

MICROSTRUCTURE-BASED COMPUTATIONAL FATIGUE LIFE PREDICTION OF POLYCRYSTALLINE ALLOYS

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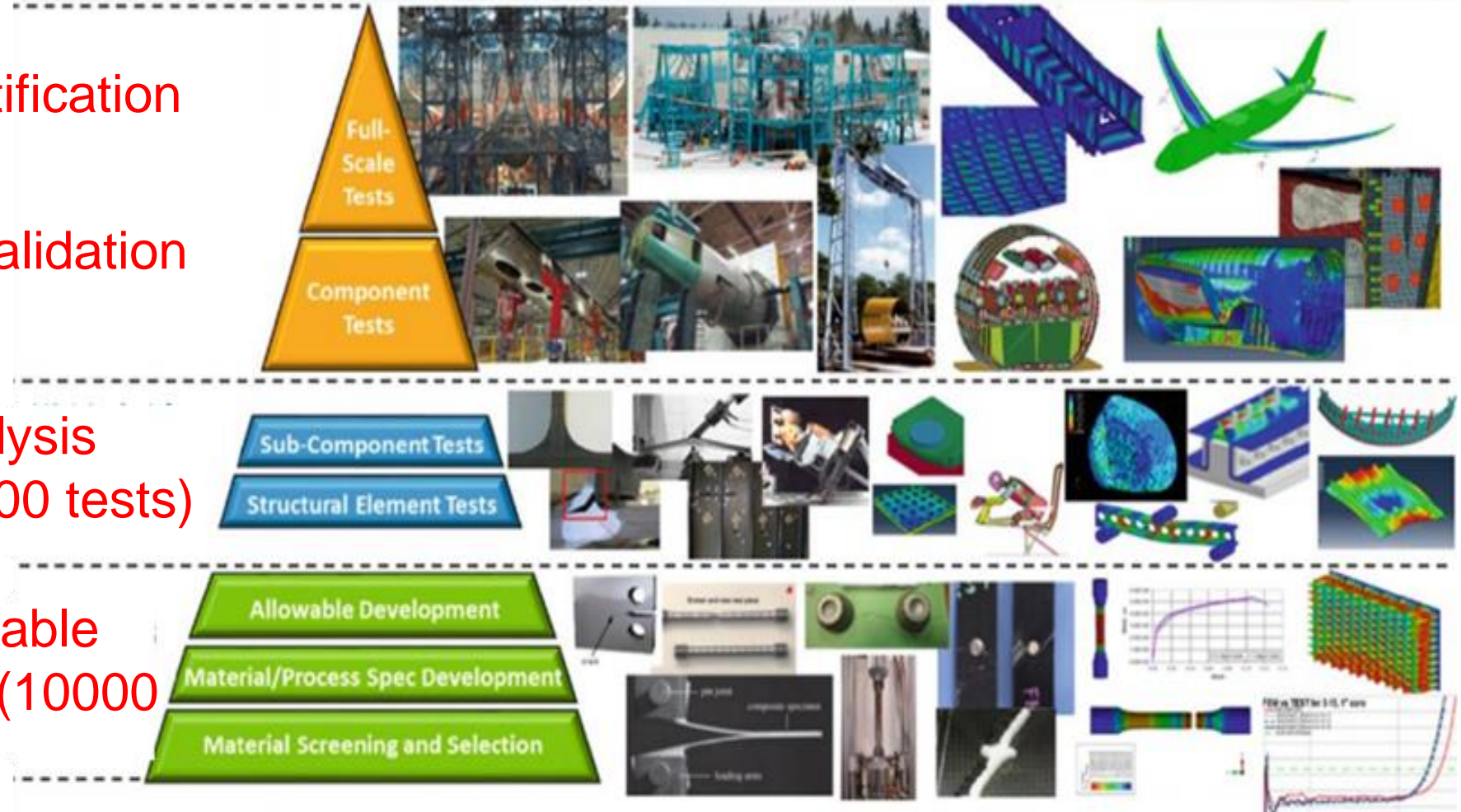
Traditional Airframe Design and Certification

Full scale certification
(<10 tests)

Component validation
(100 tests)

Design & analysis
validation (1000 tests)

Material allowable
development (10000
tests)



Factors Affecting Fatigue Strength and Life Scatter of Metals

External

- Part shape and size, and service conditions (load/constraint)
- Surface finish

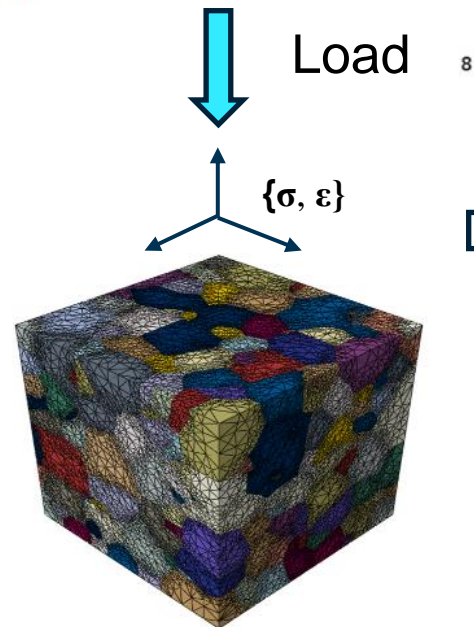
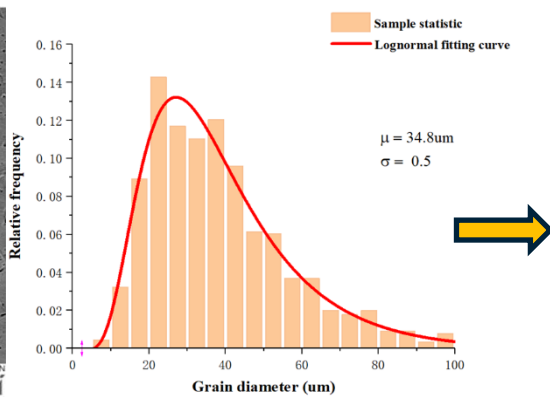
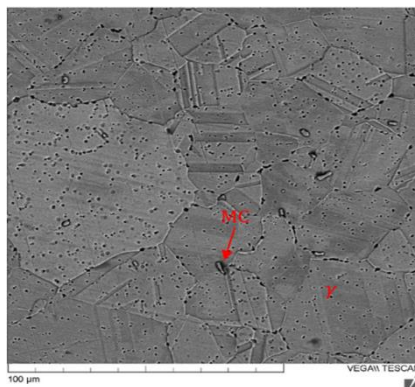
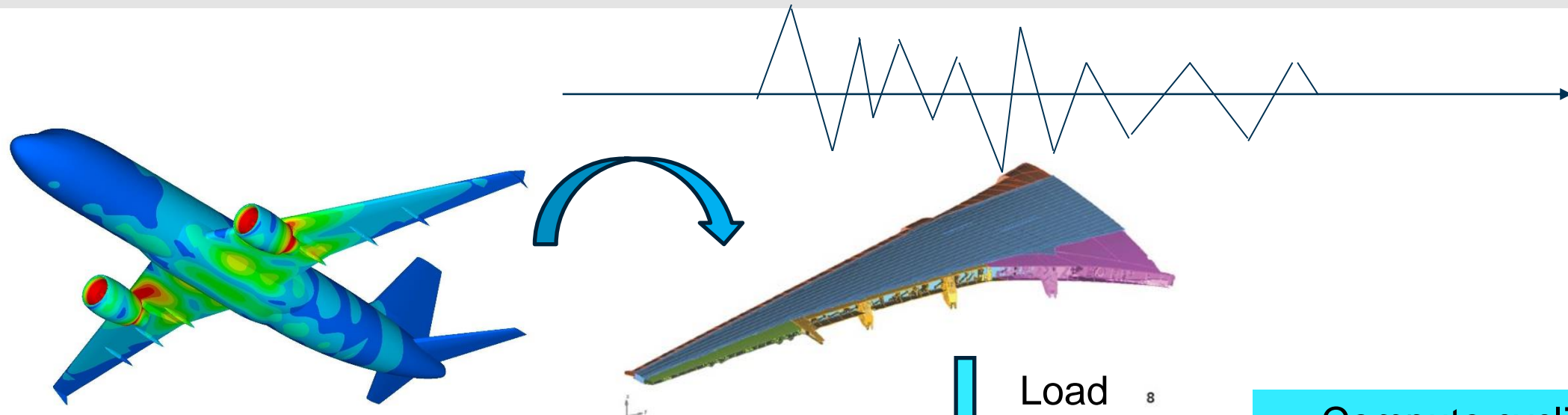
Internal

- Composition
- Microstructure (grain size and orientation, and inclusions, manufacturing defects)
- Residual stress

Objective

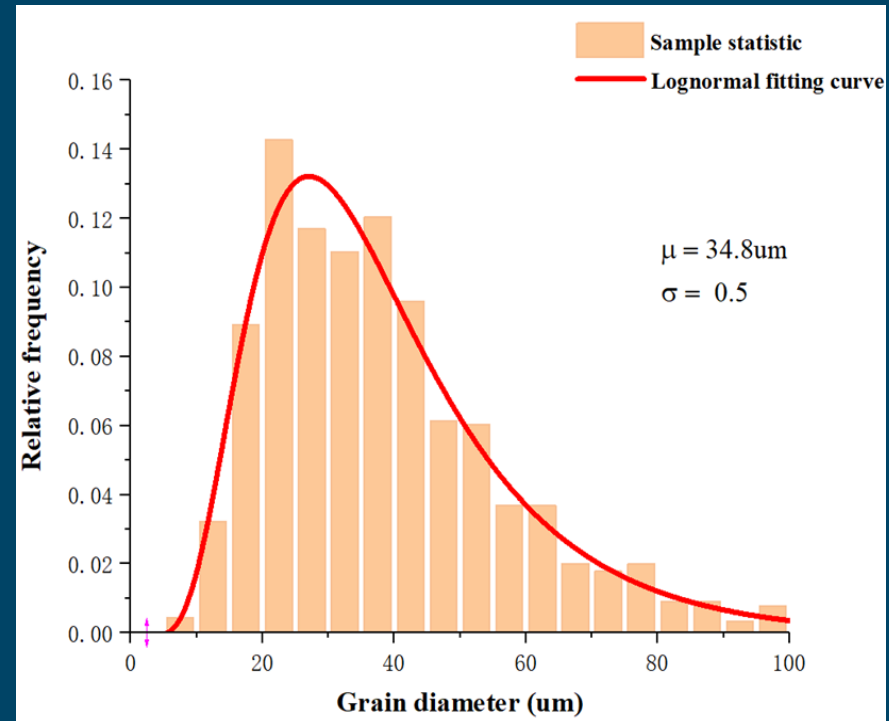
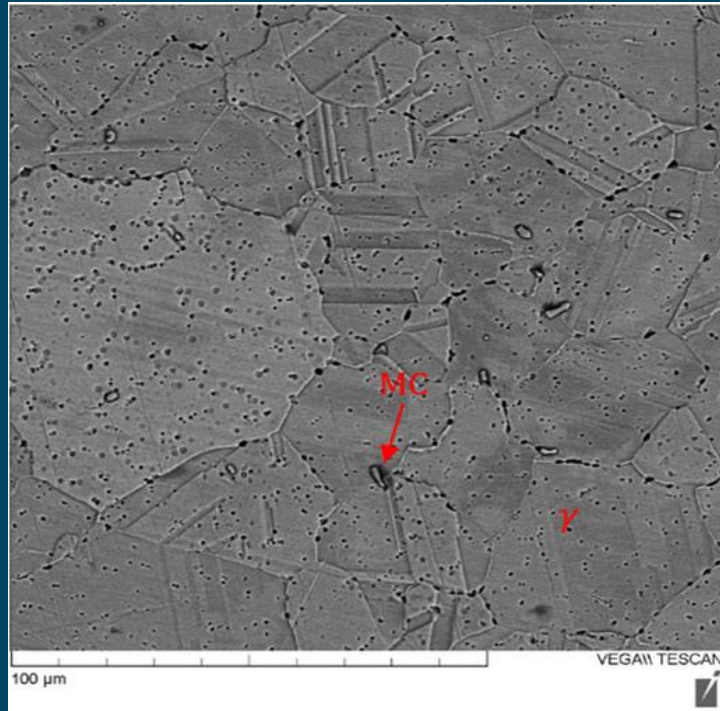
- To develop computational fatigue life prediction and uncertainty quantification model to support Certification by Analysis (CbA), first achieve a high confidence at the coupon level based on material properties and microstructure, and move up to higher-level applications in the Certification Process (The Pyramid)

The Approach: Physics-based simulation of fatigue from microstructure to airframe structure



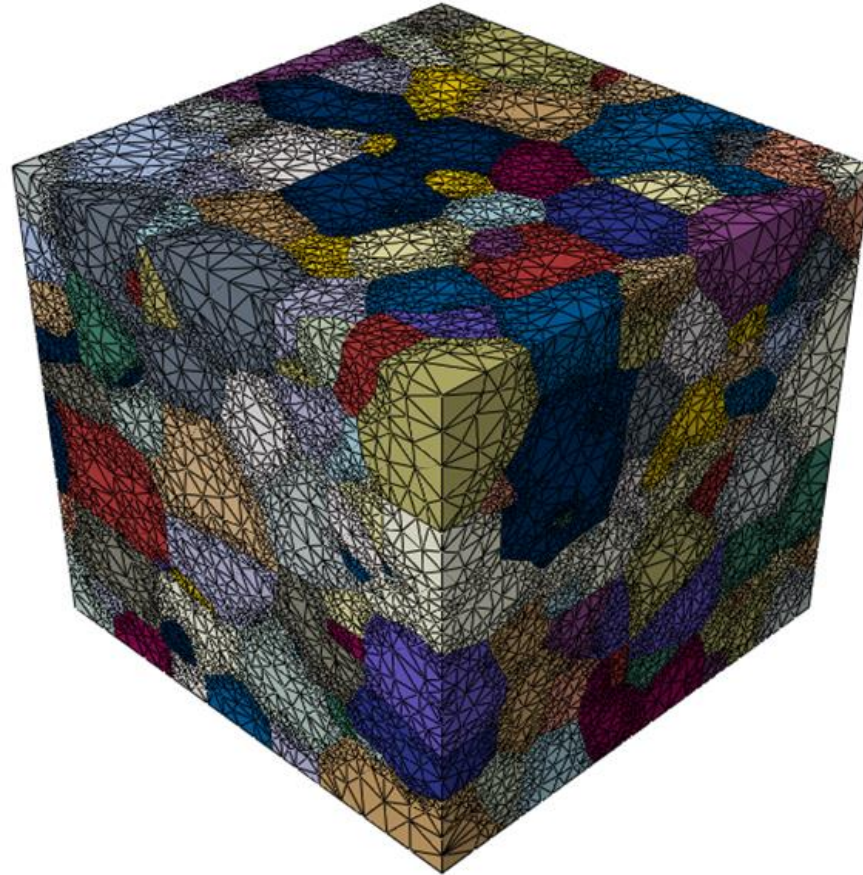
- Compute cyclic stress-strain curve (verification)
- Compute fatigue life
- Machine Learning for Microstructure-Uncertainty relationship

Microstructure Characterization—Haynes 282



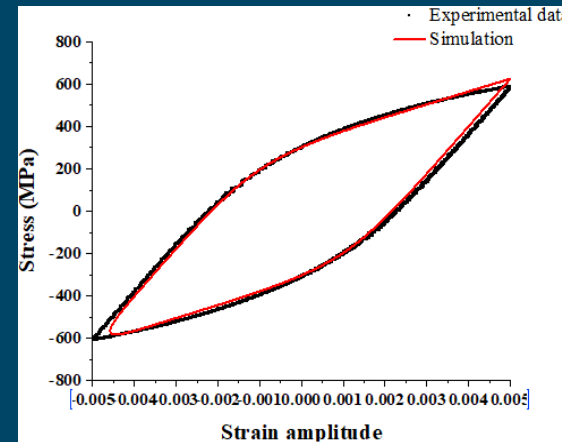
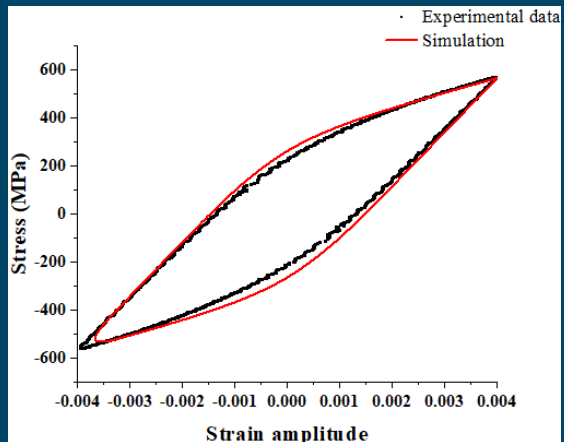
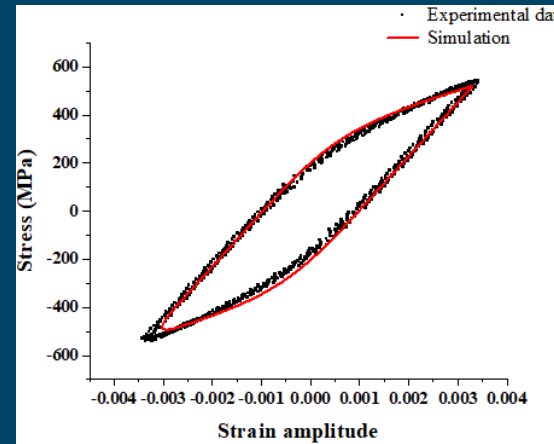
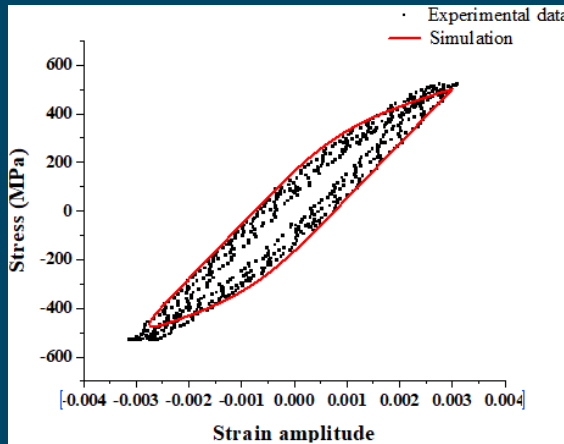
Voronoi Tessellation to Construct RVE

- An RVE of $500 \times 500 \times 500 \mu\text{m}^3$ cubic volume containing 625 grains
- Grain orientation is randomly assigned
- Automated meshing with tetrahedral (C3D4 in Abaqus) element



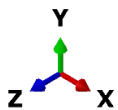
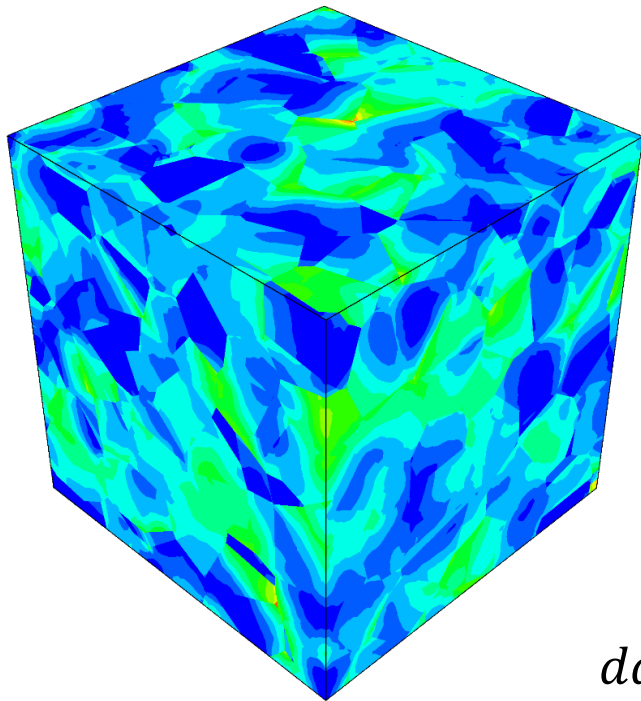
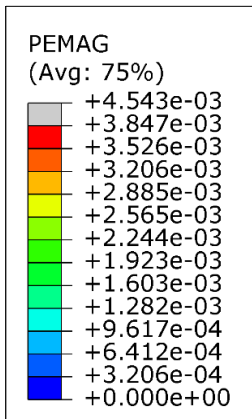
- *Anisotropic elasticity*
- *Hill's potential and kinematic hardening at grain level*

Calibration to material's hysteresis behavior—the Material's Constitutive Law



Fatigue Life Calculation based on Microstructural Strain

A) Plastic strain distribution (high load) B) Stress distribution (high load)



$$N_c = \frac{8(1 - \nu)w_s}{3\mu b} \Delta\varepsilon_p^{-2}$$

Material property inputs:

b - Burgers vector,

μ - shear modulus,

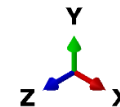
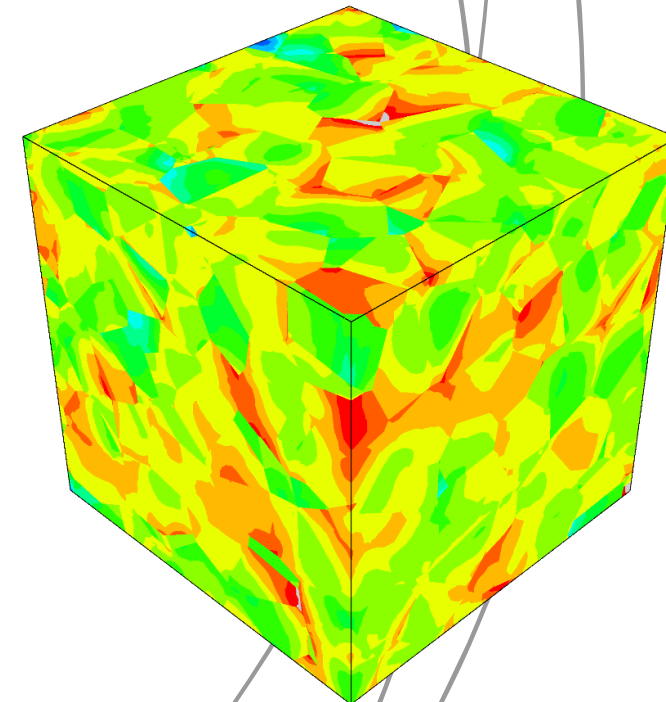
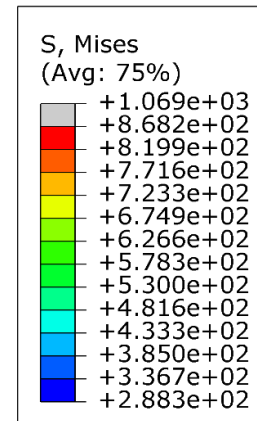
ν - Poisson's ratio

w_s - the surface energy

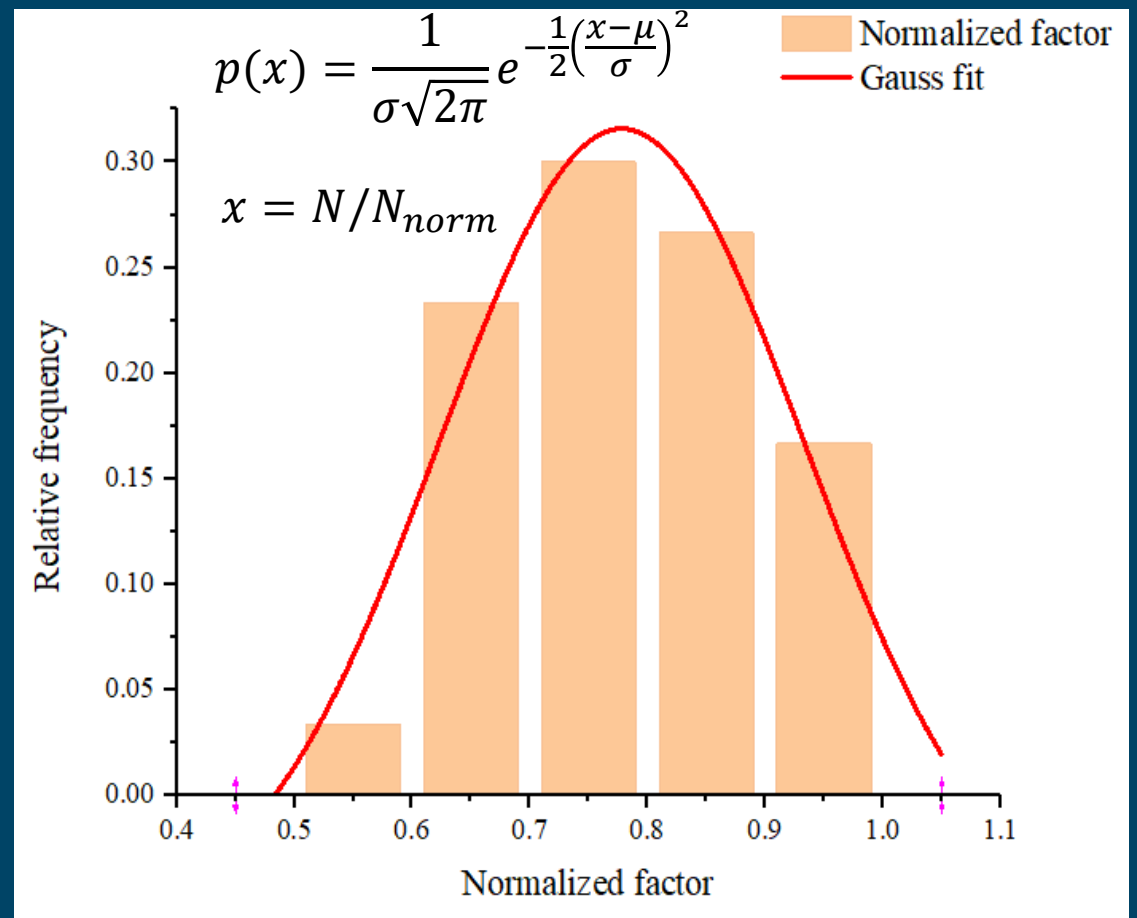
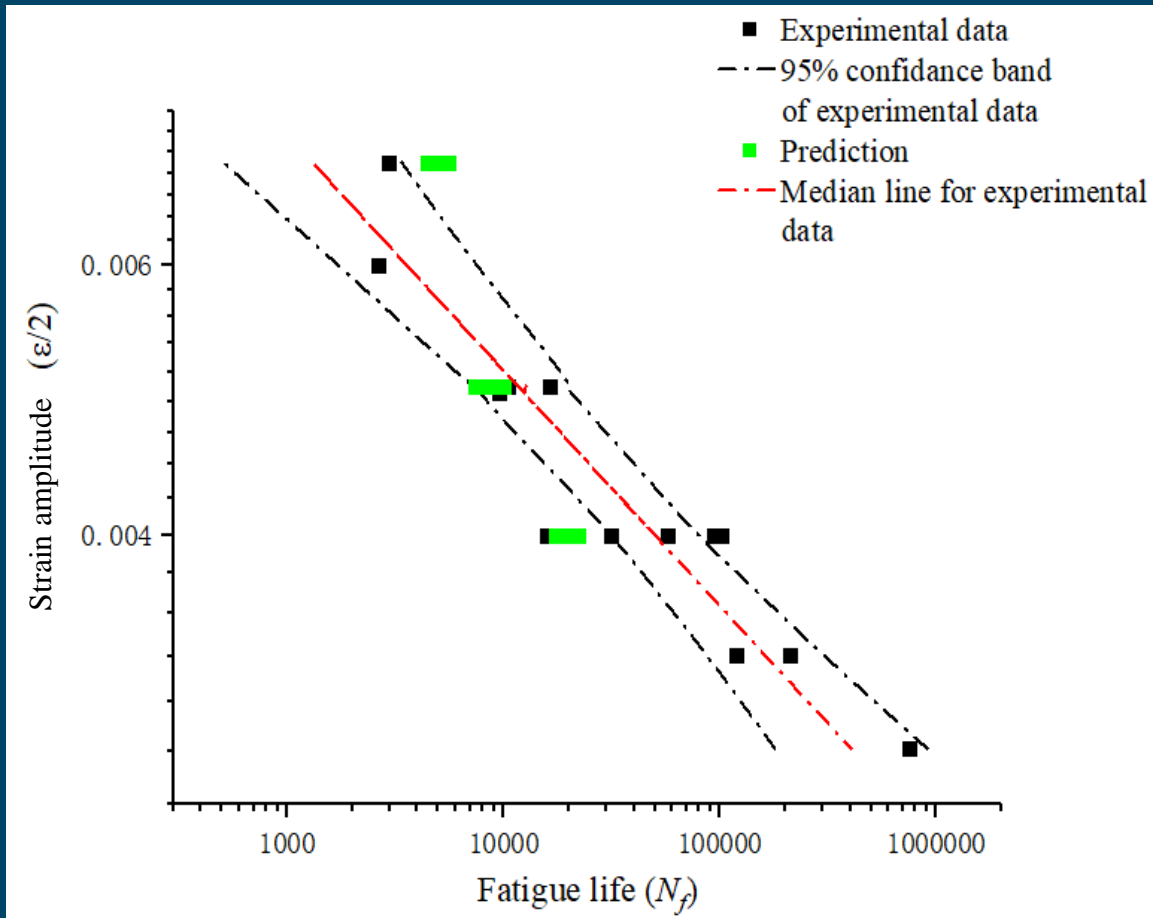
σ_T - UTS

K_{IC}

$$\frac{da}{dN} = \frac{\pi^2}{8} \left(\frac{\Delta\sigma}{2\sigma_T} \right)^2 \frac{\Delta\varepsilon_p}{(2n + 1)} a$$



Validation and Uncertainty quantification



Thank you

