

ECNDT

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Manufacturing Quality Control of High-Pressure Composite Cylinders by Acoustic Emission

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1. Composite cylinder applications: high-pressure storage and transport of gases



CNG - Compressed Natural Gas (WP 200 bar)
H2 - Compressed Hydrogen Gas (WP 200/350 bar)



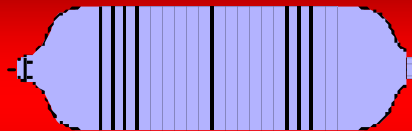
**Breathing Air
(WP 300 bar)**

1. Composite cylinders designs

Various Designs of Composite Cylinders

Fibres:
 Glass
 Aramid
 Carbon

Matrix Materials:
 Polyester
 Epoxy
 Nylon

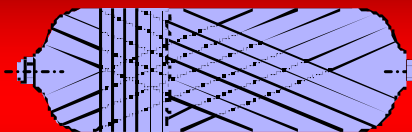


Hoop wrapped

Liner:

Al (6061 T6)
 Al (6069)
 Al (70XX)
 34CrMo4

Type II



Fully wrapped

Liner:

Al (6061 T6)
 Al (6069)
 Stainless Steel
 Nylon
 Polyethylene
 etc.

Type III

Type IV

2. EU IP “STORHY” / SP “Safety Aspects and Requirements (SAR)” – 2005 ... 2008

The production and application of high-pressure cylinders made of composite materials requires reliable and efficient non-destructive test methods to assure a high safety level of pressure cylinders.

One task of SP SAR:

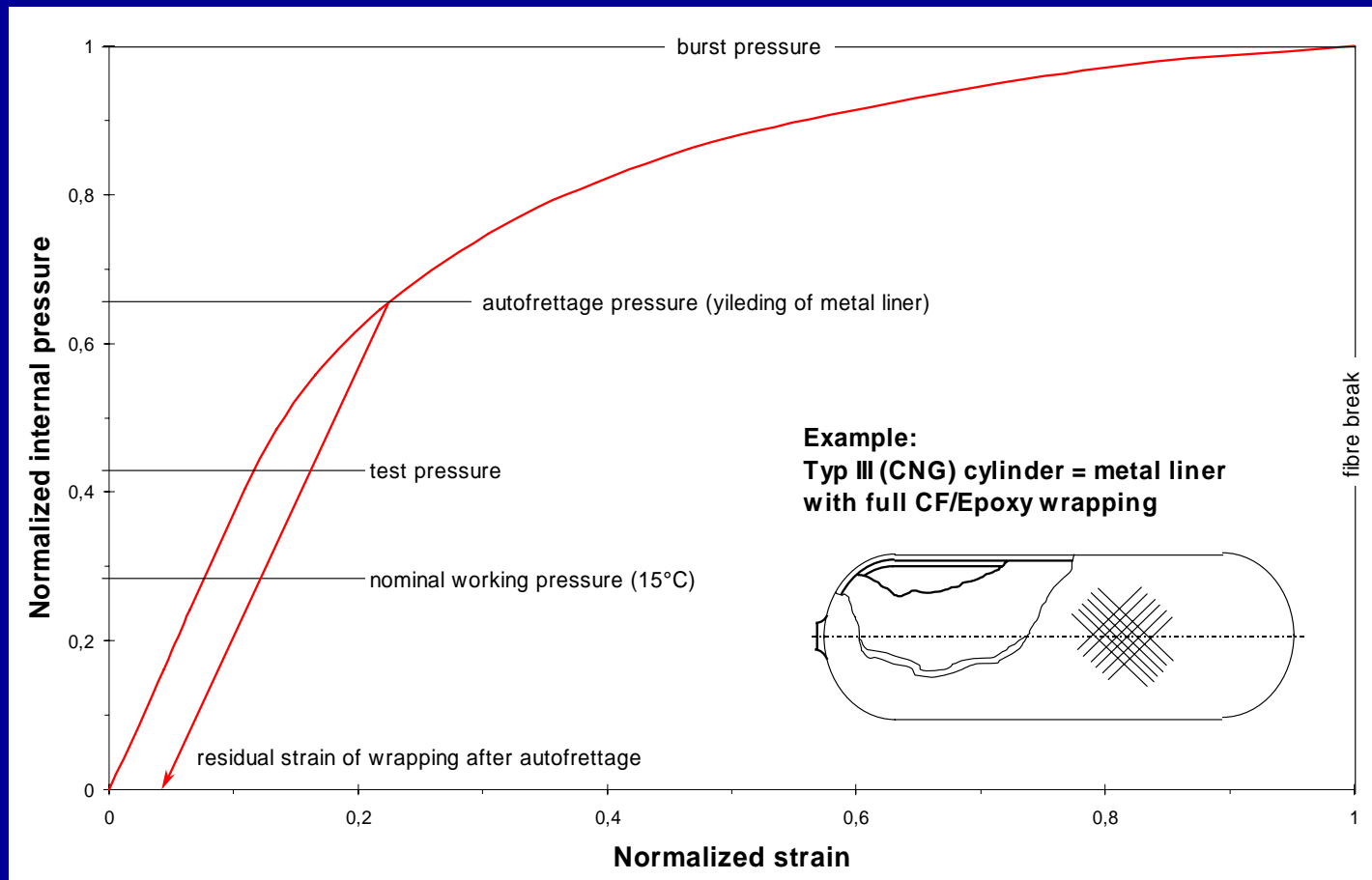


Improvement of operational safety of cylinder design types of the next decade by development of NDT methods and testing procedures especially based on acoustic emission (AE) for

- a) manufacturing quality control**
- b) in-service inspection**
- c) structural health monitoring.**

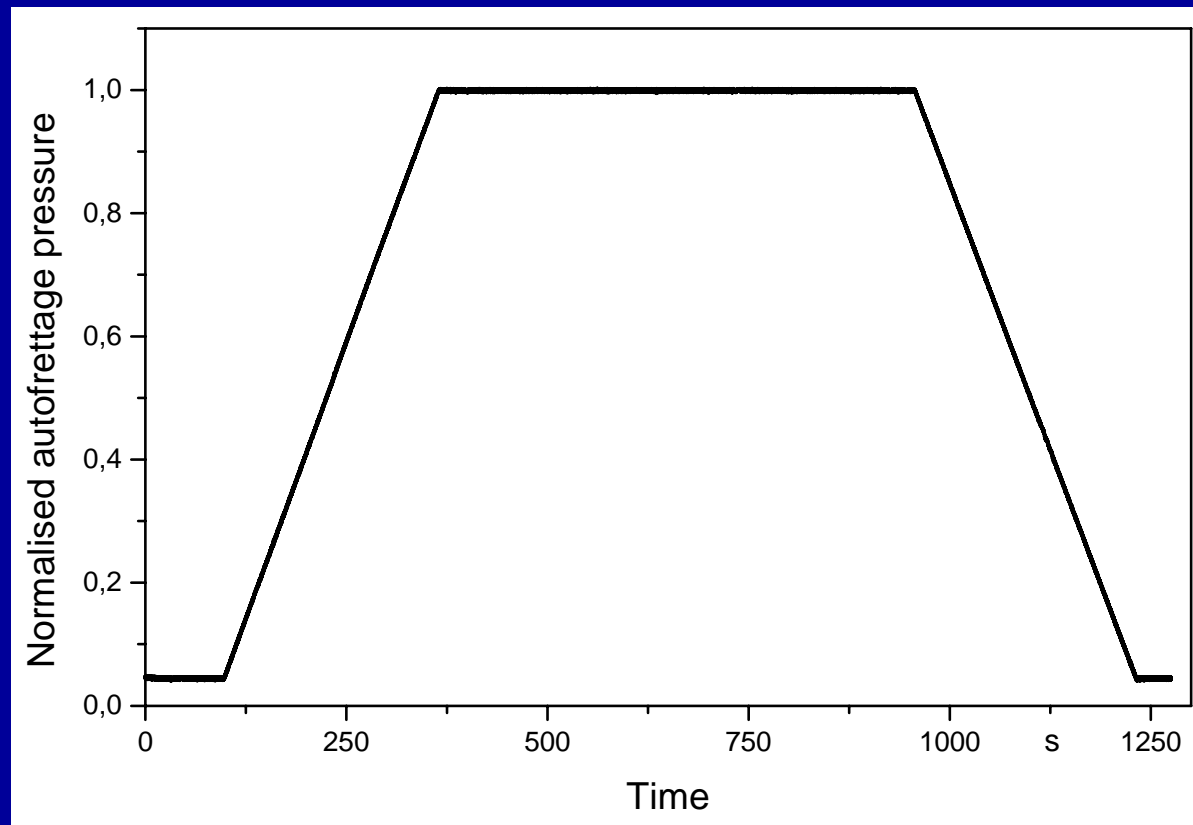
3. Autofrettage process: principle

The autofrettage process realises a characteristic residual stresses state for improvement of long-term cycling / fatigue behaviour.



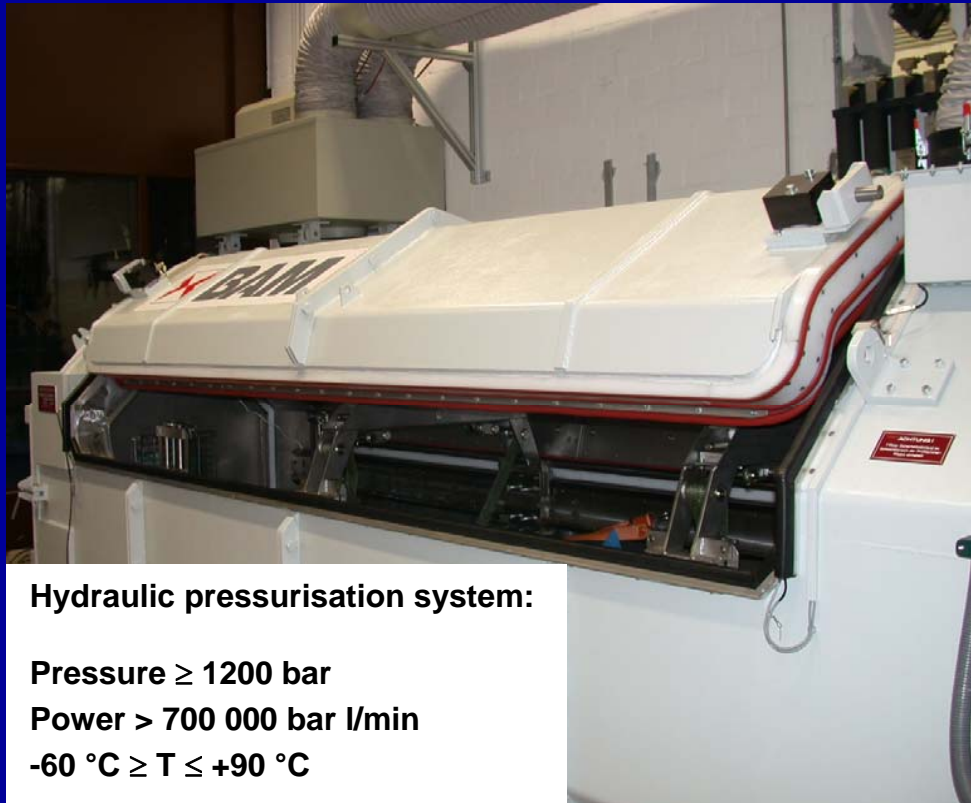
3. Autofrettage process: AT pressurisation profile

During laboratory AT studies a pressurisation rate similar to real production conditions was applied.



4. Test equipment

Combination of extensive hydraulic cycling or bursting (up to 3500 bar) and NDT monitoring systems (AT, SG) is a powerful equipment for testing and real-time evaluation of cylinders.

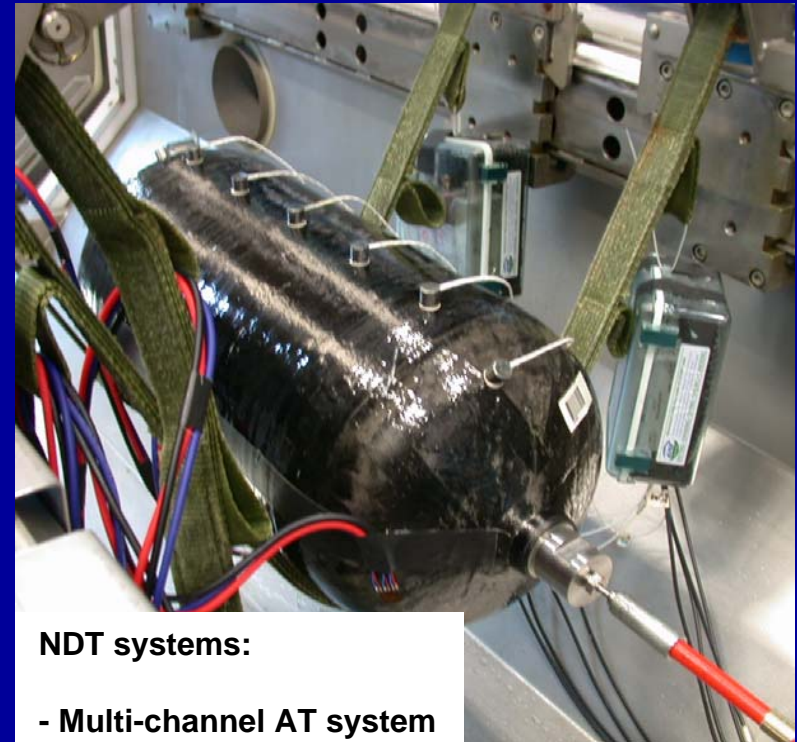


Hydraulic pressurisation system:

Pressure ≥ 1200 bar

Power $> 700\,000$ bar l/min

$-60\text{ °C} \geq T \leq +90\text{ °C}$

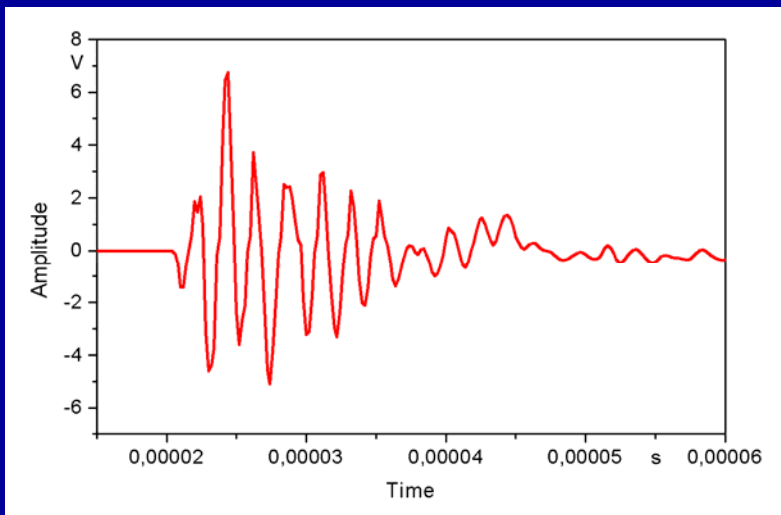


NDT systems:

- Multi-channel AT system
- Strain gauges

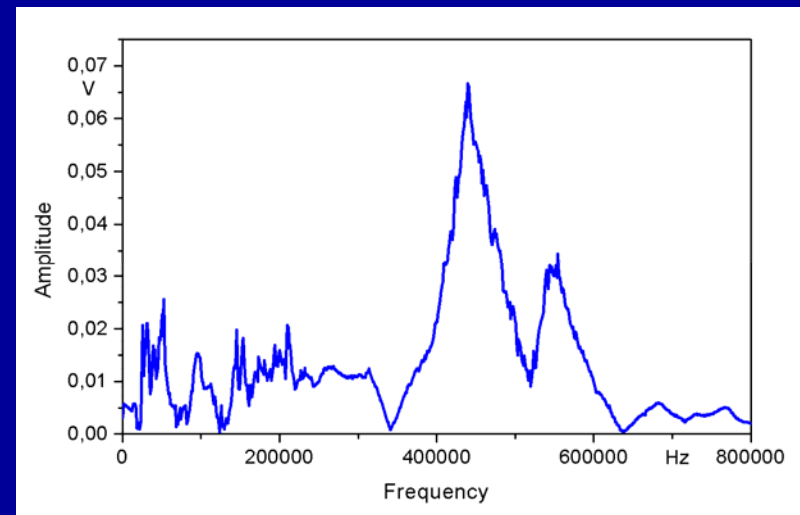
5. AE signals

Structures under load stimulate acoustic waves from micro-failure processes (AE sources). After travelling through the structure acoustic waves hit the AE transducer which convert surface motions into electric AE signals.



“Waveform” features

- Peak Amplitude
- Rise Time
- Counts
- Energy
- Duration

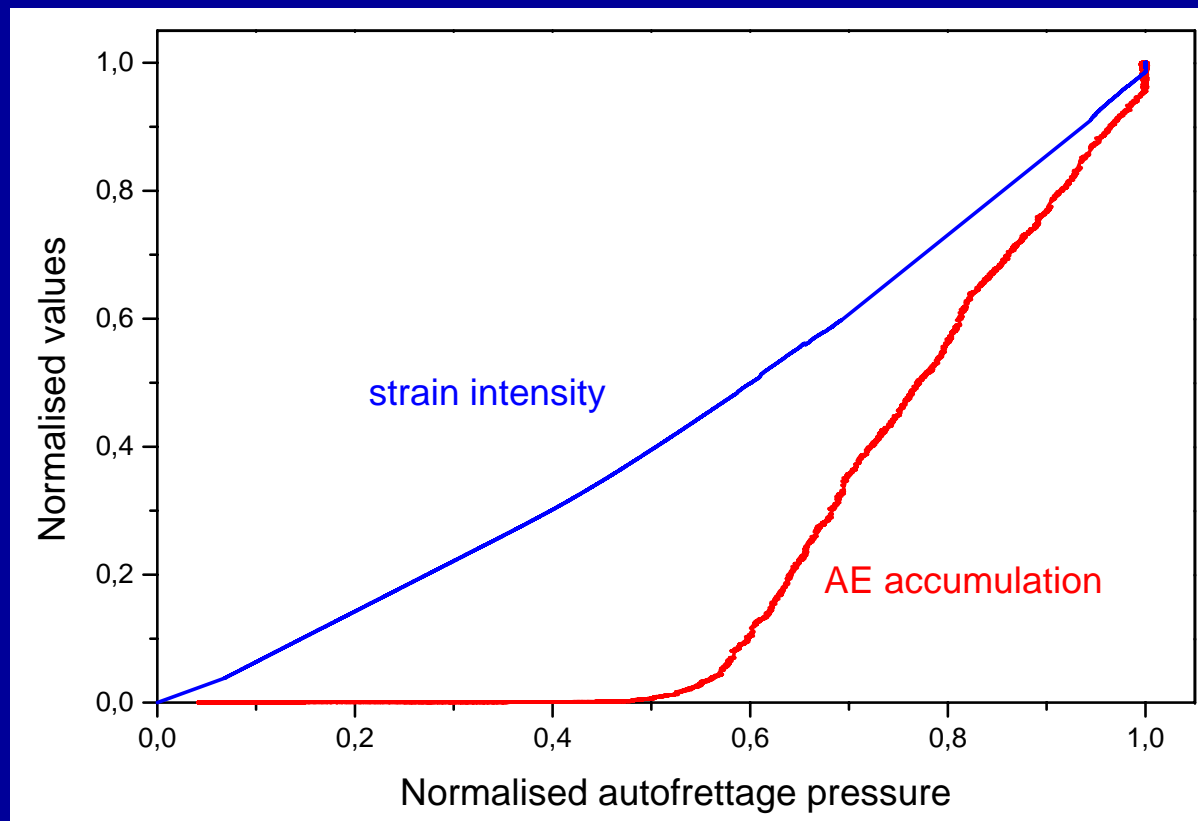


Spectrum features

- Peak Frequency
- Centroid (Mean) Frequency
- Partial Powers of spectral segments

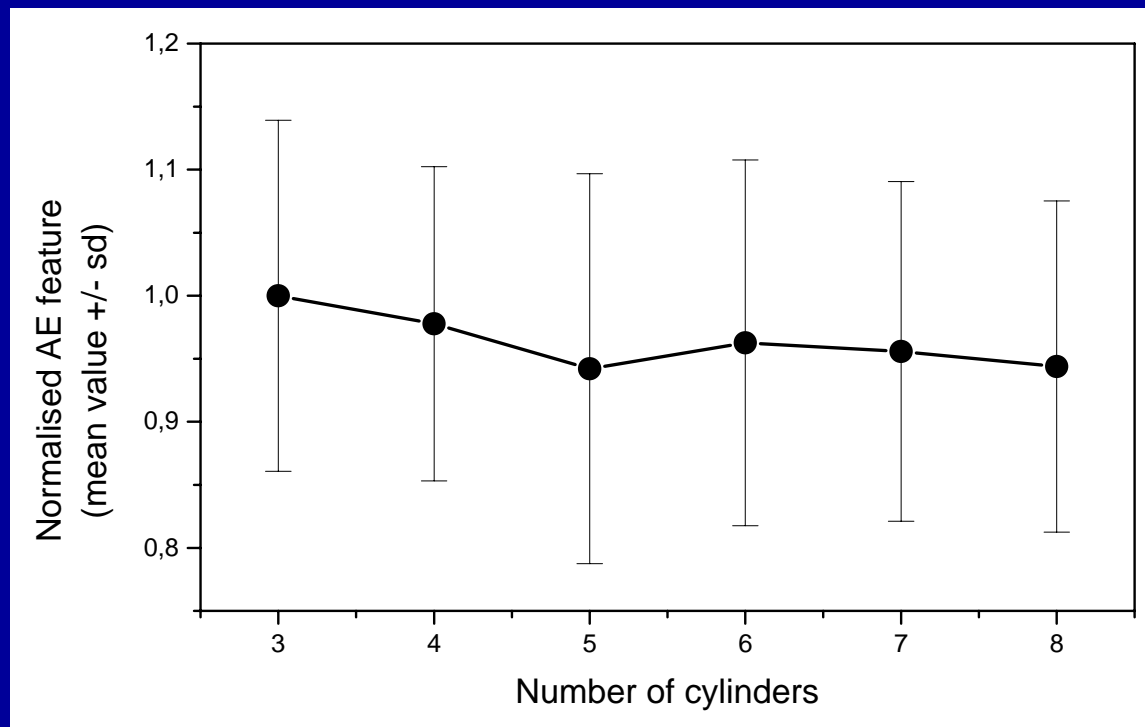
6. AT and SG measurement during autofrettage

Acoustic emission monitoring and strain gauge measurements were carried out during autofrettage processes. AT clearly shows onset and progression of micro-failure.



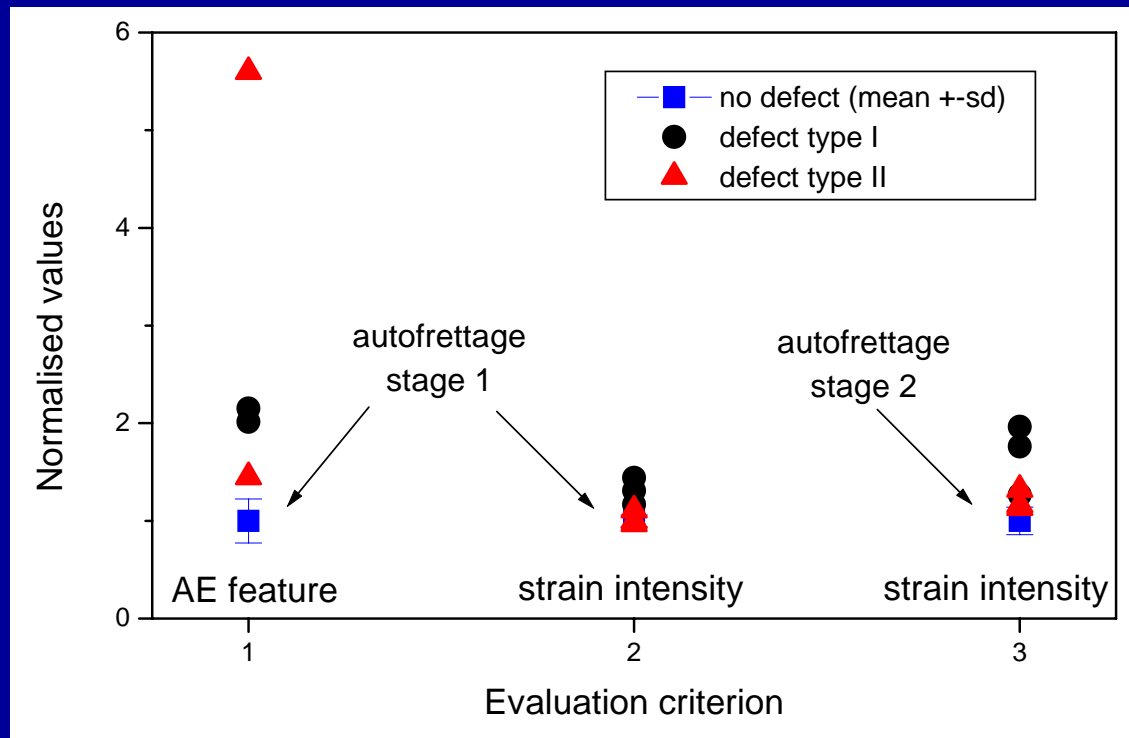
7. Evaluation of cylinder manufacturing quality: determination and statistics of AE “reference curves”

Basis of evaluation of manufacturing quality is monitoring of AE “reference curves” and statistical analysis of AE features for a minimum number of cylinders without manufacturing defects.



7. Evaluation of cylinder manufacturing quality: using of AE and strain criteria

The AE “reference curve” is characterized by statistics of multiple AE features / criteria which can be used (single or combined) to evaluate the production quality of composite cylinders reliable. Strain intensity values provide information about the cylinder quality at specific autofrettage stages only.



7. Evaluation of cylinder manufacturing quality: using of multiple AE criteria (single or combined)

AE criterion	Defect type I (cylinder 1)	Defect type I (cylinder 2)	Defect type II (cylinder 3)	Defect type II (cylinder 4)	“Defect” type III (cylinder 5)
1	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✗
3	✓	✓	✗	✓	✗
4	✓	✓	✗	✓	✗
5	✓	✓	✓	✓	✓
6	✓	✓	✓	✓	✗
7	✓	✓	✓	✓	✗
8	✓	✓	✓	✓	✗
9	✓	✓	✓	✓	✗
10	✓	✗	✓	✓	✗

✓ = manufacturing defect detected ✗ = ... defect not detected

8. Summary

The new AT concept for composite cylinders

- 1. ... allows a comprehensive assessment of cylinders**
- 2. ... uses well experienced hardware**
- 3. ... is useful for periodic testing, supervision of filling procedures, supports design optimisation and is valid for QM issues**
- 4. ... works with a sophisticated numerical concept for analysis and evaluation of AT results**
- 5. ... gives clear support for accept/reject decisions**
- 6. ... can be build in a small device easy to operate.**

**Thank you
for your attention!**