Acceptable Peak Temperature and Thermal Stress in Ti6Al4V Target of ILC Positron Source

A. Ushakov[1], S. Riemann[2] and G. Moortgat-Pick[1]
[1]University of Hamburg, [2]DESY

POSIPOL Workshop, CERN

3 September 2018

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

LINEAR COLLIDER COLLABORATION

Outline

- Deformation of Ti6Al4V targets by 14 MeV e^- pulsed beam of the Mainz Microtron
- Stress-strain curves of Ti-alloy (Grade 5) at elevated temperatures
- Plastic flow simulations in ANSYS above yield point (yield strength)
- Allowed thermal stress at different temperatures
- Summary

Targets and Used MAMI Electron Beam (March 2016)

Targets

Electron beam for all targets:
14 MeV, 50 µA during pulse, σ = 180 µm

#1: **1 mm** thickness
wo thermal contact to holder
2 ms pulses, 100 Hz
~18.5h of irradation

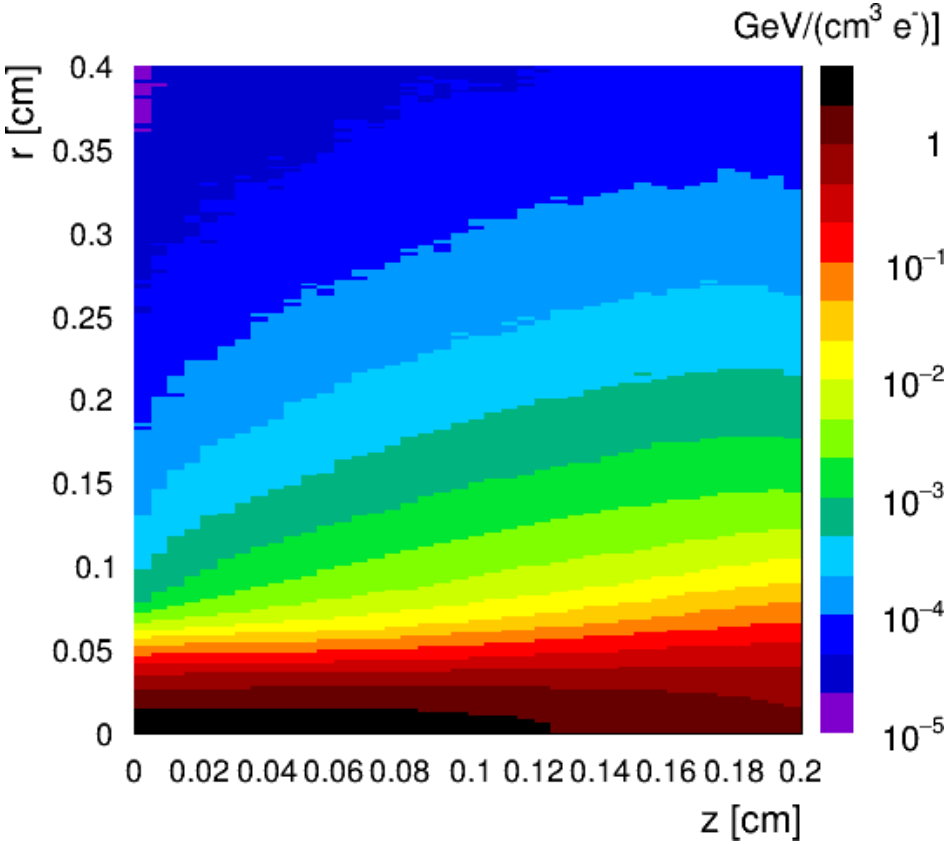
#2: 1 mm thickness
with thermal contact to holder
3 ms pulses, 67 Hz
~4h of irradation

#3: **2 mm** thickness
wo thermal contact to holder
2 ms pulses, 100 Hz
~14.5h of irradation

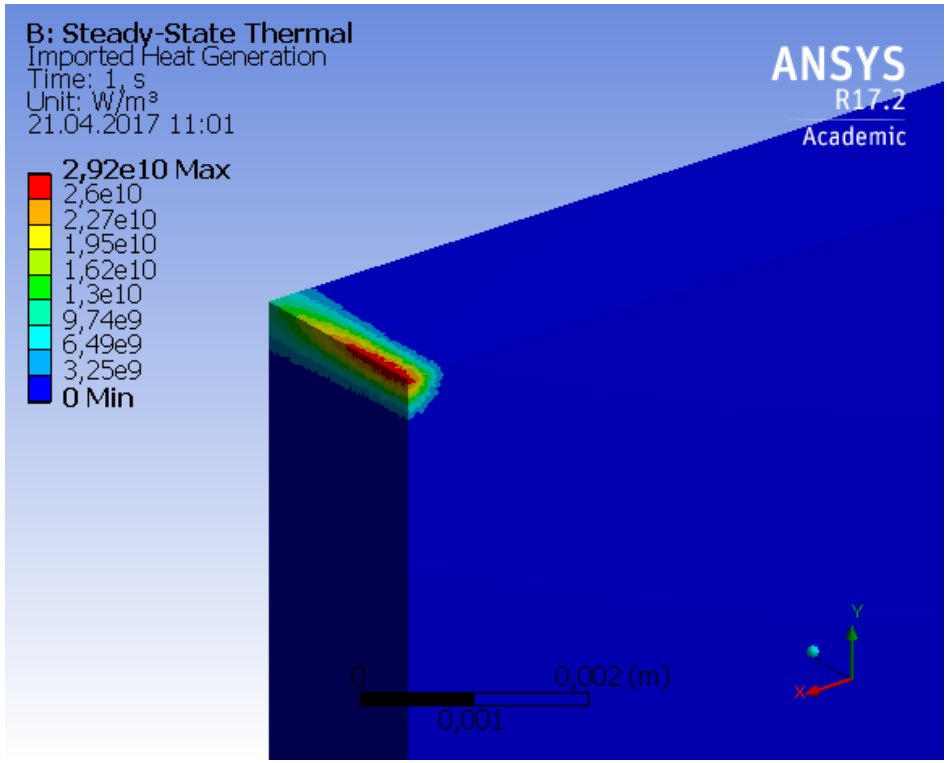
#4: not used

Energy Deposition and Average Heating Power

Energy Deposition by Beam (FLUKA)



Average Heating Power Imported in ANSYS

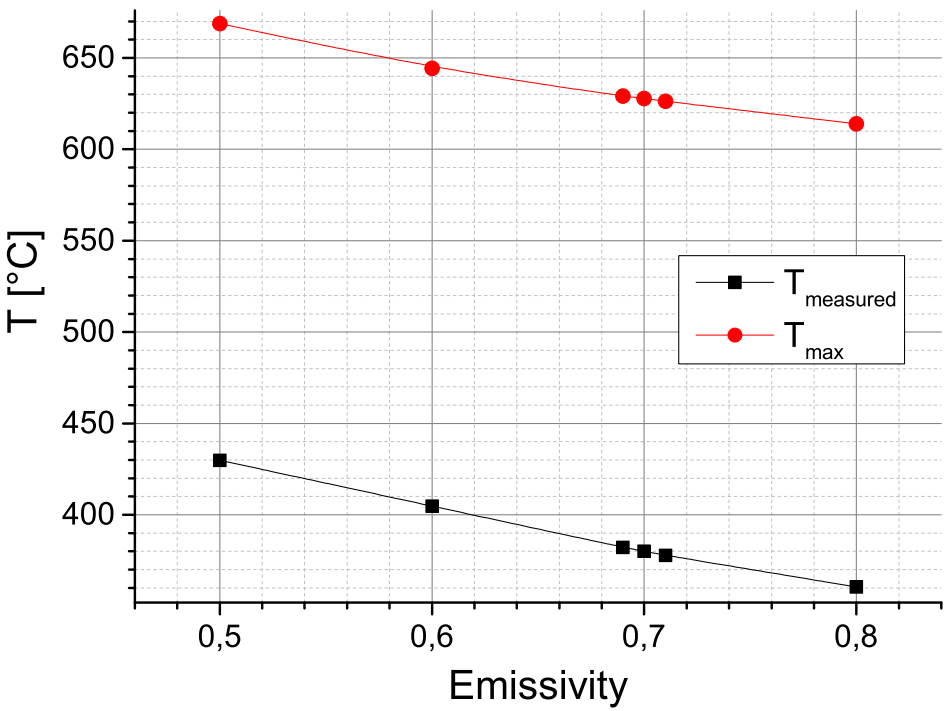


Average Temperature vs Emissivity

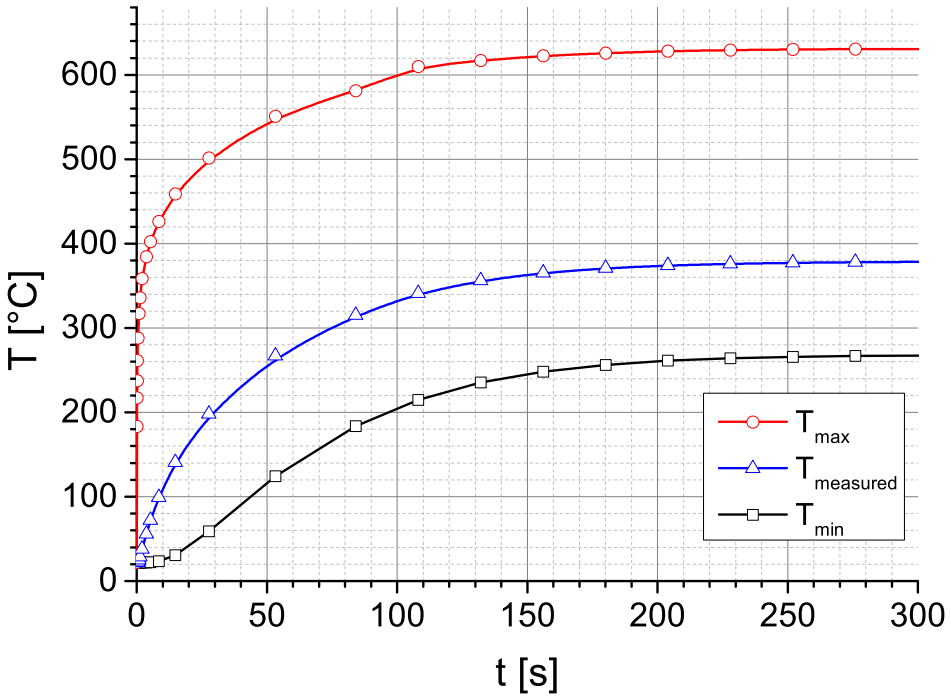
1 mm Target, 50 μA, 2 ms, 100 Hz

Temperature was measured by thermocouple at ≈ 5 mm distance from middle of the beam.
After switching beam on $T_{measured}$ has achieved saturation level at $T = 381°C$ after 6 min of irradiation.

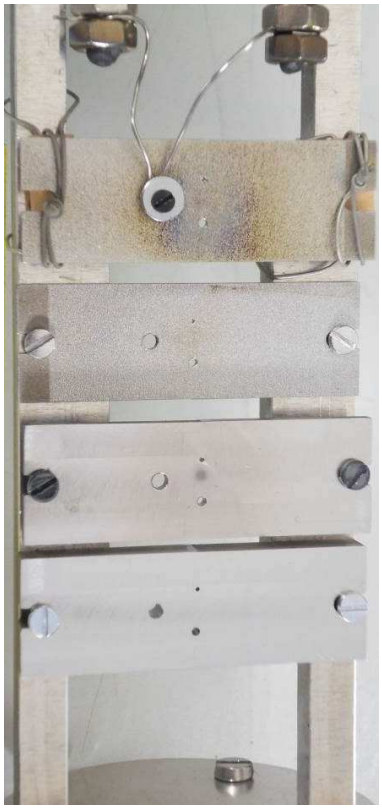
Temperature vs Emissivity



Temperature vs Time ($\varepsilon = 0.7$)



Peak Average Temperature of Different Targets

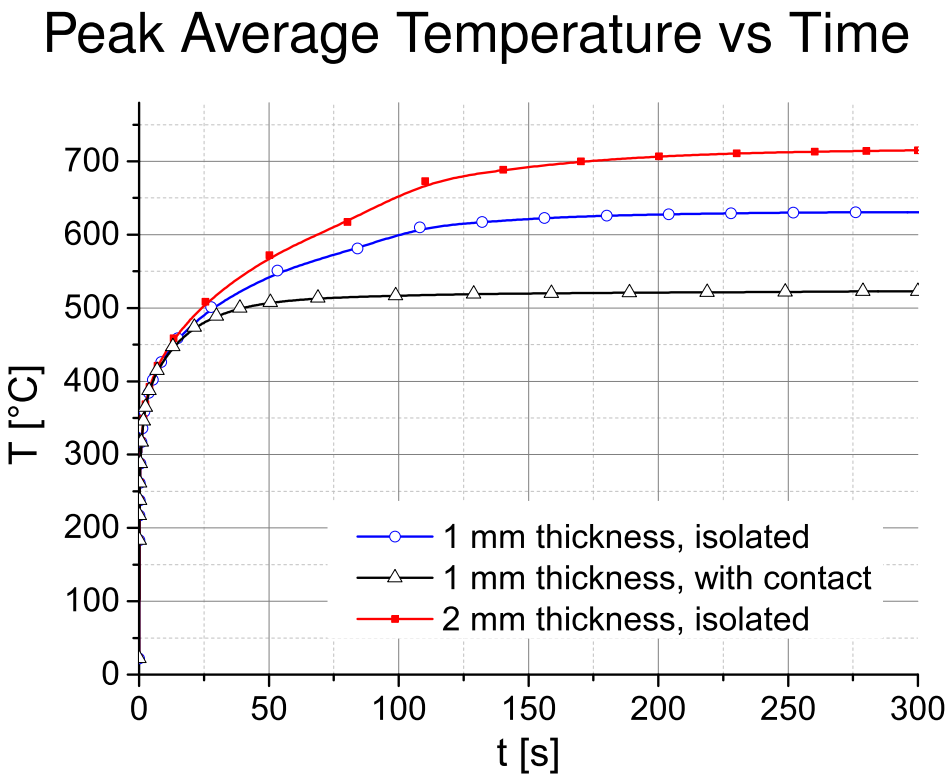


#1: 1 mm thick, therm. isolated
2 ms, 100 Hz

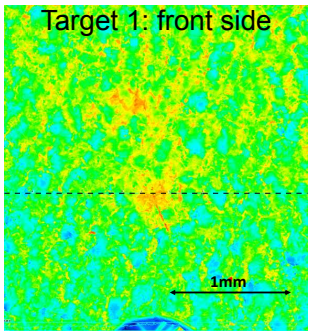
#2: 1 mm thick, with th. contact
3 ms, 67 Hz

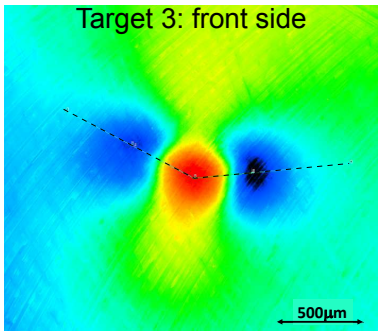
#3: 2 mm thick, therm. isolated
2 ms, 100 Hz

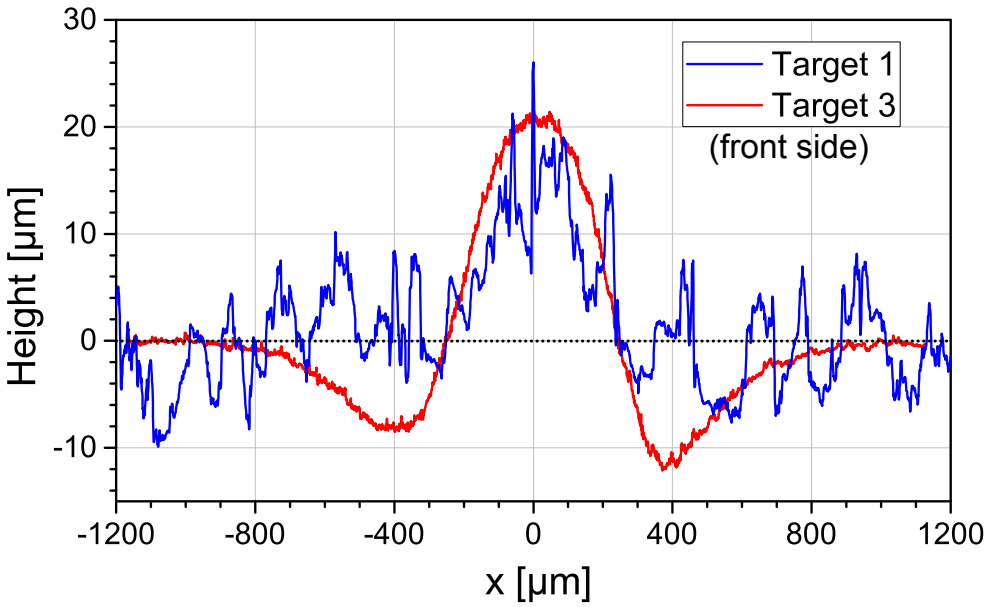
#4: not used



Deformation of Targets

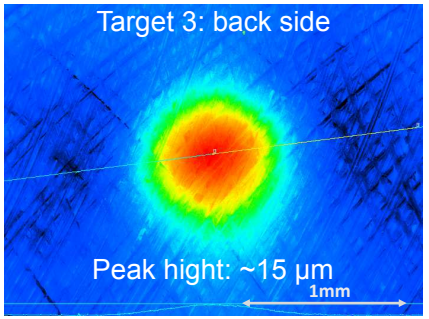






No visible deformation on back side of target 1

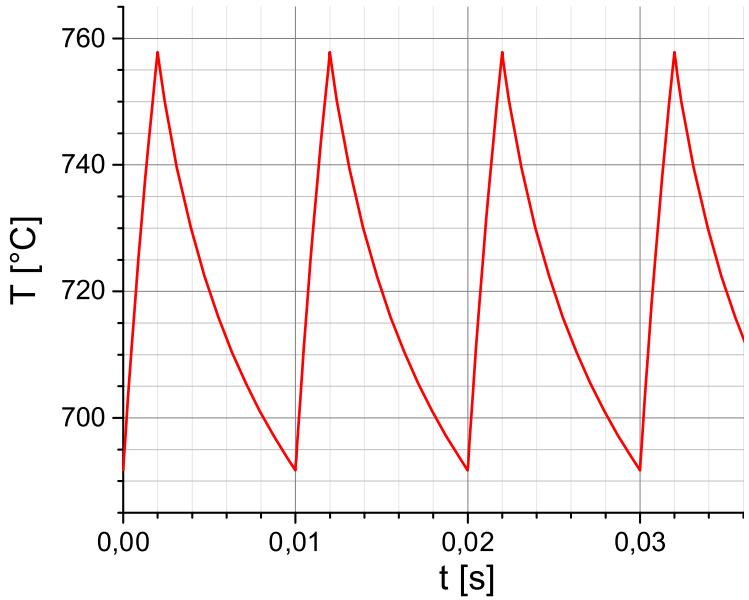
No visible deformation on both sides of target 2

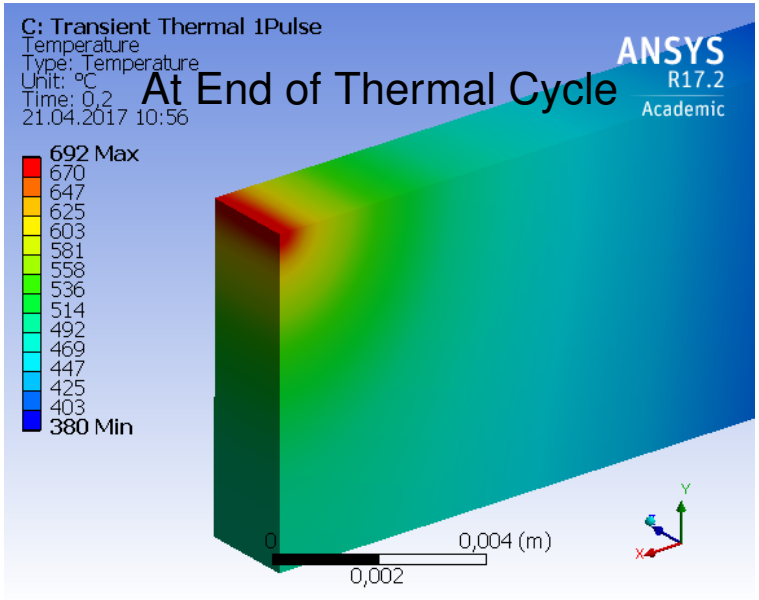


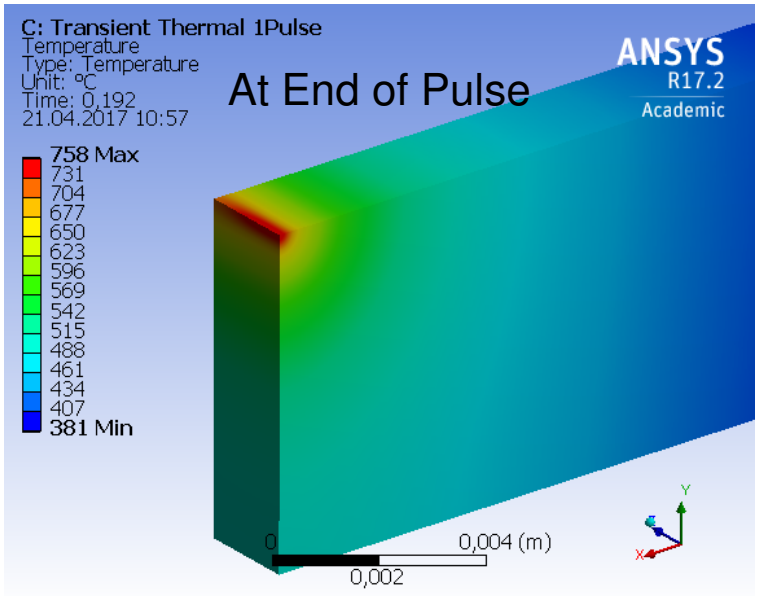
Can ANSYS be used for the prediction of target deformation?

Thermal Cycles and Temperature Distributions

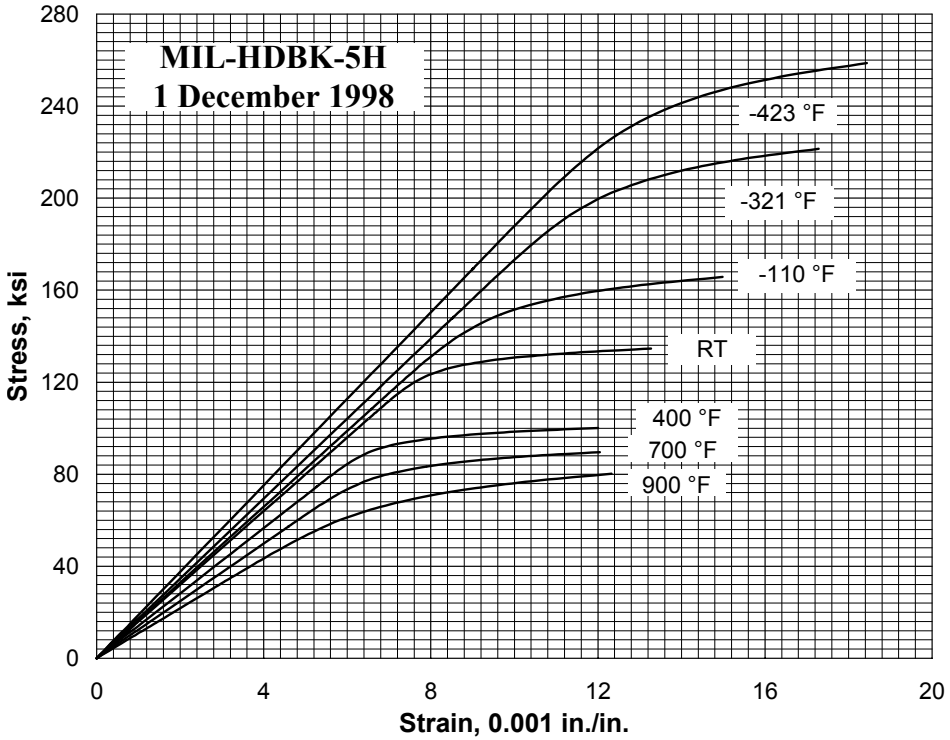
2 mm Target, 50 μA, 2 ms, 100 Hz, $\varepsilon = 0.7$

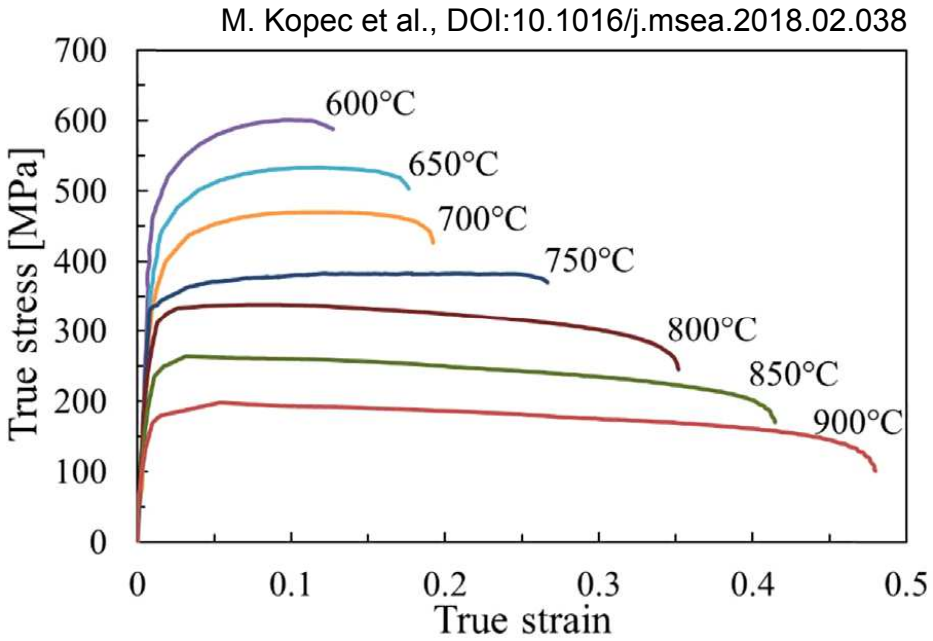






Data on Stress-Strain Curves

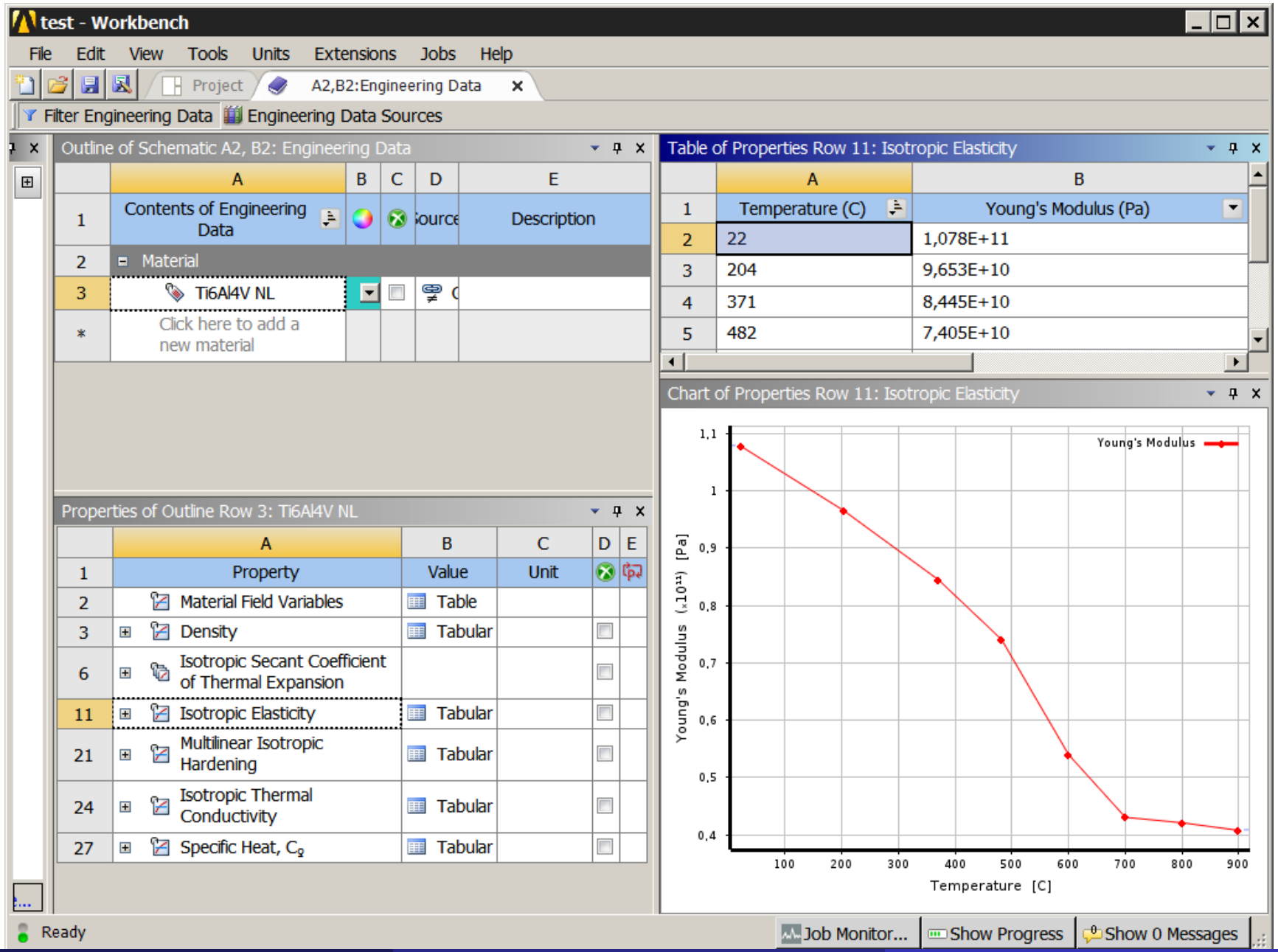




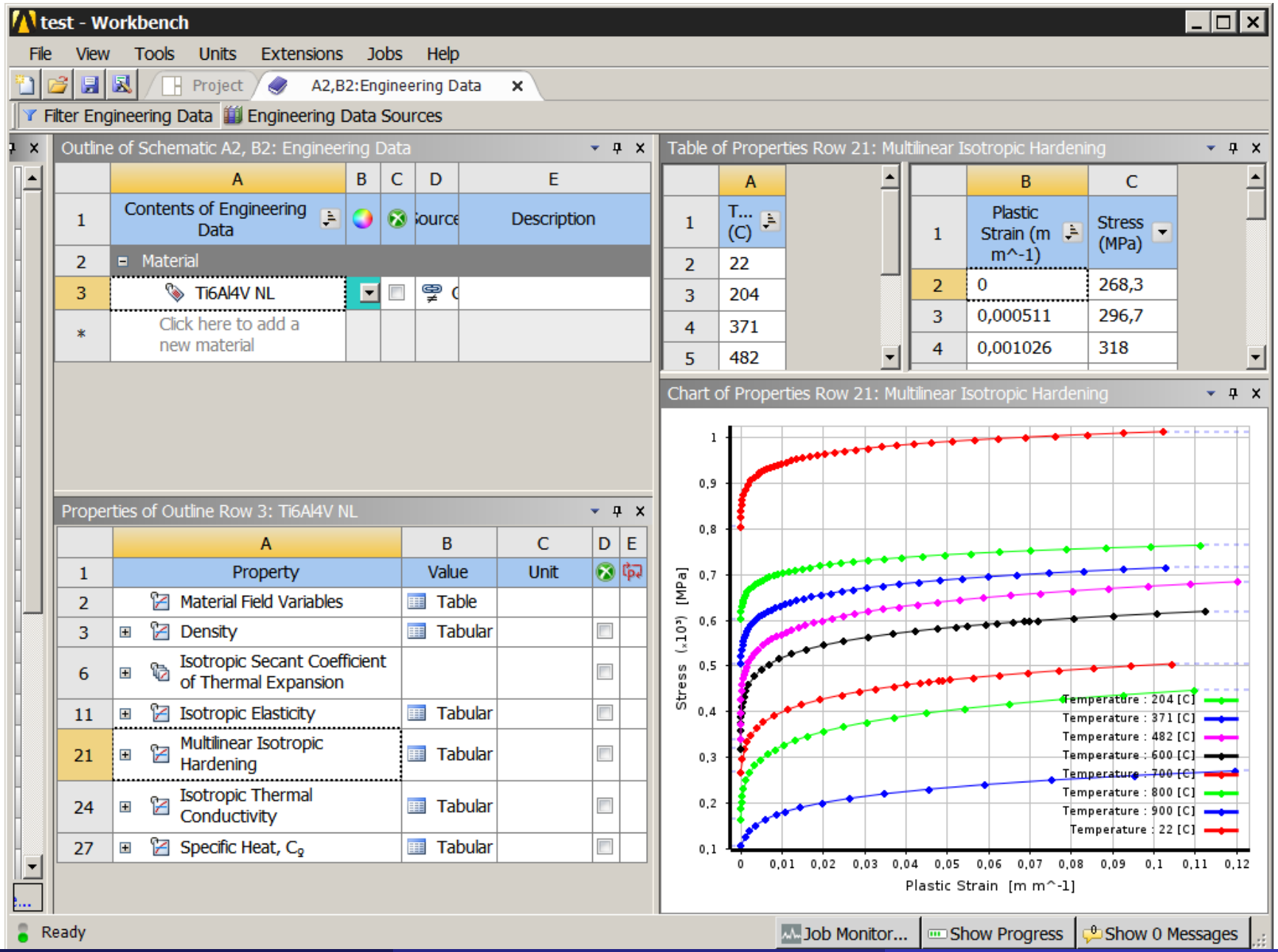
[MIL-HDBK-5H]: Military Handbook “Metallic materials and elements for aerospace vehicle structures”, MIL-HDBK-5H, 1 December 1998, 1651 pp.

[Kopec]: M. Kopec et al., Materials Science and Engineering A 719 (2018) 72-81

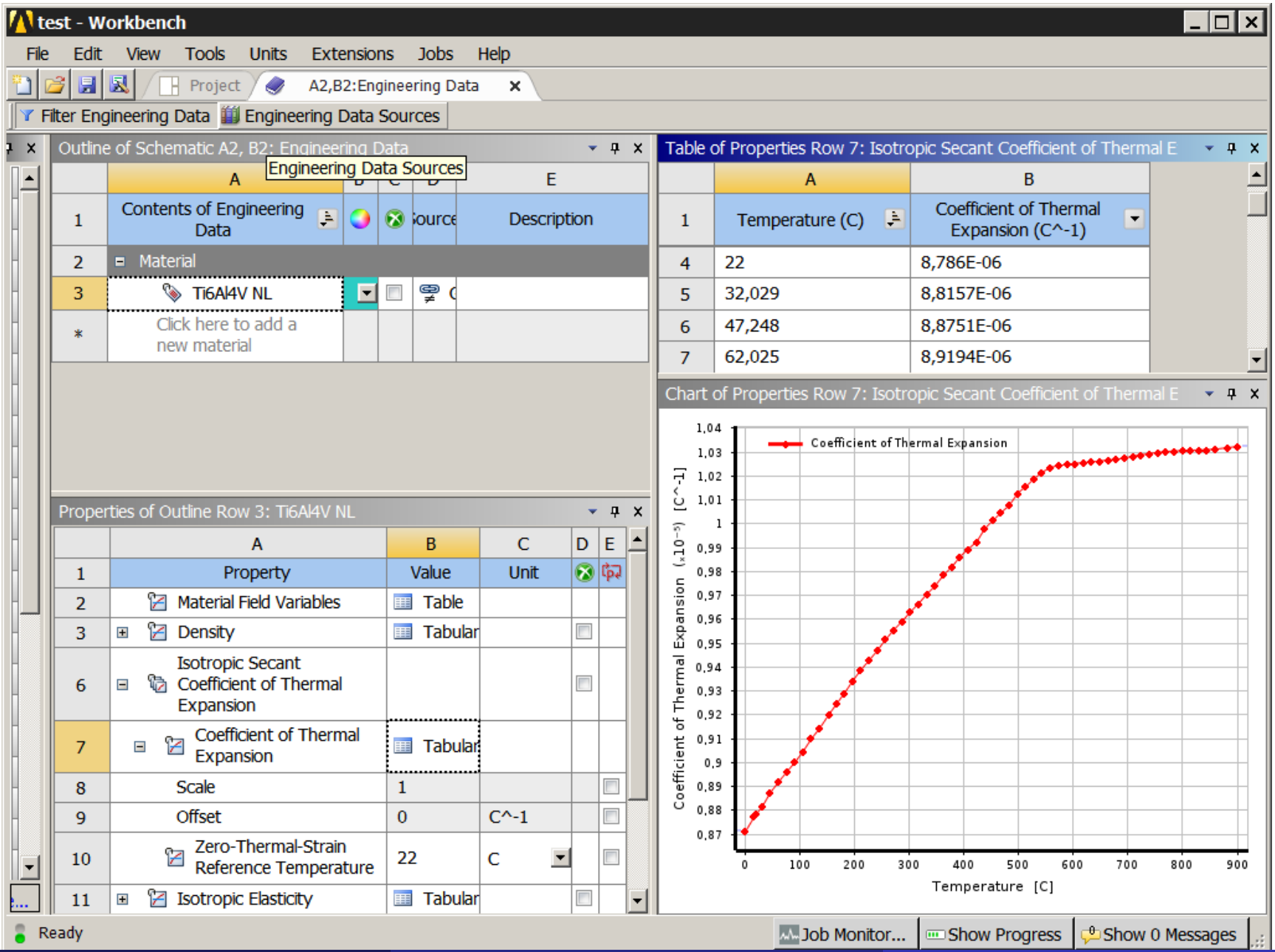
Young's Modulus



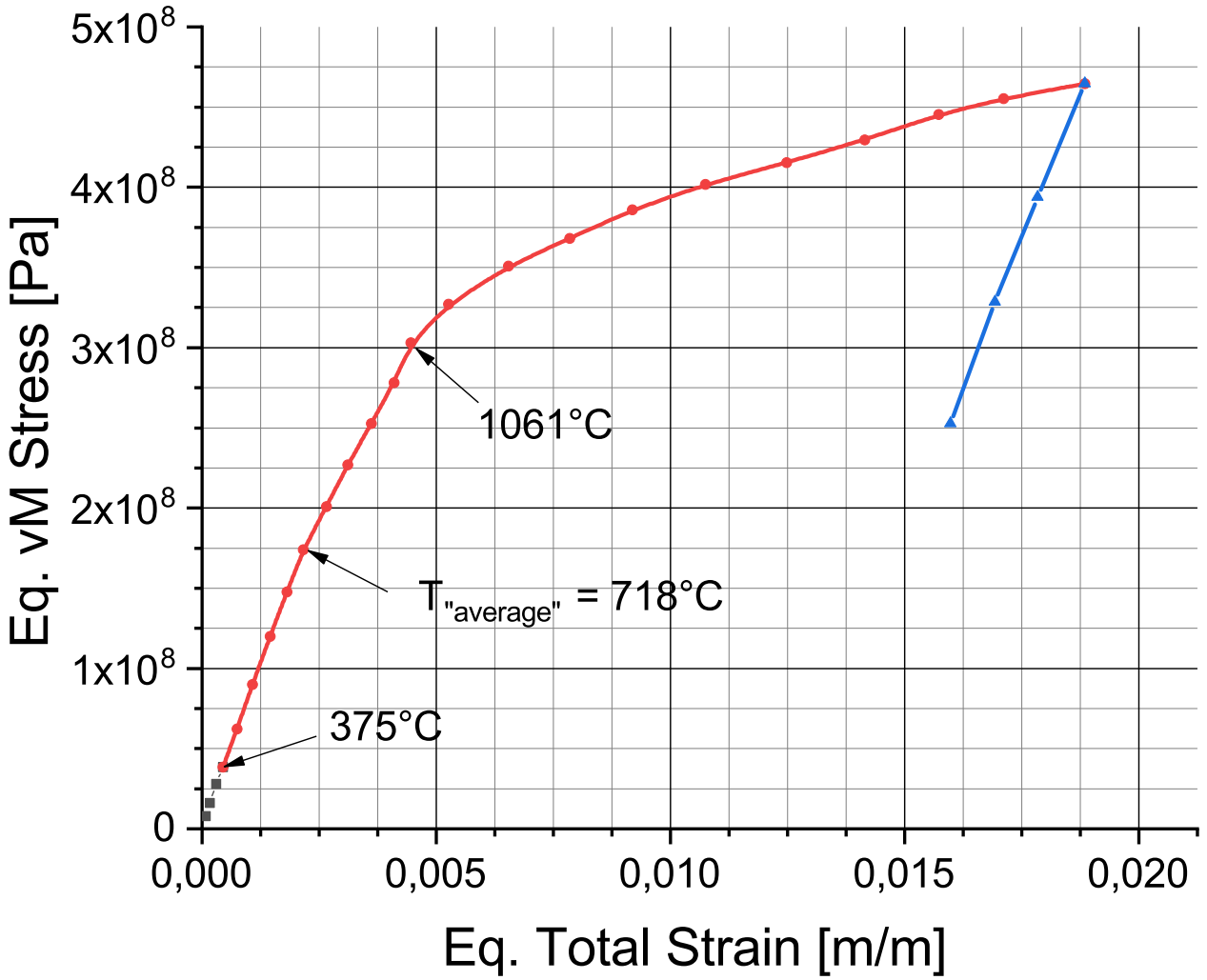
Multilinear Hardening



Coefficient of Thermal Expansion (MILHDBK5H)

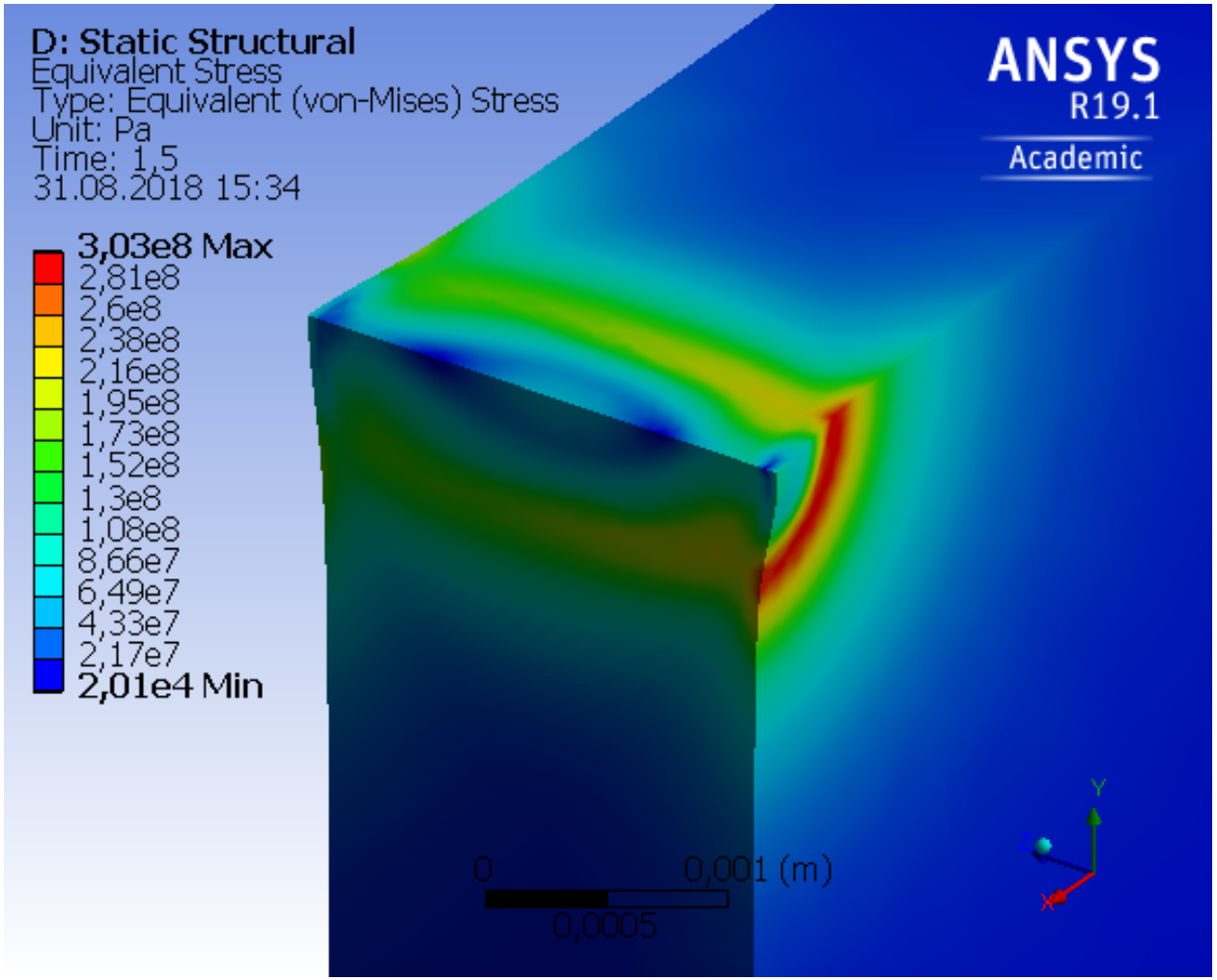


Thermal “Cycle” Starting at 375°C

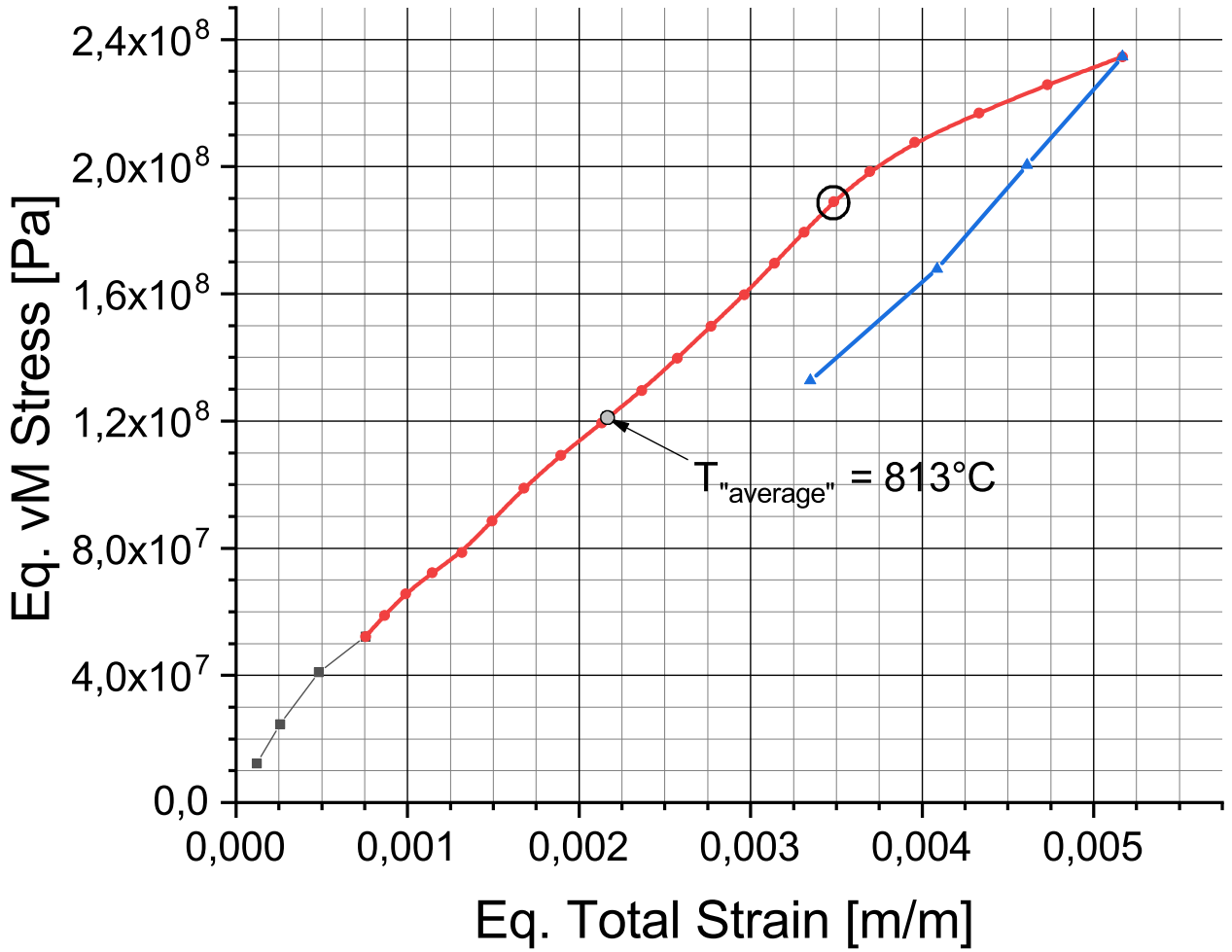


Highest equivalent von Mises stress in elastic region is 303 MPa

Distribution of Equivalent Stress

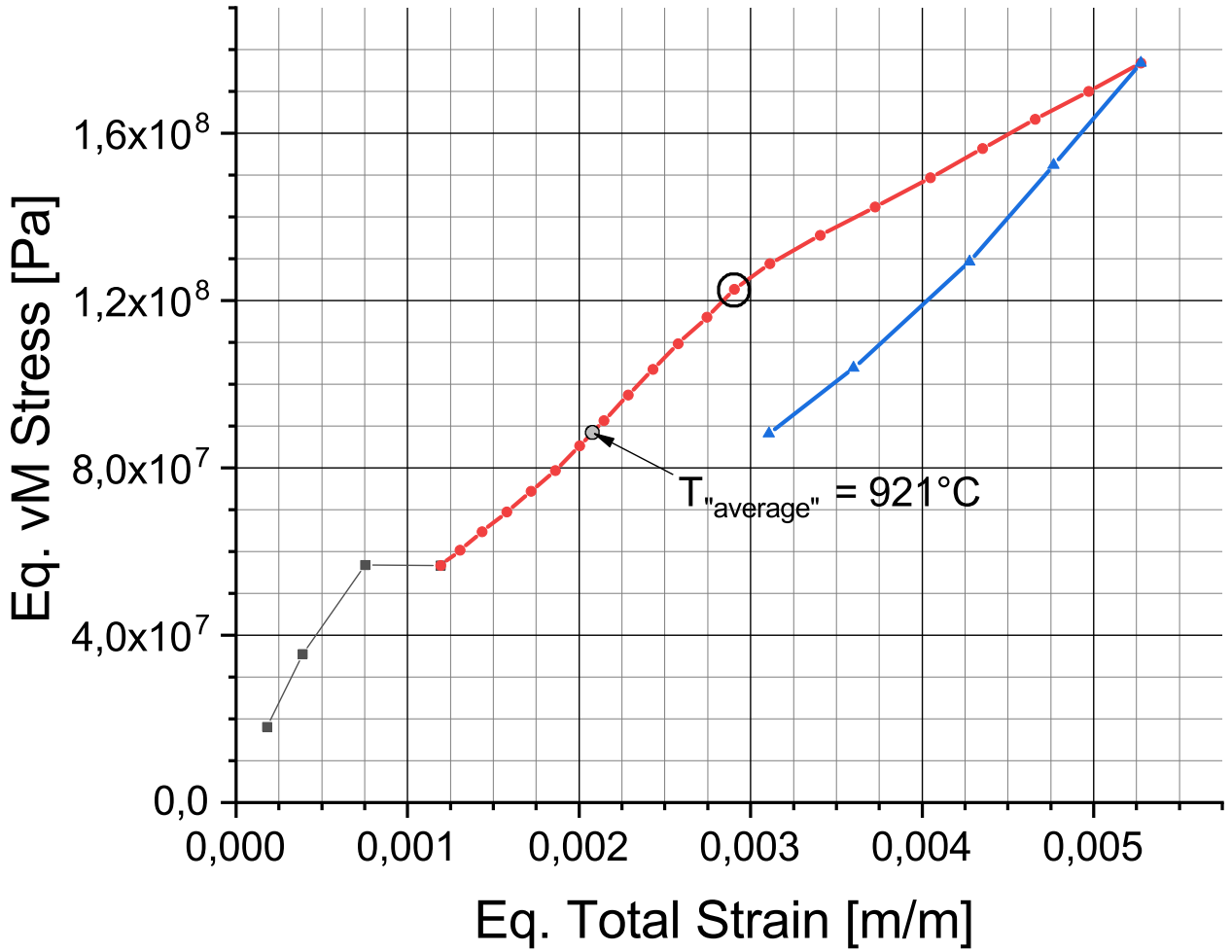


Thermal “Cycle” Starting at 548°C



Highest equivalent von Mises stress in elastic region is 189 MPa

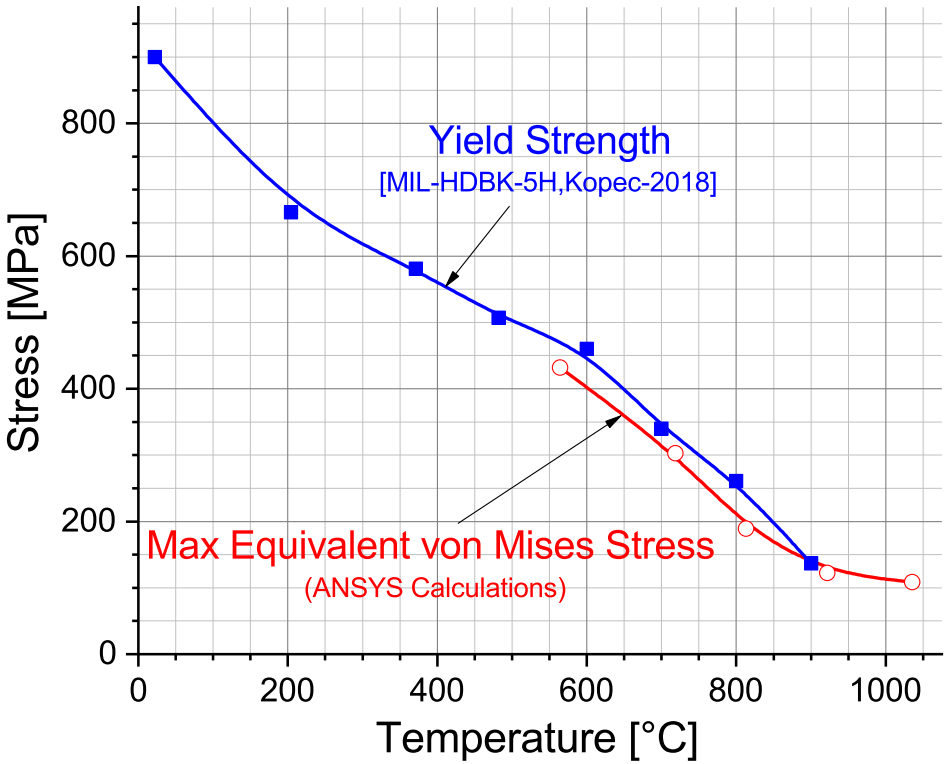
Thermal “Cycle” Starting at 717°C



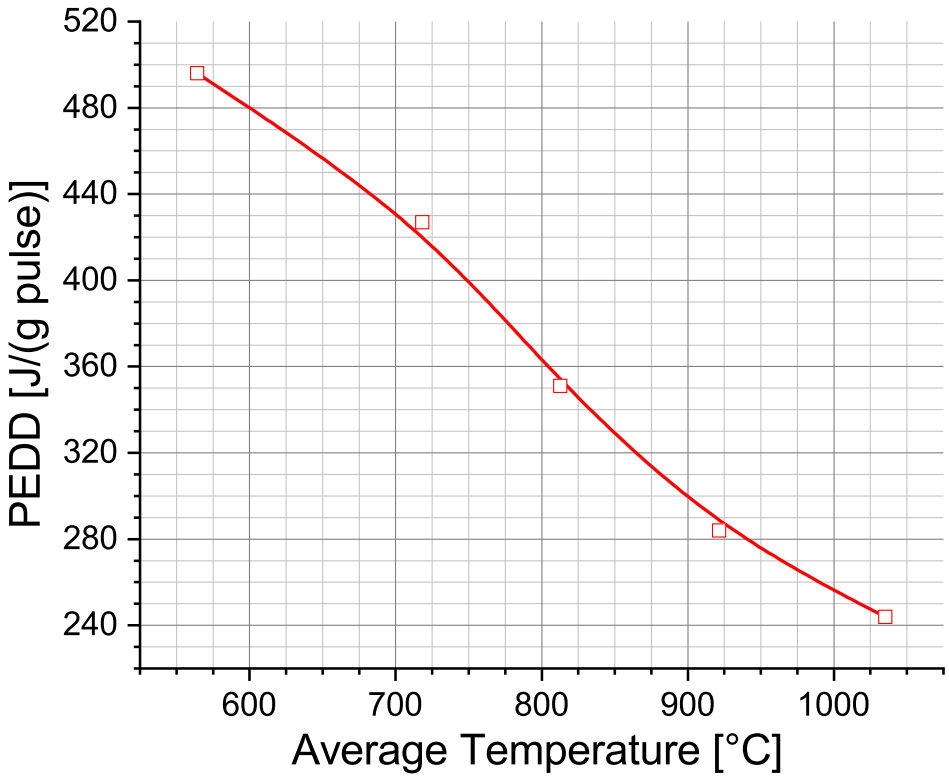
Highest equivalent von Mises stress in elastic region is 123 MPa

Maximum Allowed Thermal Stress and PEDD in Ti6Al4V at Elevated Temperatures

Yield Strength and Max. Elastic Eq. von Mises Stress vs Temperature



Maximal PEDD vs Temperature



Summary

- Adding temperature dependent elasticity and hardening data to the material properties in ANSYS allows making estimations of temperature and stress at which material starts to deform plastically.
- Simulations have shown that the maximum equivalent stress of elastically deformed by beam Ti6Al4V target is approx. 10% below the yield strength.
- Transition from elastic to plastic deformation occurs at 600°C average temperature when the equivalent von Mises stress reaches 400 MPa.
- At higher temperatures the limits go down quickly, for example, at 800°C average temperature: equivalent stress has to be $<$ 200 MPa.
- Further studies are needed to include impact of radiation damage and weakening of material caused by repeatedly applied loads (fatigue).

Many thanks to all people involved in "Target Experiments"

University Hamburg and DESY

Alexander Ignatenko
Gudrid Moortgat-Pick
Alena Prudnikava
Sabine Riemann

University Mainz

Kurt Aulenbacher
Thomas Beiser
Philipp Heil
Valery Tyukin

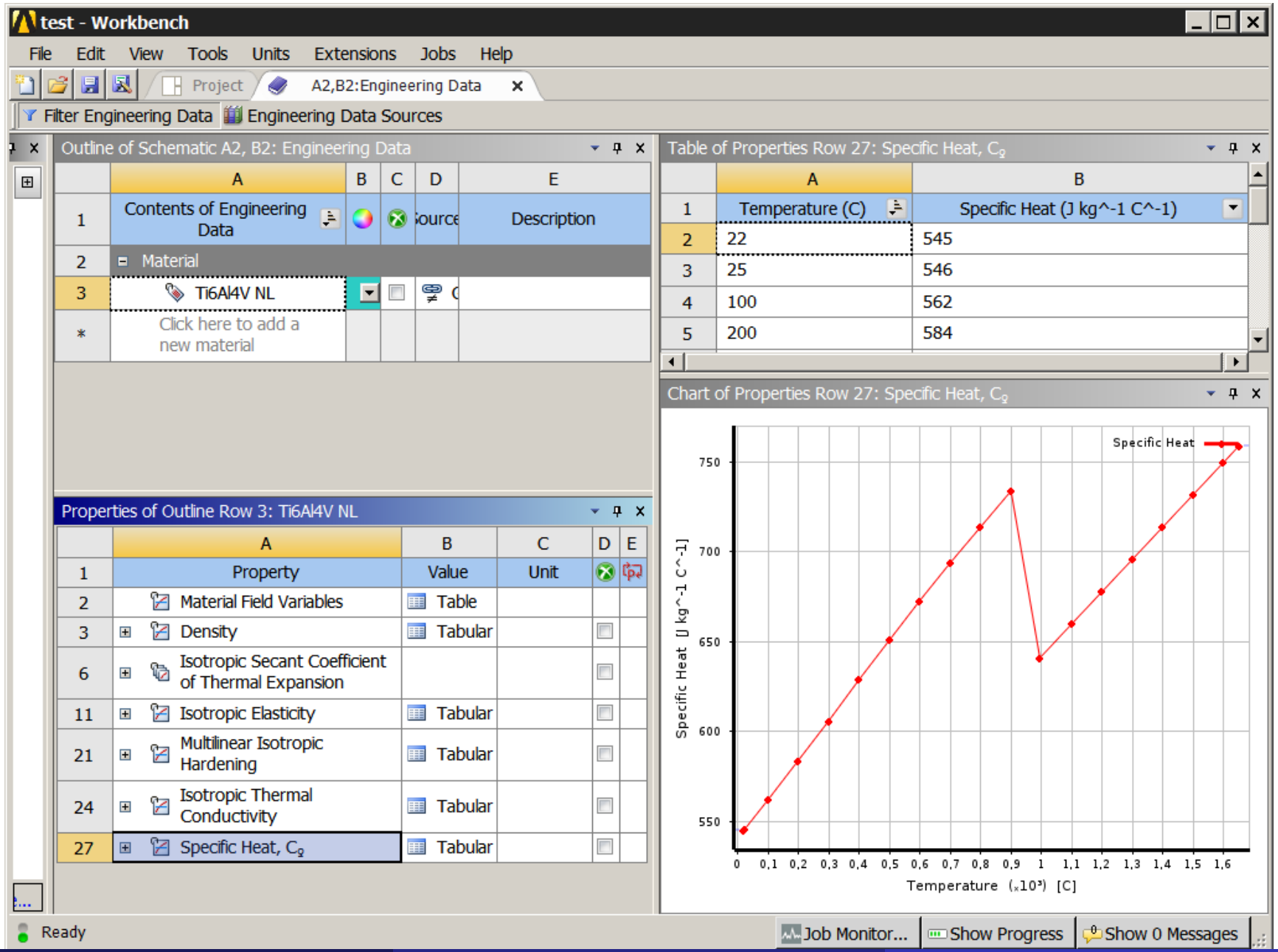
Helmholtz Zentrum Berlin

Yegor Tamashevich

CFEL, Hamburg

Alexander Kothe
Thorsten Uphues

Specific Heat



Transverse Beam Size