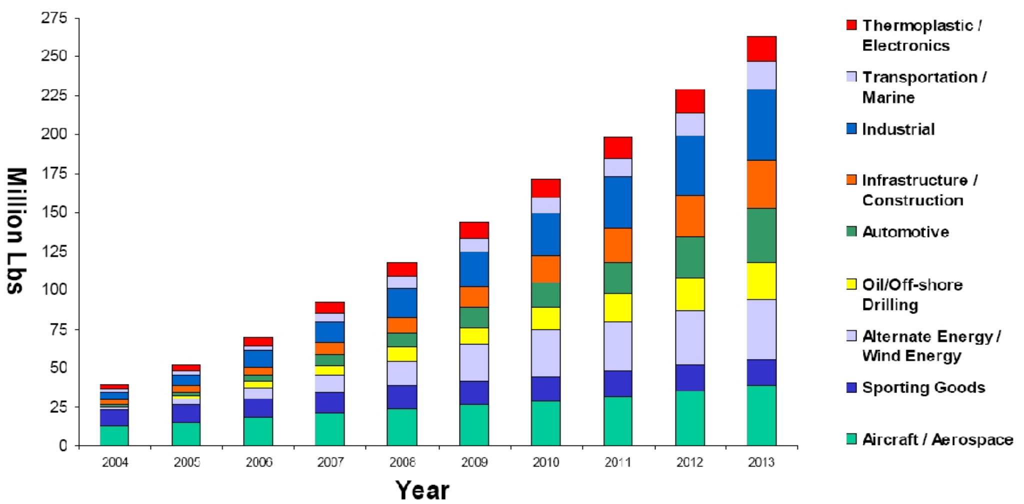
Reinforcing fibers characteristics

Properties	Glass fiber	Basalt fiber	Aramid fiber	Carbon fiber
Strength		+	+	++
Impact strength	■	+	++	
Fatigue strength	■		+	++ ■
Creep resistance	■	■	+	++
Resistance to acidic, basic, damp environment	■	■	+	++
Radiation resistance	■ ■	■		+
Fire resistance		+	■	+
Prica	+ ■ +	+	–	– –

Carbon fiber production



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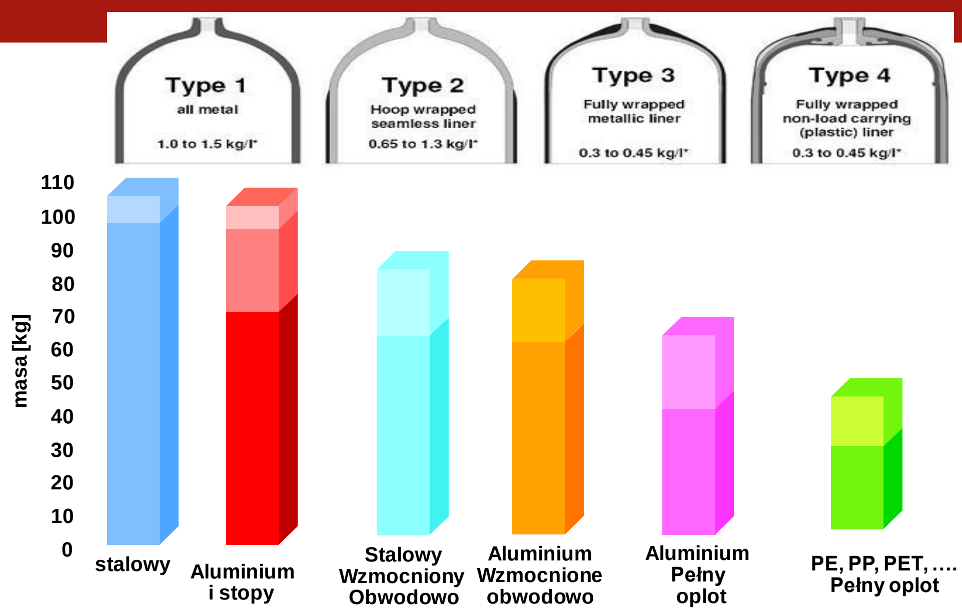
Vessel mass comparison according to vessel type



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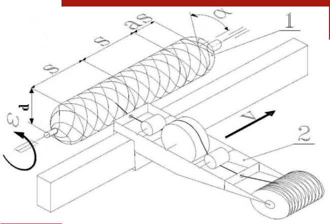
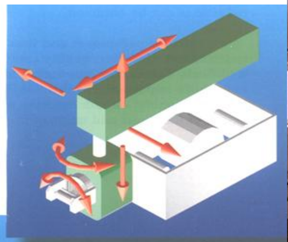
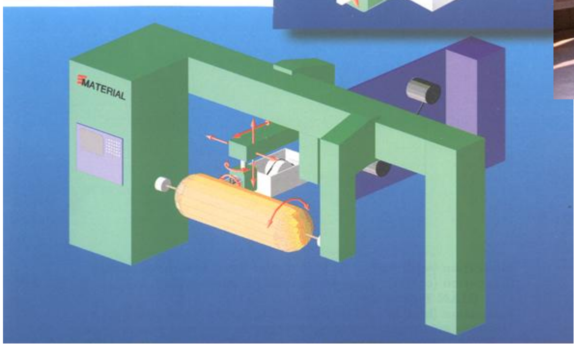
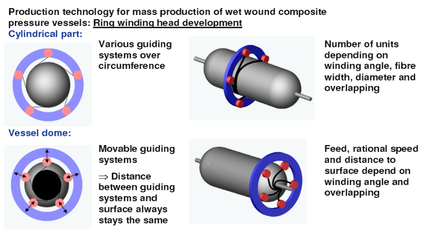
Filament winding









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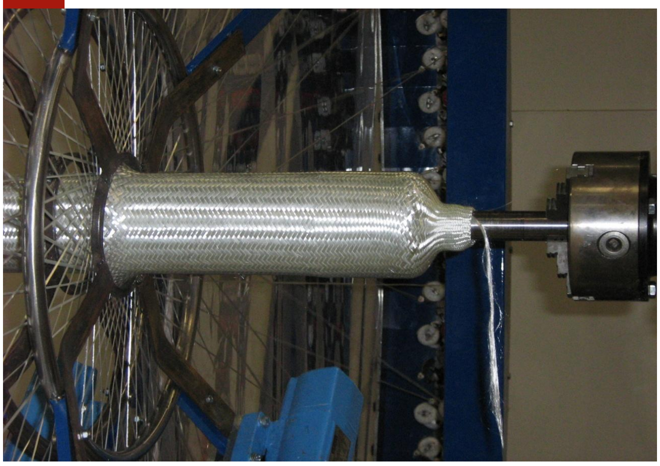
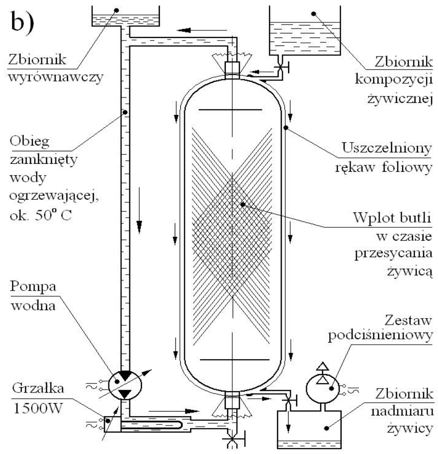
Braiding of a vessel at TU Dresden





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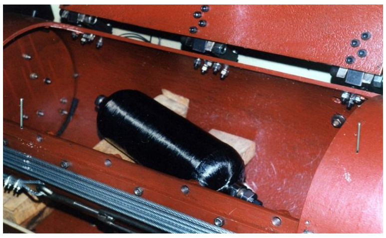
Vessels made at the Institute



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Liners made in the Institute

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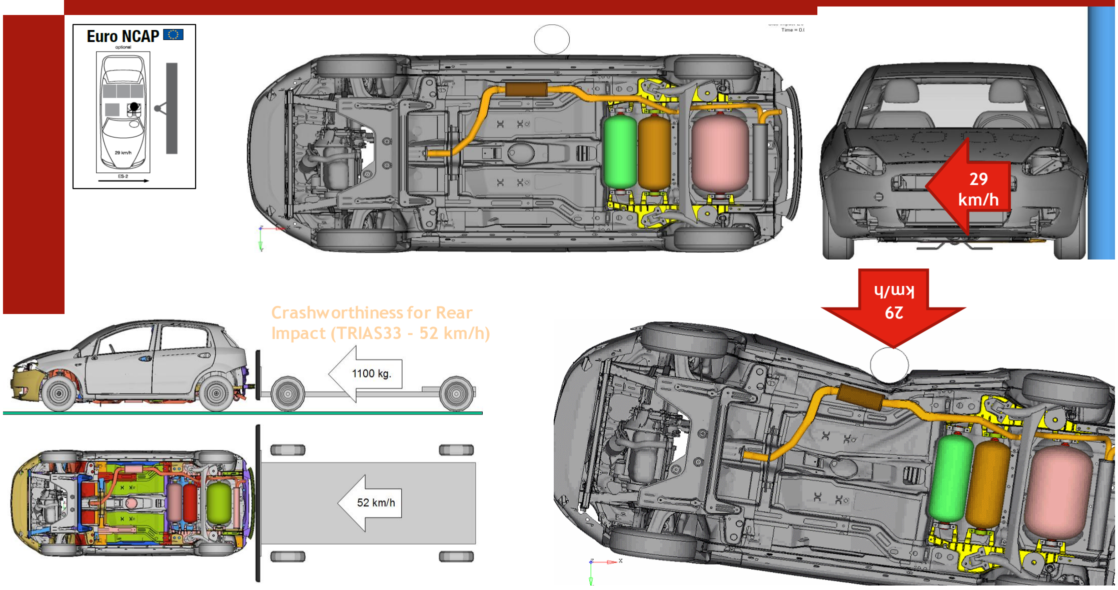
Gas storage for CNG engines

Focus on WP5: Vehicle Performance Assessment

Crashworthiness for Side Pole Impact



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Safety: Testing of CH2 Cylinders

- B1 Tensile Test
- B2 Softening/Melting Temperature Test
- B3 Glass Transition Temperature Test
- B4 Resin Shear Strength Test
- B5 Coating Test
- B6 Coating Batch Test
- B7 Hydrogen Compatibility Test
- B8 Hardness Test
- B9 Burst Test (minimal burst pressure value 164.5 MPa)
- B10 Ambient Temperature Pressure Cycling Test (45k pressure cycles 2 – 87.5 MPa)
- B11 LBB Performance Test
- B12 Bonfire Test
- B13 Penetration Test
- B14 Chemical Exposure Test
- B15 Composite Flaw Tolerance Test
- B16 Accelerated Stress Rupture Test
- B17 Extreme Temperature Pressure Cycling Test (-40°C and 85°C, relative humidity 95%)
- B18 Impact Damage Test
- B19 Leak Test
- B20 Permeation Test
- B21 Boss Torque Test
- B22 Hydrogen Gas Cycling Test
- B23 Hydraulic Test

*** Draft ECE Compressed Gaseous Hydrogen Regulation, Revision 12b, 12.10.03, GRPE Informal Group: Hydrogen/Fuel Cell Vehicles**

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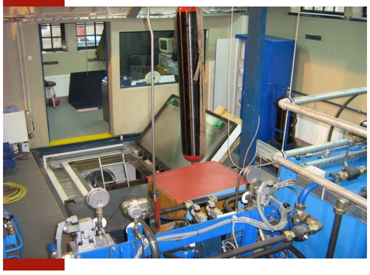
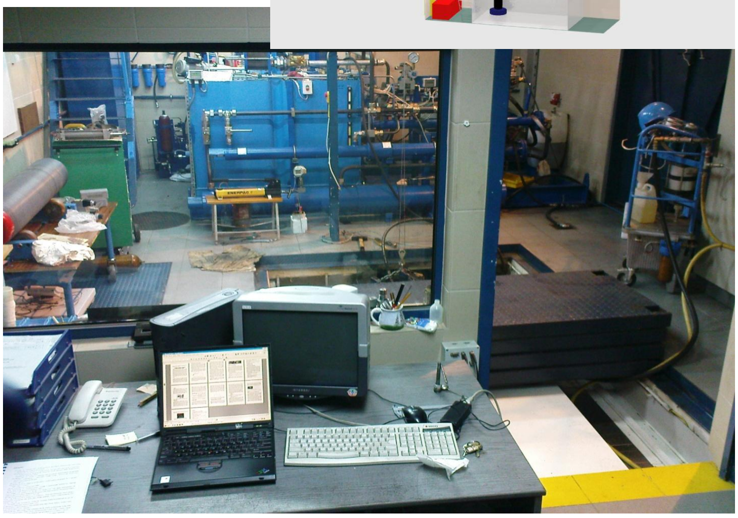
High-pressure Vessels Laboratory





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Burst tests

WUT tests characteristics:

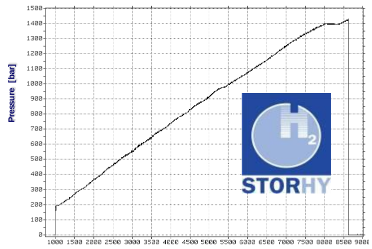
- **Max. test pressure - 3000 bar**
- **Rate of pressurization – max 5 bar/s**
- **Working medium – degassed water**

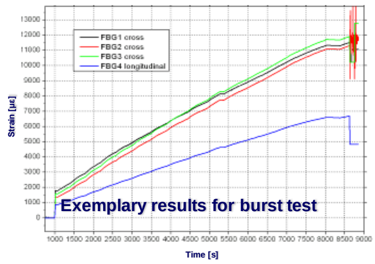
Burst pump

Control panel

Pneumatic engine

Hydraulic Burst Test at ambient temperature





Burst Test Results:

- maximum burst pressure more than 1645 bar
- optical sensors registered strain changes during pressurization
- slope of a green curve changed during pressurization

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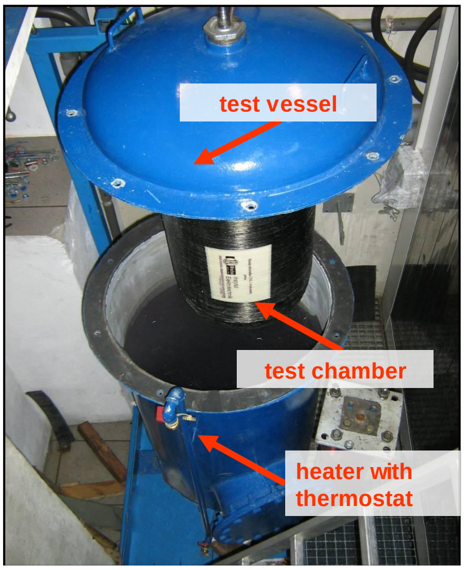
Accelerated stress rupture test setup



Stress rupture test procedure (in accordance with ECE R110):

1. A cylinder shall be immersed in water at 65 °C.
2. Then cylinder shall be pressurized to 260 bar and held at this pressure and temperature for 1000 hours (~6 weeks).
3. Burst test – the minimum burst pressure shall exceed 85% of designed burst pressure.

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High temperature creep test

A.18. High temperature creep test – test procedure

One finished cylinder was tested as follows:

a) The cylinder was pressurised to <u>26 MPa</u> and held at a temperature of <u>100 °C</u> for not less than <u>200 hours</u>

b) Following the test, the cylinder shall be put to the hydrostatic expansion test A.11, the leak test A.10, and finally the burst test A.12.

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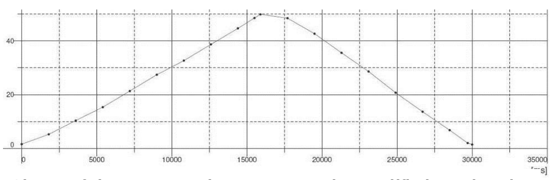
Cycling tests

WUT tests characteristics:

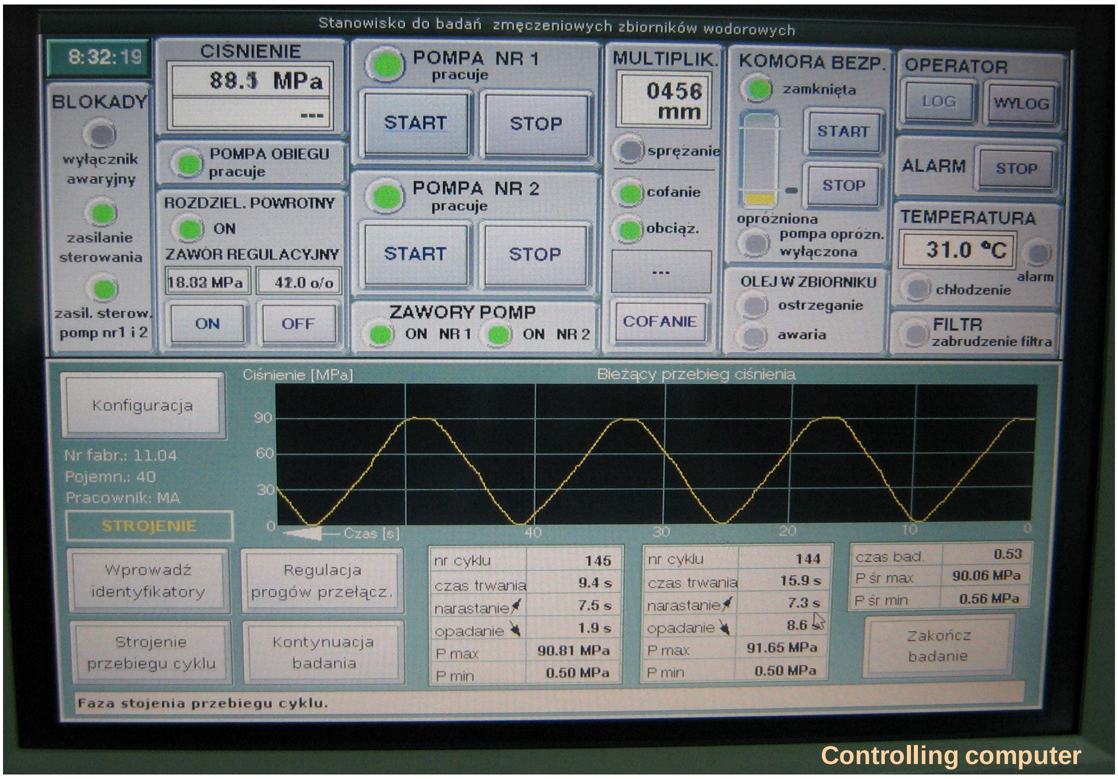
- **Max. cyclic pressure - 1400 bar**
- **Min. cyclic pressure - 0 bar**
- **Number of cycles - < 10 cycles / min (depending on vessel capacity, cyclic pressure, etc.)**
- **Working medium - oil, glikol**

Hydraulic equipment for cycling tests



Shape of the pressure-time curve can be modified. During the whole cycle increase and decrease time of the pressure is controlled.

Control panel



Controlling computer

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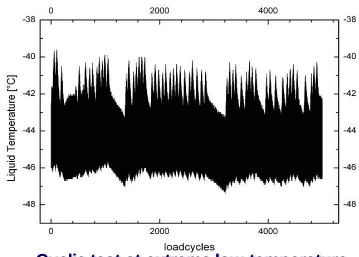
Extreme Temperature Pressure Cyclic Tests

Extreme temperature test characteristics:

- **Min. chamber temperature – 52 °C**
- **Max. chamber temperature + 90 °C**
- **Max. humidity 100%**

Climatic chamber

Test vessel inside the climatic chamber



Cyclic test at extreme low temperature

(2 cycles/minute)

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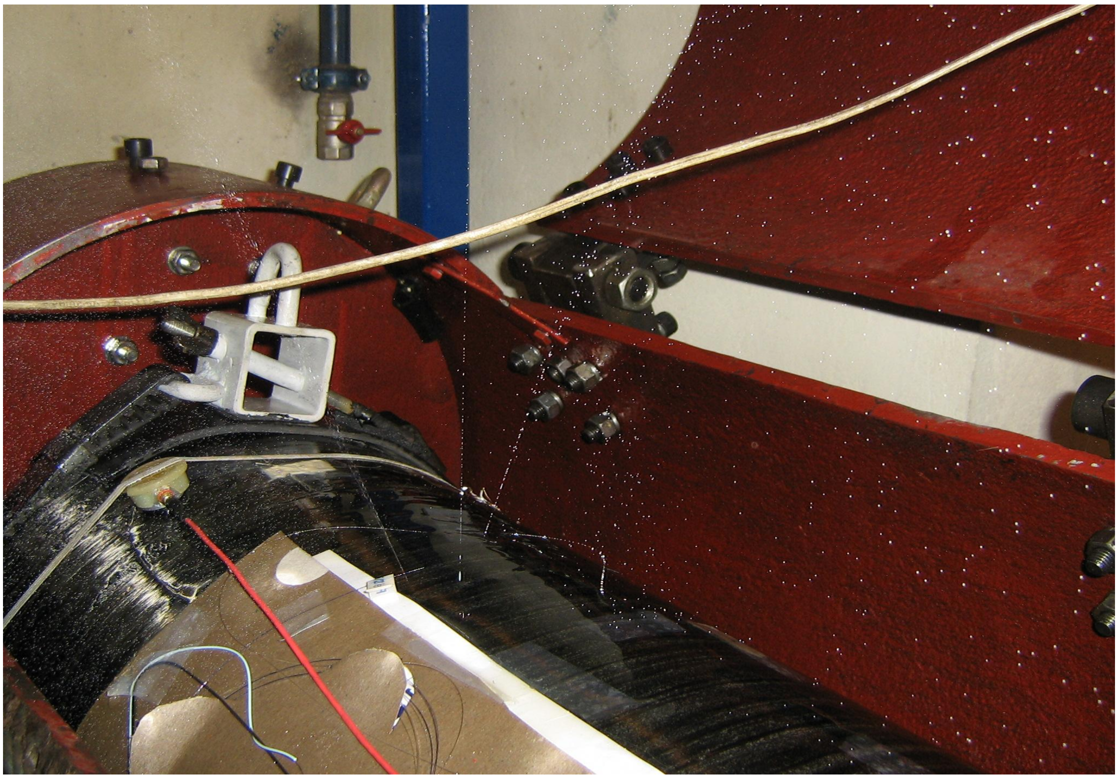
Type-3 hydrogen vessel during a fatigue test



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Test of vessel notch resistance

a) Placement of the notch

b) Vessel rupture

c) Damage site

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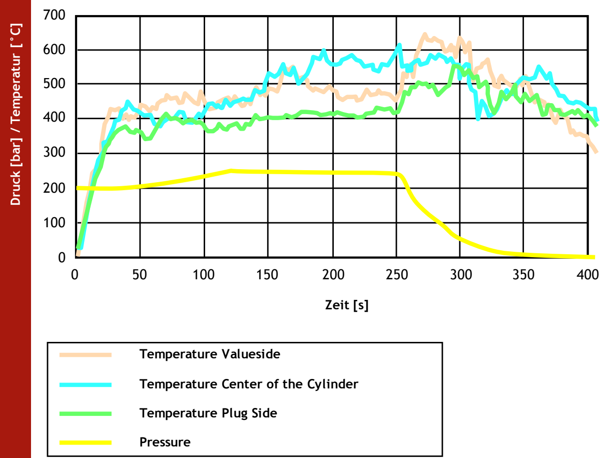
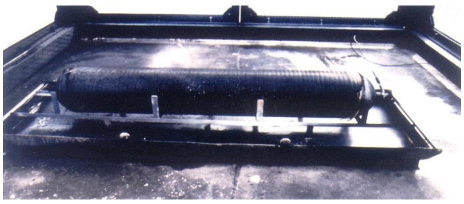
Fire test - 200atm, natural gas





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Destructive tests of a vessel using gas

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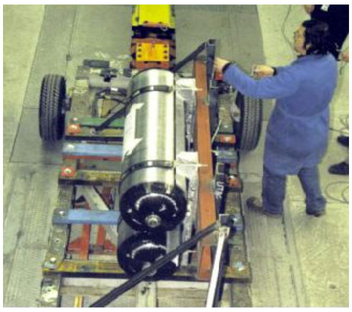
Dynamic strength tests



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Impact damage test procedure (in accordance with ECE R110 – for CNG):

1. Cylinder shall be dropped in a horizontal position with the bottom 1.8 m above the surface.
2. Cylinder shall be dropped vertically on each end at a sufficient height above the floor or pad so that the potential energy is 488 J, but in no case shall the height of the lower end be greater than 1.8 m.
3. One cylinder shall be dropped at a 45° angle onto a dome from a height such that the centre of gravity is at 1.8 m, if the lower end is closer to the ground than 0.6 m, the drop angle shall be changed to maintain a minimum height of 0.6 m and a centre of gravity of 1.8 m.
4. Cylinders shall be pressure cycled (20 ÷ 260 bar for 1,000 cycles x specified service life in years). The cylinders may leak but not rupture, during the cycling.



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Tests of resistance to chemically-aggresive environment (battery acid)

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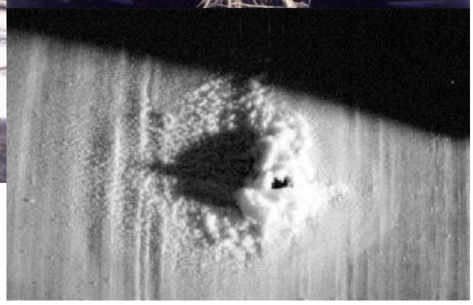
Reaction on ballistic penetration



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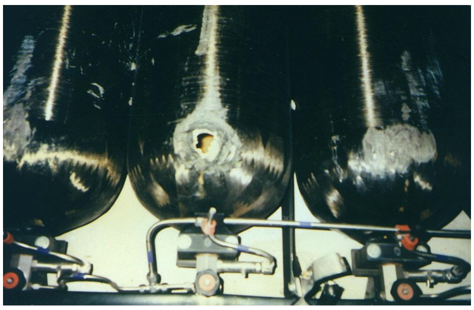
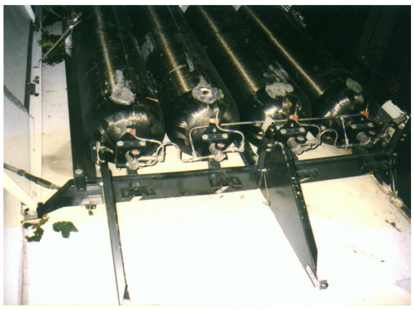
Collision under the viaduct





- **Ciśnienie 200 barów, zerwana i zniszczona osłona**
- **jeden zbiornik został rozszczelniony**
- **w pozostałych nastąpiło uszkodzenie płaszcza nośnego**

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Auto Fire with Compressed Natural Gas (CNG) Fuel Tank Explosion

March 2007, Seattle, USA

- Honda Civic CNG

Source: www.seattle.gov/fire/publications/CNGAutoFire/CNG%20Auto%20Fire%20May%202007.ppt

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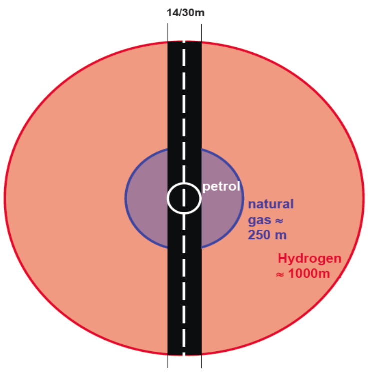
The explosion hazard for CNG i CH2 pressure vessels



Ranges of flight path of splinters (the assumptions are based on gaseous burst experience of BAM)

The range test of high pressure vessels

Source: BAM

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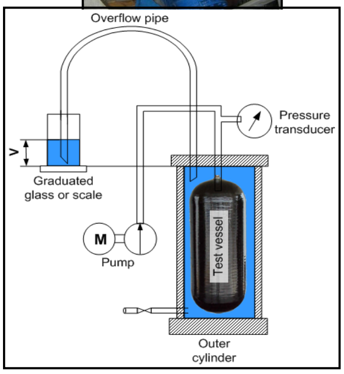
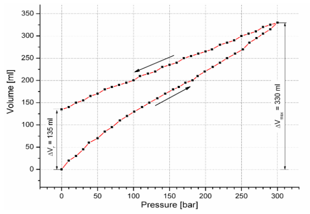
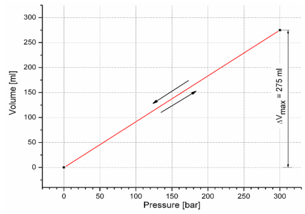
Hydrostatic expansion test - Water jacket test



Water jacket test procedure:

1. **A test vessel shall be filled with a nearly incompressible liquid (usually water or oil)**
2. **Then test vessel shall be immersed in another cylinder fully filled with water.**
3. **Then cylinder shall be pressurized to 300 bar and held at this pressure for at least 30 seconds and depressurized again.**
4. **The water level in the graduated glass is then examined.**





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CH2 vessel, over 1640 bar burst pressure

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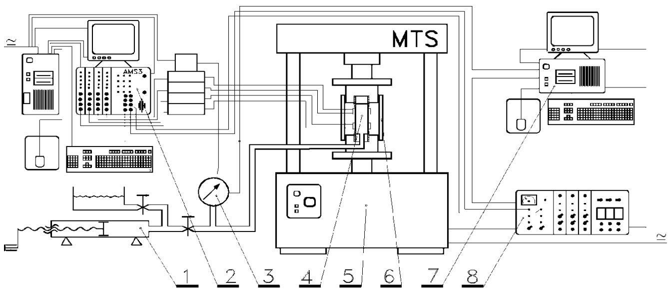
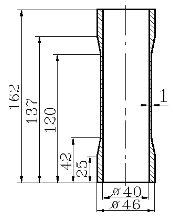
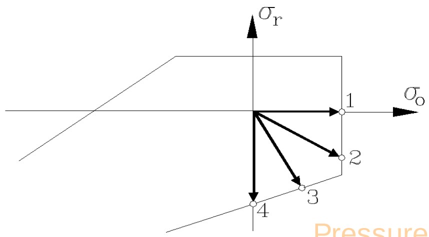
The scheme of the burdening composite pipe in any system principal stresses:

1 - pump, 2 - apparatus for measuring the effects of EA,
3 - Pressure transmitter, 4 - tested composite pipe,
5 - testing machine, 6 - security guard,
7 - control computer, 8 - strain gauge bridge







Pressure tests of tubular specimens

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Test emplacement

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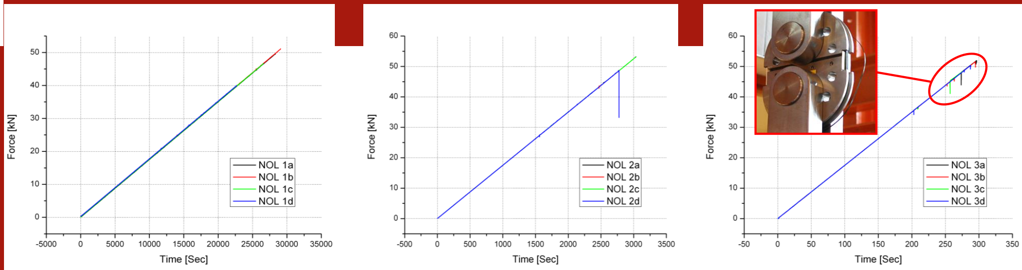
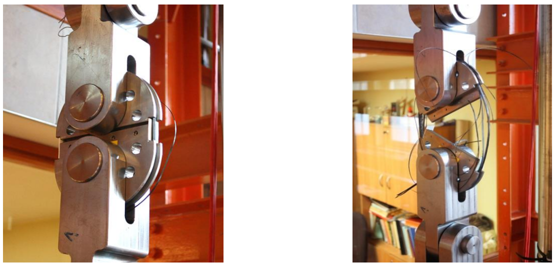
Slow tensile tests



Increase of loading force in a function of the duration of the experiment (1.75 N/sec, 17.5 N/sec and 175 N/sec)



NOL specimens during the slow tensile test

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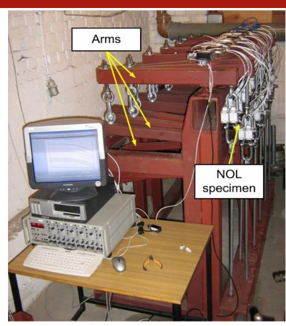
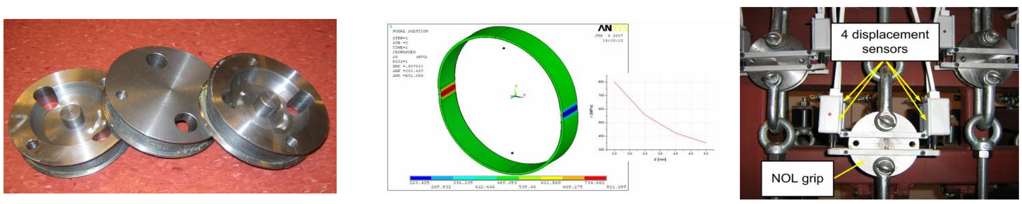
Creep test (Static fatigue) of composite for high pressure H2 vessels

- Creep strength of composite material for high pressure vessels evaluation.
- Specimen load level responds to the load in vessel's composite layer (when it is filled with CH2).
- The ring NOL (Naval Ordnance Laboratory, USA) specimen was assumed:
  - fiber continuity (without breaks),
  - ring shape specimen corresponds to the strain state in cylindrical part of vessel,
  - NOL specimens dimensions were obtained by FEM modeling and tensile tests





NOL specimens (photo and FEM model) as well as innovative displacement sensor heads

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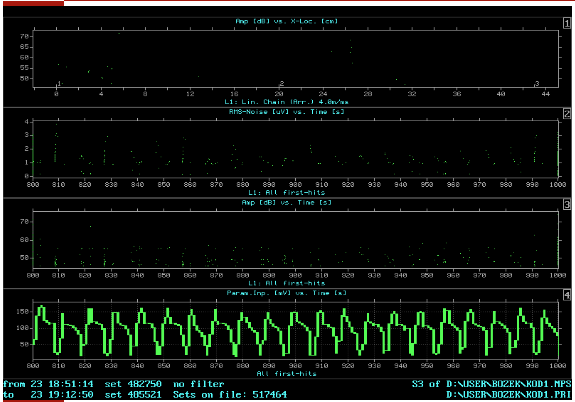
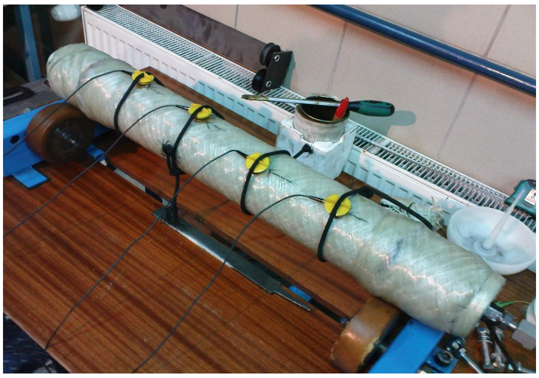
Acoustic emission recorded during fatigue testing of the tank

1 - the location of the event, 2 - RMS time,
3 - amplitude of events in time, 4 - pressure course.





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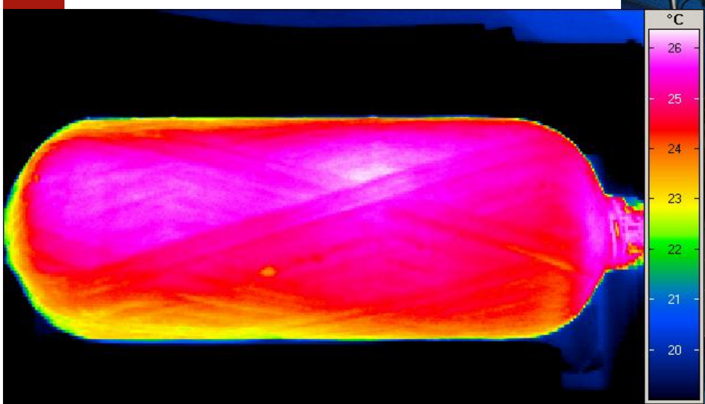
Temperature distribution at the surface of a vessel during fatigue test.



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Burst vessels after pressure tests

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Fatigue test using elastoric filling

MTS hydraulic pulsator

Pipe specimens

Thermographic system VarioCAM hr head

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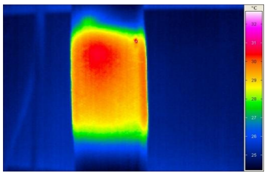
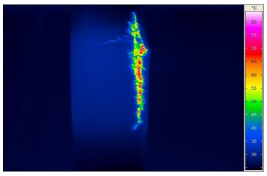
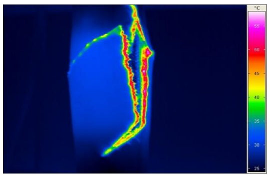
Thermal images show probable fault zones in fatigue test



Stan próbki przed rozerwaniem

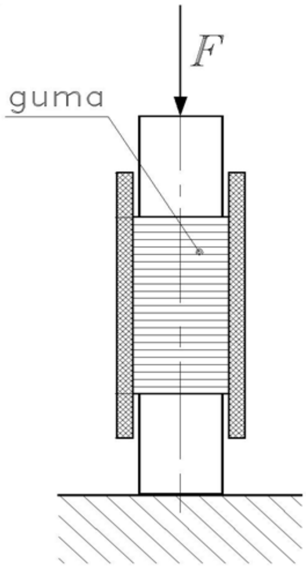


Moment rozerwania próbki



Stan próbki po rozerwaniu

Próbka po rozerwaniu



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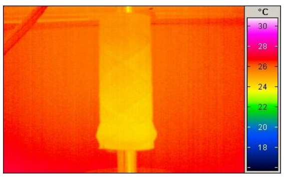
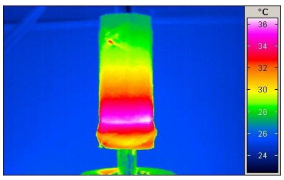
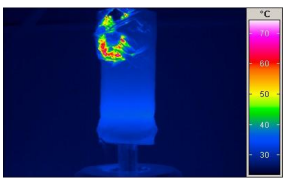
Thermal images show probable fault zones in fatigue test (cylindrical part of filament winding pressure vessel)



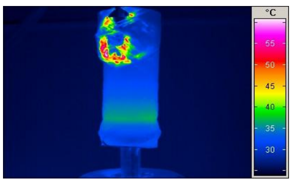
Stan spoczynkowy próbki



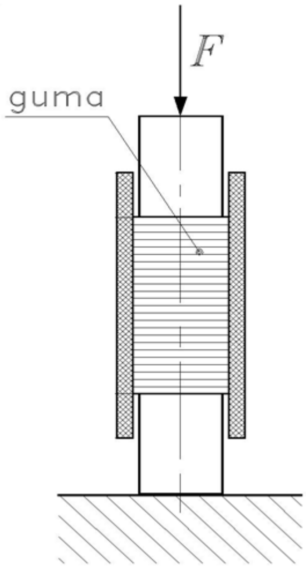
Stan próbki przed rozerwaniem



Moment rozerwania próbki



Stan próbki po rozerwaniu



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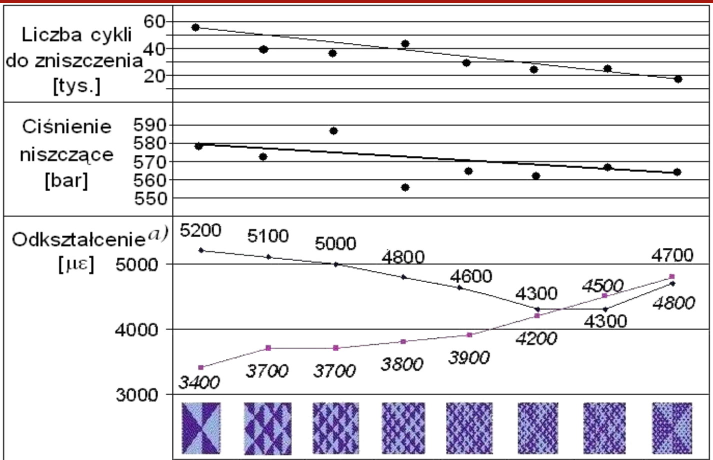
Tests of the cylindrical part filament winding pressure vessel



Numer architektury	Nr1	Nr8	Nr6	Nr4	Nr7	Nr3	Nr5	Nr2
Liczba przeplotów	128	240	336	416	480	528	560	576
Udzial pustek [%]	1,9	4,3	4,2	5,6	7,1	8,8	8,7	7,9
Grubość ścianki [mm]	4,22	4,25	4,24	4,27	4,26	4,30	4,32	4,32
Odkształcenie objętościowe [cm^3]	410	416	412	408	424	412	416	425
Udziały wagowe włókna szklanego [%]	75,5	77,1	76,9	76,8	76,3	76,1	76,7	77,1