Accelerated Mechanical Testing: Investigation of NASA HR-1 using Profilometry-Based Indentation Plastometry

Marcus Gaiser-Porter, Plastometrex

Thomas Southern, Plastometrex

Colton Katsarelis, NASA Marshall Space Flight Center

Plastometrex

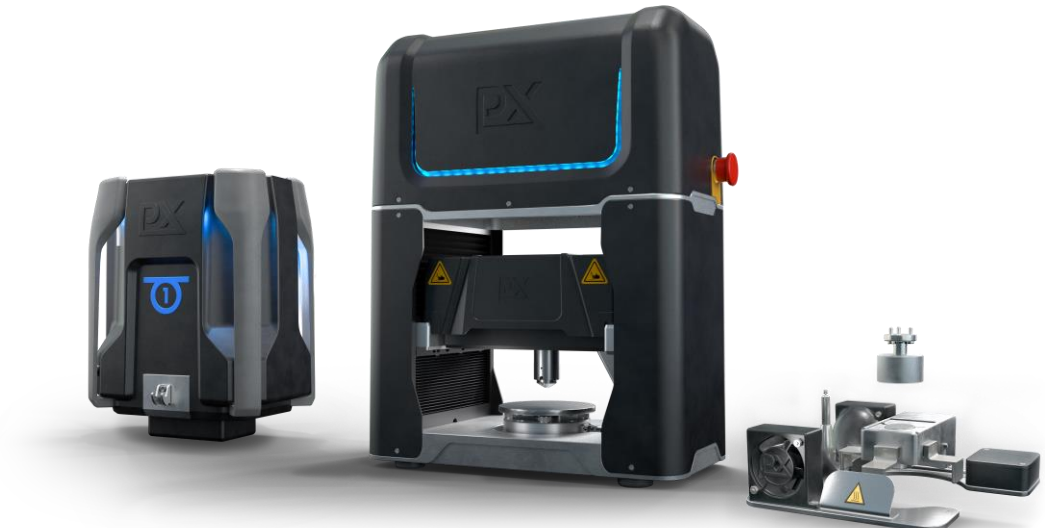
NASA



Marcus Gaiser-Porter
Applications Engineer
m.gaiser-porter@plastometrex.com

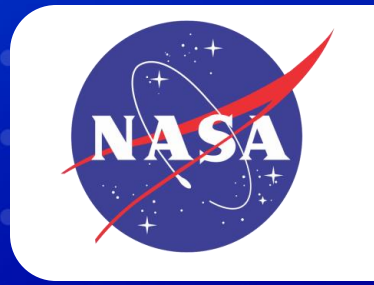
Introductions: PLX and myself

Marcus is an Applications Engineer at Plastometrex, world leaders in profilometry-based indentation plastometry (PIP), a testing method to extract mechanical properties using indentation.



Talk Overview

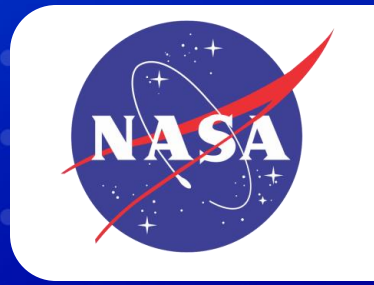
- Introduction to Profilometry-based Indentation Plastometry
- NASA HR-1 and NASA HR-2 – Fe-Ni Superalloys for Hydrogen Rich Environments
- Part Mapping – Influence of Geometry and Print Conditions
- Rapid High Temperature Characterisation
- Summary



Plastometrex

Talk Overview

- Introduction to Profilometry-based Indentation Plastometry
- NASA HR-1 and NASA HR-2 – Fe-Ni Superalloys for Hydrogen Rich Environments
- Part Mapping – Influence of Geometry and Print Conditions
- Rapid High Temperature Characterisation
- Summary



Plastometrex

Introducing PIP

The principle of Profilometry-based Indentation Plastometry (PIP) has four key steps



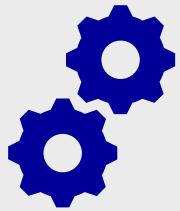
Indent sample

A small indent is created on the material's surface using the PLX-Benchtop.



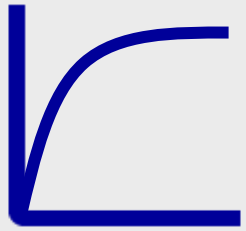
Measure shape

The indent is scanned by an integrated profilometer, which captures the shape of the material deformation.



Analyse data

The software runs a simulation, adjusting the material properties until the simulated indent matches the real one.



Stress-strain curves

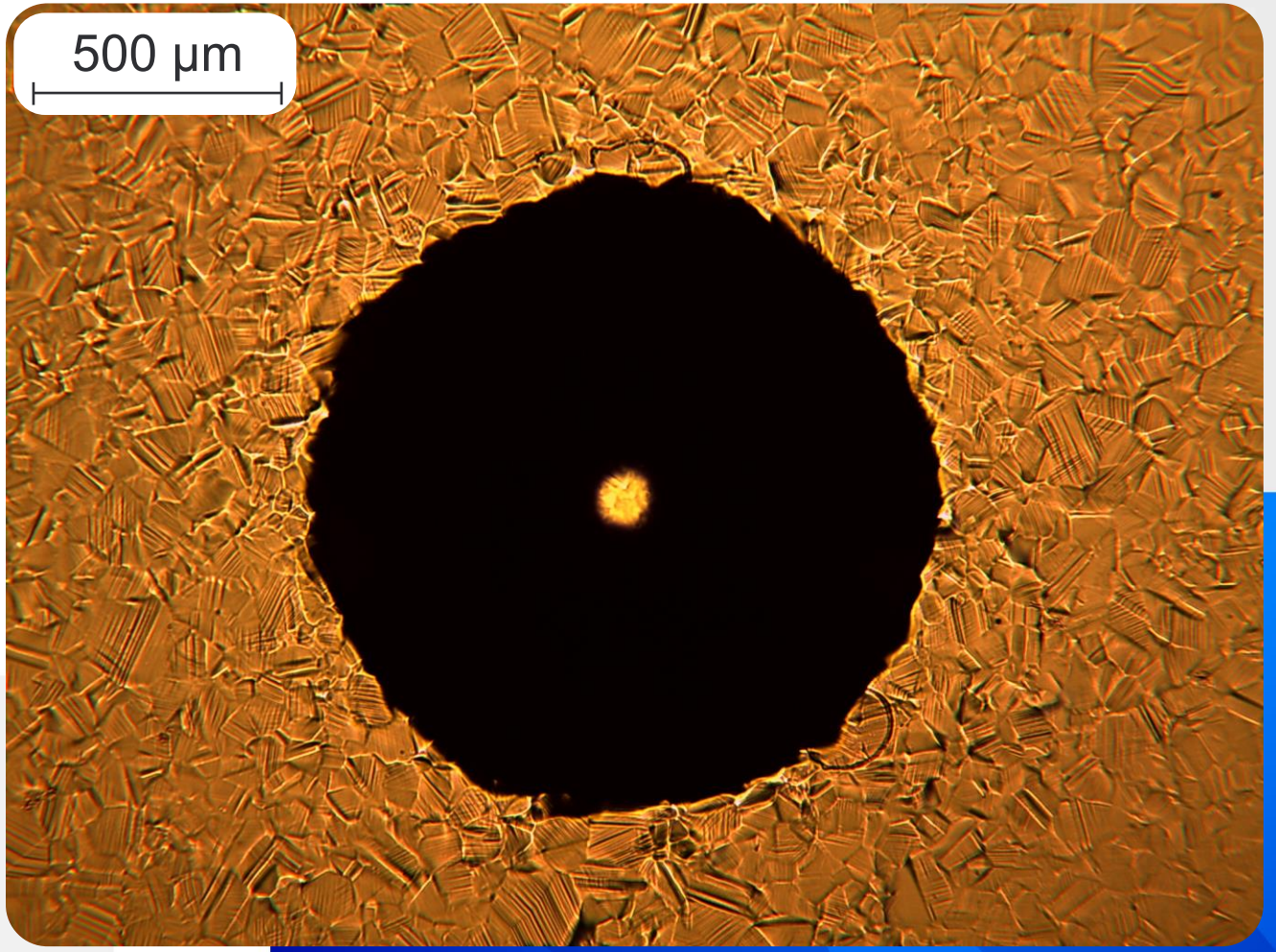
Once matched, the user is presented with a stress-strain curve,.

Indentation

Spherical indenter to produce radially symmetric indents.

Important to indent many grains to get a bulk response.

Typical indents around 100 - 200 μm deep.



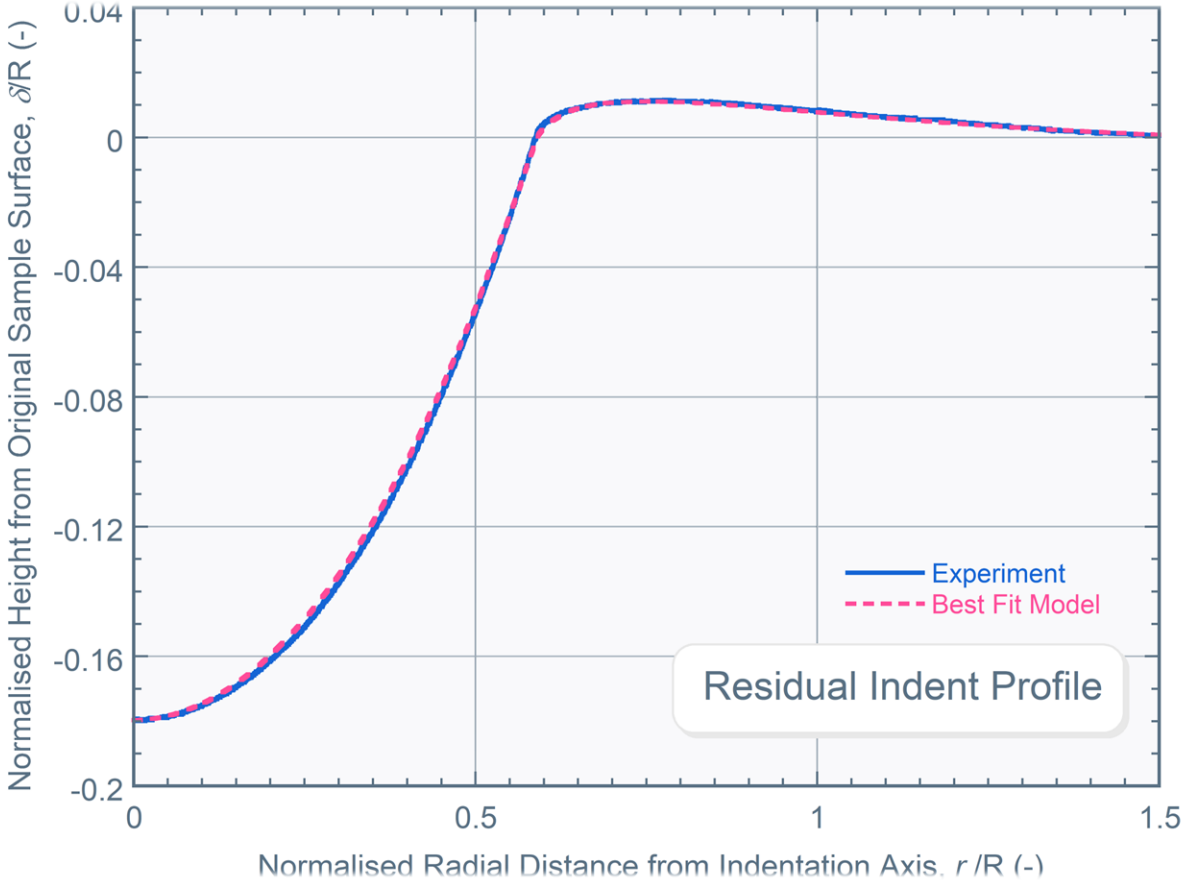
Finite Element Analysis

The Voce equation is used to describe plasticity:

$$\sigma = \sigma_S - (\sigma_S - \sigma_Y) \exp\left(\frac{-\varepsilon}{\varepsilon_0}\right)$$

Where σ_Y : yield stress, σ_S : saturation stress, ε_0 : characteristic strain.

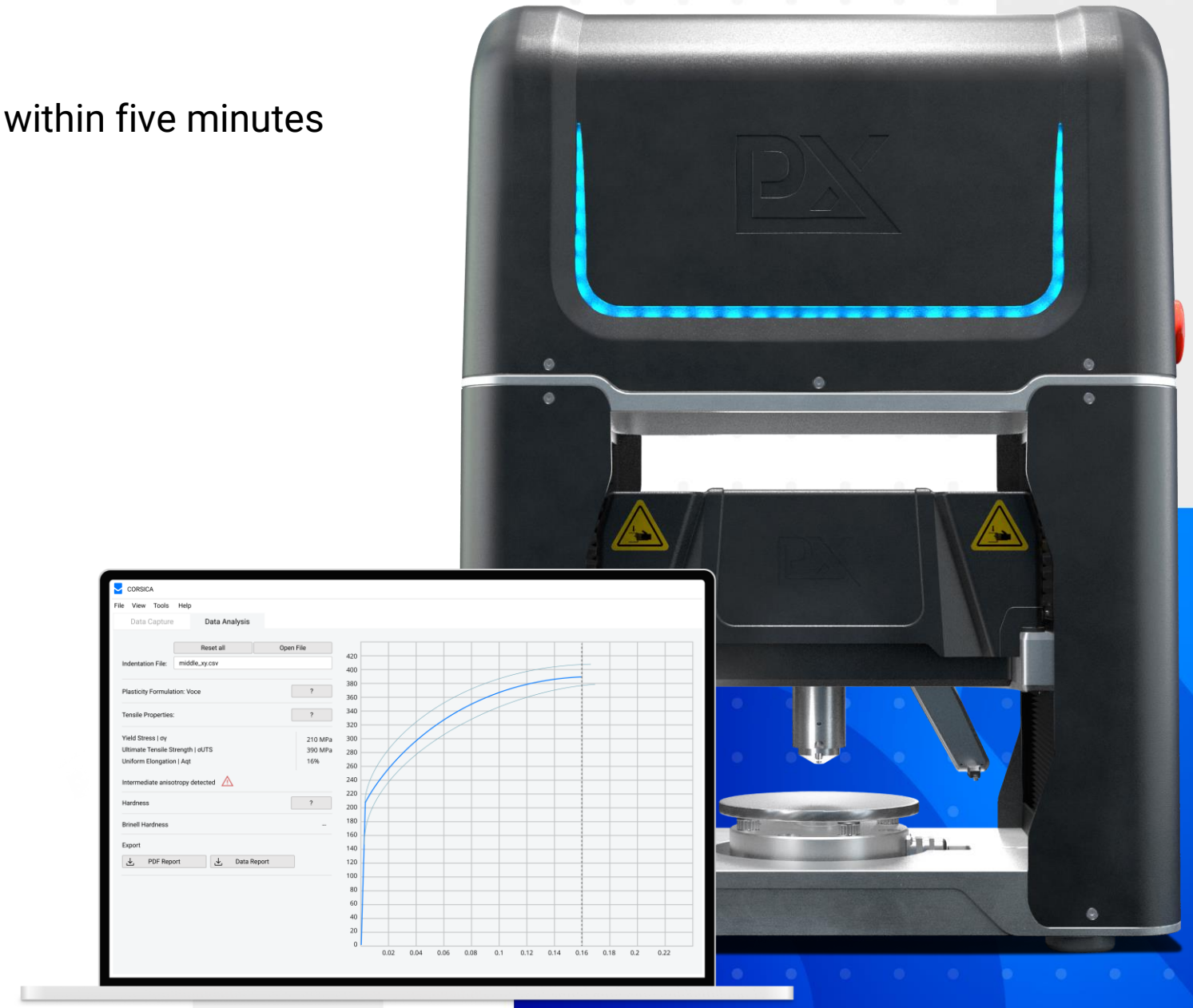
The approximate Young's modulus of the material is required as an input.

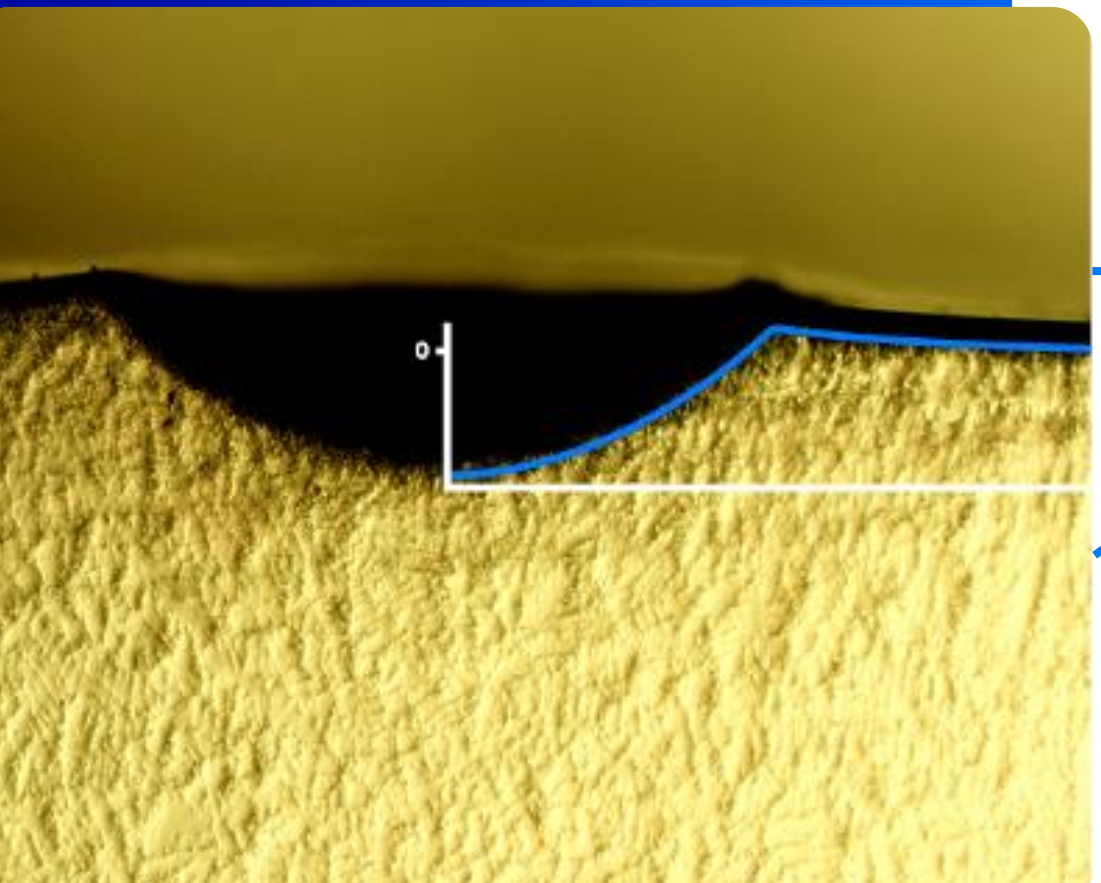


PLX-Benchtop

Fully automated process, results within five minutes

- Stress-strain curves up to UTS
- Surface roughness
- Hardness
- Anisotropy detection







Sample Specification

Surface Finish
P1200 or 600-gritt

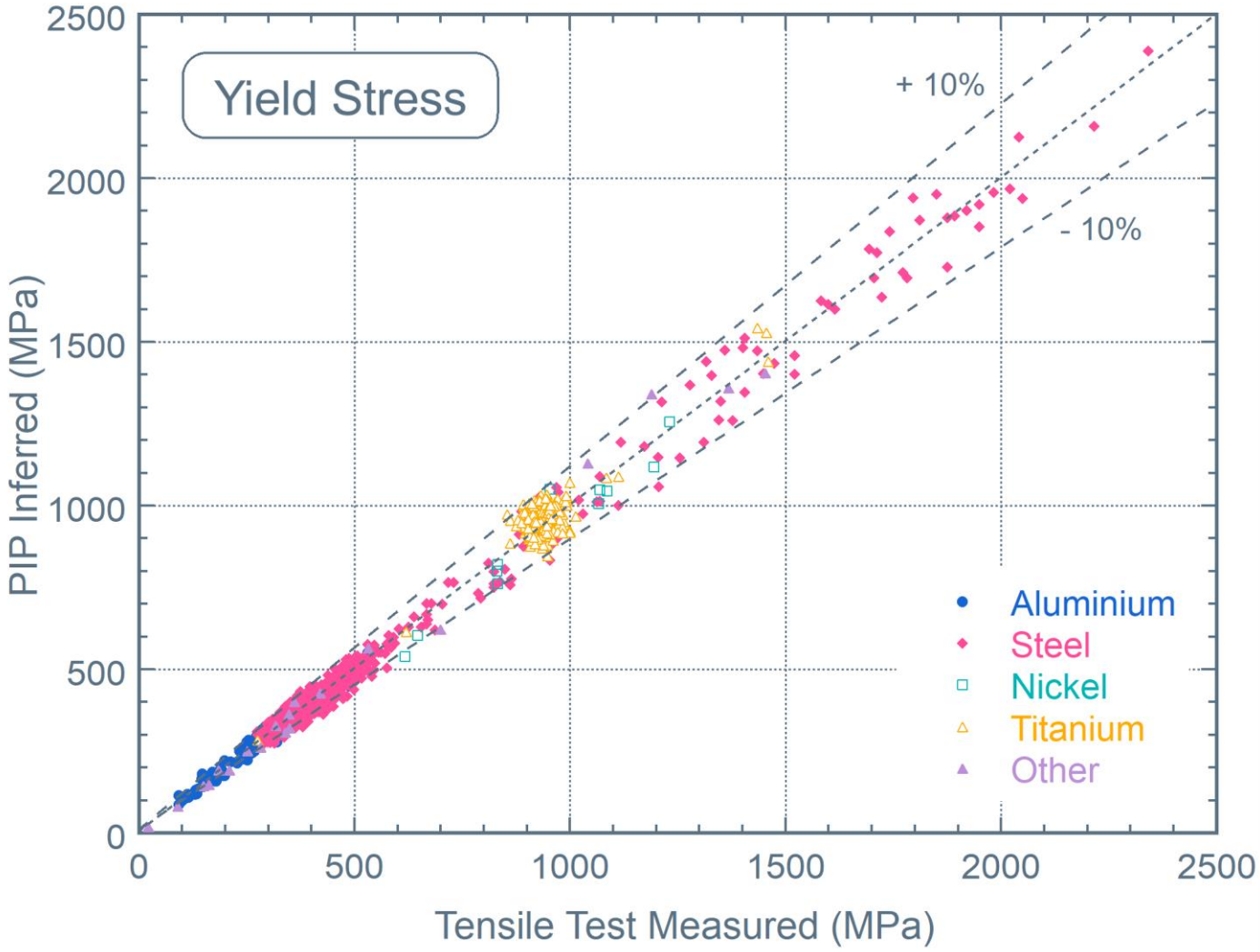
Diameter
Minimum : 3 mm
Maximum: 150 mm

Thickness
Minimum : 1.5 mm
Maximum: 70 mm

Validation

PIP has been widely validated against the results of conventional tensile testing. PIP captures the values of yield stress and ultimate tensile strength.

	Yield Stress (%)	Ultimate Tensile Stress (%)
Average agreement	5.9	4.1

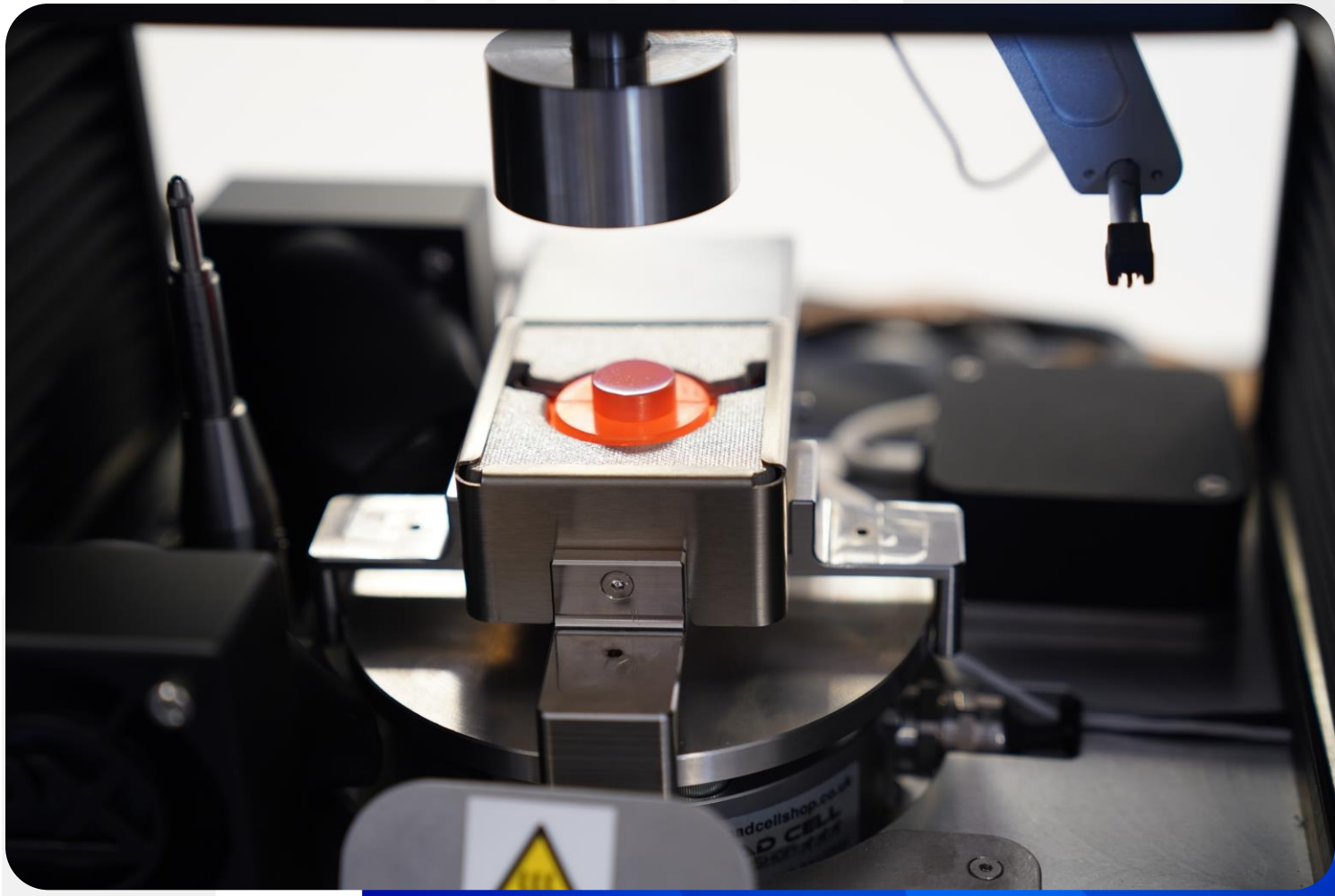


PLX-HotStage

Modular attachment to PLX-Benchtop.

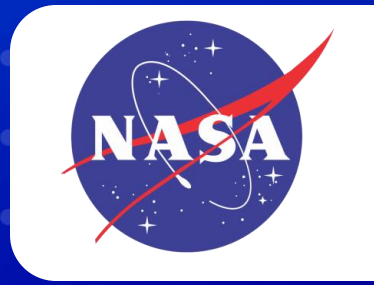
Elevated temperature testing up to 800°C (~1500°F).

Small sample size enables rapid testing.



Talk Overview

- Introduction to Profilometry-based Indentation Plastometry
- NASA HR-1 and NASA HR-2 – Fe-Ni Superalloys for Hydrogen Rich Environments
- Part Mapping – Influence of Geometry and Print Conditions
- Rapid High Temperature Characterisation
- Summary



Plastometrex

Introduction to NASA HR-1 and NASA HR-2

High strength Fe-Ni superalloy specifically designed for resistance to hydrogen environment embrittlement.

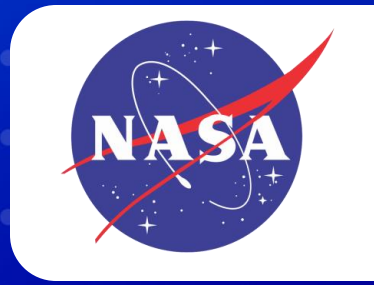
Both alloys have good printability and parts are manufactured via both directed energy deposition (DED) and laser powder bed fusion (LPBF).



Additive Manufacturing of NASA HR-1 Material for Liquid Rocket Engine Component Applications, Colton Katsarelis, Po Chen, Paul Gradl, Chris Protz, Zachary Jones, David Ellis, Laura Evans, JAANAF Dec 2019, Report Number: M19-7797

Talk Overview

- Introduction to Profilometry-based Indentation Plastometry
- NASA HR-1 and NASA HR-2 – Fe-Ni Superalloys for Hydrogen Rich Environments
- Part Mapping – Influence of Geometry and Print Conditions
- Rapid High Temperature Characterisation
- Summary



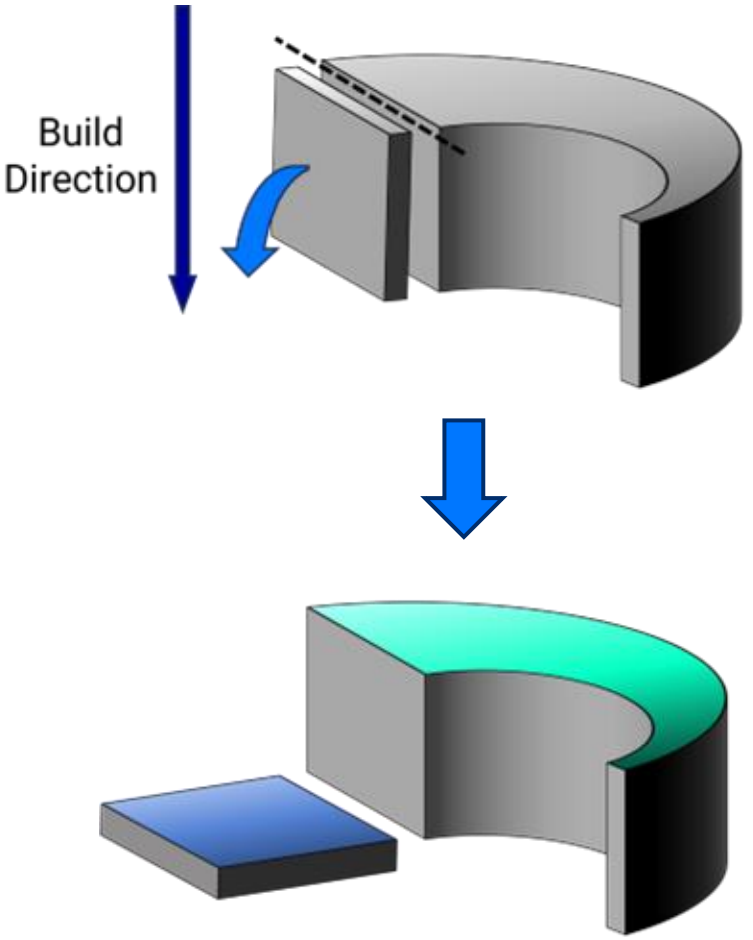
Plastometrex

Part Mapping – Experimental Details

C-ring made of NASA HR-1 manufactured using LPBF.

Mapping of mechanical properties performed in two perpendicular faces using PIP:

- In a 6 mm grid pattern in the XZ plane
- In rows going around the arc of the C-ring

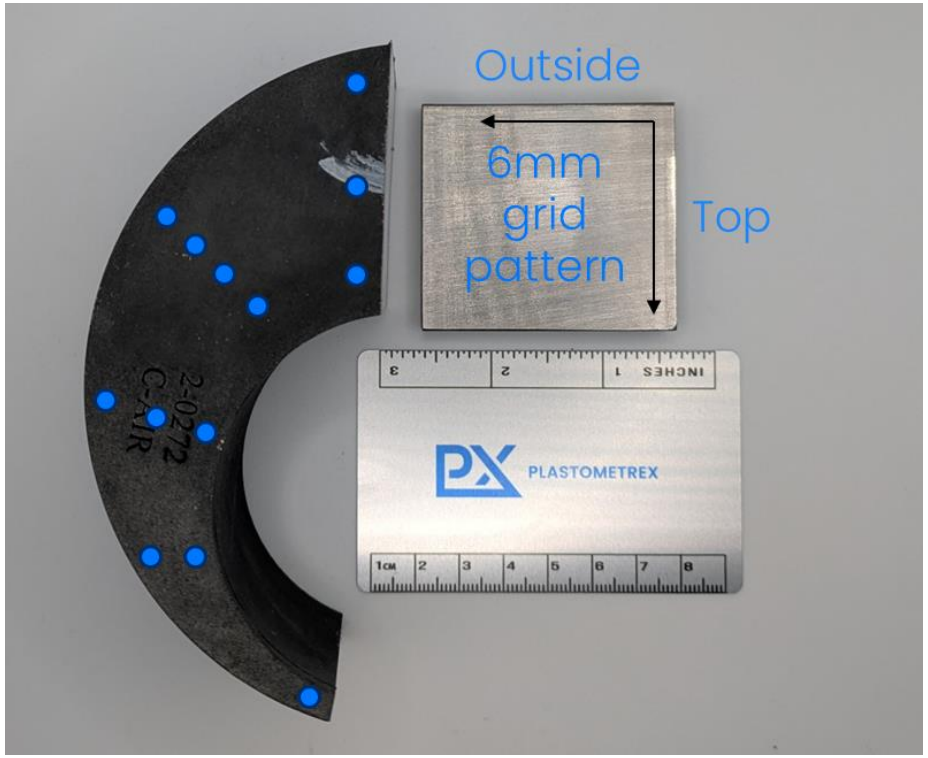


Part Mapping – Experimental Details

C-ring made of NASA HR-1 manufactured using LPBF.

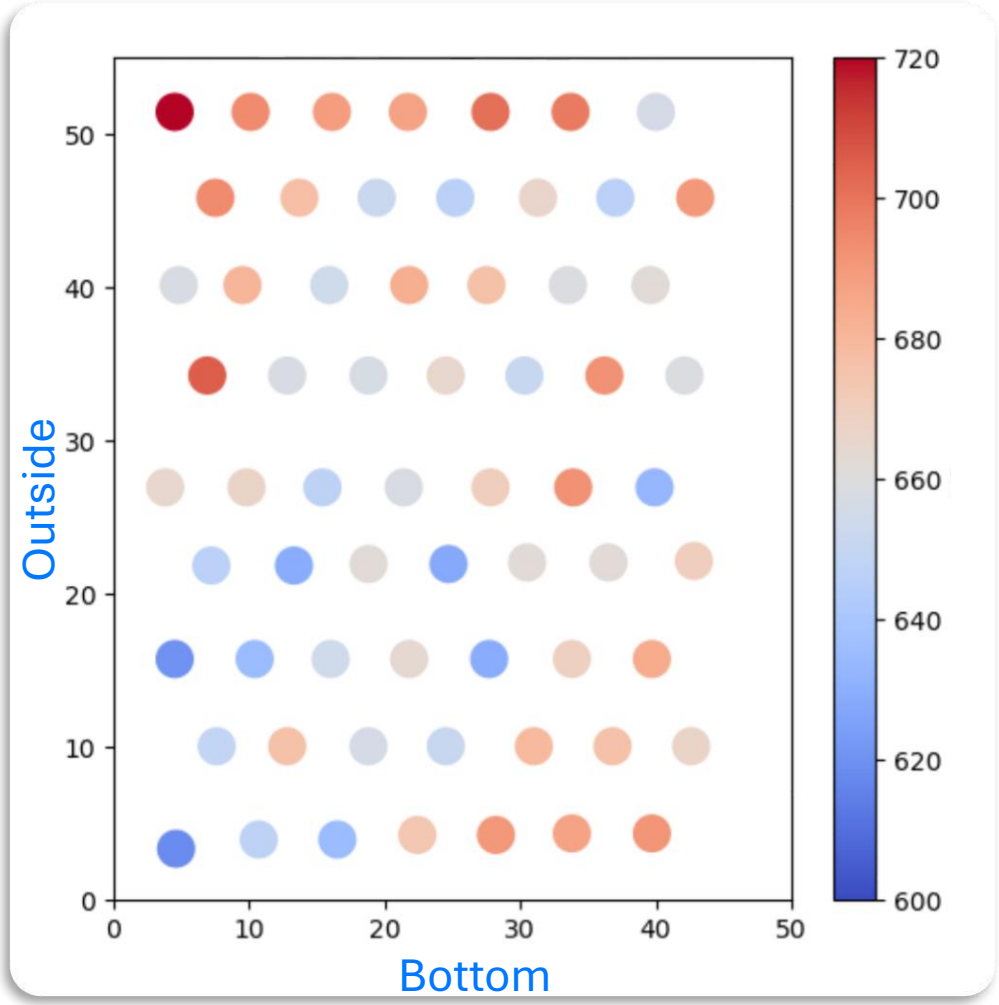
Mapping of mechanical properties performed in two perpendicular faces using PIP:

- In a 6 mm grid pattern in the XZ plane
- In rows going around the arc of the C-ring



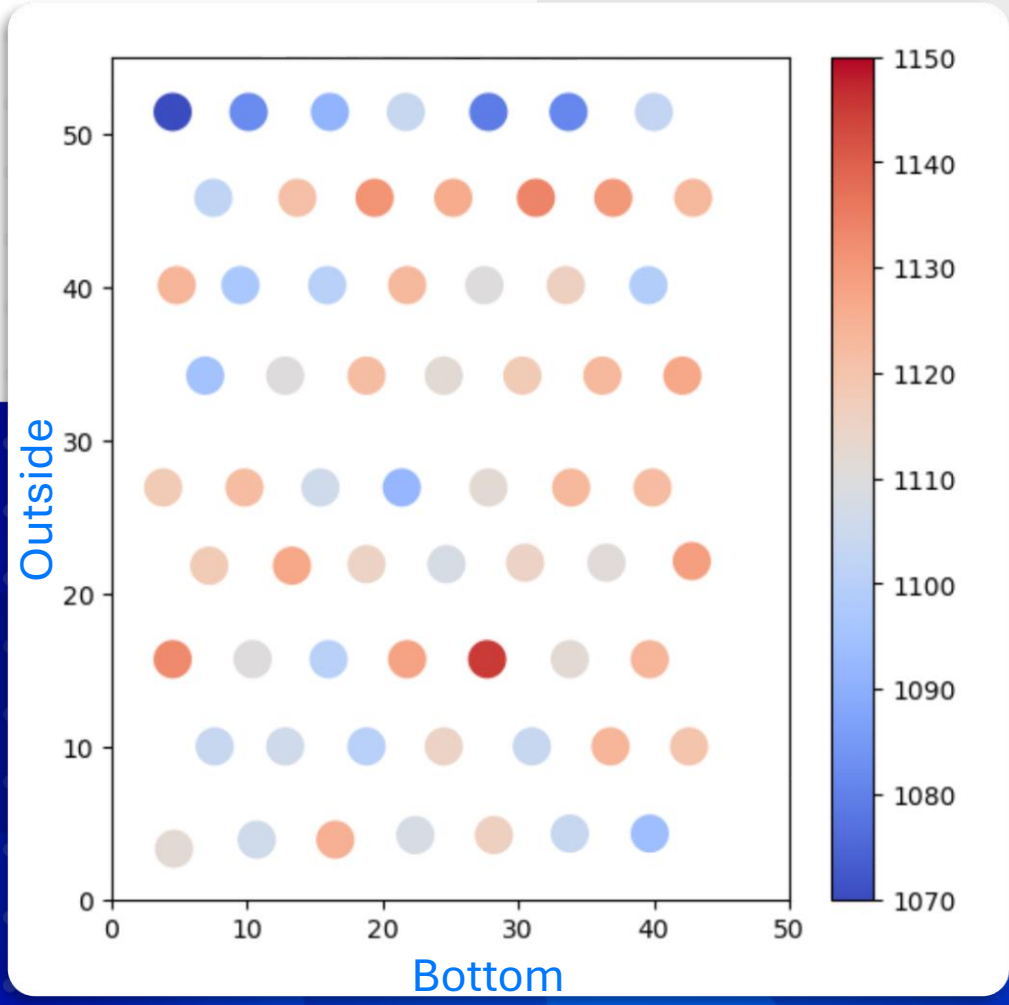
XZ Cross-Section Mapping

Yield Stress



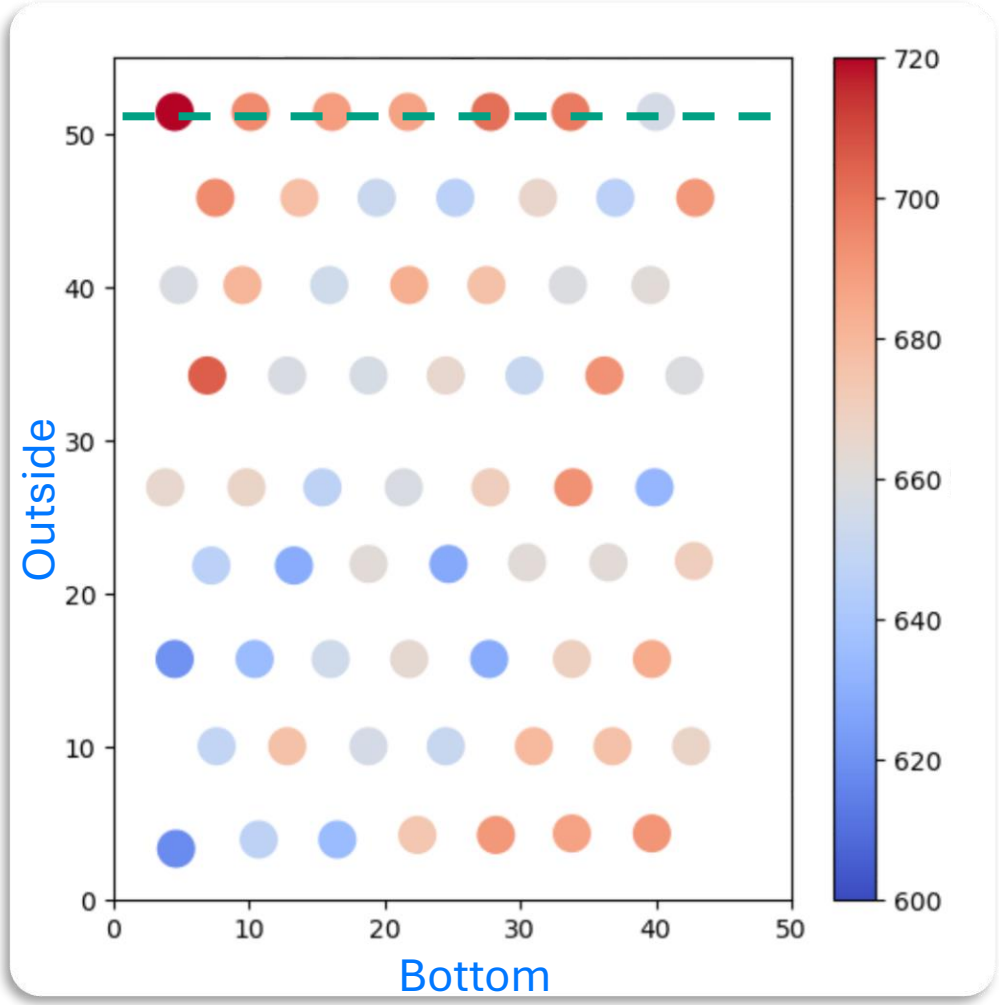
C-ring is fairly homogeneous in cross-section

Ultimate Tensile Strength



XZ Cross-Section Mapping

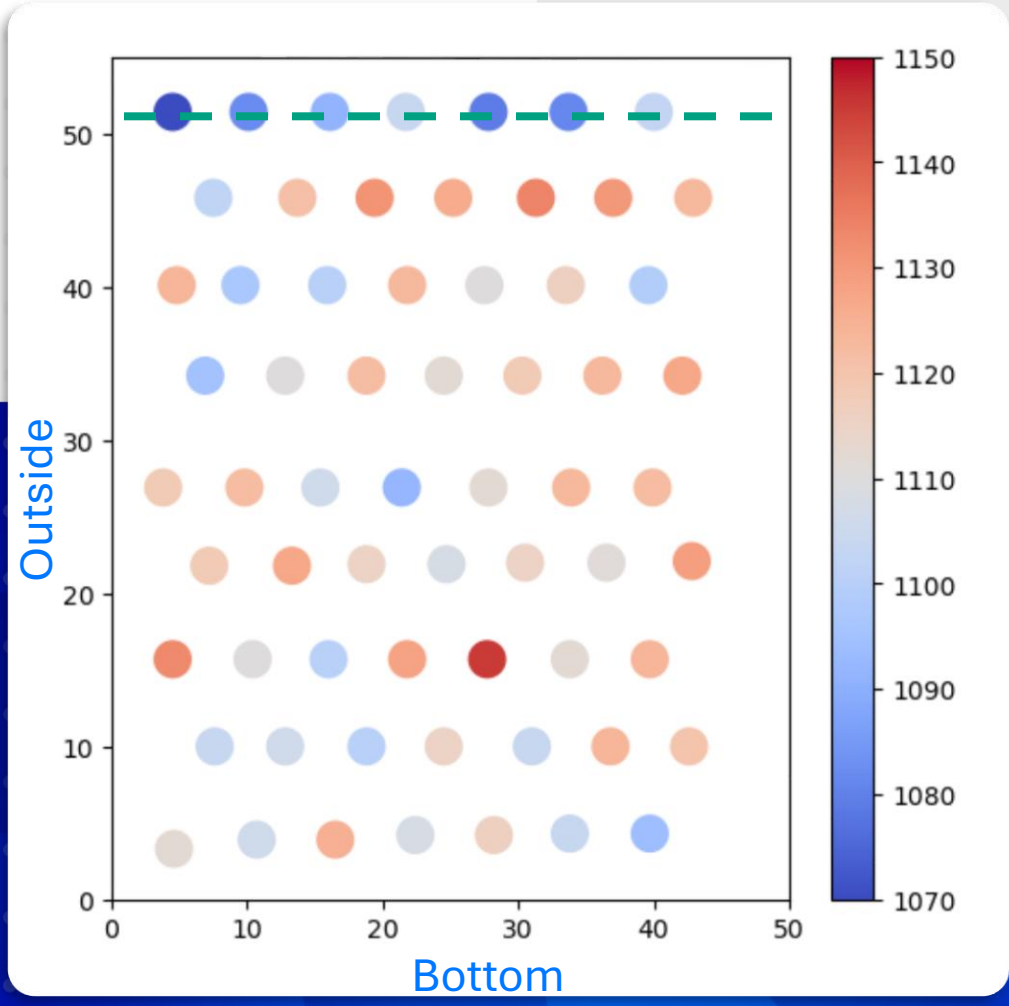
Yield Stress



Pause in build along dashed line – higher YS and lower UTS measured at top

C-ring is fairly homogeneous in cross-section

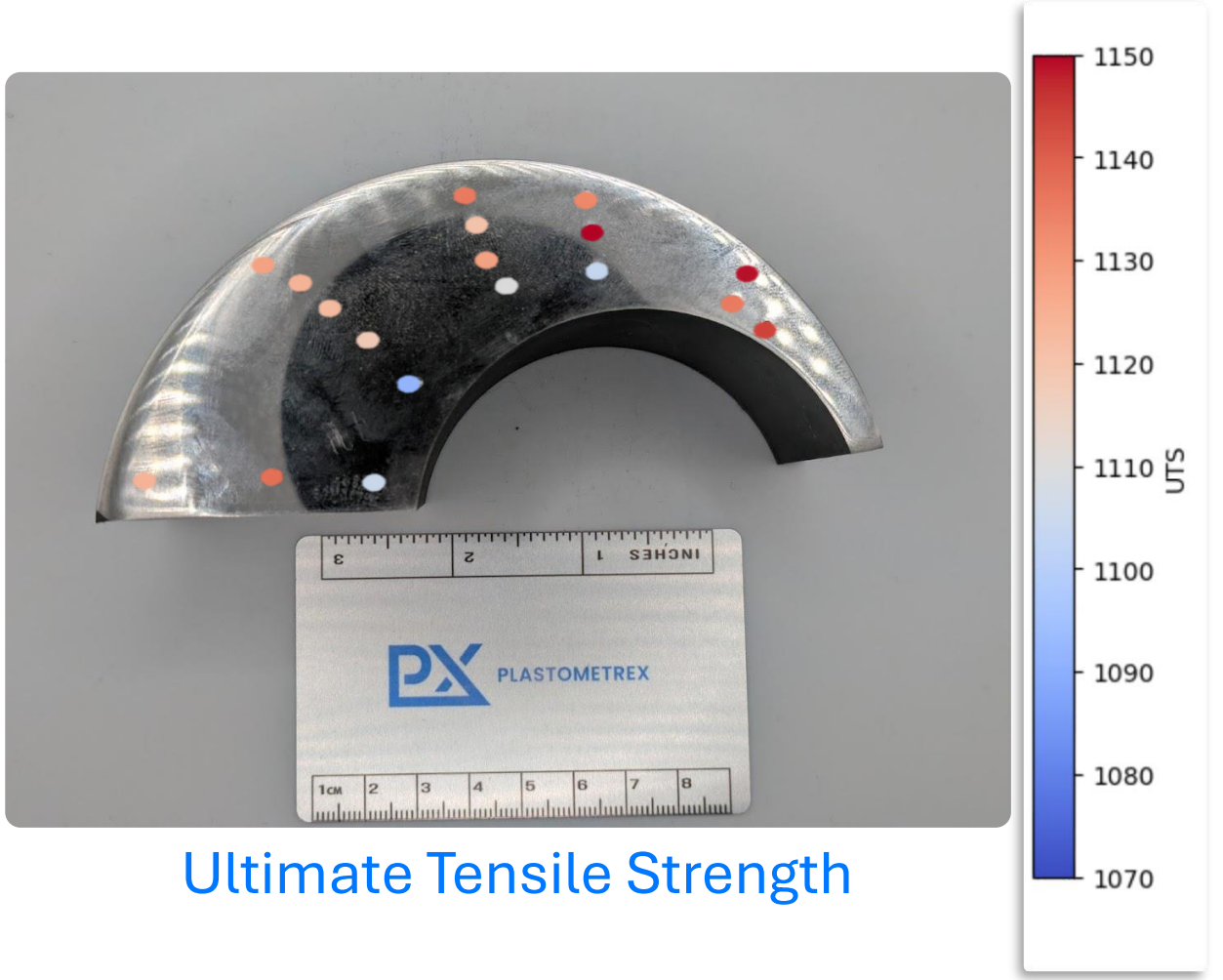
Ultimate Tensile Strength



C-ring mapping – changing properties with geometry

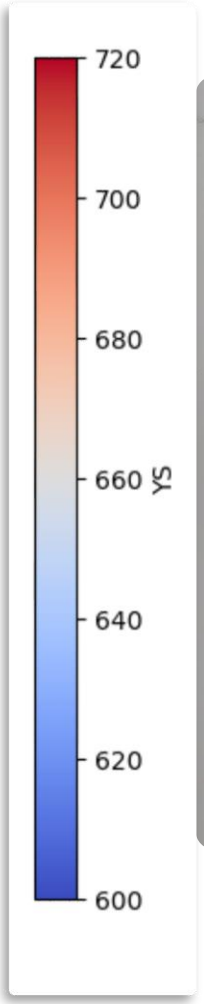


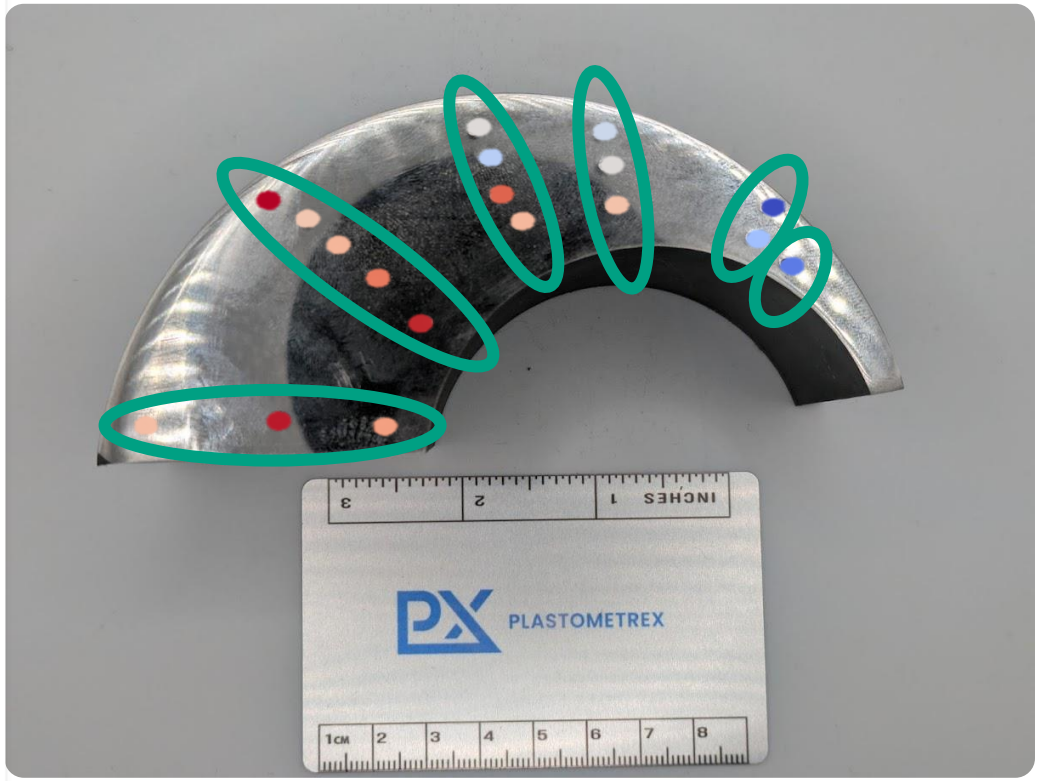
Yield Stress



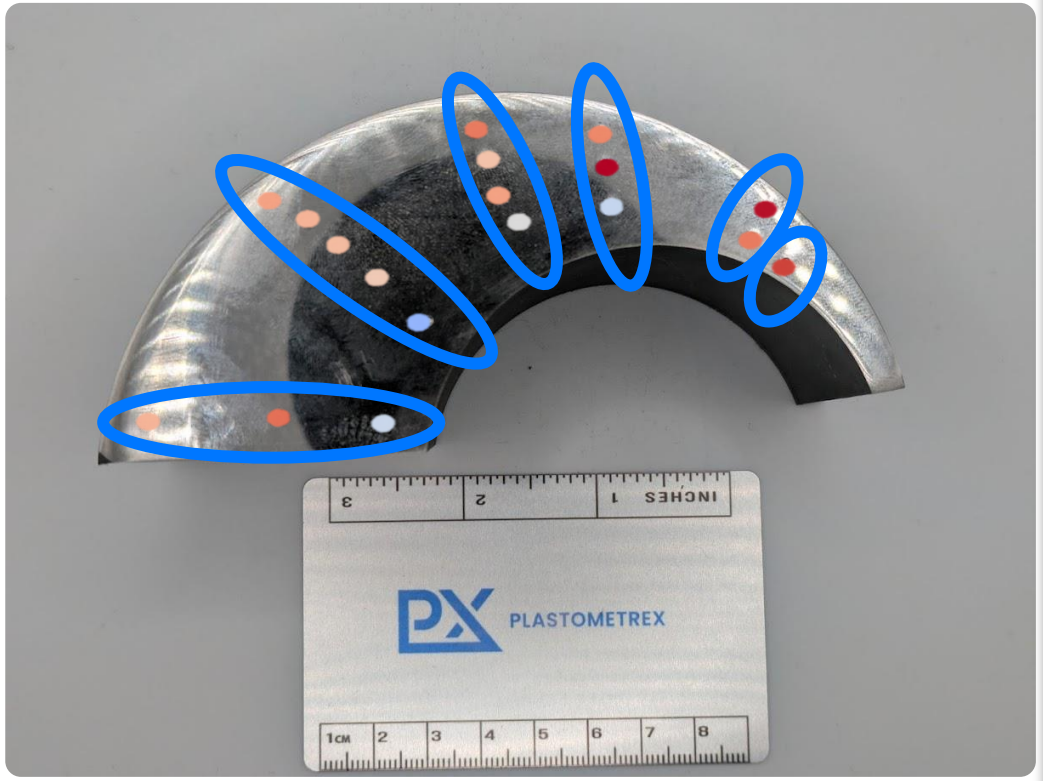
Ultimate Tensile Strength

C-ring mapping – changing properties with geometry

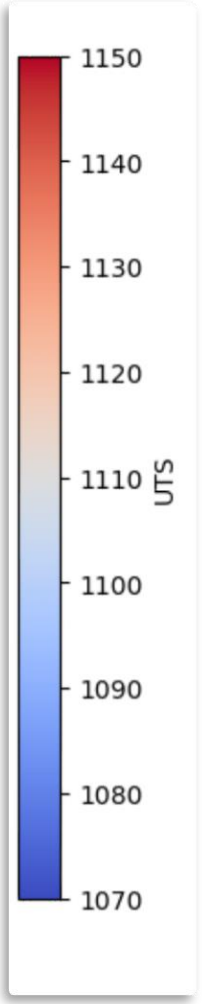




Yield Stress



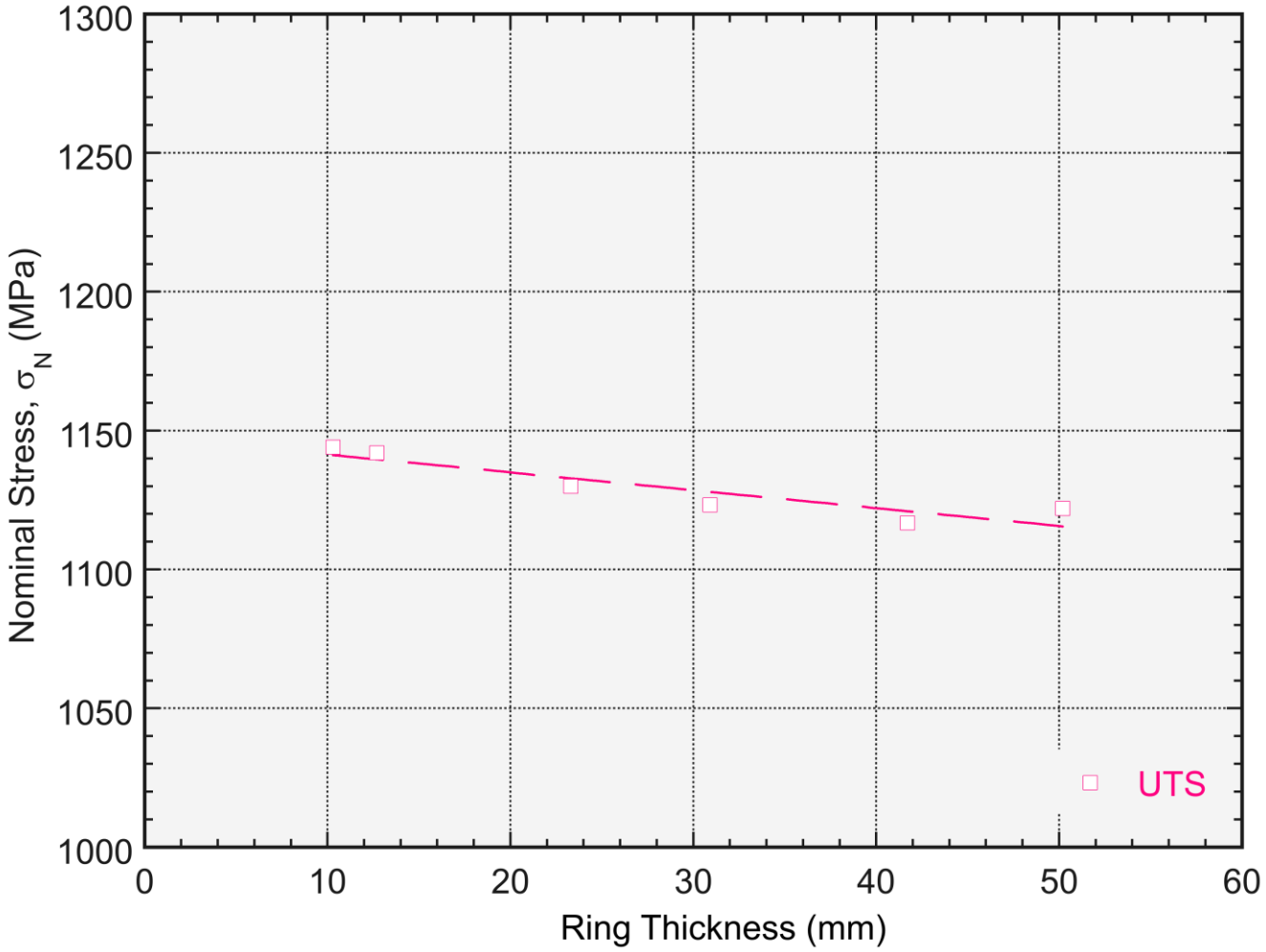
Ultimate Tensile Strength



C-ring mapping – changing properties with geometry

Limited effect on UTS results.

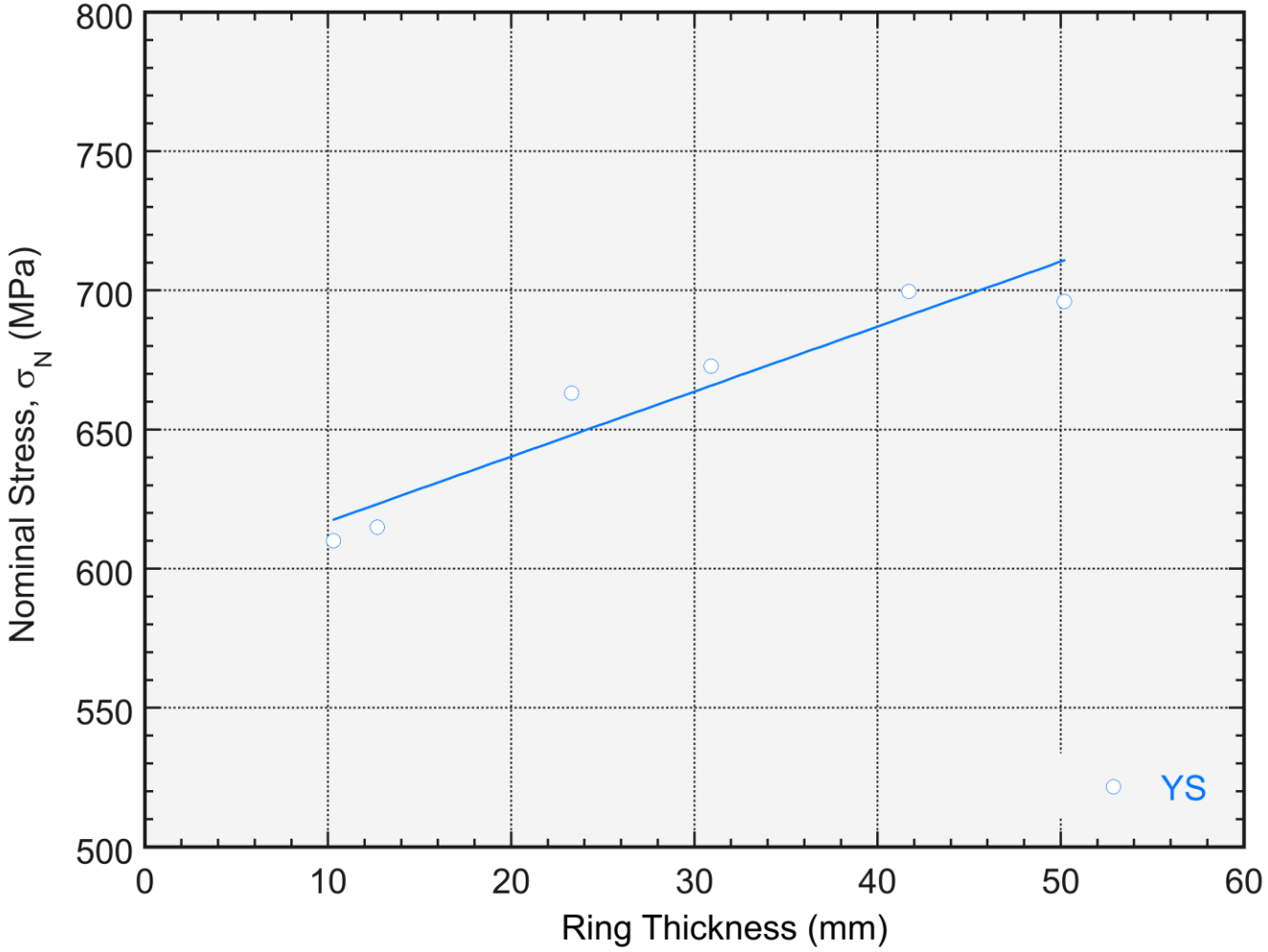
Clear increase in yield stress with increasing ring thickness.



C-ring mapping – changing properties with geometry

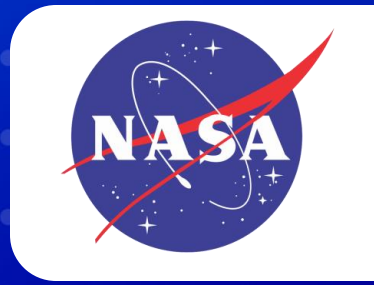
Limited effect on UTS results.

Clear increase in yield stress with increasing ring thickness.



Talk Overview

- Introduction to Profilometry-based Indentation Plastometry
- NASA HR-1 and NASA HR-2 – Fe-Ni Superalloys for Hydrogen Rich Environments
- Part Mapping – Influence of Geometry and Print Conditions
- Rapid High Temperature Characterisation
- Summary



Plastometrex

High temperature testing of NASA HR-1 and NASA HR-2

PIP testing on DED NASA HR-1 and LPBF NASA HR-2.

Tests performed on 15 mm discs up to 800°C.

Max test time at 800°C was less than an hour. Testing complete temperature range took less than a day for each material.



20 °C → 800 °C

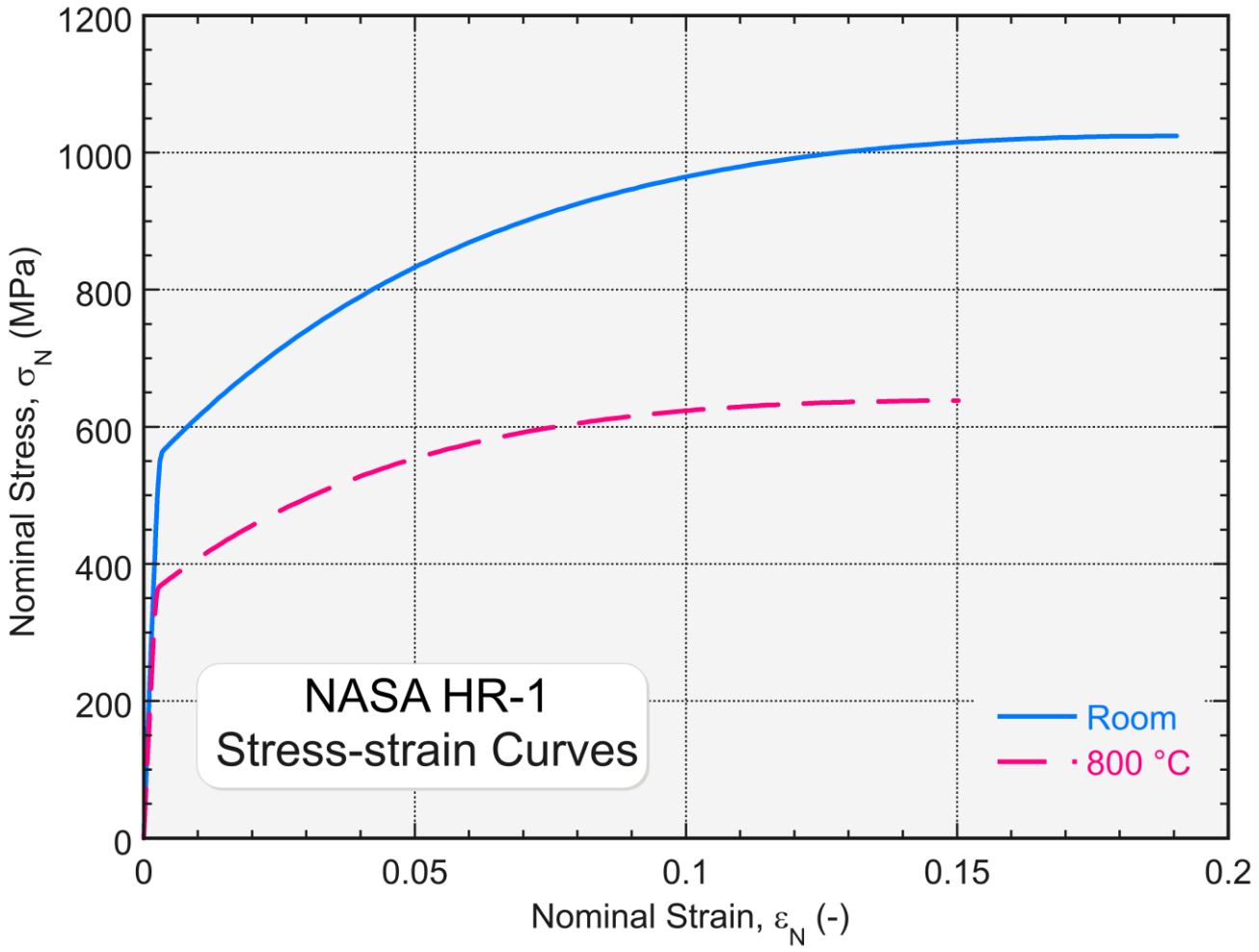
High temperature PIP testing

DED NASA HR-1

Full stress-strain curve derived at each test temperature.

Agreement with corresponding high temperature tensile excellent up to 650°C.

Beyond 650°C, creep likely to be affecting both PIP and tensile.



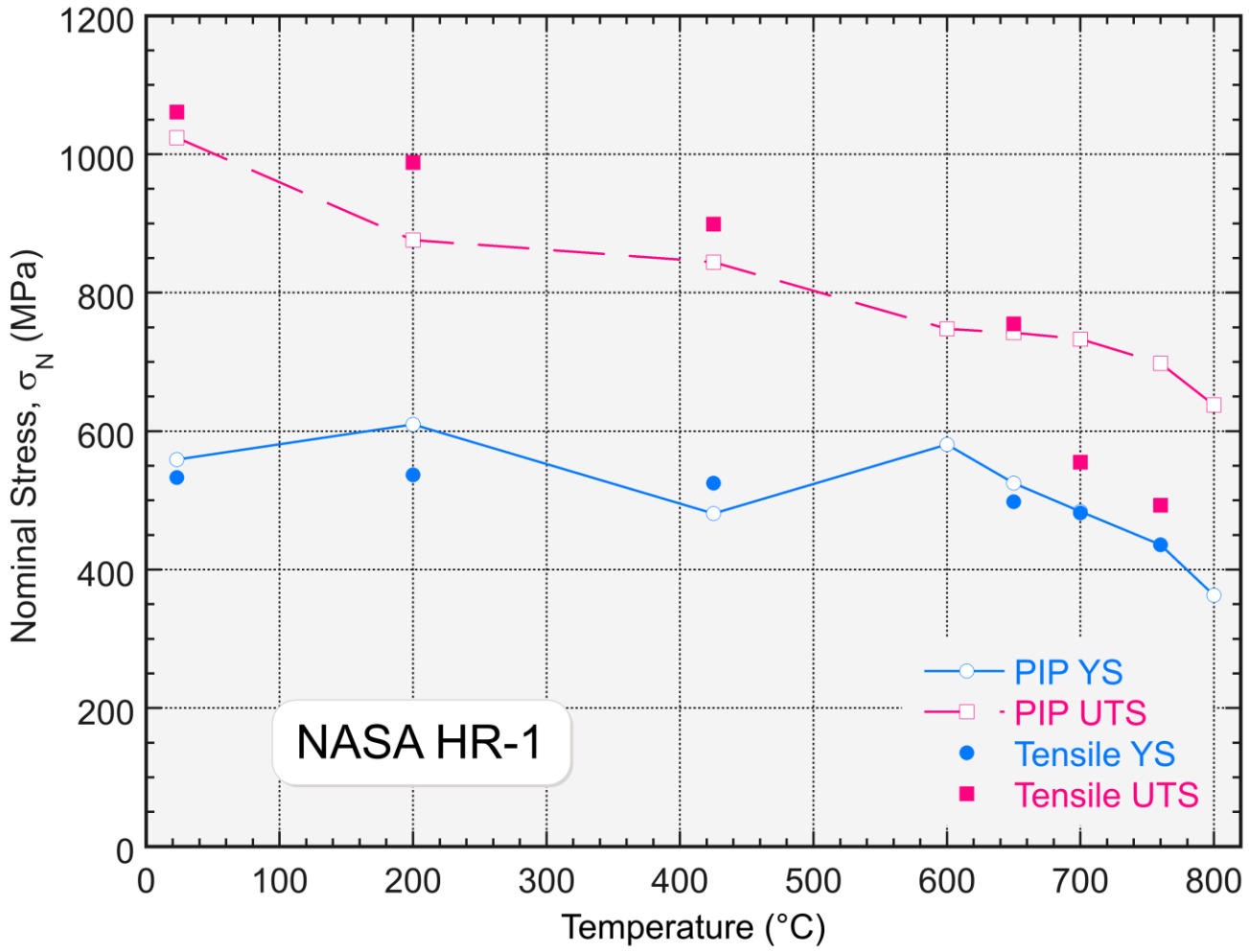
High temperature PIP testing

DED NASA HR-1

Full stress-strain curve derived at each test temperature.

Agreement with corresponding high temperature tensile excellent up to 650°C.

Beyond 650°C, creep likely to be affecting both PIP and tensile.



High temperature PIP testing

LPBF NASA HR-2

Two different heat treatment conditions, HT1 and HT2.

Difference in first HT stage of 27°C (~4%).

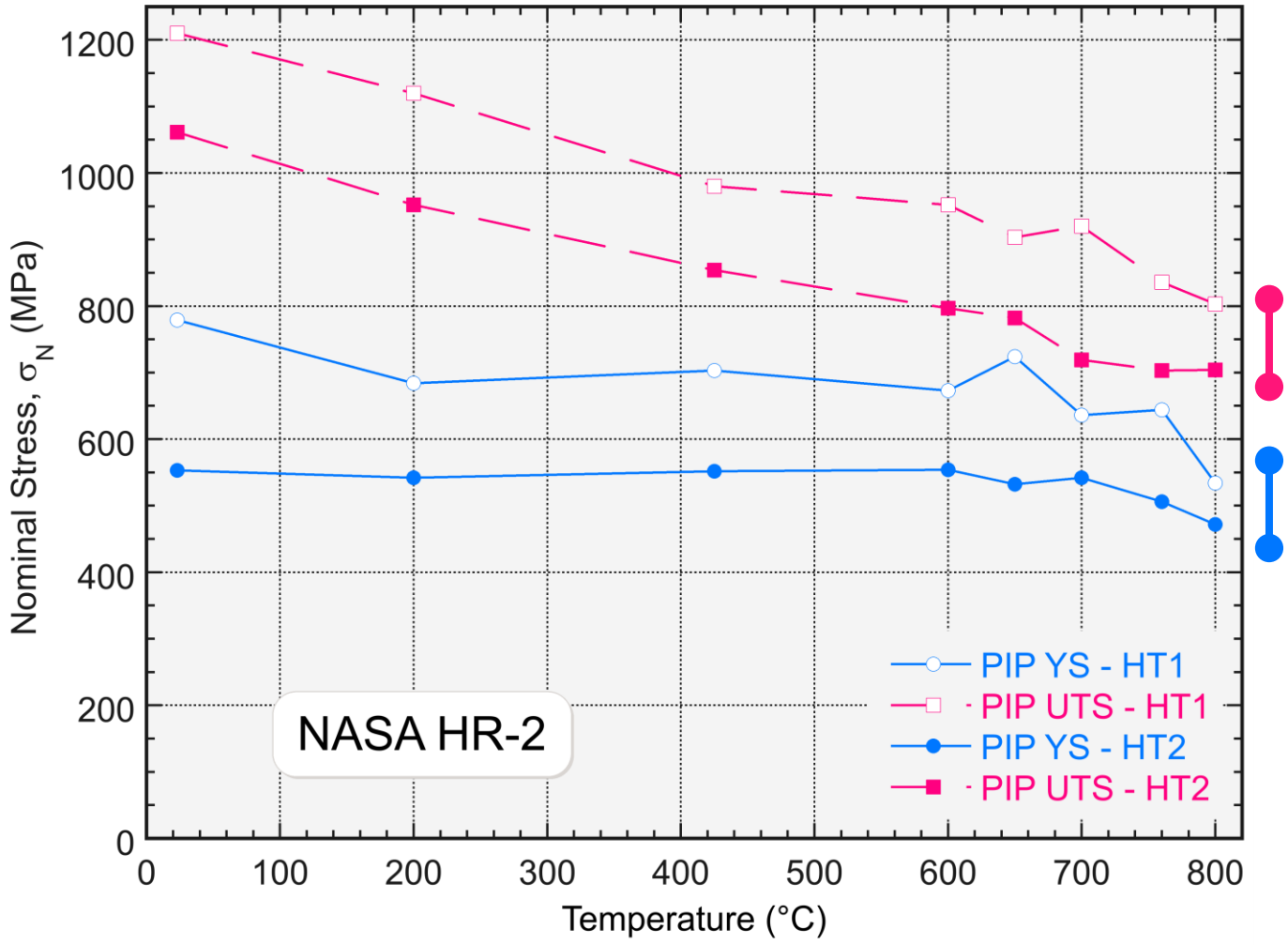
Sample	Heat treatment stage 1	Heat treatment stage 2
NASA HR-2 HT1	16 hours @ **718°C**	16 hours @ 621°C
NASA HR-2 HT2	16 hours @ **691°C**	16 hours @ 621°C

High temperature PIP testing

LPBF NASA HR-2

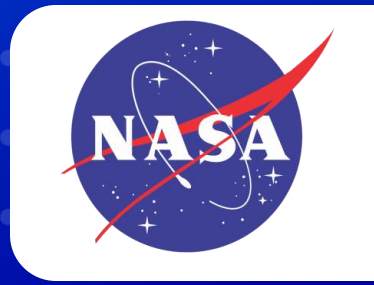
High sensitivity of mechanical properties to HT condition.

Emphasises importance of process control and monitoring.



Talk Overview

- Introduction to Profilometry-based Indentation Plastometry
- NASA HR-1 and NASA HR-2 – Fe-Ni Superalloys for Hydrogen Rich Environments
- Part Mapping – Influence of Geometry and Print Conditions
- Rapid High Temperature Characterisation
- Summary



Plastometrex

Summary

PLX-Benchtop can be used to generate stress – strain curves from small samples.

Part geometry and process control in AM can have a significant impact on performance

New mechanical testing approach can provide significant value for rapid material evaluation

