KRP Mechatec

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CRYOGENIC MATERIAL TESTING

SPECIAL REQUIREMENTS FOR TEST SETUP AND TEST PERFORMANCE DEMONSTRATED ON ADDITIVE MANUFACTURED LIGHTWEIGHT ALLOYS

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- Demand of cryogenic testing
- Cryogenic temperature ranges and cooling methods
- Building cryogenic test setups
  - Material
  - Design
- Performing cryogenic tests
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Demand on cryogenic testing

- Space:
  - liquid propellant tank structures (20K for LH)
  - cryogenic instruments
- Fusion Research:
  - superconducting magnet structures (4K)
- Automotive
  - liquid hydrogen tank structures
- Goal:
  - material characterisation
  - component / structure verification

Temperatures and cooling methods

- Overview on typical temperature ranges, cooling methods and cooling equipment

Temperature	Method	Equipment	
"hot" to -140°C (-180°C)	evaporative cooling of liquid nitrogen	thermal chamber	
-196°C (77K)	direct immersion in liquid nitrogen	test dewar	
-196°C to -263°C (10K)	evaporative cooling of liquid helium	helium dewar gas phase	
-269°C (4K)	direct immersion in liquid helium	helium dewar liquid phase	

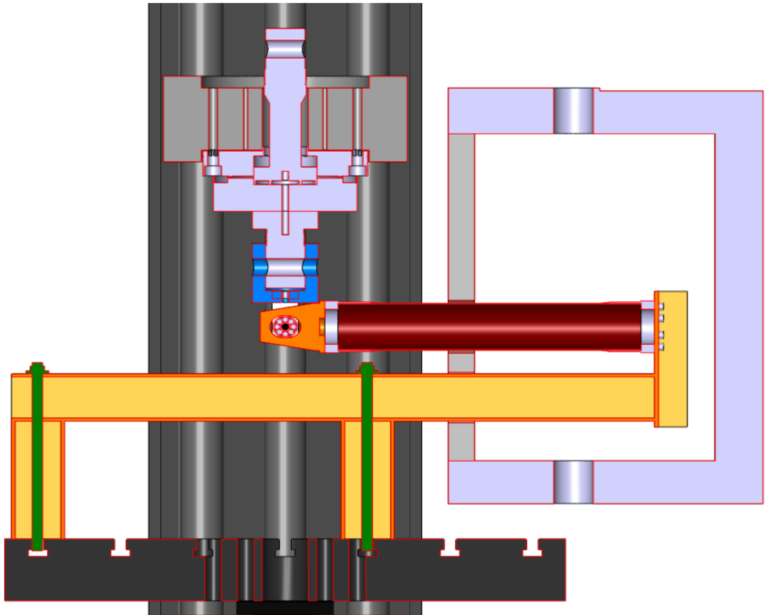
Cooling Fluids

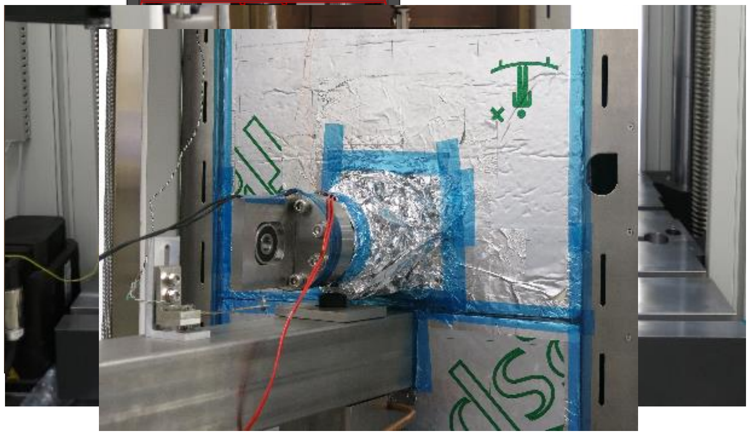
- Comparison of Nitrogen and Helium

Temperature	Nitrogen	Helium	Ratio He / N2
Temperature	-196°C / 77K	-263°C / 4K	-
Density liquid in kg/L	0,8076	0,1785	0,22
Heat of vaporisation in kJ/kg	199	21,1	0,11
Cost per liter in €	0,1	3	30
Cost per cooling 1kg stainless steel to liquid temperature in €	0,06	108	**1677**
Delivery	by truck stored in big tanks	On-site helium liquefier	
Gas recoverage	not required	strongly recommended	

Thermal chamber (RT to -140°C)

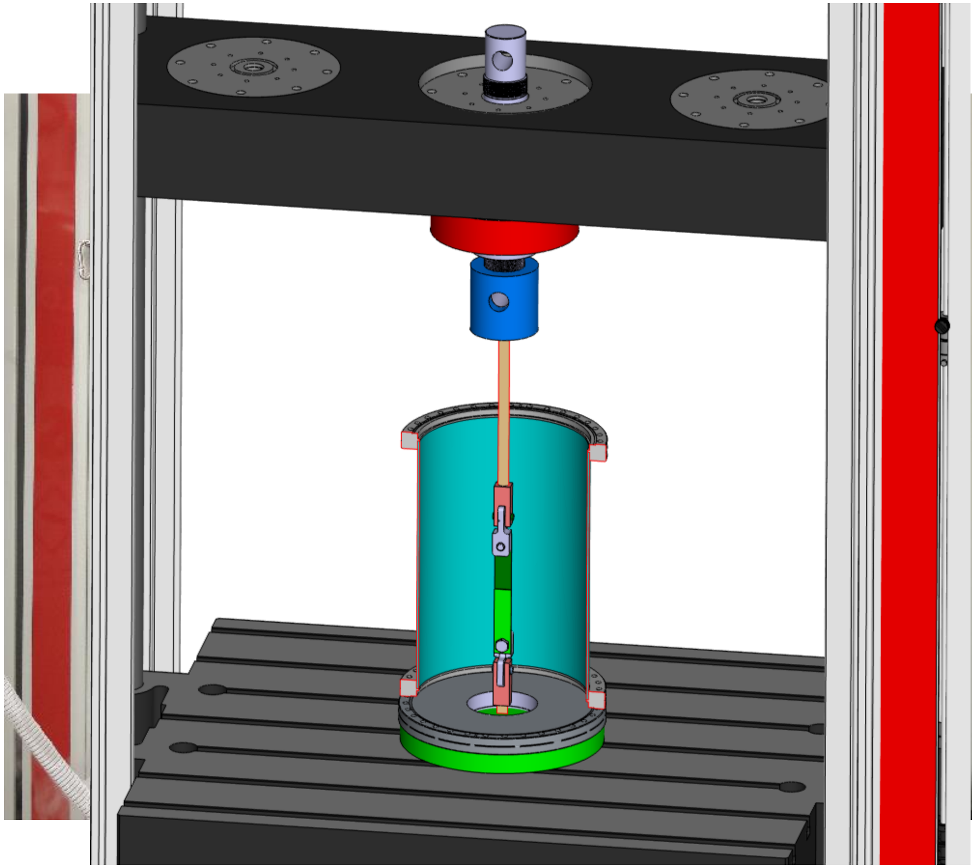
- „+”
  - Wide temperature range, and integrated easy control
  - Feedthrough of fixed and moving test machine interface
- „-“
  - Limited cryogenic range (commercial -140°C, self build to -180°C)





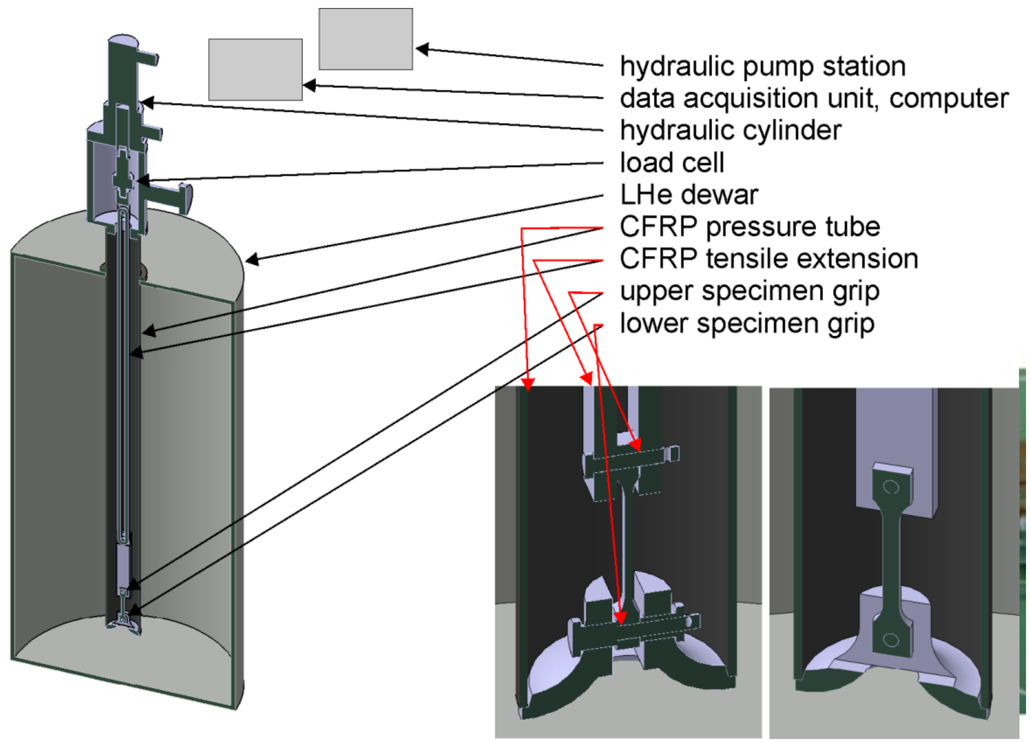
Direct immersion in liquid nitrogen

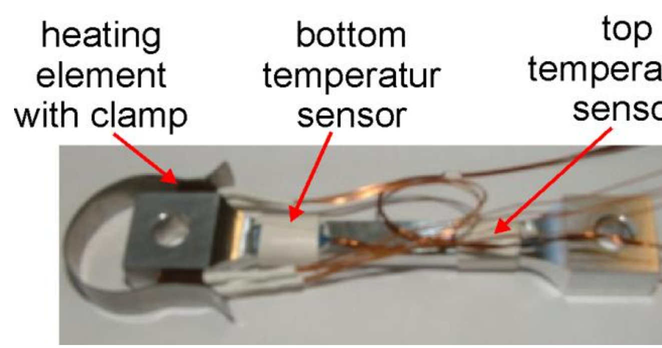
- „+”
  - High cooling rate
  - Flexible cryostat design
- „-“
  - Fixed temperature
  - Risk of thermoelastic damage of the test setup / test machine during cooling down



Evaporation of liquid helium

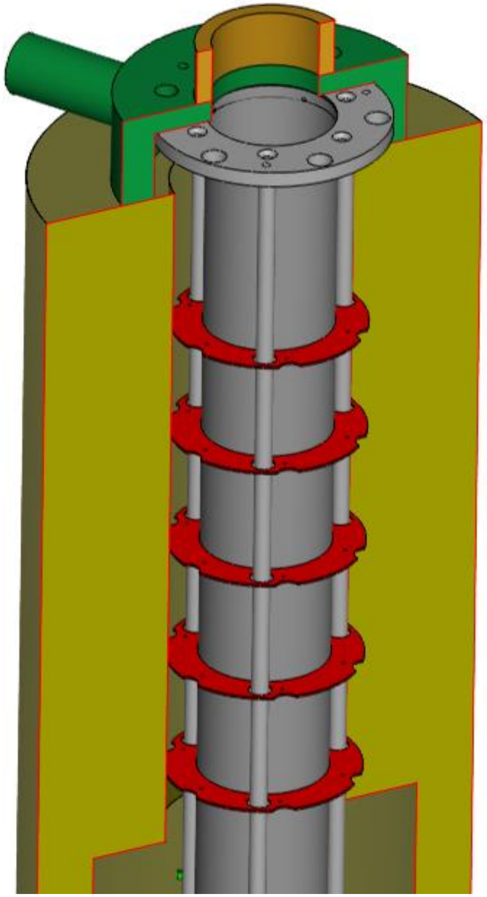
- „+”
  - Wide temperature range (77K to ~10K)
- „-“
  - Temperature gradient along specimen needs to be compensated by electrical heating
  - Low cooling rate
  - High Cost
  - Temperature Control and LHe flow control required





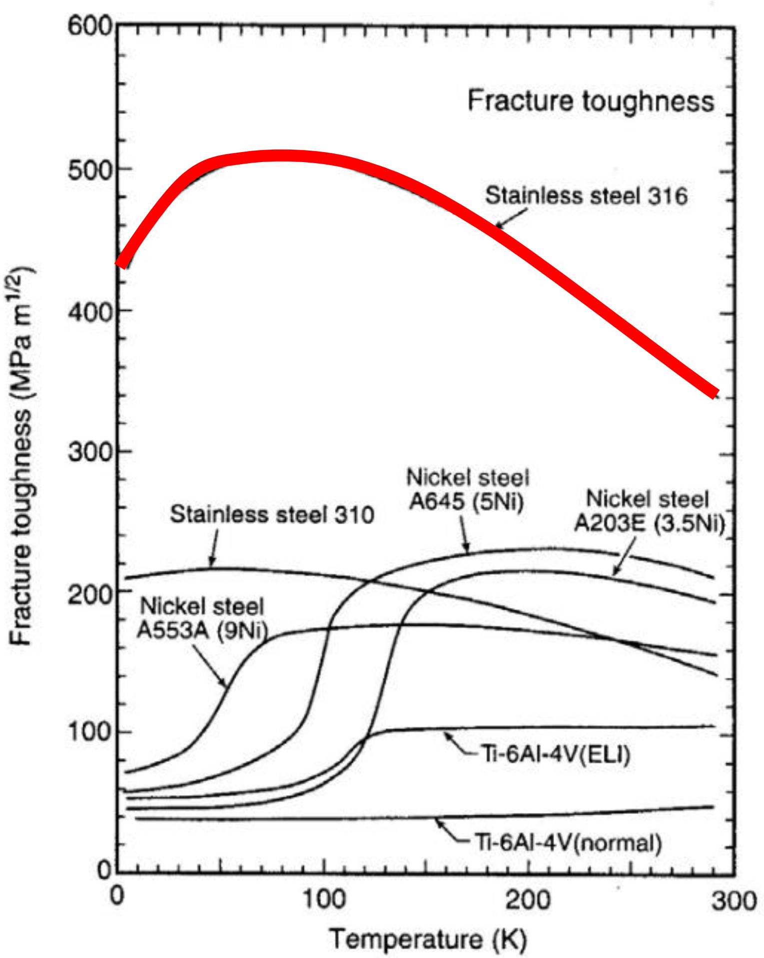
Direct immersion in liquid helium

- „+”
  - Lowest cryo-temperature
- „-“
  - Fixed temperature
  - Risk of thermoelastic damage during cooling down
  - High cost
  - Baffle system required



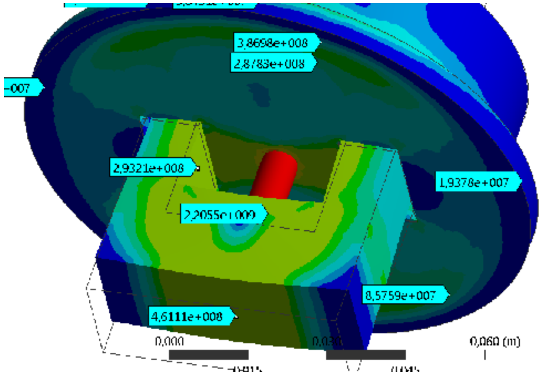
Cryogenic test setups - Materials

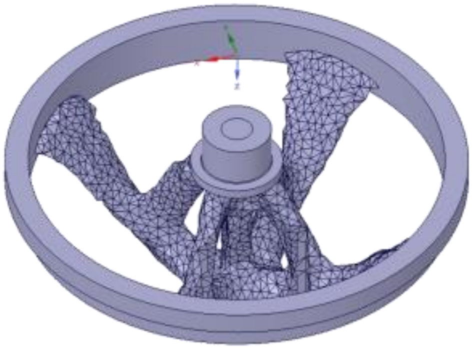
- Stainless steel is mainly used
  - Low embrittlement and thus robust against transient forces during specimen failure
  - Low thermal conductivity (good isolation of load bearing parts)



Cryogenic test setups - Design guidelines

- Mechanical design
  - “mass is money” at LHe!
  - FEM to identify load paths and optimize w.r.t. mass (morphological optimization)
  - Assess maximum load capacity of test setup at different temperatures (w.r.t. temperature depended yield strength)
  - Take care not to overload stainless steel setups at RT or high temperature

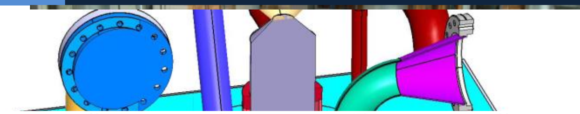




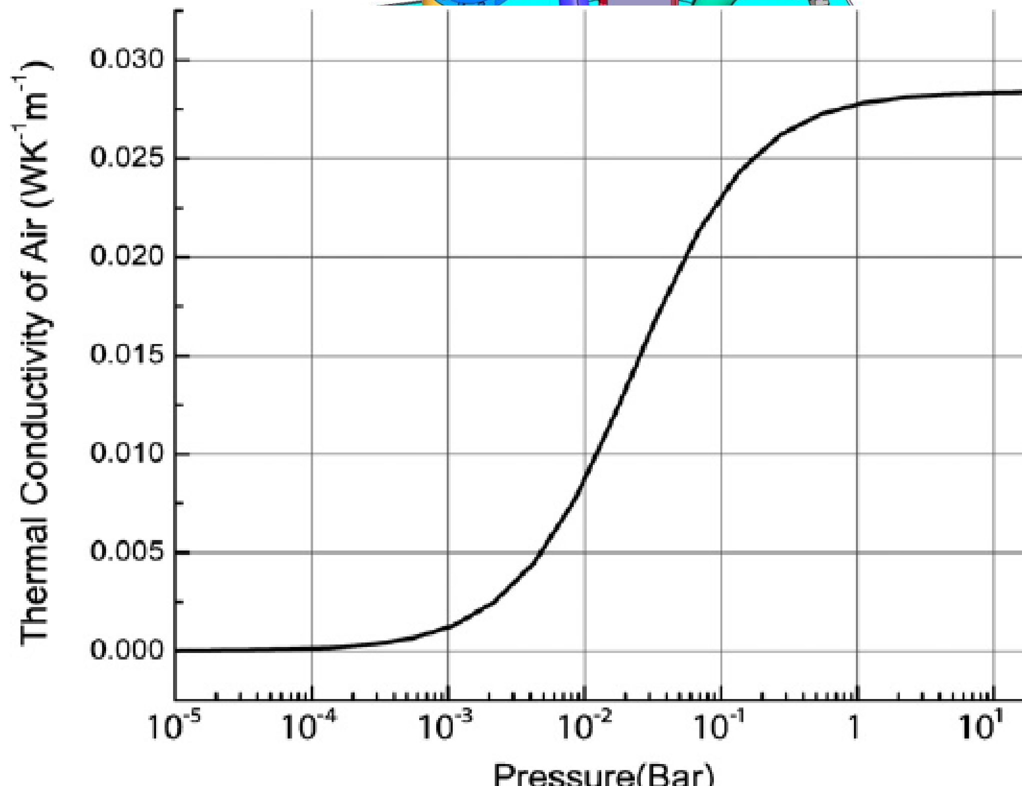
Cryogenic test setups - Design guidelines

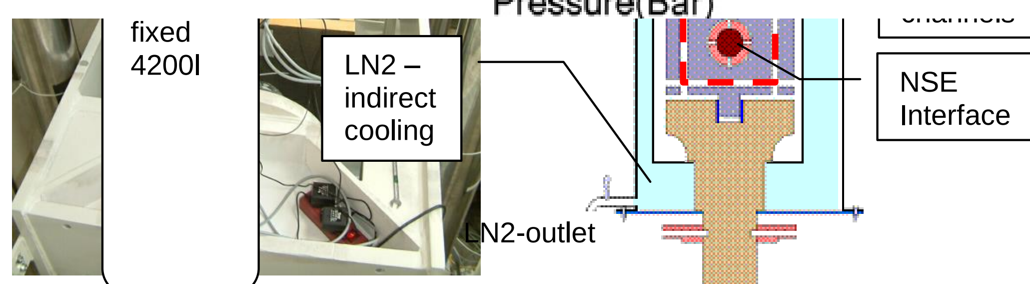
- Thermal design
  - FEM to identify temperature distribution and achievement
  - Evaluate cooling time and cost per test

Cryogenic setups – Vacuum environment



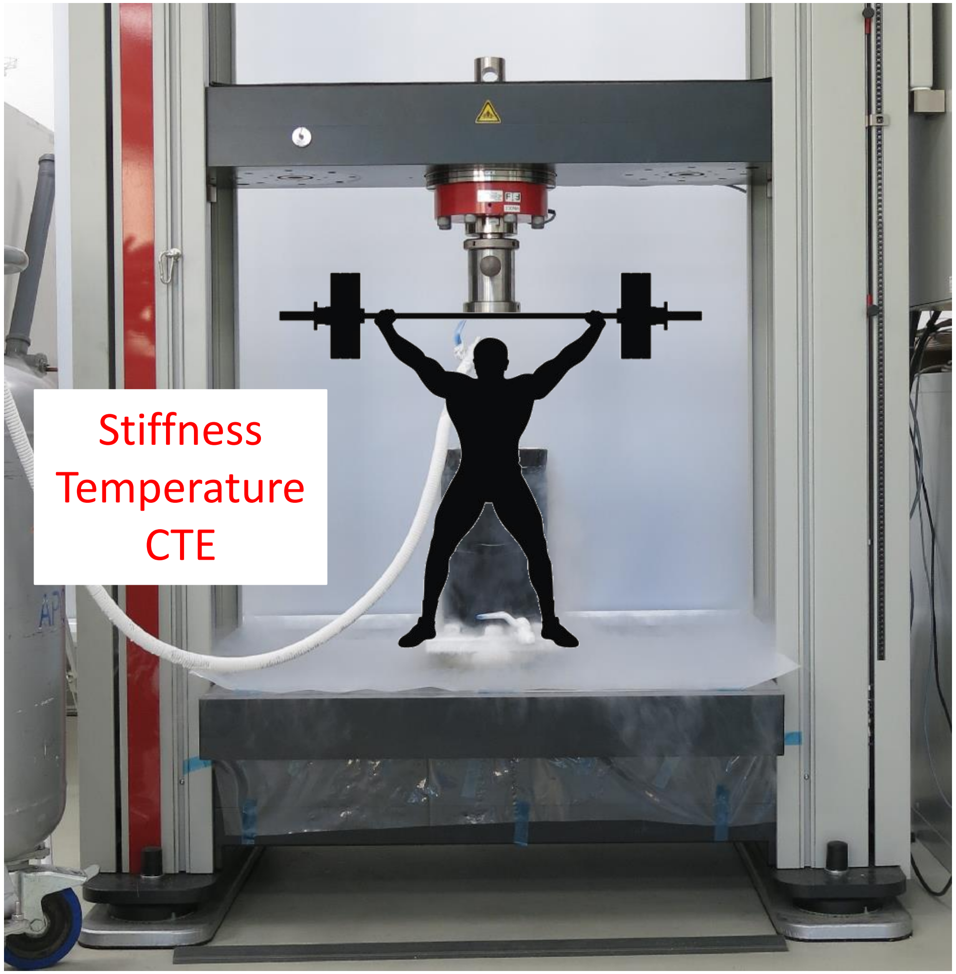
- Low convective heat transfer
- Two axis friction test 2MN/2MN at -190°C under vacuum
  - vacuum sealing in cryogenic temperature: CF flanges
  - Internal and external cooling of load bearing paths
- Heat transfer coefficient from 150°C to 250°C at 50kN





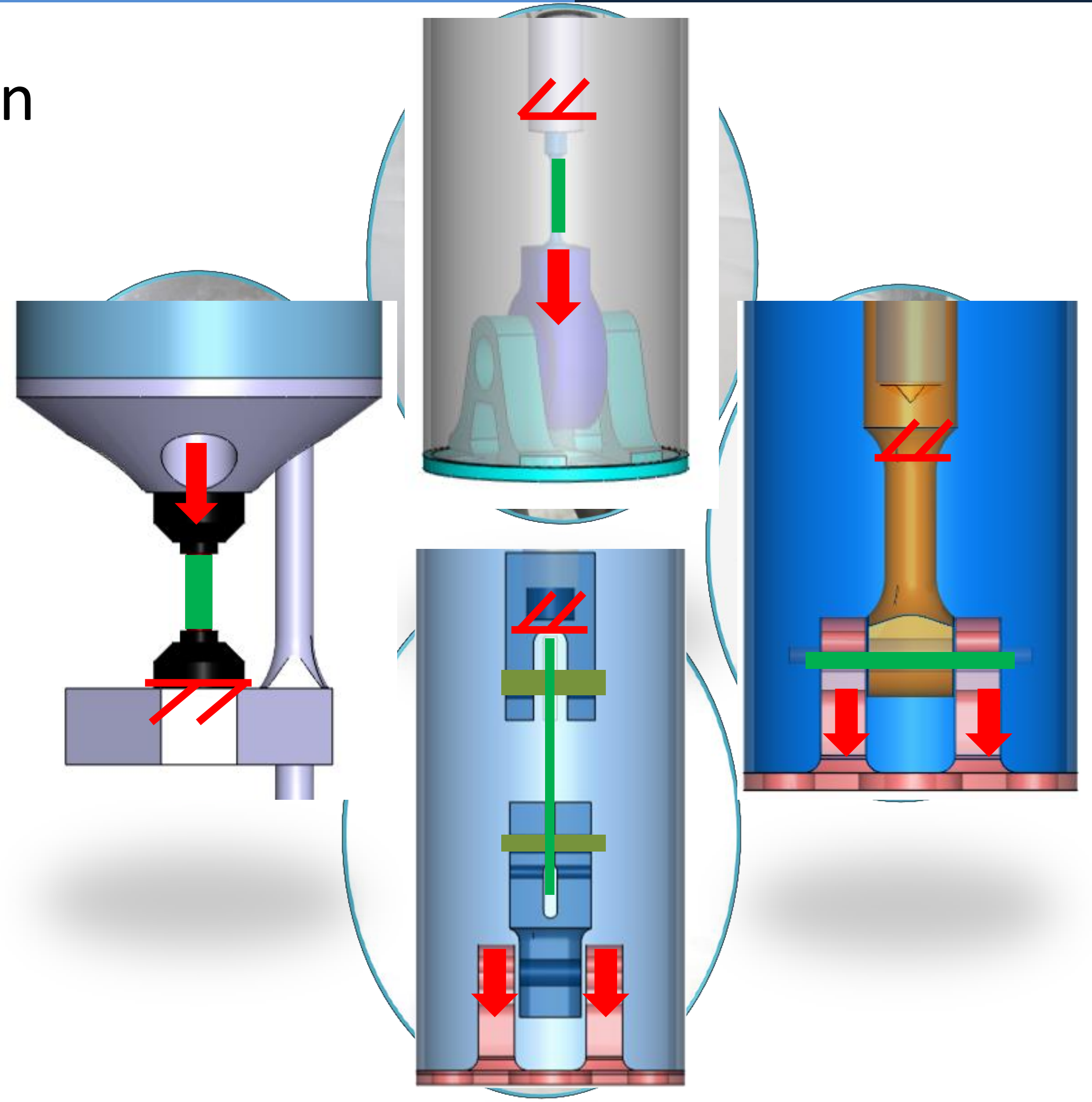
Cryogenic test performance

- Select temperature compatible strain gauges, extensometers and temperature sensors
- Protect test machine from condensed water
- Monitor oxygen in test lab
- Take into account liquid oxygen and liquid hydrogen
- Provide gaps for different thermal expansions
- Don't block test machine during cooling down and heating up – high risk of overload and destruction



Application example – 3D printed metals

- Test setup design
  - Tension
  - Compression
  - Shear
  - Pin Bearing

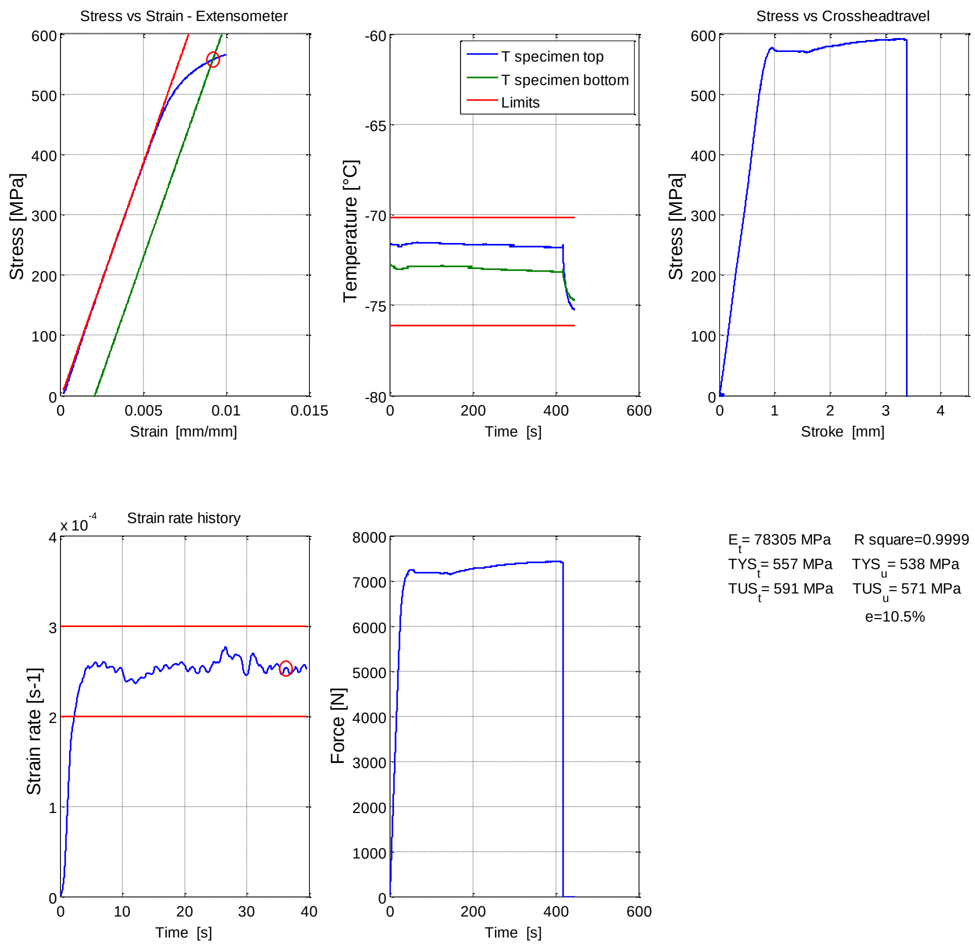


Application example – 3D printed metals

- Temperature levels
  - RT
  - 200K (-73°C)
  - 77K (-196°C)
  - 4K (-269°C)

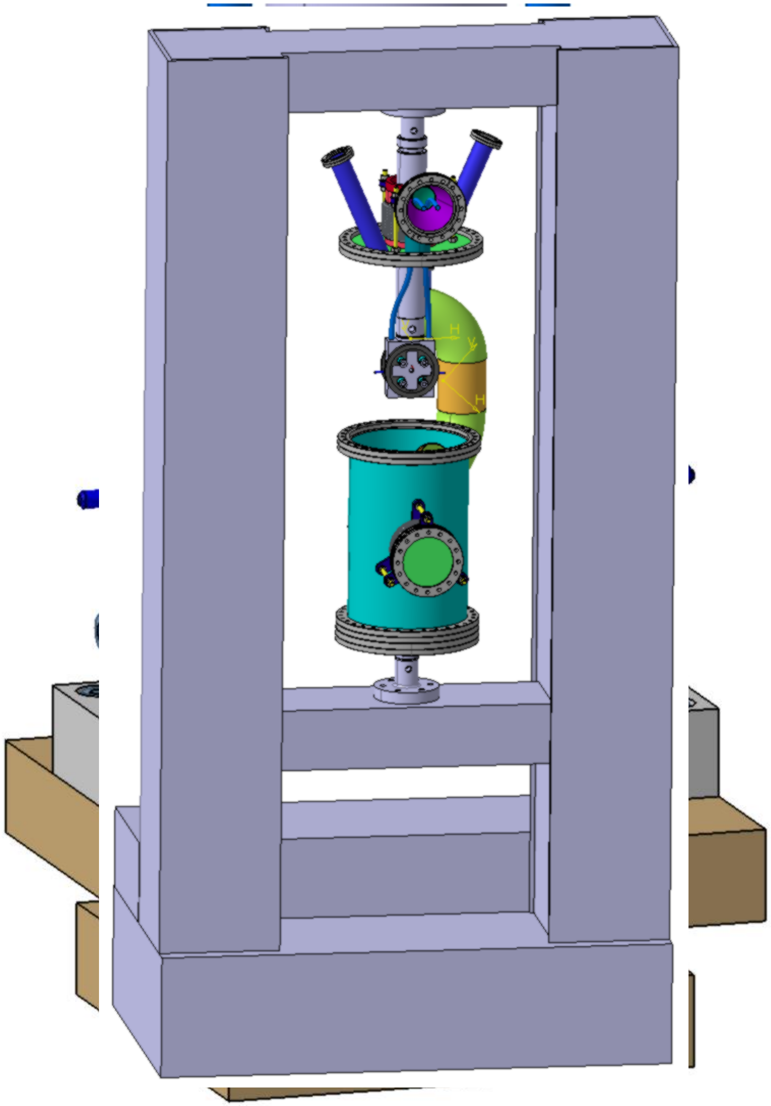
Application example – 3D printed metals

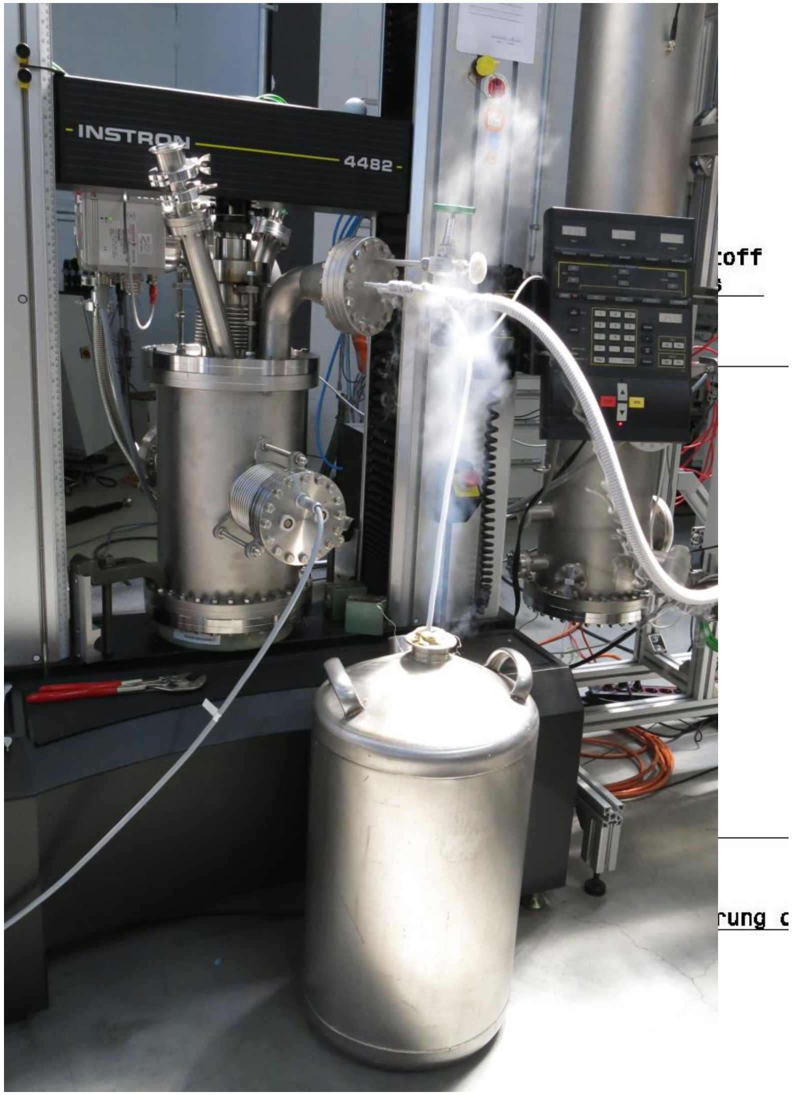
- Test performance
  - Cooling down
  - Strain control during yield
  - Switch to stroke control after Rp0.2 has been reached
  - Retract extensometer
  - Load until failure



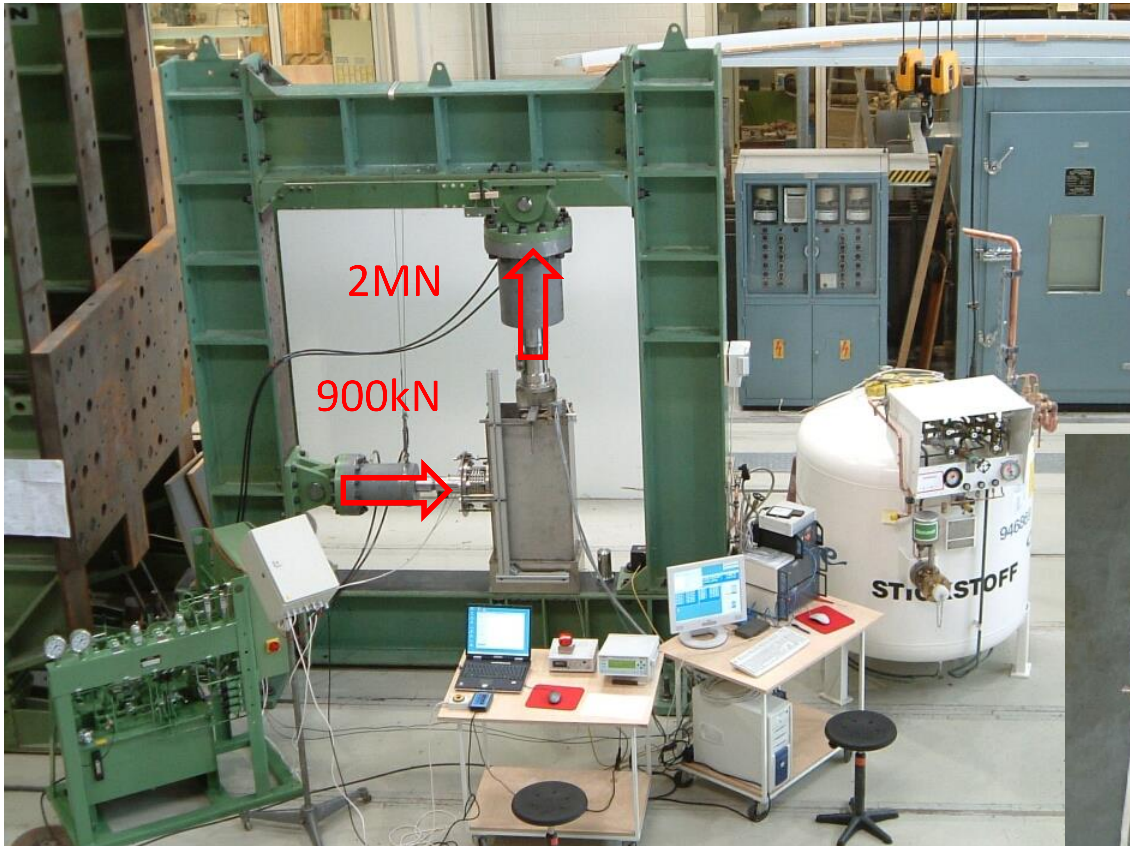
- Keep in mind: Safety first
- Thank you for your attention!
- Questions?

Further Cryogenic Test Examples





Further Cryogenic Test Examples



Two axis cryogenic loading test

Leakage test of
LN2 cryostat