Tensile Testing on Aluminium 2219 at 20 K

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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)

  heating element with clamp
  bottom temperature sensor
  top temperature sensor
Test description / specimens (2)

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

- 8 per batch: specimens at 20 K
  - 5 per batch: strain gauge equipped (cured)
  - 3 per batch: no strain gauge

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

- 10 specimens
- 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 $6 \times 10^{-5} \, \text{s}^{-1}$ to $8 \times 10^{-4} \, \text{s}^{-1}$ were applied;
    - for comparison: ASTM 1450 proposes $< 10^{-3} \, \text{s}^{-1}$

  - 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 $R_m \rightarrow$ 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**

\[ \Delta T = \frac{\varepsilon \cdot \sigma}{\rho \cdot c} \]

With

- **maximum plastic strain**: \( \varepsilon = 0.05 \)
- **stress during plastification**: \( \sigma = 640 \text{ MPa} \)
- **density**: \( \rho = 2800 \frac{\text{kg}}{\text{m}^3} \)
- **heat capacity**: \( c = 0.92 \frac{\text{kJ}}{\text{kgK}} \)

\[ \Delta T = 12.4 \text{K} \]

→ 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)