EASI-STRESS

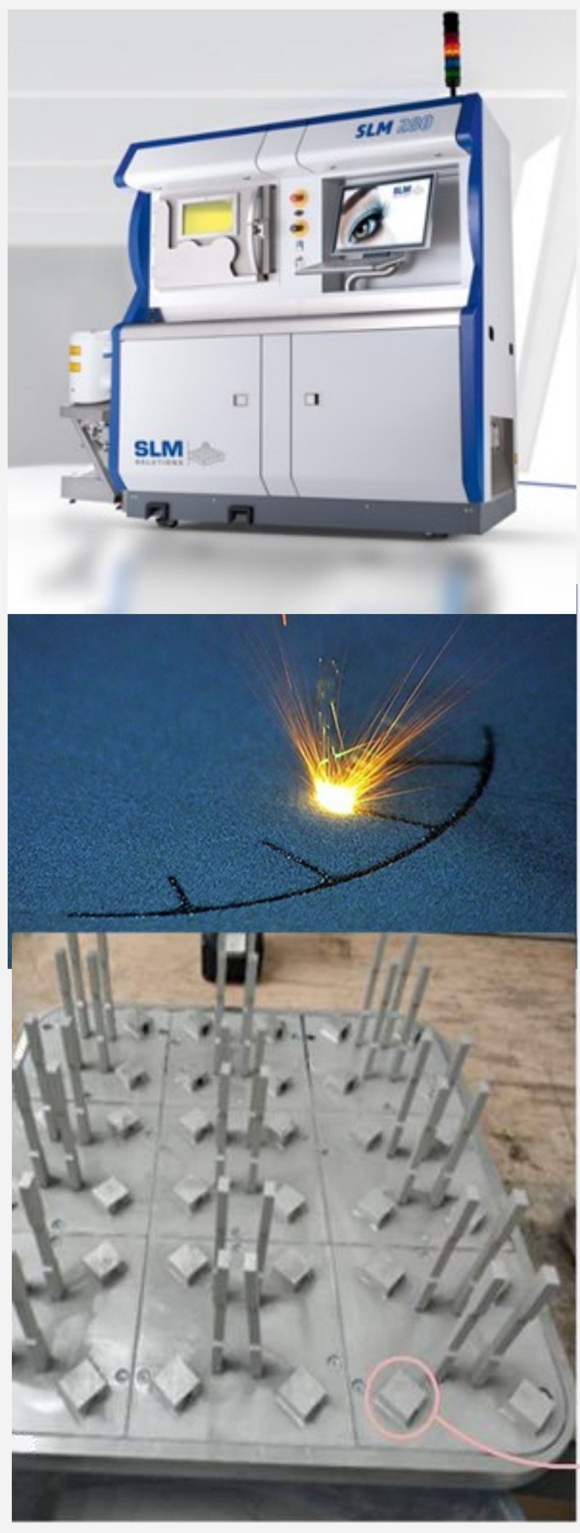
European Activity for Standardization of Industrial Residual Stress Characterization

Validating predictive additive manufacturing models of EASI-STRESS stainless steel residual stress benchmarks

Introduction

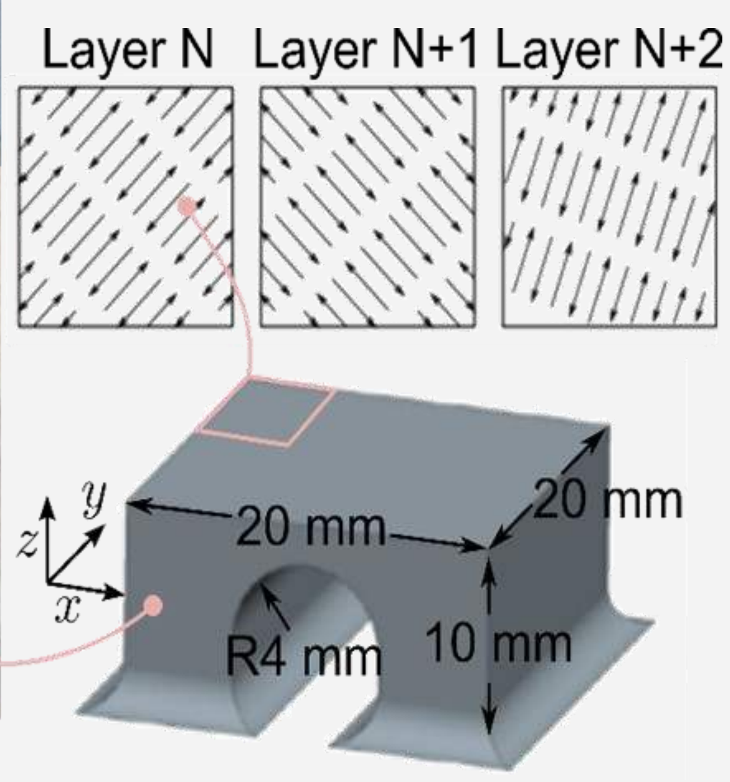
Residual stresses imparted by additive manufacturing (AM) with metallic systems remains a challenging aspect of product design for many industries. The final residual stress state in additively manufactured components is the net effect of thermal, mechanical, and in some cases thermodynamic aspects. While there are multiple computational tools available that promise predictive capabilities, the challenge remains to AM practitioners to determine the best approach to optimize which physics need to be considered and over what length scale. To address this paradigm, the EASI-STRESS programme has developed an additively manufactured benchmark, realized in 316L stainless steel with laser powder bed fusion (LPBF). This benchmark has been subjected to a campaign of neutron and high energy synchrotron diffraction residual stress measurements, which are intended to provide validation datasets of modelling approaches.

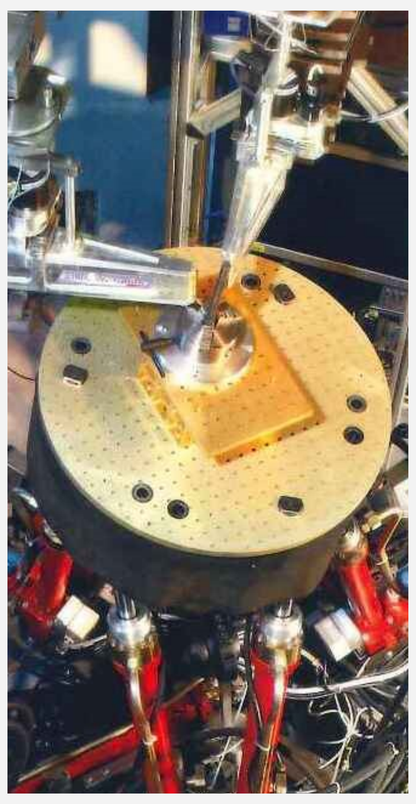
Benchmark overview



Identical benchmark components have been achieved with commercially available LPBF equipment including MetalFAB, EOS and SLM Solutions, as assessed on the basis of microstructure and geometries obtained.

Residual stresses in the as-built and heat-treated condition have been measured with neutron and synchrotron diffraction techniques. Facilities at the ILL and Hereon were employed with current best practices and compared to the predictions of both inherent strain and thermomechanical modelling.

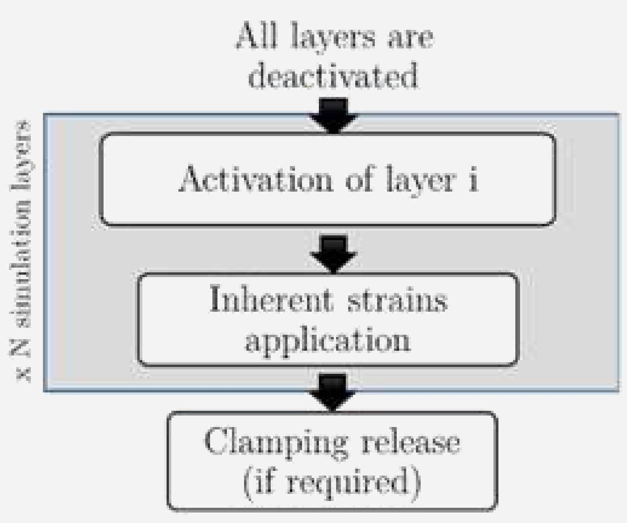


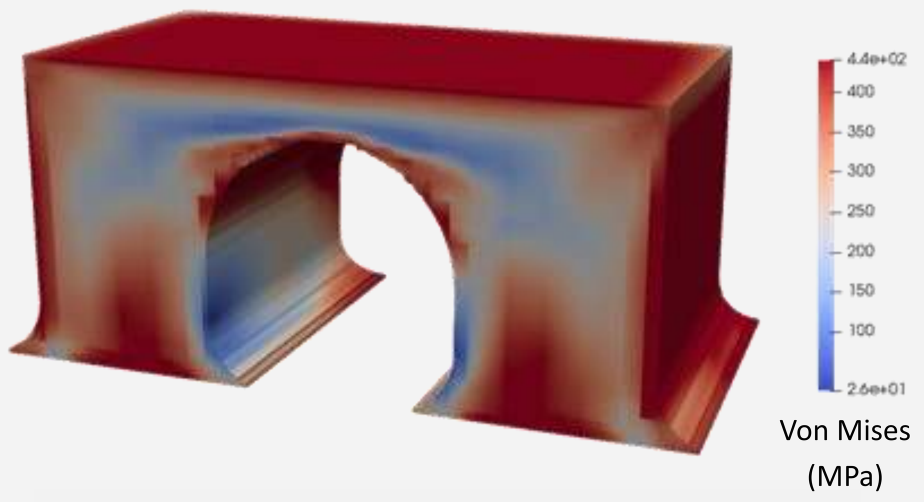


Inherent strain approach

The inherent strain approach groups all inelastic strains developed into a single source by empirical calibration assuming isotropy. The stress developed is then calculated with a finite element approach with a bottom-to-top macro-layer.

$$\varepsilon^{in} = \varepsilon^{total} - \varepsilon^{elastic} = \varepsilon^{thermal} + \varepsilon^{plastic} + \varepsilon^{phase} + \varepsilon^{creep} \qquad \sigma = M \cdot \varepsilon^{in}$$

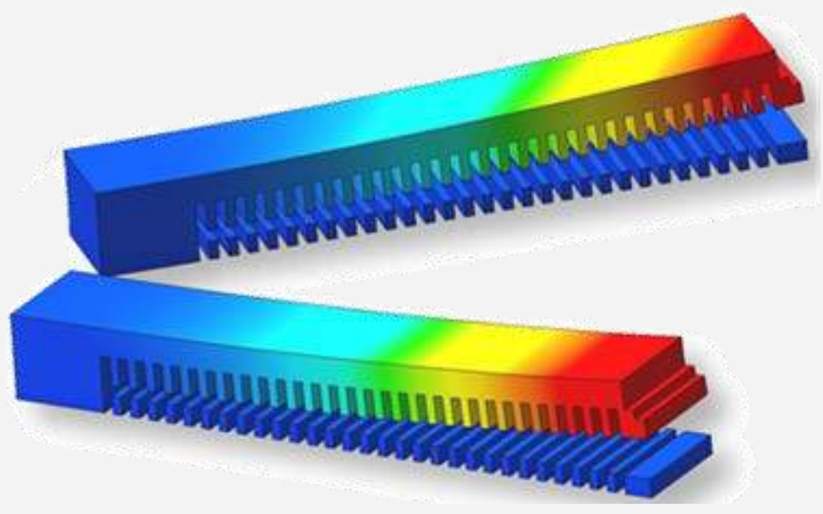




Thermo-mechanical approach

A sequentially coupled approach which first solves for thermal fields as they evolve on a per-layer basis (1), and then calculates the total strain as the sum of those produced due to plastic and thermal effects (2). The resulting stress is calculated on the same basis as the inherent strain technique.

$$(1) \quad \rho c_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + Q^{laser} \qquad (2) \quad \varepsilon^{in} = \varepsilon^{plastic} + \varepsilon^{thermal}$$



This requires the use of empirical approaches for heat source calibration and net impact of scanning at the macro-level of simulation. Further experimental data is required to capture plasticity.

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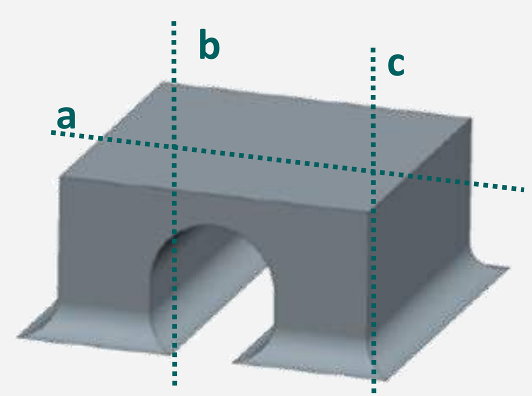
Simulating Manufacturing

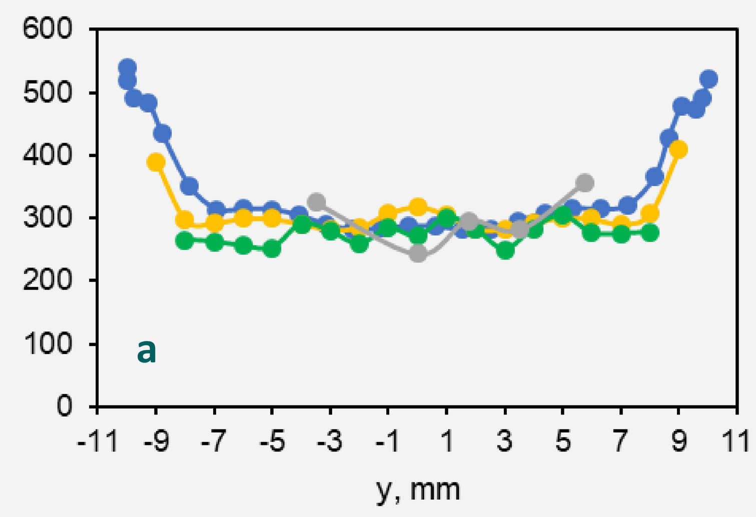
Results

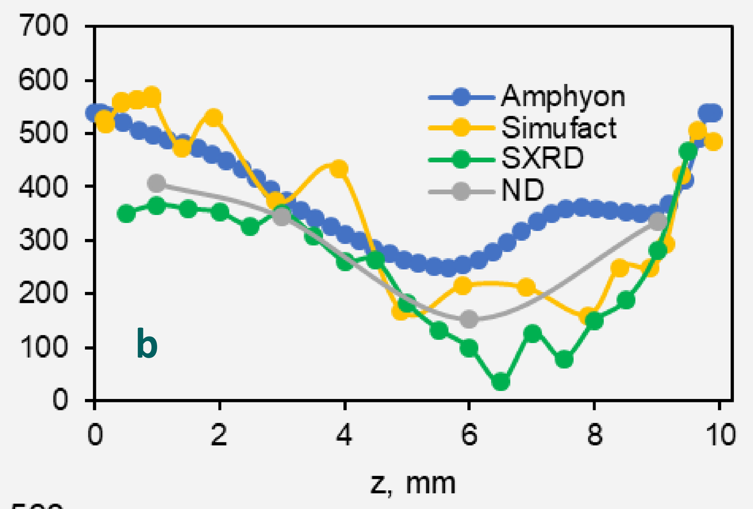
The subject benchmark samples showed an effective test of residual stress characterization, both from an experimental standpoint and a predictive modelling approach.

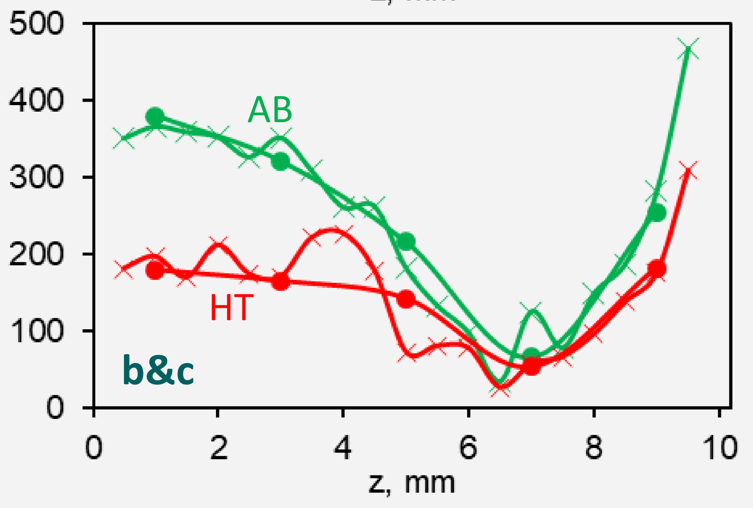
Synchrotron and neutron diffraction measurements were been conducted, which confirmed that thermo-physical approaches provide closer predictions to those made by inherent strain frameworks.

This component is responsive to heat treatment for the reduction of residual stress magnitude in a heterogeneous manner, which a thermo-physical approach is best poised to predict.









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