euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025

www.euspen.eu

Influence of laser scanning strategy on dimensional accuracy in PBF-LB manufactured AlSi10Mg Hollow Lattice Structures using XCT

Ibon Holgado[1], Naiara Ortega[1, 2], Soraya Plaza[1, 2], José A. Yagüe-Fabra[3], Herminso Villarraga-Gómez[4]

[1] *Aeronautics Advanced Manufacturing Center (CFAA), Parque tecnológico de Bizkaia, 202, 48170 Zamudio, Spain*

[2] *Department of Mechanical Engineering, Bilbao School of Engineering, Plaza Ingeniero Torres Quevedo 1, 48013 Bilbao, Spain*

[3] *I3A, University of Zaragoza, María de Luna 3, 50018 Zaragoza, Spain*

[4] *Carl Zeiss Industrial Quality Solutions, LLC, Wixom, MI, USA*

Ibon.holgado@ehu.eus

Abstract

This study examines the influence of hatch infill and multiple contour scanning strategies on geometric deviations in AlSi10Mg thin hollow lattice structures (HLS) fabricated via laser powder bed fusion (PBF-LB). X-ray computed tomography (XCT) is used as a dimensional metrology tool to evaluate roundness and wall thickness variations across different sub-millimeter nominal thicknesses. Results indicate that hatch infill induces higher HLS inner section roundness values than multiple contour strategy, attributed to localized energy density differences. Additionally, voxel size significantly impacts roundness measurements, with discrepancies between 25 µm and 44 µm voxel size scans reaching 20 µm.

Hollow lattice structure, X-ray computed tomography, metrology, laser powder bed fusion

1. Introduction

Hollow lattice structures (HLS) represent a novel class of engineered materials with applications in aerospace and thermal management systems. HLS contribute to the development of more sustainable engines by enabling weight reduction while maintaining high mechanical performance. Moreover, HLS enable the simultaneous flow of fluids through separate channels within the lattice, enhancing heat dissipation efficiency compared to conventional solid-strut lattices [1].

Despite advances in Additive Manufacturing (AM), particularly Laser Powder Bed Fusion (PBF-LB), the fabrication of HLS remains a significant challenge. Defect formation mechanisms inherent to AM hinder the industrial adoption of HLS, particularly in aluminum alloys, which have been shown to be more prone to geometric deviations and defects [2]. Although the literature efforts on HLS topologies research, the widespread adoption of these structures remains constrained by the lack of a standardized, robust quality assessment methodology to ensure that HLS components meet functional requirements [1]. Specifically, deviations in the inner tubular cross-section can induce pressure losses, negatively affecting coolant flow and heat transfer performance.

Recent studies have explored the influence of PBF-LB processing parameters on thin-walled structures. Wu et al. [2] analyzed scanning strategies to optimize dimensional accuracy, while Hassanin et al. [3] explored laser path impact in lattice structures and micro-channels. The findings highlight the critical role of PBF-LB scanning parameters, though their correlation with geometric deviations remains unclear, making dimensional accuracy in HLS manufacturing a major challenge.

To address the need for standardized quality control, X-ray computed tomography (XCT) has emerged as a key metrological tool for assessing internal and external geometries with high resolution. However, the primary challenge associated with XCT is measurement uncertainty, which affects the reliability of reported dimensional data. The XCT measurement uncertainty stem from multiple error sources inherent to the XCT scanning process. Recent studies highlight the significant influence of voxel size on dimensional fidelity, particularly in submillimeter-scale components, though its impact remains insufficiently characterized. The minimum achievable voxel size, constrained by sample dimensions and material properties, often exceeds critical feature sizes, compromising measurement accuracy [4].

This study investigates the influence of hatch infill and multiple contour laser scanning strategies on geometric deviations in AlSi10Mg HLS, employing XCT as a dimensional metrology tool. Additionally, this research examines the impact of voxel size variation (25 µm and 44 µm) on roundness deviations and wall thickness measurement accuracy in PBF-LB-produced HLS. A prototype HLS test object is used to evaluate the suitability of XCT for quality control in hollow lattice structures, contributing to the development of more reliable and traceable metrological frameworks for these advanced engineering components.

2. Materials and methods

A HLS test specimen of AlSi10Mg was fabricated using a RenAM 500Q PBF-LB system under manufacturer-recommended conditions. The unit cell (8 × 8 × 8 mm³) was arranged in a 3 × 3 × 4 lattice with 2.2 mm outer diameter hollow struts, following a body-centered cubic configuration with z-axis reinforcement (BCCz), a flexion-dominated topology commonly used in load-bearing applications. To assess the effect of scanning strategies on manufacturing quality, processing parameters were systematically varied across eight 4 mm-high regions. Each region was fabricated with different laser scanning strategies and wall thicknesses (Figure 1). A minimum wall thickness of 0.3 mm was chosen, as thinner walls require a single laser track, restricting the use of multiple scanning strategies. Thickness variations were achieved by adjusting the inner diameter of the hollow struts. Hatch infill and multiple contour scanning strategies were selected based on their reported optimization in the literature [2].

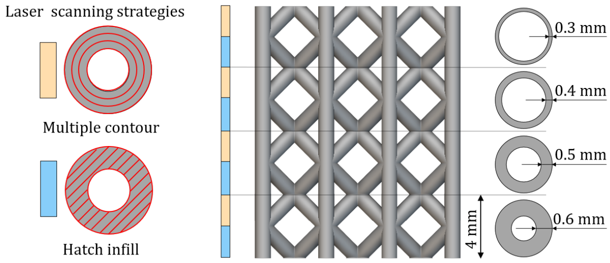

Figure 1. PBF-LB parameters for each region in the HLS structure.

The HLS test specimen was scanned twice using an Rx Solutions EasyTom XL XCT system at two magnifications. The first scan, with a 44 µm voxel size, ensured the maximum magnification with a manageable file size below 30 GB, typical for industrial applications. The second scan, at 25 µm voxel size, maximized magnification while keeping the entire component within the detector's field of view during a 360° rotation. XCT data post-processing included roundness measurements of inner and outer profiles (determined using the least squares method) and wall thickness measurements, calculated as the radial difference between least-squares-fitted outer and inner circumferences. Measurements were taken at 1 mm equidistant intervals above and below the interface where processing parameters were modified. Representative roundness and thickness values for each manufacturing region were defined as the mean of 16 z-axis reinforcement hollow struts, with standard deviation quantifying variability.

3. Experimental results

Figure 2 presents the ratio of the calculated mean roundness values to nominal thickness for the hollow struts fabricated using hatch infill and multiple contour scanning strategies, after post-processing the 25 µm voxel size scan. The results show that the outer roundness of the hollow struts is consistently greater than the inner roundness, except for the 0.3 mm nominal thickness, where fabrication was predominantly constrained to a single laser track, resulting in differences of less than 5 µm, which are considered negligible in this study.

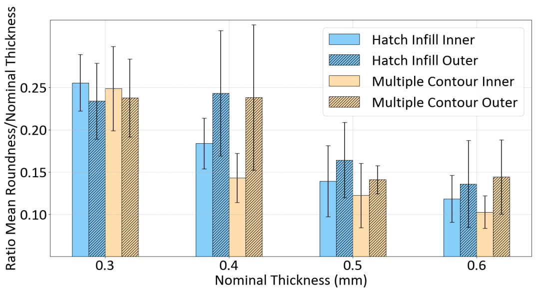

Figure 2. Ratio of the mean roundness to nominal thickness for each laser scanning strategy at the different nominal thicknesses of the HLS.

For inner HLS sections, the hatch infill strategy consistently yielded higher roundness values compared to contour scanning. This deviation is attributed to localized energy density differences inherent to each scanning strategy. Specifically, hatch infill results in a higher localized energy input due to the closer overlap between successive laser tracks, reducing heat dissipation efficiency. In contrast, contour scanning exhibits a more uniform thermal distribution. The reduced heat conduction pathways in HLS inner sections limit thermal dissipation, thereby increasing melt pool instability, resulting in greater geometric heterogeneity upon solidification.

The effect of voxel size on roundness and thickness measurements of HLS was evaluated by analyzing the differences between values obtained from post-processing 25 µm and 44 µm voxel size scans (see Figure 3).

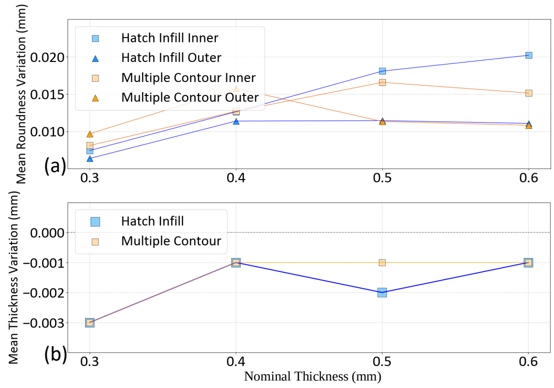

Figure 3. Measurement variations between 25 µm and 44 µm voxel size scans. (a) Mean roundness and (b) mean thickness variations of HLS.

A progressive increase in roundness variation is observed with increasing nominal thickness, suggesting asymptotic stabilization beyond 0.6 mm. Notably, the magnitude of this variation reaches 20 µm, highlighting the significant impact of voxel size on dimensional accuracy as the feature size approaches the instrument's resolution threshold. For larger-scale features such as wall thickness, the variation shows no discernible trend with nominal thickness and remains negligible.

5. Conclusions

This study investigated the impact of hatch infill and multiple contour scanning strategies on geometric deviations in AlSi10Mg HLS fabricated using PBF-LB. Experimental results support recommending multiple contour strategy to improve manufacturing quality in the inner sections of HLS, as it consistently results in lower form errors than hatch infill, particularly for applications where internal surface integrity is critical, such as thermal management systems. However, when the internal diameter exceeds 1.6 mm, increased heat dissipation allows multiple contour and hatch infill strategies to achieve comparable geometric outcomes. The influence of voxel size (25 µm and 44 µm) on XCT-based measurements was also analysed and discussed. Future work should focus on refining metrological frameworks (consider wider voxel size range) for XCT-based HLS assessments, including measurement uncertainty, to enhance measurement reliability. Additionally, further investigation into hybrid scan strategies (e.g., hatch combined with single or double contour) is recommended to support process optimization in HLS manufacturing.

Acknowledgements

Grant PID2020-118478RB-100 funded by MCIN/AEI/10.13039/501100011033. This research was also funded by the Basque Government through the ELKARTEK program, grant number KK-2024/00080.

References

[1] Noronha J, Qian M, Leary M, et al. 2021 *Current Opinion in Solid State and Materials Science* 25 100940.

[2] Wu Z, Narra S P and Rollett A 2020 *Int. J. Adv. Manuf. Technol.* 110 191-207 https://doi.org/10.1007/s00170-020-05827-4.

[3] Hassanin H, Finet L, Cox S C, et al. 2018 *Additive Manufacturing* 20 144-155.

[4] Sun W, Giusca C, Lou S, Yang X, et al. H 2022 *Additive Manufacturing* 50 102558.