In-situ X-ray diffraction of additive manufacturing to aid in tool steel grade development

INDUSTRIAL PILOT PROJECT

THE INDUSTRIAL CHALLENGE

A major challenge in the design of new martensitic tool steel grades for producing hot-work tools by additive manufacturing (AM) by laser-powder bed fusion (L-PBF) is to overcome their crack susceptibility. The L-PBF process results in a complex thermal history as the laser repeatedly melts the surface and heats the adjacent material. The hot-work tool steels undergo phase transformations both during solidification and in the solid-state as martensite forms. It is a real challenge to deconvolute the microstructure and stress evolution necessary to understand how to improve the material and its printability.

WHY USE A LARGE-SCALE FACILITY?

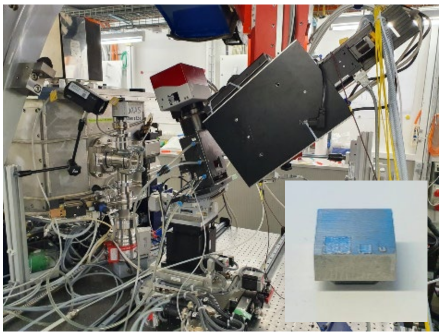
using conventional lab-based X-ray diffraction (XRD) techniques after the process since the thermal history is unknown. The high intensity and spatial resolution of synchrotron sources, combined with ultrafast detectors, allows X-ray diffraction (XRD) studies of how the material evolves during the printing process. In this manner, the phase and stress evolution can be captured during the process and compared to the thermal history.

HOW THE WORK WAS DONE

At the Paul Scherrer institute a research group have constructed a miniaturized L-PBF printer to be used at the MicroXAS beamline of the Swiss Light Source (SLS). This allows real-time diffraction studies while building small structures. The focused X-ray beam with low energy (3-23 keV) makes it possible to perform diffraction measurements of a fixed volume, smaller than a melt pool, as the laser scans across the surface. In this way, one can monitor as the material is heated and melted by the laser, solidified, and eventually transformed to martensite. It is further possible to see the influence of heat flow as the laser scans adjacent areas during the build. The ultrafast detectors with acquisition rates of up to 40 kHz permit sufficient time resolution to capture the process. Due to the travel restrictions during the pandemic, the experiments were kindly conducted by Steven Van Petegem at PSI.

THE RESULTS AND EXPECTED IMPACT

An example of the small structures built, and the information acquired during the build can be seen below.



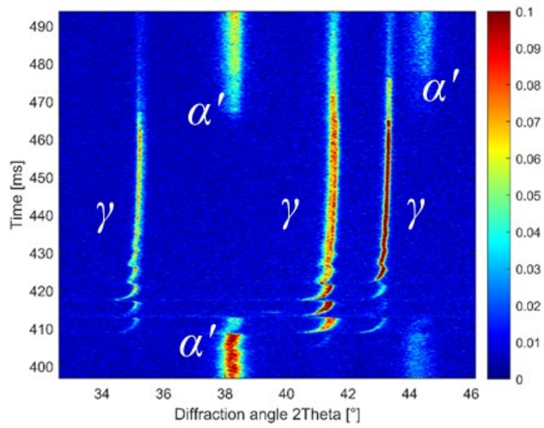


Figure a) The miniSLM mounted at MicroXAS, and small printed structures (4x4, 2x2 and 1x1 mm^2). **b)** Phase evolution (including heating, melting, solidification of γ austenite and later α' martensite formation) in the 2x2 mm^2 structure as the laser is scanning across one layer. Each laser scan is completed in ~4 ms, and the bending of the X-ray lines is due to the changing temperature.

The measurements have resulted in novel information about the local thermal history and resulting microstructure evolution during the L-PBF process for these types of steels. The information gives clues to the continued development work at Uddeholm.

Contacts: Christos Oikonomou – Uddeholm, christos.oikonomou@uddeholm.com
Niklas Holländer Pettersson– Royal Institute of Technology, KTH, nikpet@kth.se
Greta Lindwall – Royal Institute of Technology, KTH, gretal@kth.se

Vinnova's project No: 2019-05276 **Duration:** February 2020 – December 2021

Funded by Sweden's Innovation Agency, Vinnova, in order to build competence and capacity regarding industrial utilisation of large-scale research infrastructures such as MAX IV and ESS.