Multi-Scale Characterisation for Additive Manufacturing Applications using X-ray Computed Tomography

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ABSTRACT

The proposed multiscale tomography method examines healable alloys by combining Micro-CT and Nano-CT scans for high-resolution characterization. To enable precise correlation between scans at different scales, a specialized sample holder facilitating alignment of the Regions of Interest was developed. The presented methodology is suitable for the cylindrical–shaped samples. The methodology is demonstrated particularly on Almazium samples manufactured by Laser Powder Bed Fusion (LPBF). The multiscale approach provides detailed insights into porosity distribution and morphology, while allowing the evaluation of the alloy healing process over time. This approach facilitates the refinement of alloy composition and manufacturing parameters. Healable alloys have significant applications in the automotive, aerospace, space, and defence industries, where their ability to self-repair microcracks enhances durability, reduces maintenance costs, and improves overall structural reliability.

I Concept

INTRODUCTION

Aluminium alloys are widely recognized as essential structural materials. The healing of these alloys brings an interesting opportunity for self-repair of microcracks and damage, which enhances their favourable mechanical properties. The advent of metal Additive Manufacturing (AM) has further expanded the potential of these alloys, with Laser Powder Bed Fusion (LPBF) emerging as a prominent fabrication method [1]. However, challenges such as porosity, microstructural inhomogeneities and changes in mechanical behaviour in fabricated parts require advanced characterization techniques to optimize alloy properties. To address these challenges, the presented methodology introduces a multiscale tomography approach combining Micro-CT and Nano-CT for the detailed evaluation of healable aluminium alloys [2]. A specialized sample holder ensures precise alignment of Regions of Interest (ROIs) across different scales, facilitating a more accurate analysis of porosity distribution and self-healing efficiency.

MICRO-CT AND NANO-CT DATA ACQUISITION

For data acquisition were utilized two CT scanners. The Micro-CT scanner ThermoFisher Heliscan MK1 and RIGAKU nano3DX submicron-CT scanner. The scanners differ among other things in the X-ray geometry, where microCT system utilizes cone beam geometry, and submicron-CT system use near-parallel beam geometry.

Table 1: Acquisition parameters of CT measurements

Parameter	Micro-CT scan	Micro-CT scout scan	Nano-CT scan
Trajectory	Helical	Circular	Circular
Voltage	120 kV	120 kV	50 kV
Current	170 µA	170 µA	24 mA
Filtration	1.5mm Al	1.5mm Al	0.1mm Al
Exposure time	0.7s	0.4s	12s
# projections	2880	800	800
Scan duration	4h 21m	35m	2h 55m
Voxel size	4.97 µm	8.07 µm	528 nm

SAMPLE AND HOLDER DESIGN

The testing specimen was fabricated as a cylindrical structure with a diameter of 10 mm and a height of 5 mm, including the lattice-like pattern on its surface. Firstly, a µCT scan of the entire sample was conducted to characterize porosity, guiding the selection of the Region of Interest (ROI) for higher-resolution nCT imaging. A specialized correlative sample holder (see Fig. 1) was attached above the selected ROI using high-strength epoxy adhesive. The scout scan of the sample with the holder was acquired, followed by size reduction using a metallographic saw, producing a cubic segment approximately 1.5 mm wide. Further refinement was done through laser cutting, forming a cylindrical pillar (1 mm in height, 700 µm in diameter) using a femtosecond laser inside a TriBeam microscope (see Fig. 2). Correlative markers were added via Plasma Xe FIB milling to aid dataset registration between nCT and µCT scans. In consequent nCT imaging, two datasets were acquired: Interface-nCT at the interface between the pillar and the correlative holder necessary for data registration, and another ROI-nCT focusing on the selected ROI.

Dataset alignment was performed in three steps:

(1) the µCT scout scan was registered to the original whole-sample µCT scan based on morphological features

(2) the scout scan was aligned with the interface-nCT scan using the correlative holder as a reference

(3) the ROI-nCT scan was positioned using the field-of-view shift from the interface-nCT scan

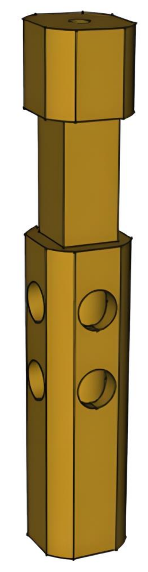

Fig1.: Correlative sample holder

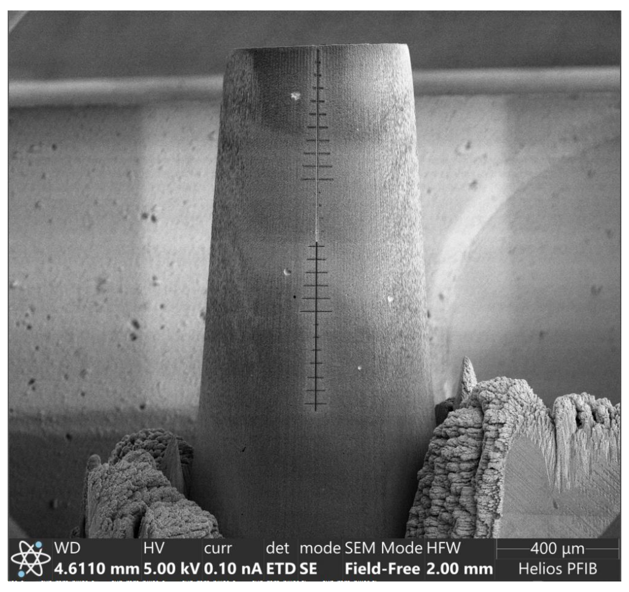

Fig2.: Cylindrical pillar – ROI for nCT investigation containing correlative markers.

II Procedure

THE PROCEDURE OF MULTISCALE DATA CORRELATION

Micro-CT scan of the entire sample. Lattice-like pattern on the surface facilitate data registration.

Analysis of the porosity distribution of the sample to determine the selection of ROI for further investigation.

Attachment of the correlative holder, and acquiring the scout scan of the sample with the holder attached.

Sample size reduction to the ROI for nano-CT investigation, and fabrication of the correlative markers on the sample.

Correlation of micro-CT and nano-CT scans. Datasets are aligned using correlative holder and markers as the reference.

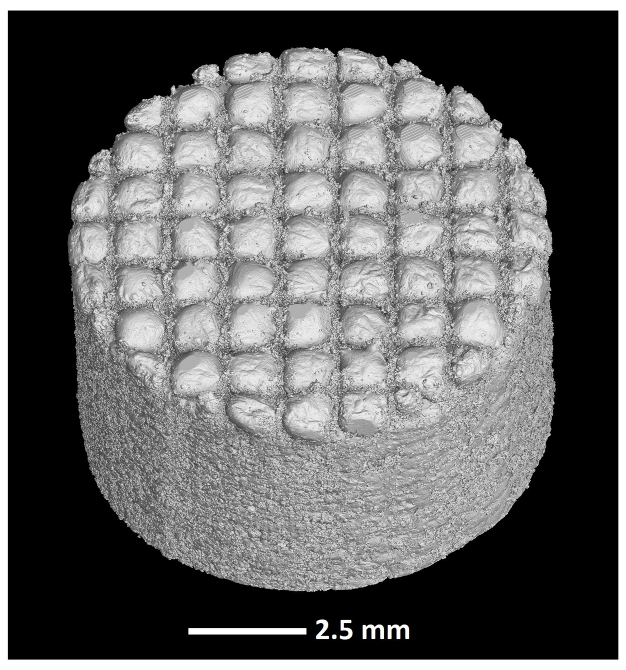

Fig3.: Micro-CT scan of the entire sample

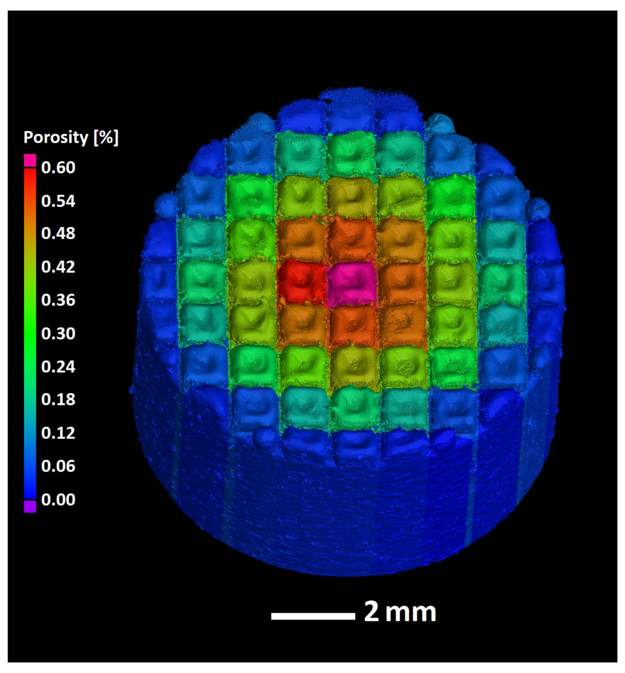

Fig4.: Analysis of the porosity distribution

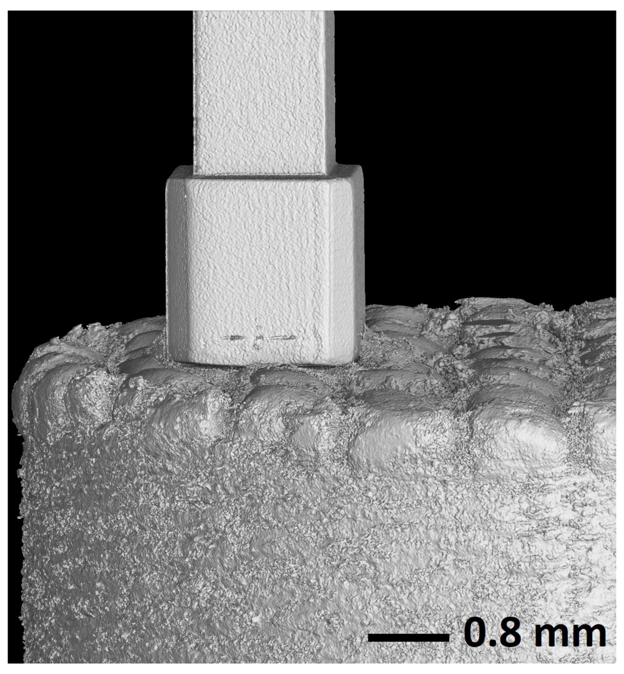

Fig5.: Micro-CT scout scan with the correlative holder attached

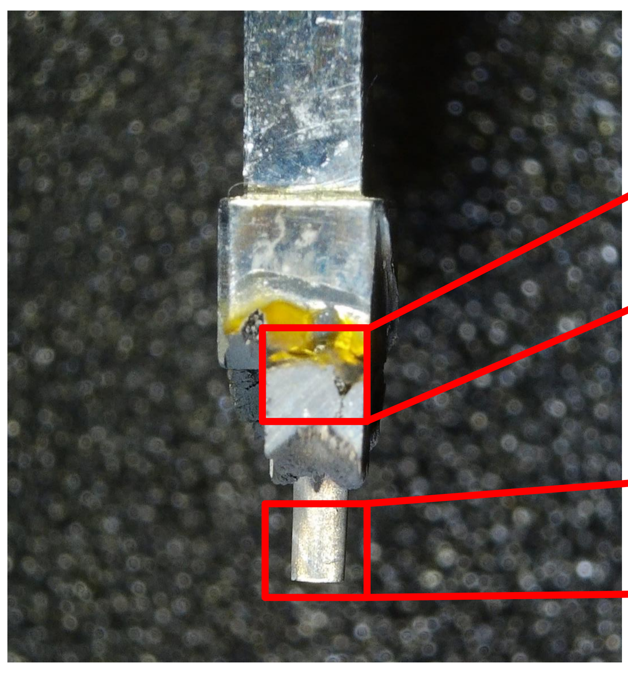

Fig6.: Detail on the ROI fabricated for nCT investigation. Captured by LCD microscope

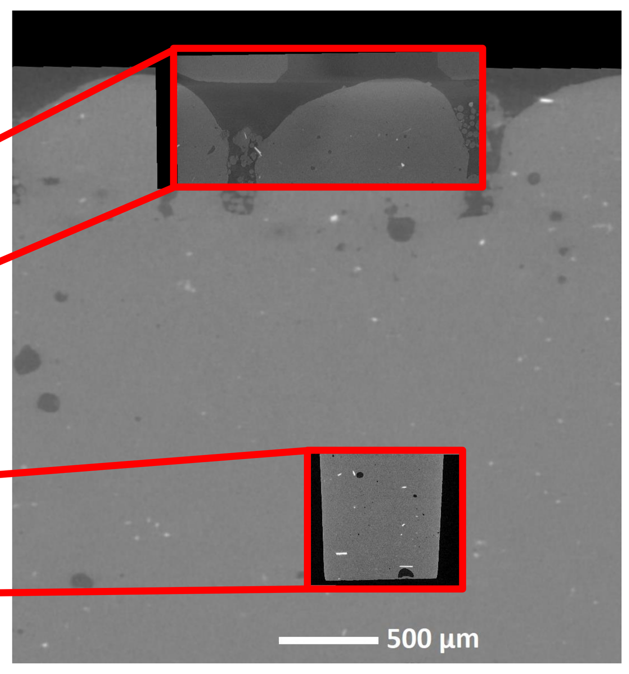

Fig7.: Correlated micro-CT and nano-CT scans with different voxel sizes

III Results and Conclusion

RESULTS

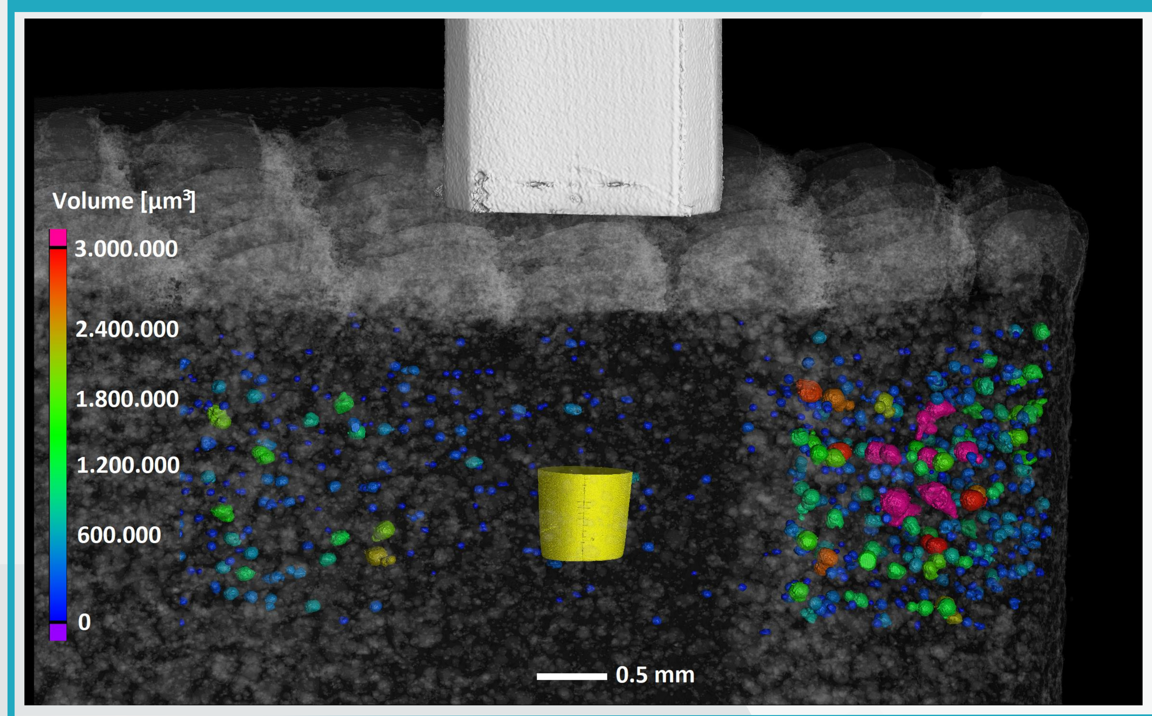

Fig8.: Correlation of Micro-CT and Nano-CT (yellow) scans. The correlation was achieved by using the correlative holder (image top). In the Micro-CT scan, porosity is detected, with pore volume visually distinguished by different colours. Nano-CT scan serves for detailed investigation of porosity, inclusions, their morphology and spatial distribution.

CONCLUSION

The presented multiscale tomography methodology represents an approach for the characterization of healable aluminium alloys samples produced by additive manufacturing. Combination of Micro-CT and Nano-CT scans and correlative sample holder used for data registration, enables material characterization across different scales. It is particularly valuable for assessing porosity, microstructural inhomogeneities, and mechanical behaviour prediction, which are critical factors in optimizing alloy performance. Additionally, the approach allows for direct evaluation of the healing process by comparing pre- and post- healing alloy states. Demonstrated on LPBF-manufactured Almazium alloy, this methodology supports the refinement of alloy composition and manufacturing parameters. Future work will extend this technique to even deeper insight into the sample by SEM imaging with X-ray CT data correlation. The presented approach contribute to the development of more resilient materials for applications in automotive, aerospace, space, and defence industries.

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