INDUSTRIAL DEVLOPMENT PROJECTS

In-situ X-ray diffraction studies for enhanced understanding of the martensite transformation during additive manufacturing of steels

THE INDUSTRIAL CHALLENGE

Additive manufacturing (AM) of metallic components promotes more sustainable products by reducing waste material, decreasing weight, and enhancing properties through microstructure modification. For steels, AM allows the production of complex-shaped, high-strength parts that are unattainable with conventional manufacturing methods. Despite recent advancements, challenges persist due to issues with residual stresses, distortions, and cracking. These challenges are linked to the complex microstructure evolution during the AM process. Specifically, fundamental studies are needed to understand the austenite-to-martensite transformation under the high cooling rates typical of laser-based AM.

WHY USING A LARGE SCALE FACILITY

Using *in situ* X-ray diffraction (XRD) at a synchrotron allows us to monitor phase transformations during the AM process in real time and detect transformation temperatures with high spatial and temporal resolution.,

HOW THE WORK WAS DONE

The XRD experiments were conducted with the setup for *in situ* laser powder bed fusion (PBF-LB) called "MiniSLM" (Fig. 1, left) at the microXAS beamline at the Swiss Light Source at Paul Scherrer Institut (PSI). This experimental setup allows to build several layers of metal powder on top of a build plate (Fig. 1, right). The focus was on detecting the temperature when martensite starts to form, i.e., the martensite start (Ms) temperature, and the influence of cooling rate on the Ms temperature. The experiments were performed at an X-ray beam energy of 17 keV and recorded at 20 kHz and 40 kHz. Data from a range of Fe-C compositions (0 – 0.18 wt.% C), PBF-LB scanning parameters (300 W, 150-800 mm/s) and different rectangle geometries resulting in a variety of thermal histories was acquired, resulting in 194 different measurements. Drs. Steven Van Petegem Malgorzata Makowska from PSI are acknowledged for their support.

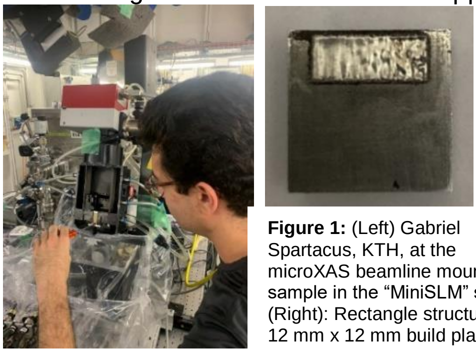

Figure 1: (Left) Gabriel Spartacus, KTH, at the microXAS beamline mounting a sample in the "MiniSLM" setup. (Right): Rectangle structure on a 12 mm x 12 mm build plate manufactured with "MiniSLM".

RESULTS AND EXPECTED IMPACT

The recorded XRD data included information on the austenite-to-martensite transformation during AM (Fig. 2). This data allows to map the austenite-to-martensite transformation in composition- and process-condition space and enables the validation of thermodynamic models.

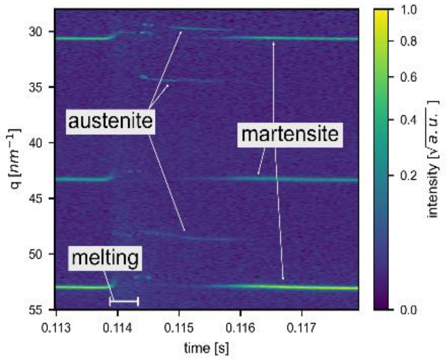

Figure 2: The XRD signal during laser scanning of a pure iron sample exhibiting the austenite-to-martensite transformation

The preliminary analysis of the *in situ* XRD results indicated that the martensite transformation depends on the PBF-LB parameters in addition to the alloy composition. In particular, it was observed that the Ms temperature decreases at high cooling rates which impacts the possibility to harden the material. This knowledge enables the design of new steel grades tailored for AM.

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