Tensile Testing on Aluminium 2219 at 20 K

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Astrium Space Transportation

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in cooperation with

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Outline

- Introduction / Motivation
- Test description
- Results
- Conclusion / Outlook

Introduction / Motivation (1)

- Vital relevance of tensile properties in development and production of spacecraft
  - Design / dimensioning aspects
  - Damage Tolerance aspects
    (in case of damage mechanics models; e.g. Rice & Tracey)

    → **Proper calibration of the models based on reliable input is essential!**
- High relevance of tensile tests for fracture control is given
- Success of a mission rises and falls also with the input from tensile tests

- **High quality and reproducibility of the tests are required**
- **Traceability and comparability of the test results are crucial**

Introduction / Motivation (2)

- At room temperature, tensile tests are well standardized
- For the operational temperature of LH2 tanks (20 K), high quality of tests is still challenging, especially wrt. industrial implementation (time and cost constraints)
- Aims of present test campaign:
  - Focus on challenges: Heat transfer, environmental control, specimen preparation
  - Further experience for the essential 20 K application since no standard for 20 K is available (for liquid He corresponding to 4 K see ASTM E 1450)
  - Estimation of the feasibility for larger test campaigns
    (large numbers of specimens are generally necessary in fundamental material characterization)

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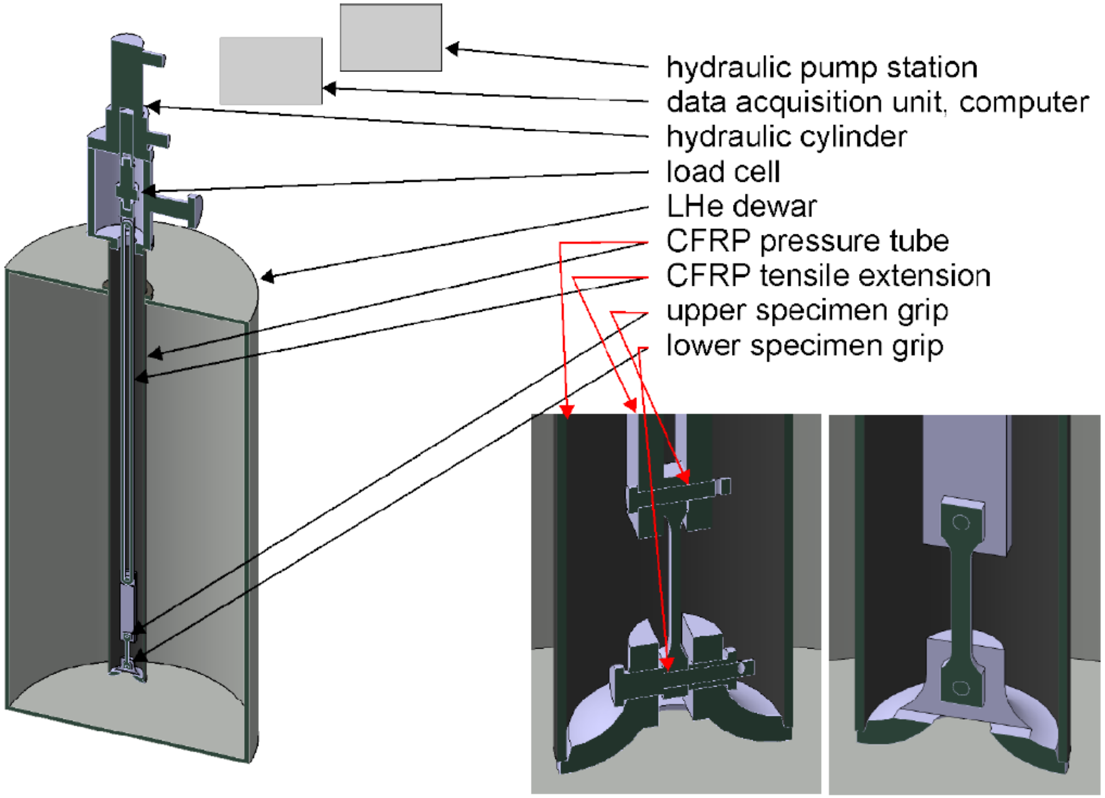
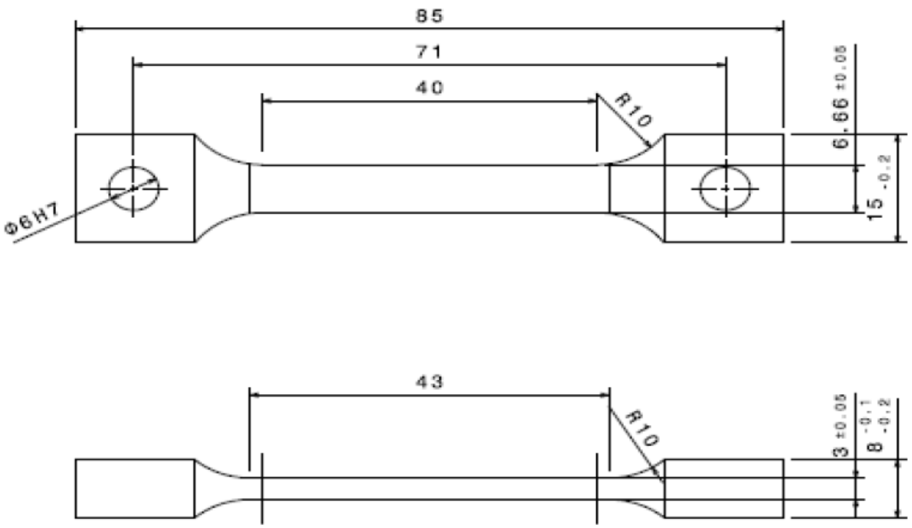
Test description / setup

- Test setup
  - Gaseous phase above liquid helium to reach 20 K
  - Test specimen located in specific height above liquid phase



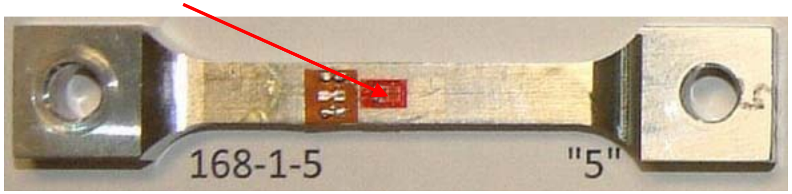
Test description / specimens (1)

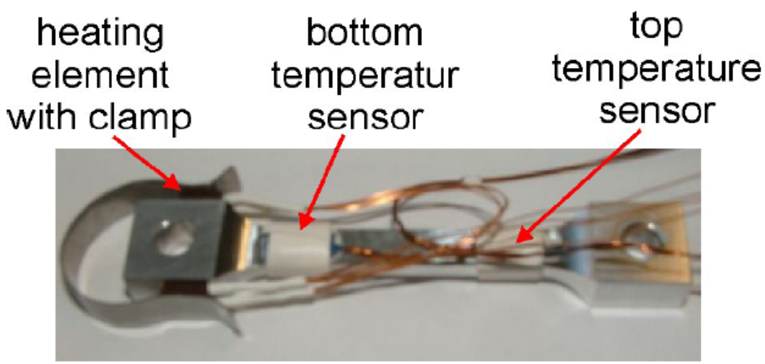
- Test specimen scaled down from DIN EN 10002



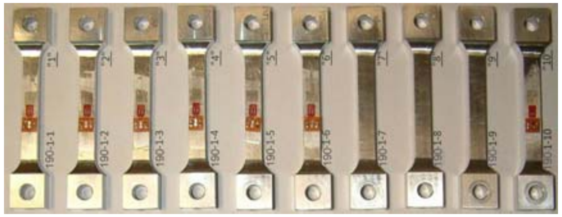
- Equipment of test specimens

strain gauge (cryogenic condition compatible)





Test description / specimens (2)



2 material batches (AA 2219 T851)
(10 specimens each)

8 per batch → specimens at 20 K

2 per batch → spare specimen & pretest at 77 K and 4 K

specimens at 20 K:

5 per batch → strain gauge equipped (cured) — 10 specimens

3 per batch → no strain gauge — 6 specimens

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Test results / evaluation focus

- Temperature / environmental stability
- Mean & lower boundary values of material properties
- Influence of curing (strain gauge application; 4h at 100°C were applied)

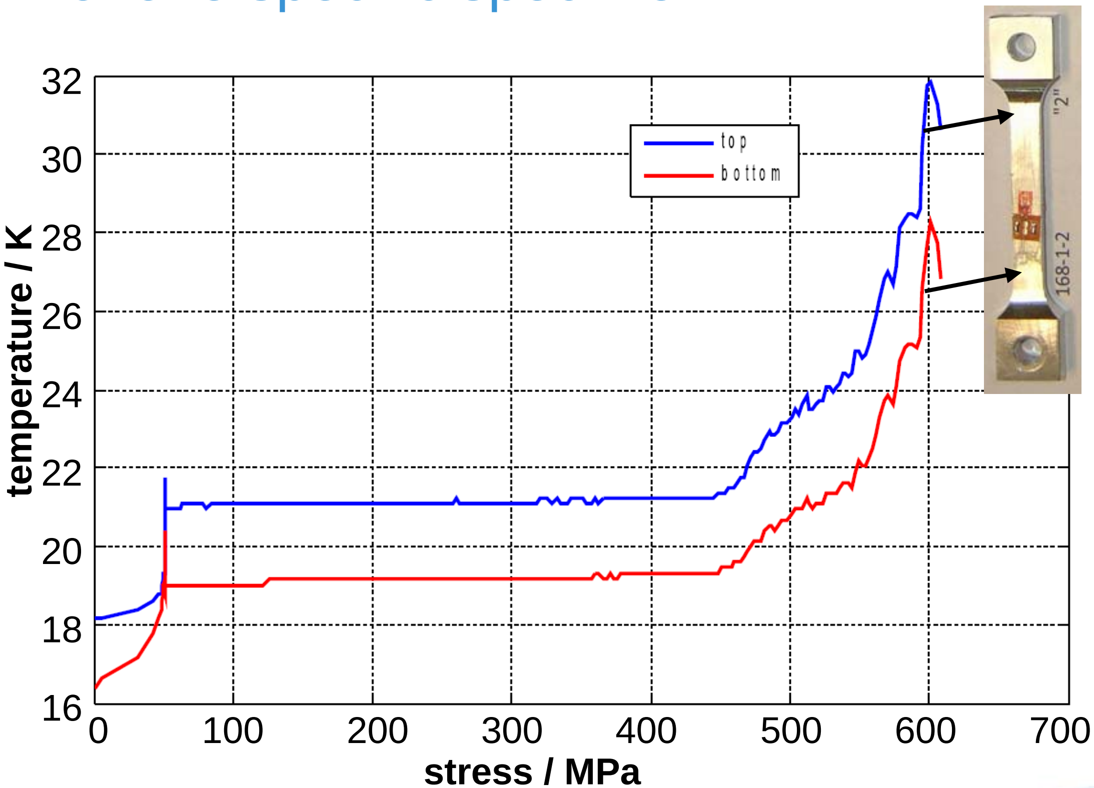
Test results / temperature stability (1)

- Temperature stability depends on possible heat generation and transfer
  - Heat generation:
    - strain rate must be slow
    - here $6x10^{-5}$ s^{-1} to $8x10^{-4}$ s^{-1} were applied;
    - for comparison: ASTM 1450 proposes < 10^{-3} s^{-1}
  - Heat transfer:
    - Liquid phase was not applicable in this case
    - in gaseous phase potential danger of excessive temperature increase

    → Investigation of temperature surge

Test results / temperature stability (2)

Temperature increase at two locations of one specific specimen



- Generation of thermal equilibrium (5 minutes at 20 K+/-2K)
- Mean temperature increase over all specimens: 11 K during plastification
- No relevance for $R_{p0.2}$
- Relevance for R_m → but conservative test results

Test results / temperature stability (3)

energy equilibrium	$W = Q$
plastification work	$W = \Delta L \cdot F = \varepsilon \cdot L \cdot \sigma \cdot A$
thermal energy	$Q = m \cdot c \cdot \Delta T = \rho \cdot (A \cdot L) \cdot c \cdot \Delta T$
temperature increase	$\Delta T = \dfrac{\varepsilon \cdot \sigma}{\rho \cdot c}$

with

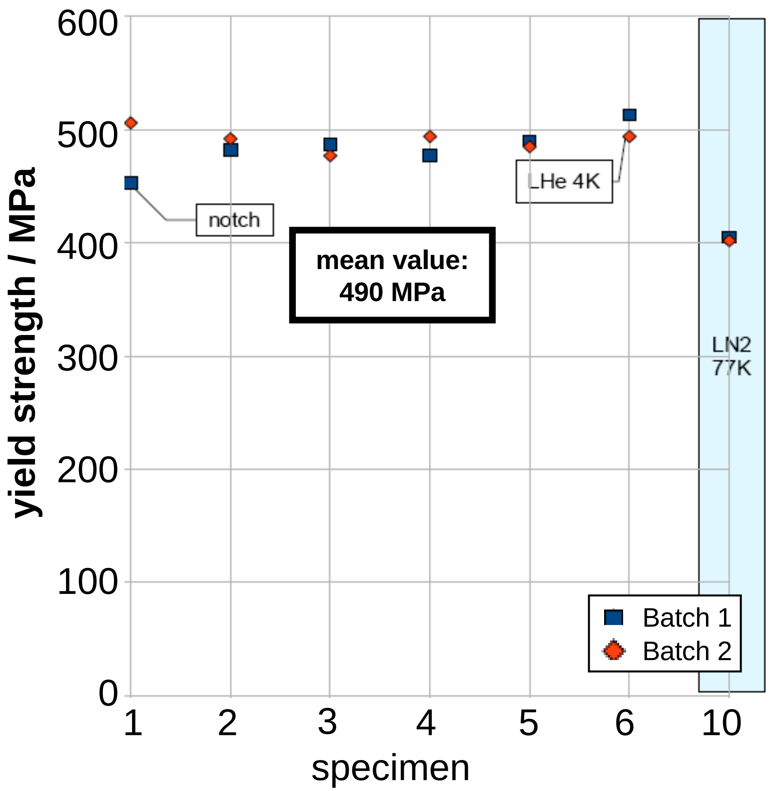
maximum plastic strain	$\varepsilon = 0.05$
stress during plastification	$\sigma = 640\,\mathrm{MPa}$
density	$\rho = 2800\,\dfrac{\mathrm{kg}}{\mathrm{m}^3}$
heat capacity	$c = 0{,}92\,\dfrac{\mathrm{kJ}}{\mathrm{kgK}}$

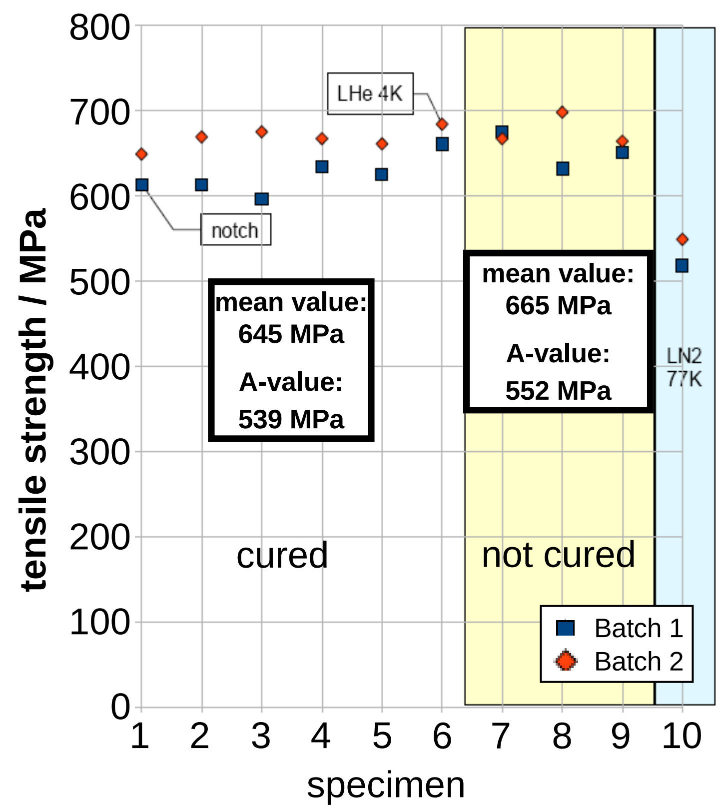
⇩

$$\Delta T = 12{,}4\mathrm{K}$$

→ Rough estimation confirms the remarked increase of approx. 11 K

Test results / strength properties





- Curing influence? → mean strength is reduced to 97%

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Conclusion / Outlook

- Temperature increase of 11 K during plastification with specimen in gaseous He phase
  - Compromise of test duration and possible heat transfer in a gaseous phase
  - Results are on the conservative side

  Outlook:
  - Improvement of heat transfer in gaseous medium and test duration?
  - Reduction of duration to achieve thermal equilibrium for industrial implementation
  - Critical review of temperature measurement and control methods (sensitive influence!)

- Minor influence of 4h curing / 100°C (strain gauge glue) on strength seems to be given

  Outlook:
  - Critical detailed analysis of the curing influence

- Small scatter in strength results throughout the batches and specimens (standard deviation ≈ 25 MPa) may refer to a generally reproducible test setup

- Establishment of a general guideline for cryogenic tests is desirable (e.g. on the basis of ASTM E 1450-03)