UFT RESPONSE OF VERTICALLY AND HORIZONTALLY PRINTED

TI-6AL-4V AND INCONEL 718

Diogo Montalvão, Sina Safari, Phil Sewell, Amor Abdelkader,

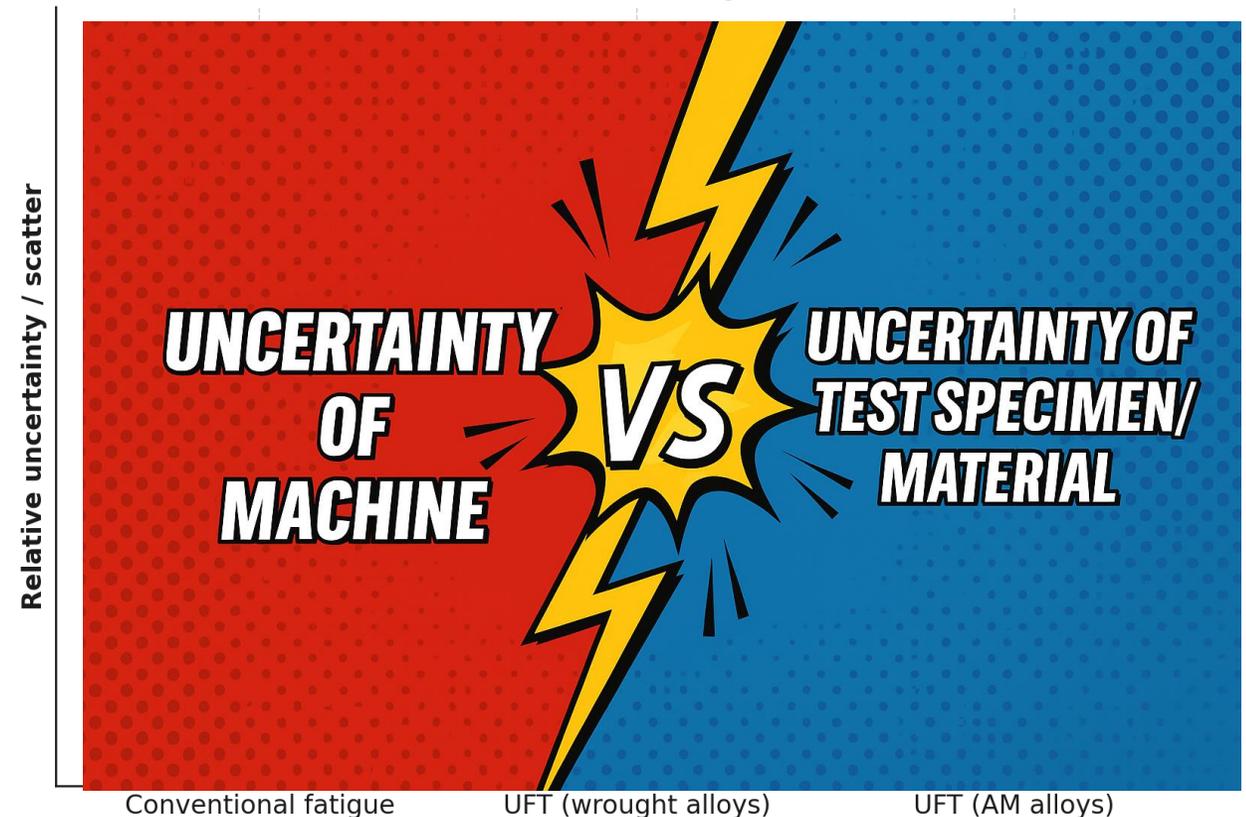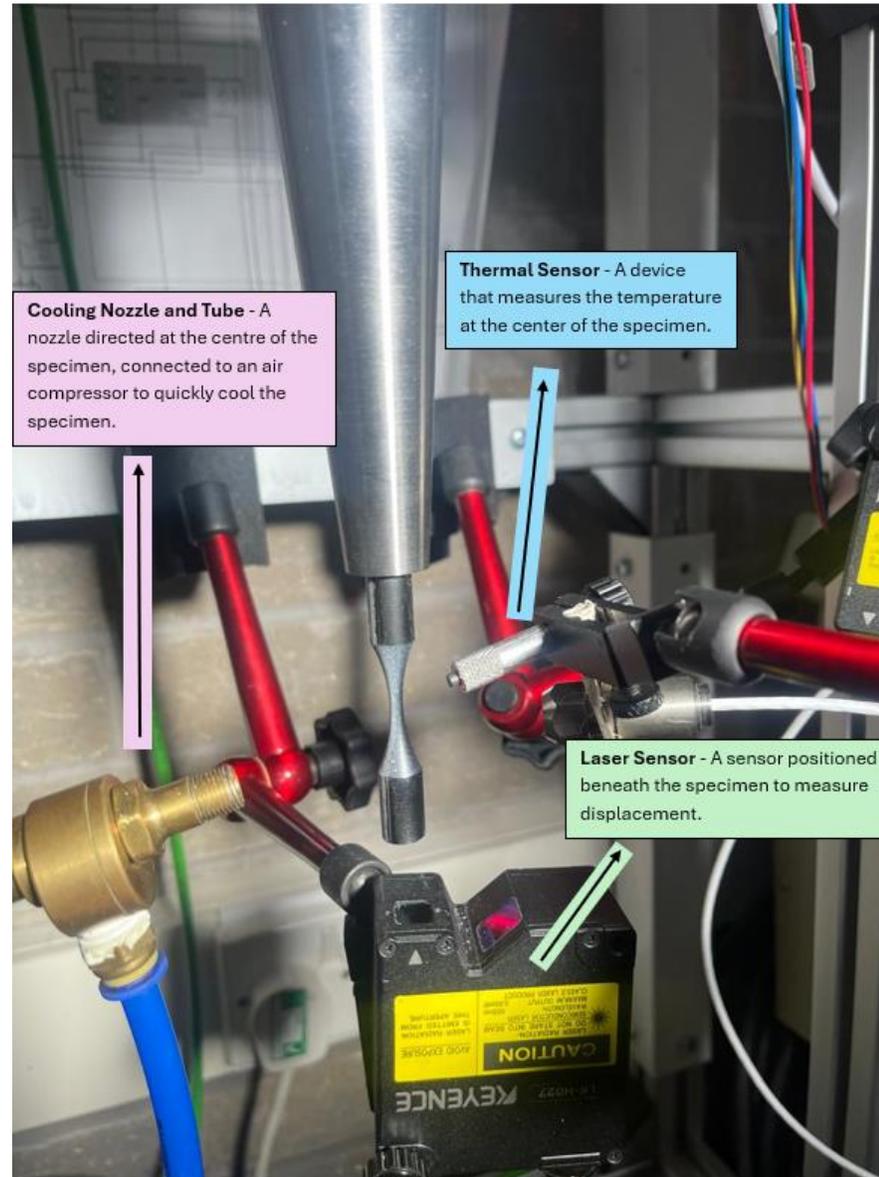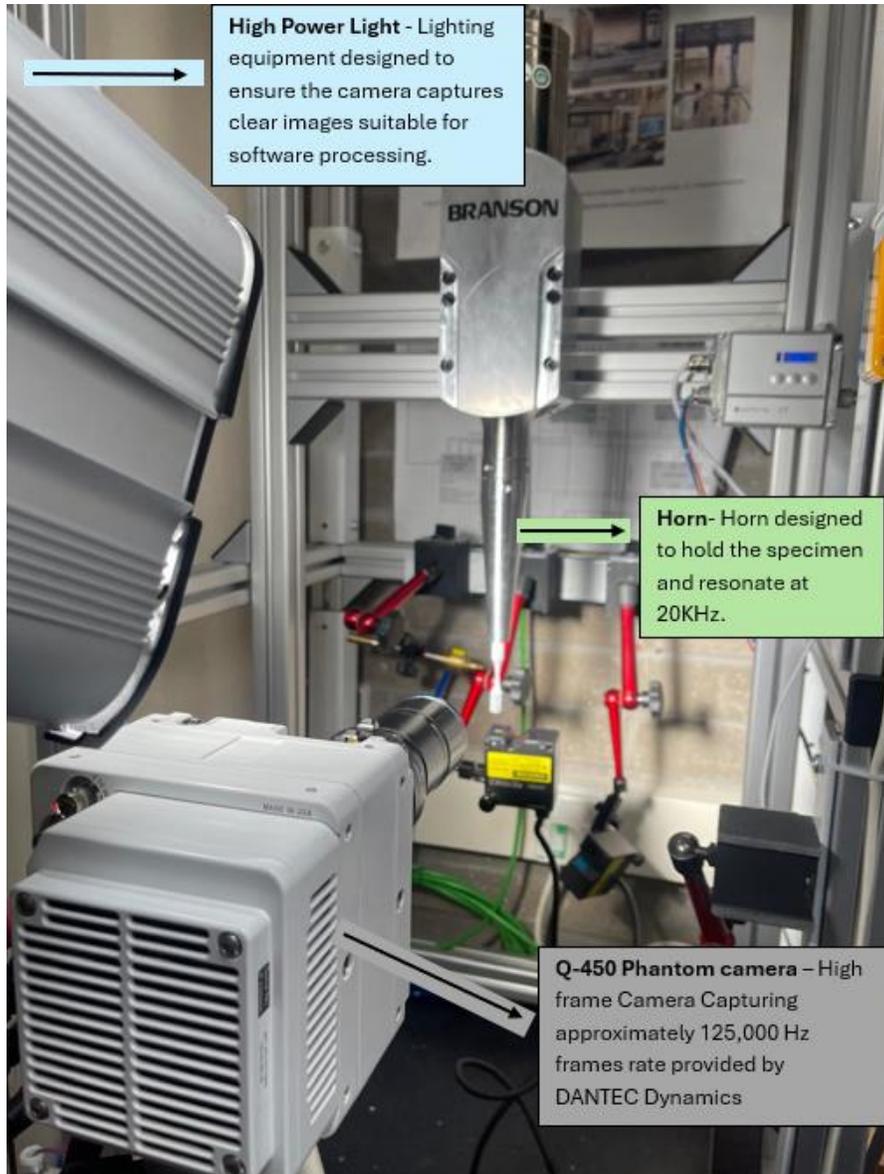**Richard Baxter, Ian Johnston, Dan McCluskey**

September 2025

ADDISONIC
Advanced Manufacturing Ultrasonic
Fatigue Prediction & Life Extension
Bournemouth University
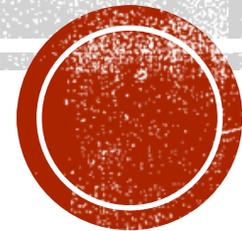
Uncertainty in Fatigue Testing with AMed Specimens

✓ **Conventional tests** → large specimens, direct strain/stress measurement, established reliability.

✓ **UFT** → requires indirect calibration (tip displacement → centre strain), sensitive to surface texture and correct frequency tuning, introduces uncertainty.

✓ **UFT + AM** → adds extra scatter due to porosity, anisotropy, microstructural variability.

Why Calibration & Uncertainty Matter in UFT (Even More for AM Specimens)

Relative uncertainty / scatter

UNCERTAINTY OF MACHINE **VS** UNCERTAINTY OF TEST SPECIMEN/ MATERIAL

Conventional fatigue   UFT (wrought alloys)   UFT (AM alloys)

Ultrasonic Fatigue testing @ Bournemouth University

High Power Light - Lighting equipment designed to ensure the camera captures clear images suitable for software processing.

Horn- Horn designed to hold the specimen and resonate at 20KHz.

Q-450 Phantom camera – High frame Camera Capturing approximately 125,000 Hz frames rate provided by DANTEC Dynamics

Cooling Nozzle and Tube - A nozzle directed at the centre of the specimen, connected to an air compressor to quickly cool the specimen.

Thermal Sensor - A device that measures the temperature at the center of the specimen.

Laser Sensor - A sensor positioned beneath the specimen to measure displacement.

Sources of uncertainties in UFT
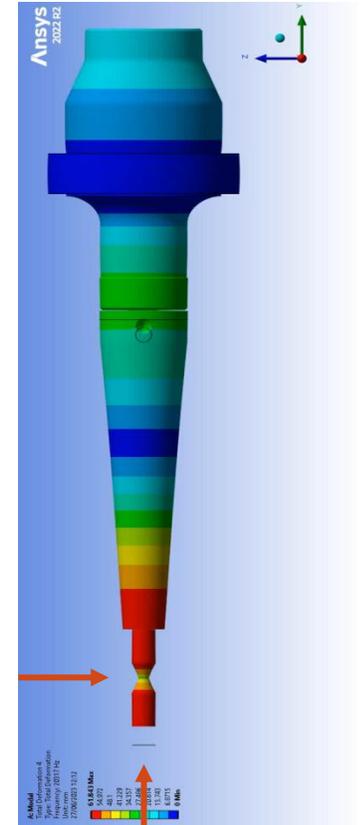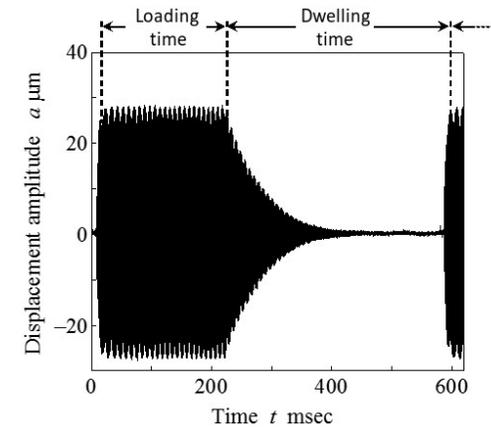
- when deriving relationship between strain and tip displacement

    - Control system
    - Laser reading
    - DIC or strain gauge reading on control volume
    - Material variability
    - Machine reassembly (beeswax)
    - Modal Coupling
    - Specimen's geometry
    - Surface texture
    - etc.
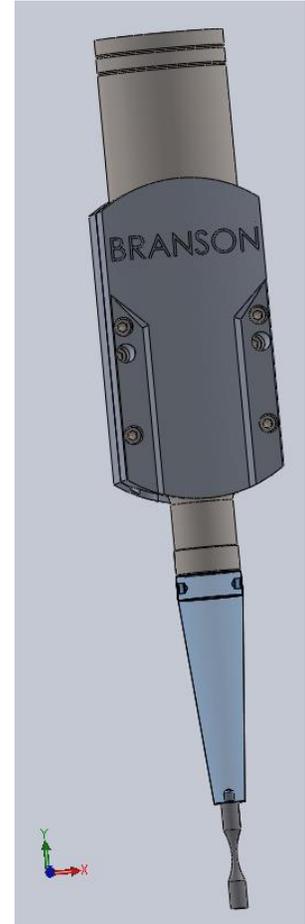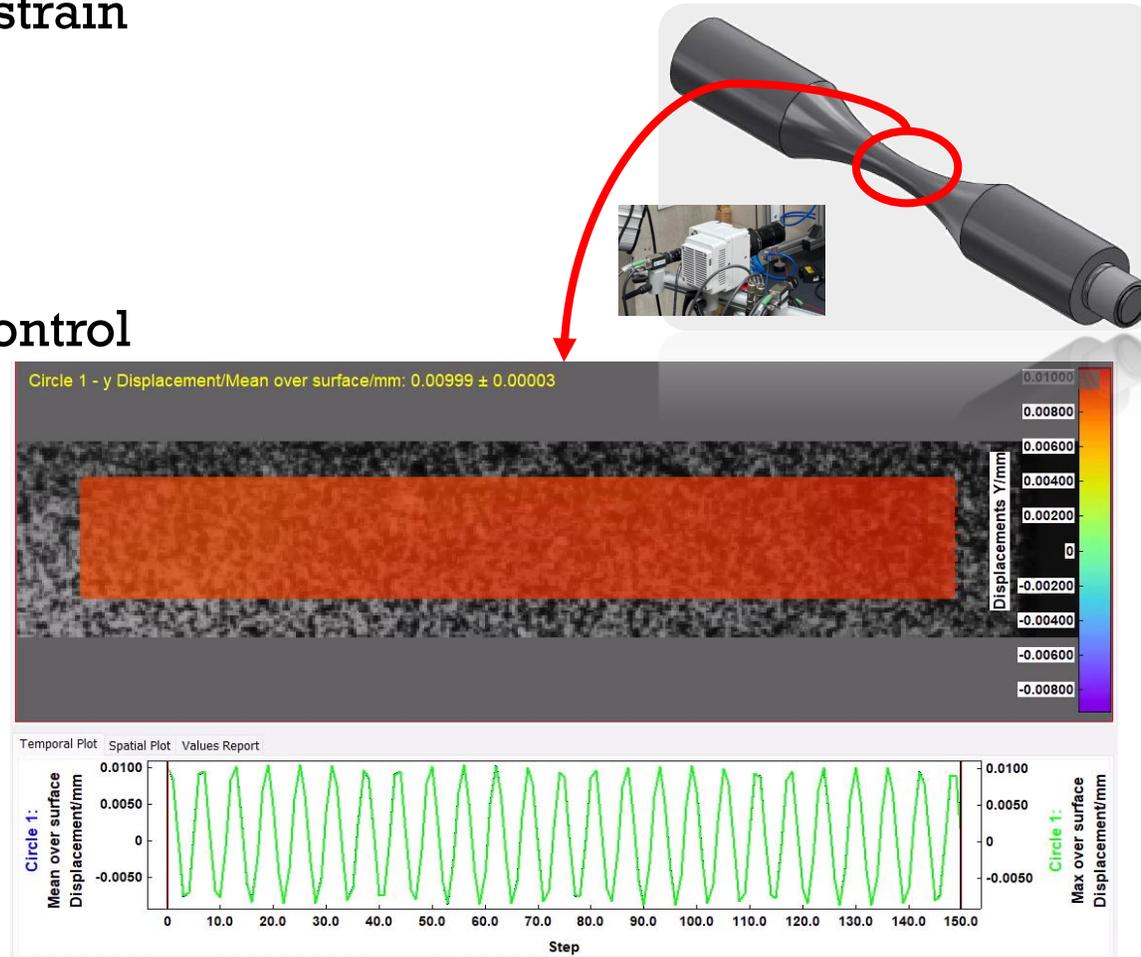
Calibration of the machine

Japanese standard: WES 1112: 2022
Method for ultrasonic fatigue testing in metallic material

✓ Calibrate and validate the laser reading and DIC system

✓ Make sure the intended mode shape is excited and there is no modal coupling

✓ Build a **statistical relationship between strain measured by DIC** and **tip displacement from laser** reading data

✓ At least **five points** shall be measured throughout the capacity range of the testing machine

✓ surface temperature measured in the high-stress part of the specimen **< 30°C**

DIC:
Stress (Strain)

LASER:
Displacement

Safari, S., Montalvão, D., da Costa, P.R., Reis, L. and Freitas, M., 2025. Statistical calibration of ultrasonic fatigue testing machine and probabilistic fatigue life estimation. International Journal of Fatigue, 199.
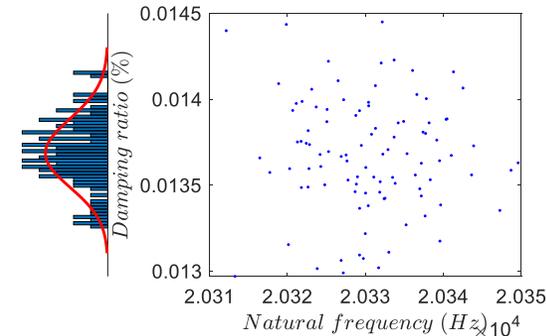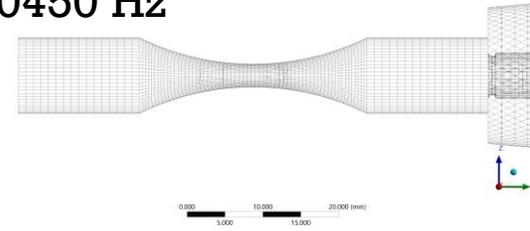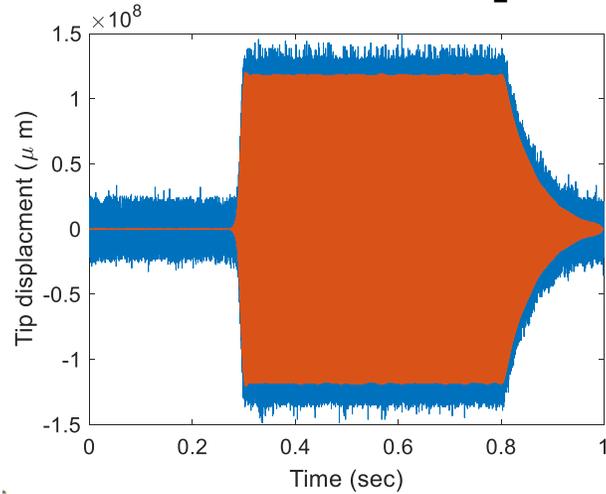
Calibration of the machine (EN8 specimens)

✓ Preparing the specimens
✓ Calibrating the laser
✓ Observing the mode shape using DIC at the tip with 10 µm

Safari, S., Montalvão, D., da Costa, P.R., Reis, L. and Freitas, M., 2025. Statistical calibration of ultrasonic fatigue testing machine and probabilistic fatigue life estimation. International Journal of Fatigue, 199.
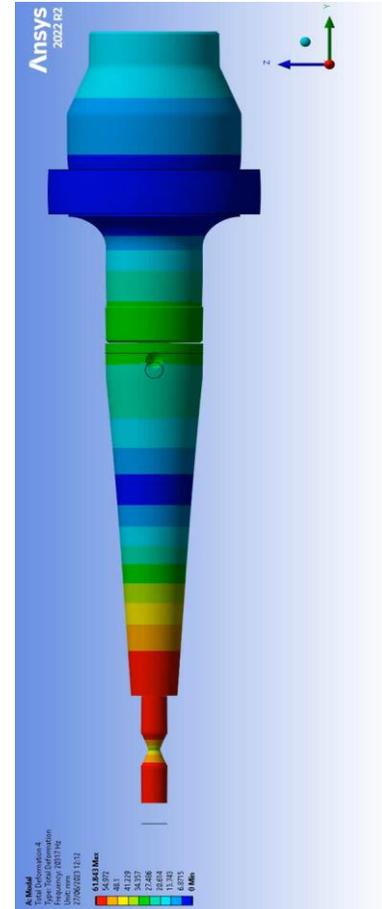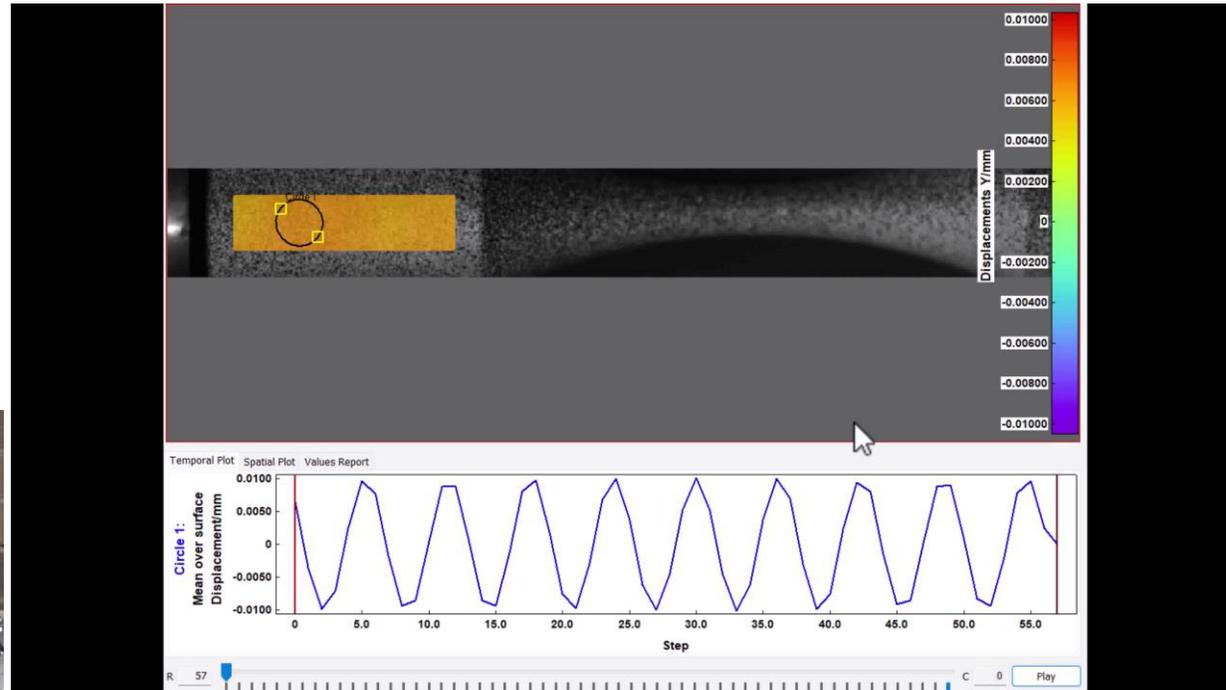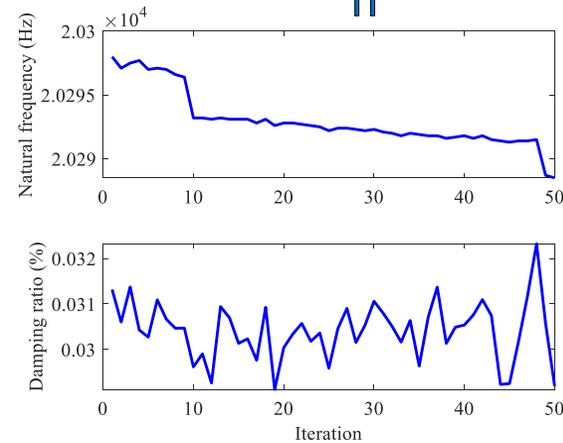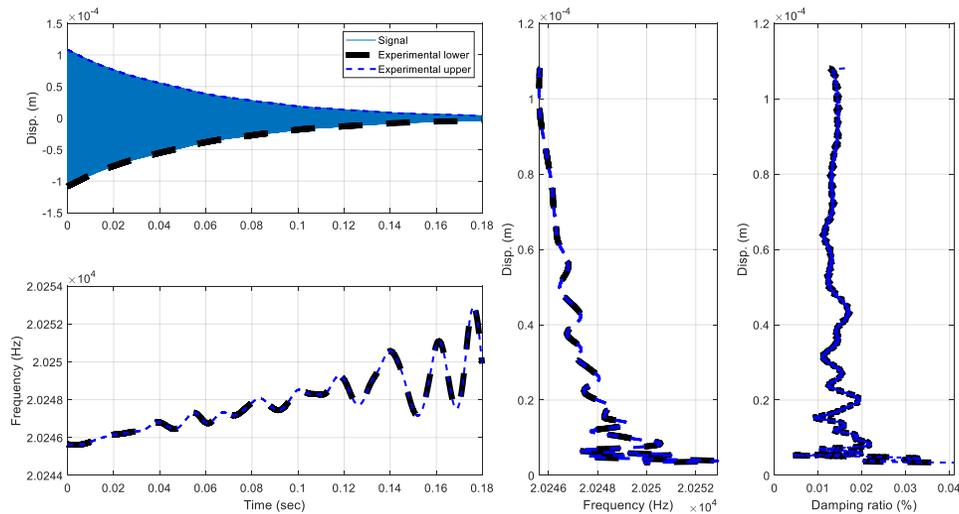
Calibration of the machine (EN8 specimens)

FE Validation   19450 Hz<Operational frequency<20450 Hz

Frequency error <0.02%

Safari, S., Montalvão, D., da Costa, P.R., Reis, L. and Freitas, M., 2025. Statistical calibration of ultrasonic fatigue testing machine and probabilistic fatigue life estimation. International Journal of Fatigue, 199.
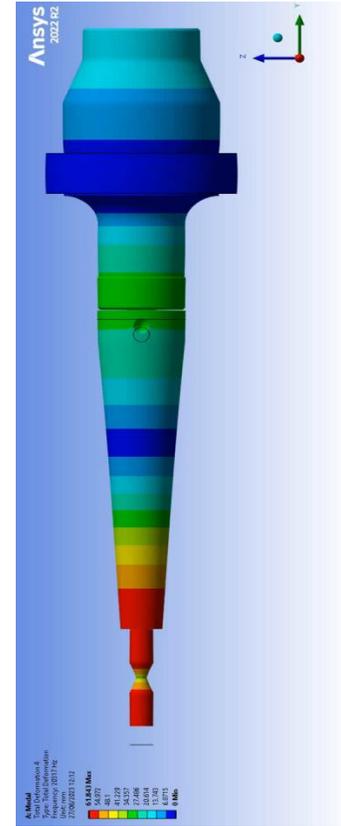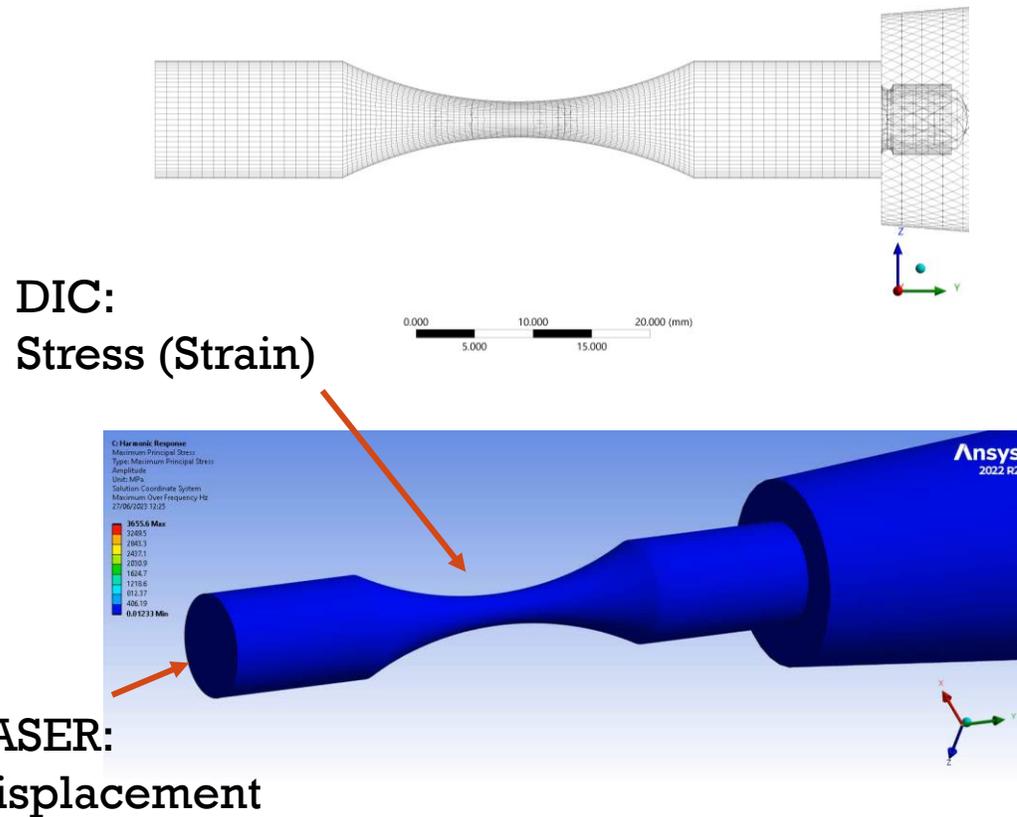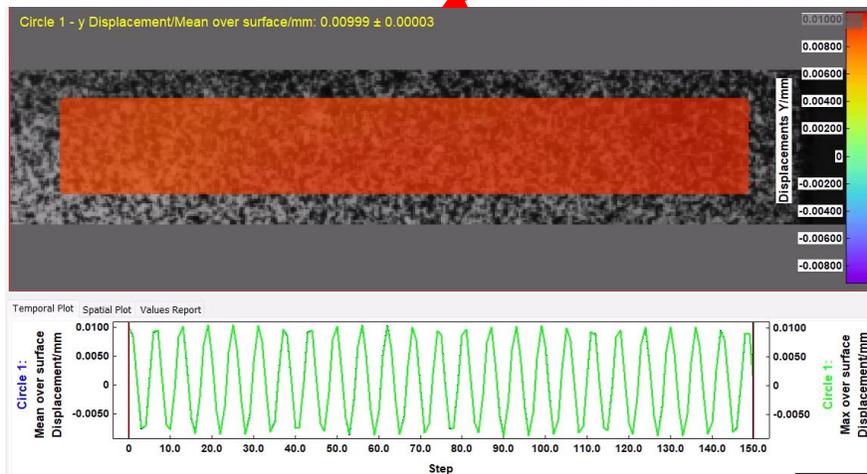
Calibration of the machine (EN8 specimens)

- **FE validation (harmonic analysis)**

DIC:
Stress (Strain)
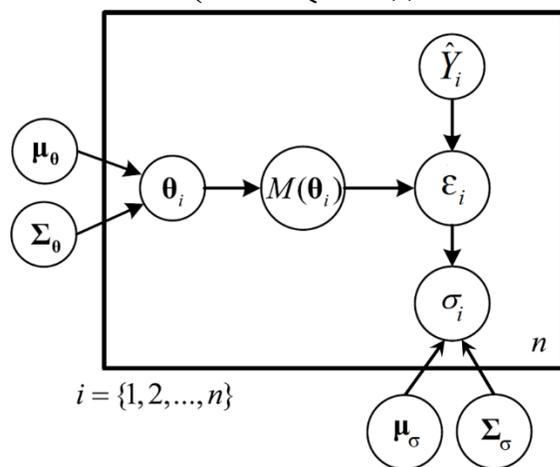
LASER:
Displacement

$y = 126.63x$

$y = 122.85x$
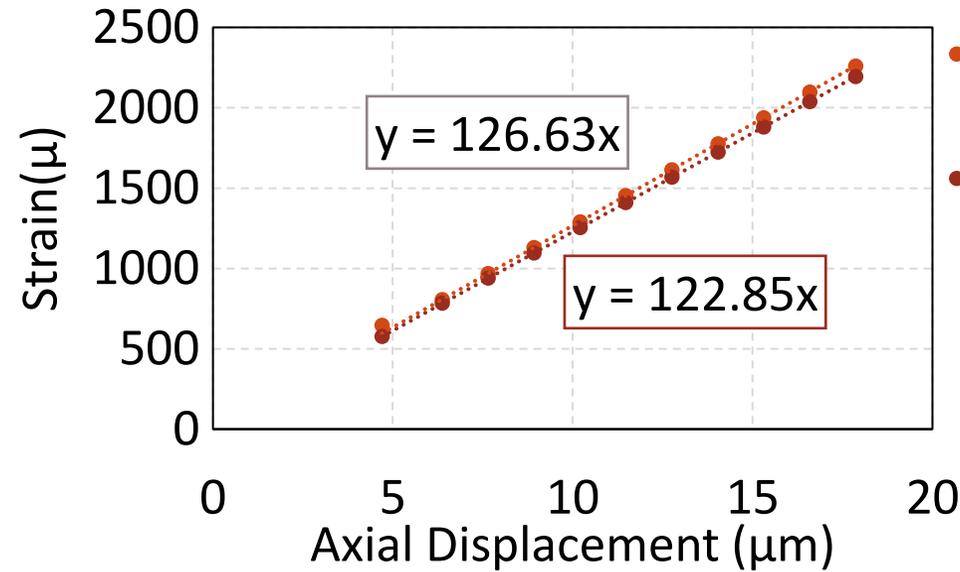
- FEA EN8

- Analytical

Lage, Y., Ribeiro, A.M.R., Montalvão, D., Reis, L. and Freitas, M., 2014. Automation in strain and temperature control on VHCF with an ultrasonic testing facility. *ASTM Special Technical Publication*, STP 1571, 80–100.

Safari, S., Montalvão, D., da Costa, P.R., Reis, L. and Freitas, M., 2025. Statistical calibration of ultrasonic fatigue testing machine and probabilistic fatigue life estimation. International Journal of Fatigue, 199.

Uncertainty Quantification: Hierarchical Bayesian inference (HBI)

Model: strain= θ(1) × displacement + ε

$(\varepsilon = \mathcal{N}(0, \sigma))$

Safari, S., Montalvão, D., da Costa, P.R., Reis, L. and Freitas, M., 2025. Statistical calibration of ultrasonic fatigue testing machine and probabilistic fatigue life estimation. International Journal of Fatigue, 199.
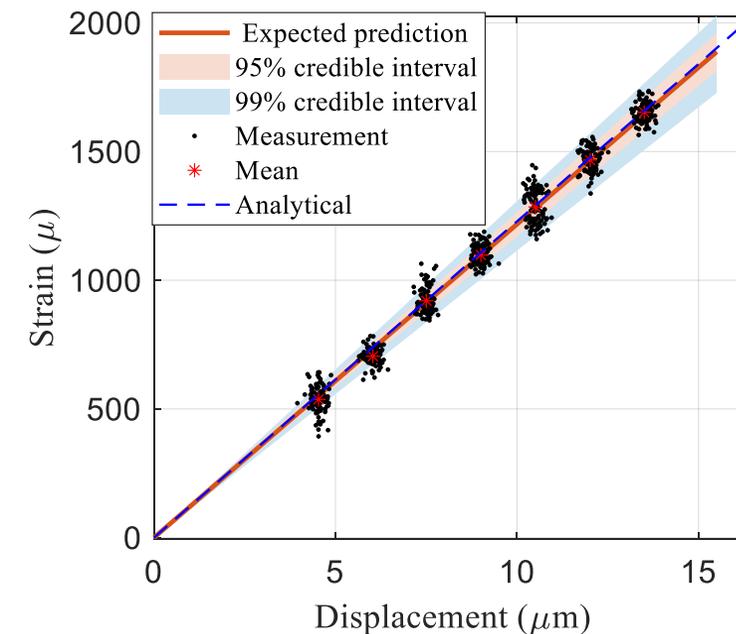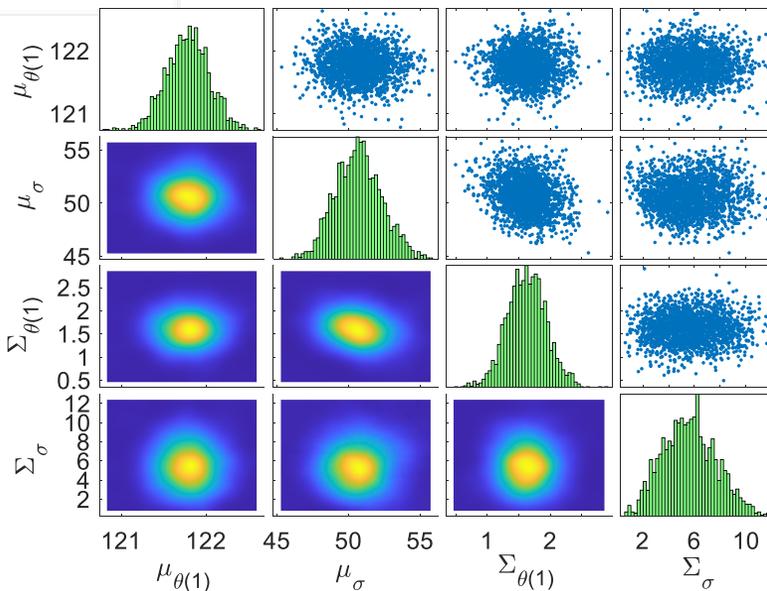
Stress-life (S-N) curve (EN8 Specimens)

EN8 steel

Model:

$$Ln(N_f) = \theta(1) \times Stress + \theta(2) + \varepsilon$$
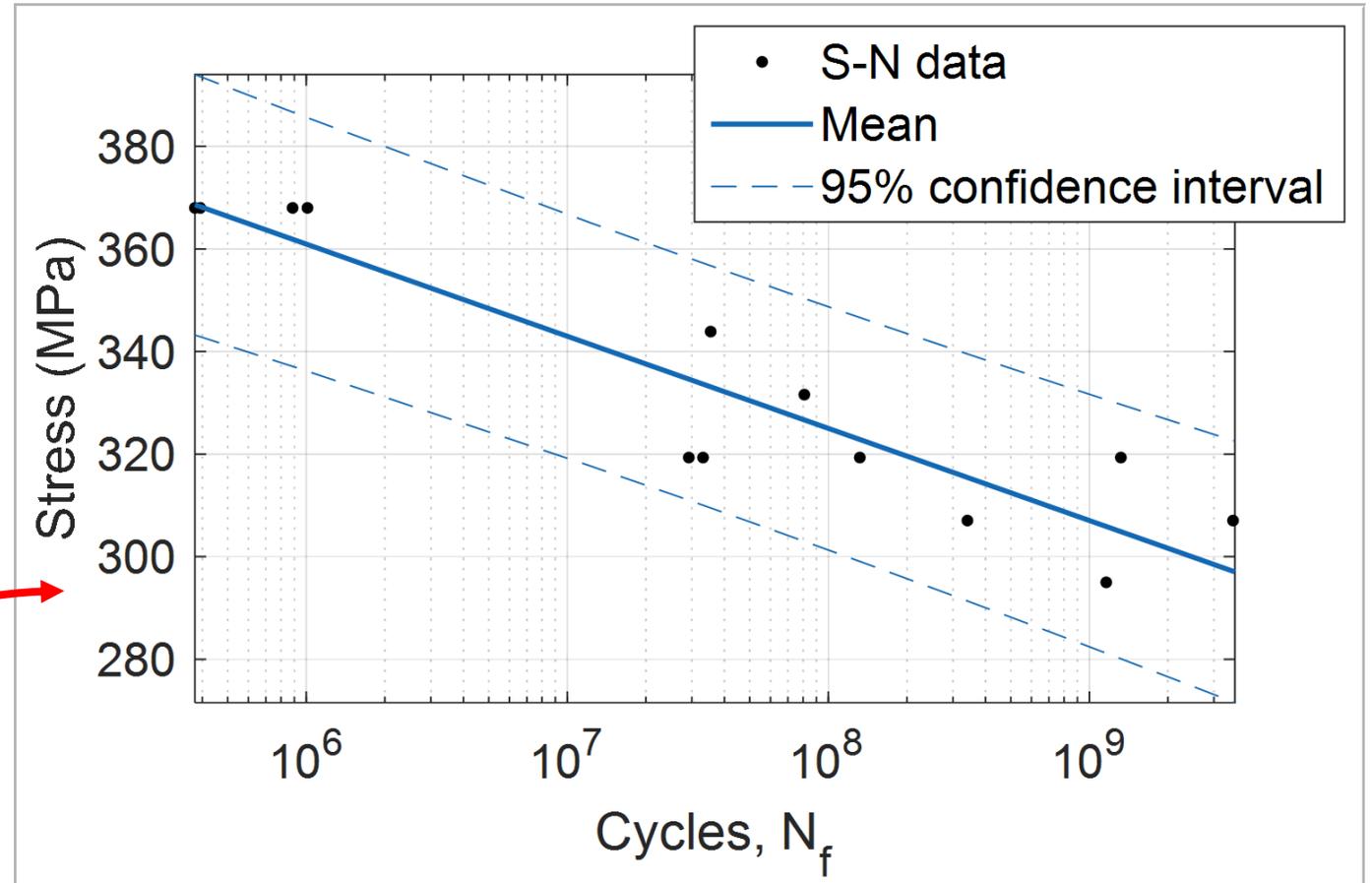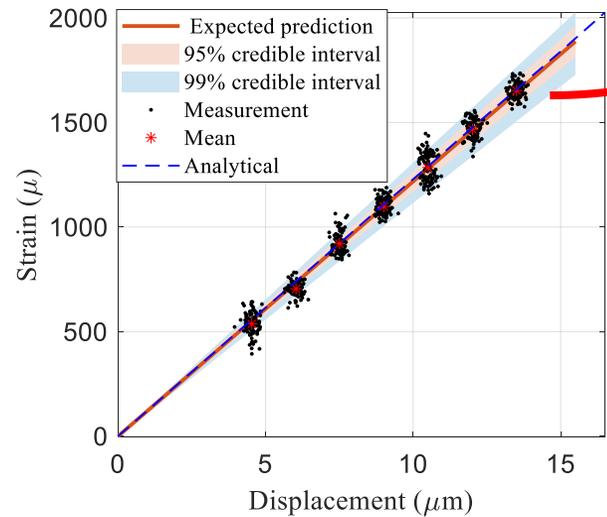
Another layer of Hierarchy is the S-N curve!

Safari, S., Montalvão, D., da Costa, P.R., Reis, L. and Freitas, M., 2025. Statistical calibration of ultrasonic fatigue testing machine and probabilistic fatigue life estimation. International Journal of Fatigue, 199.

Inconel 718
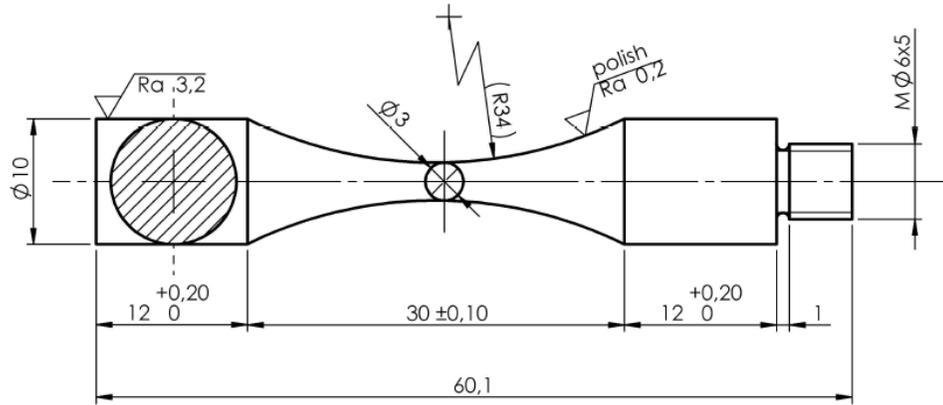
Ti64 (TI-6AL-4V)

H — Tension load parallel to layers, **Part is *strong***
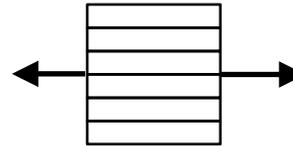
V — Tension load normal to layers, **Part is *weak***
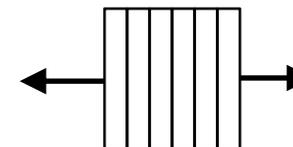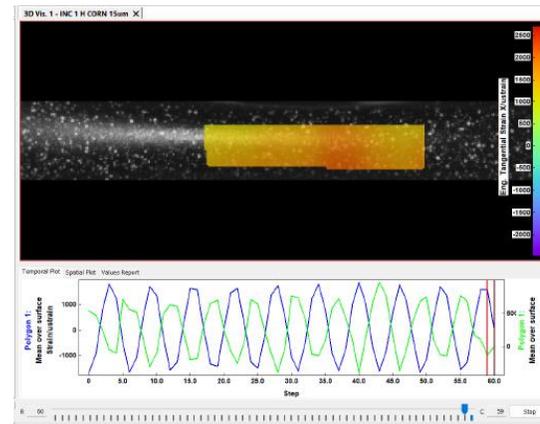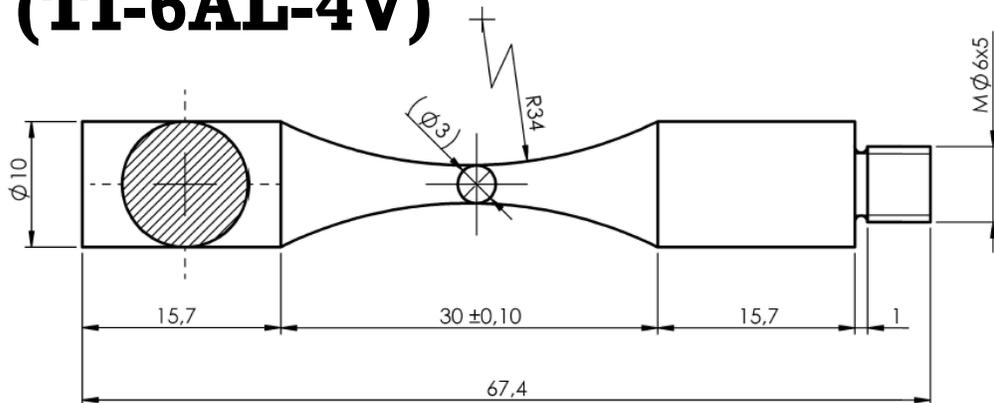
Piezoelectric Actuator (imposed displacement)

Booster (mechanical amplification)

Support (vibration node)

Horn (mechanical amplification)

Uniaxial Specimen

LASER sensor (measures displacement)

AMed Specimens
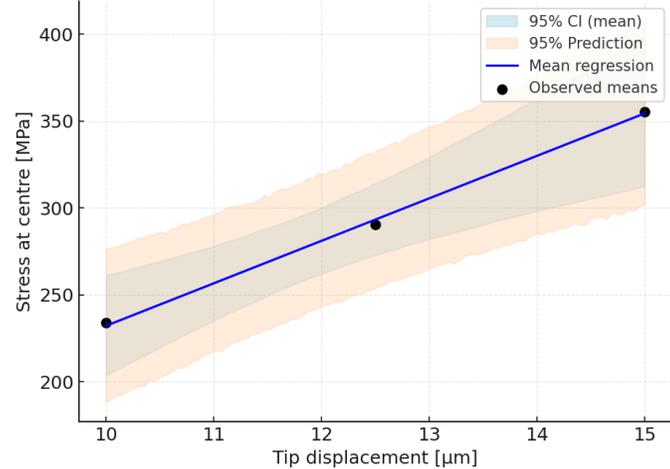# Stress @ Centre vs Displacement @ Tip
(with Monte Carlo simulations)

AMed Specimens
Stress @ Centre vs Displacement @ Tip
(with Monte Carlo simulations)

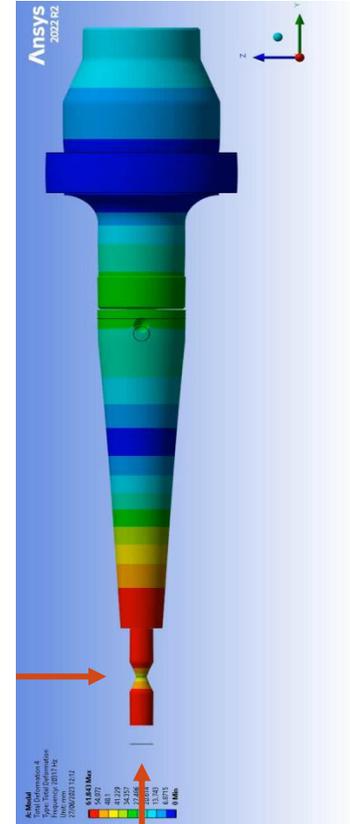Inconel 718 – Horizontal: Continuous CI vs Prediction Bands

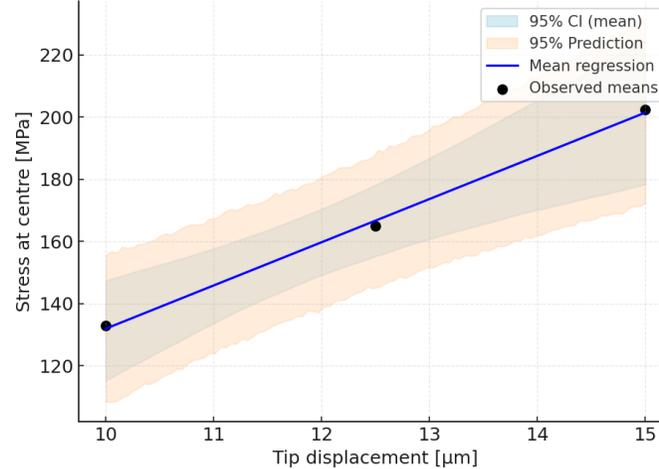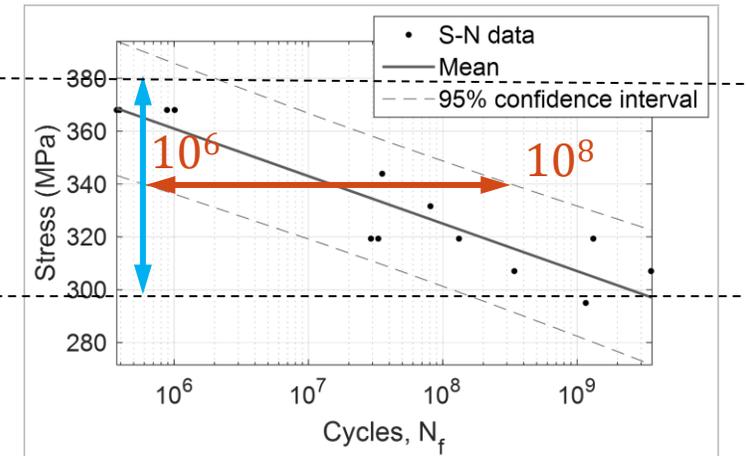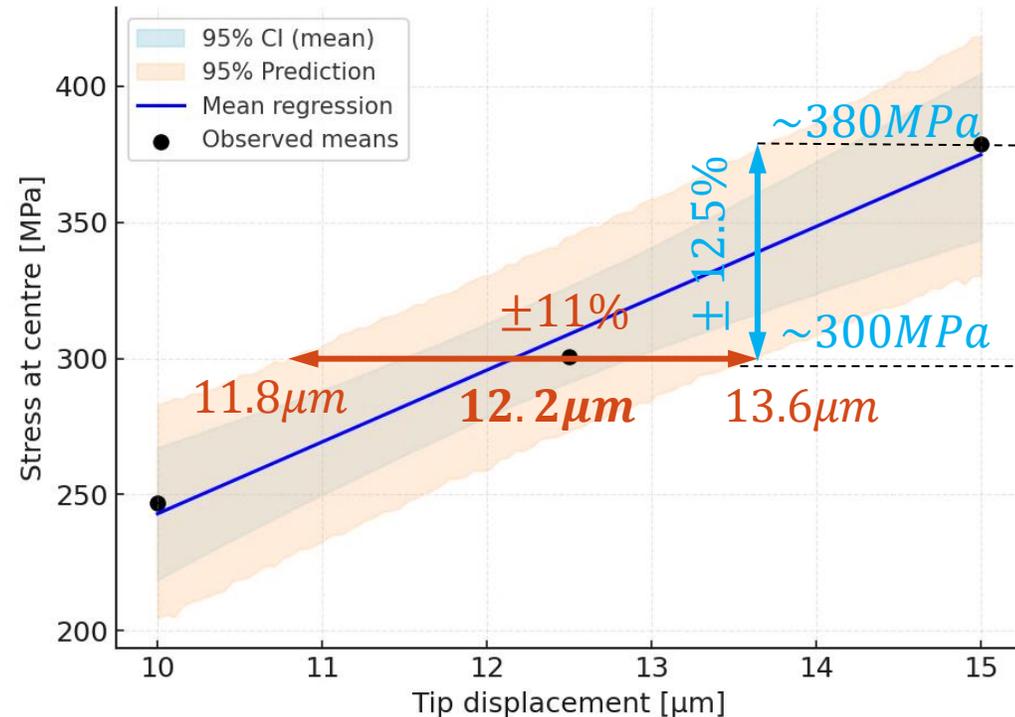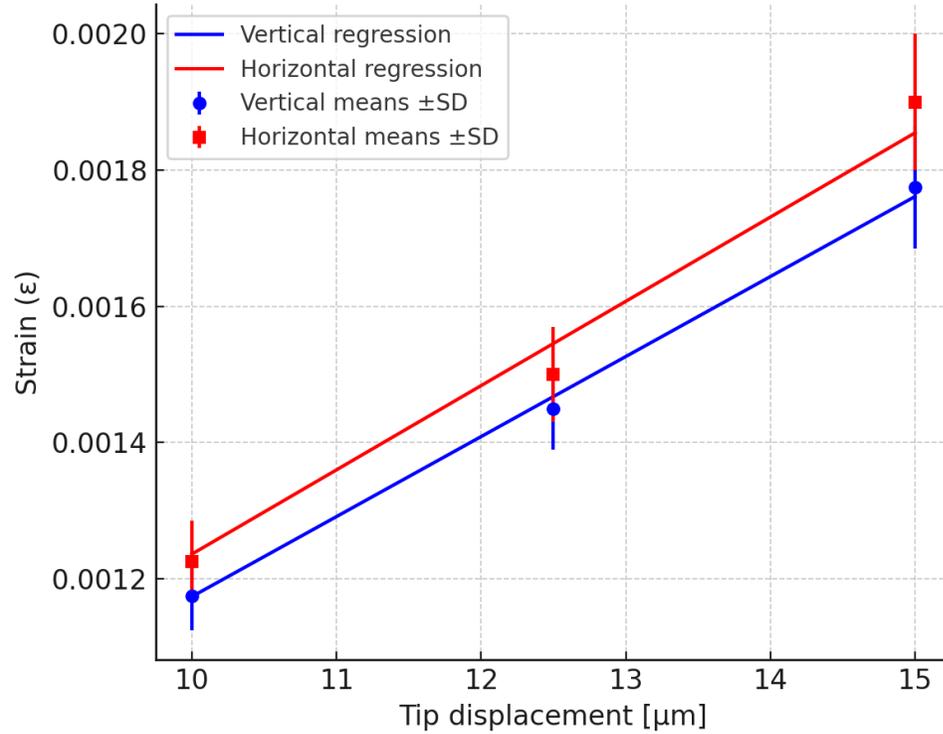The gap can be from 10^6 to 10^8!

Early fracture

Optical micrographs of Specimen TI64 V2 15um
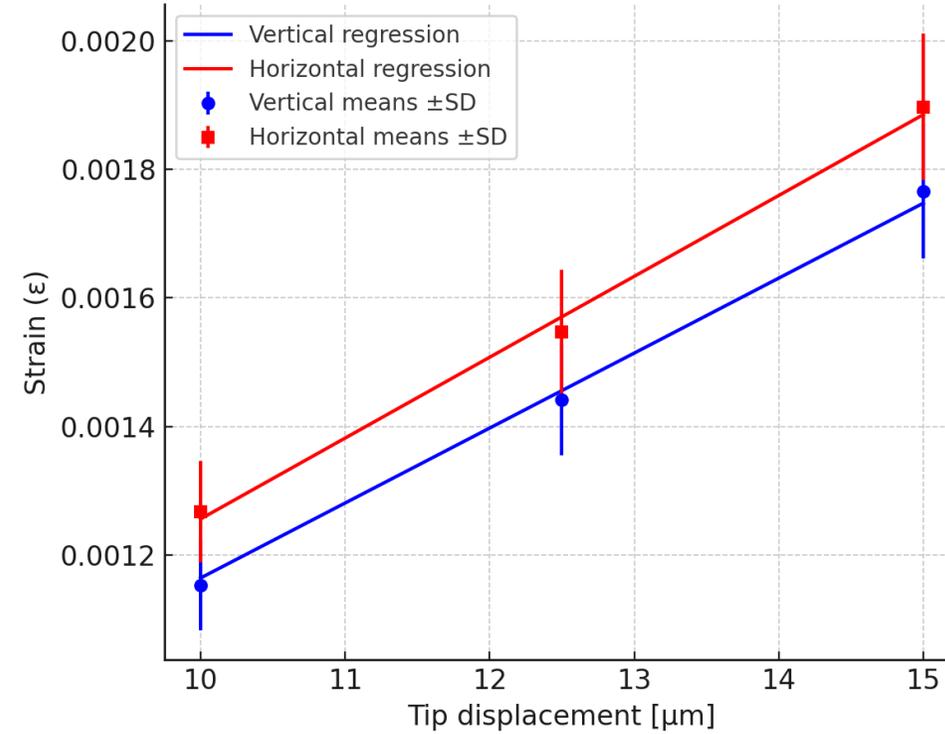
Anisotropy of AMed observed

Inconel 718: Regression with specimen scatter (±SD)

- Vertical regression
- Horizontal regression
- Vertical means ±SD
- Horizontal means ±SD

Vertical: ε = 1.17e-04·δ, R²=0.997

Horizontal: ε = 1.24e-04·δ, R²=0.982

Ti-6Al-4V: Regression with specimen scatter (±SD)

- Vertical regression
- Horizontal regression
- Vertical means ±SD
- Horizontal means ±SD

Vertical: ε = 1.16e-04·δ, R²=0.997

Horizontal: ε = 1.26e-04·δ, R²=0.996
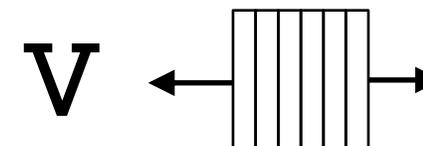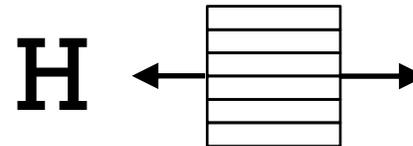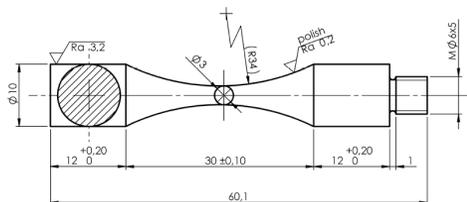
Summary

- **Anisotropy matters:** Vertical vs Horizontal builds show clear differences in AMed Ti-6Al-4V and Inconel 718.

- **Uncertainty is critical:** Calibration scatter highlights the need for robust quantification. Bayesian & Monte Carlo tools provide a framework to capture and communicate uncertainty.

- **Industrial qualification:** Quantifying anisotropy + uncertainty is essential to raise the TRL of UFT for AM VHCF testing.

- **Next steps:** Build full S–N curves and benchmark against literature to enable orientation-dependent design data.

Thank you!

Visit us at www.ADDISONIC.com

Email us at addionic@bournemouth.ac.uk

Presentation delivered by Dr Diogo Montalvão