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Accuracy estimation in the characterization of surface roughness of polymer-based lattice structures by X-ray computed tomography

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Abstract
Lattice structures have become an innovative solution for the improvement of part design, as they are able to substitute solid regions, maintain mechanical capabilities, and reduce material usage; however, dimensional quality control of these geometries is challenging. An important feature to consider for ensuring their mechanical properties is the integrity of the shape of each element of the lattice: high form errors or high roughness on the surface of the struts could cause unpredicted failures. X-ray computed tomography (XCT) is the most suitable non-destructive metrological technique for the inspection of lattices, as it is capable of characterizing internal features and hidden elements. However, traceability methods for XCT are still in development, and studies typically use calibrated devices as a reference. For this purpose, focal variation microscopes (FVMs) are widely used as reference devices for the evaluation of micro geometries such as surface roughness, due to their capability for the characterization of small areas with high resolution. This work is focused on the definition of the accuracy of XCT surface roughness measurements on polymeric strut-based lattice structures, through an intercomparison of the results obtained by this technique with the measurements from a reference device (FVM). Experimental measurements are taken on ad hoc designed test objects manufactured in polyamide 12 (PA12) using selective laser sintering (SLS). A body-centered cubic (BCC) lattice is used in workpieces, built in bases with optimized shapes for the evaluation on both instruments. Roughness parameters have been extracted from each strut, dividing into upward and downward faces depending on the orientation of the lattice printing.

Keywords: X-ray computed tomography, Additive manufacturing, Lattices.

1. Introduction

The development of newly manufacturing technologies, such as additive manufacturing (AM), has led to an improvement of the characteristics of the parts produced [1]. It has been possible through the introduction of high complexity elements in the designs, allowing better performance of the industrial products with an optimization of material usage and manufacturing time.

One of the main innovations in terms of geometries is the use of lattice structures. These elements are composed by geometrical patterns distributed along the shape, replacing solid areas with the intention of reducing the amount of material used but maintaining the mechanical properties. However, the dimensional quality control of parts with lattice structures could be challenging, as traditional coordinate measuring systems (CMS) with tactile probes or optical scanners could not evaluate hidden features. In lattices, surface texture is a particularly critical aspect to control [2], as rough features could cause an unexpected mechanical behaviour and failures.

For metrological purposes, X-ray computed tomography (XCT) rises as the most optimal option, as this technique is capable of the inspection of both external and internal elements [3]. Here, the main challenge is to ensure the traceability of the measurements, which is currently in development [4]. Substitution method is typically used; however, it is difficult to obtain reference measurements with other calibrated devices. When evaluating micro geometries such as roughness, XCT has limitations (resolution, imaging issues such as noise or artifacts) that could also reduce the accuracy on fine details, leading to the obtention of artificially smoother surfaces which do not represent the real part.

In this paper, an approach of the accuracy definition of XCT on the evaluation of surface roughness in lattice structures is presented. An intercomparison has been made between XCT and a focal variarion microscope (FVM), typically used for surface characterization, through an experimental framework with a test workpiece optimized for the evaluation by both devices. Areal parameters have been extracted from the struts, sorting by upward and downward surfaces depending on the orientation of the 3D printing, as roughness is higher in downward elements due to the manufacturing principle.

2. Design and methodology

2.1. Test workpiece

A probe designed in previous studies [5] has been used as a test artefact, which includes a 4-cell strut-based lattice (Figure 1), for a total of 16 individual struts. Body-centered cubic disposition has been selected due to the 45° orientation of the struts, which ease the measurement by FVM. Each individual cubic cell has 5 mm length, with Ø1 mm nominal diameter of the struts. An extension has been added for the optimal attachment on both metrological devices.

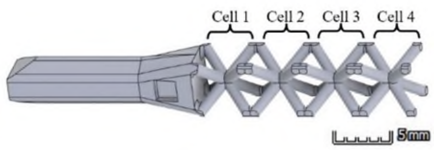

Figure 1. Strut-based lattice structure test workpiece [5].

Test workpiece has been manufactured by a selective laser sintering (SLS) device Sinterit Lisa Pro in polyamide PA12.

2.2. Measurements

Experimental measurements have been taken by a FVM InfiniteFocusSL of Alicona (integrated software IfMeasureSuite 5.3.6), using a calibrated rotary plate for a 360° scan along a horizontal axis, and by an XCT device Zeiss Metrotom 800 G3/225 kV (integrated software Metrotom OS 3.12). Relevant XCT and FVM parameters are summarized in Table 1.

Table 1. Evaluation parameters in each device.

Device	Magnification	Resolution [µm]	Time [min]
XCT	4.0	34.26 (Voxel)	15
FVM	4x AX (Lens)	0.13 (Vertical) 8.5 (Lateral)	70

2.3. Surface processing

Surfaces of the lattices have been divided into individual struts for post processing and roughness parameter extraction (Figure 2a). Each strut has been cut in half, separating upward and downward surfaces (Figure 2b). Cylindrical form has been removed (Figure 2c) to obtain the final flat surface.

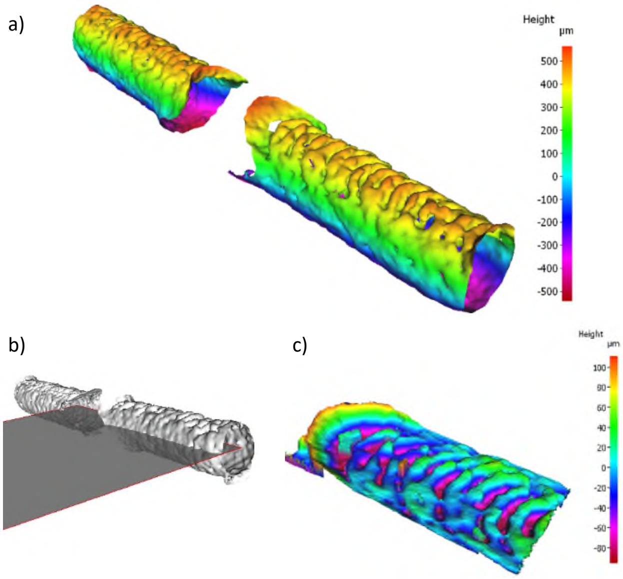

Figure 2. Data process for roughness parameters obtention. a) Single strut. b) Upward and downward surface division. c) Form removal.

Flattened surfaces have been filtered according to normative [6, 7], considering a L-filter nesting index (hi-pass filter) of 0.8 mm and an S-filter nesting index (low-pass filter) of 2.5 µm. Areal roughness parameters (Sa, Sq and Sz) have been extracted. Complete post processing has been done using software IfMeasureSuite 5.3.6.

3. Results

Mean values and standard deviations of areal parameters Sa, Sq and Sz have been calculated and grouped by technology and surface position. Results are shown in Figure 3.

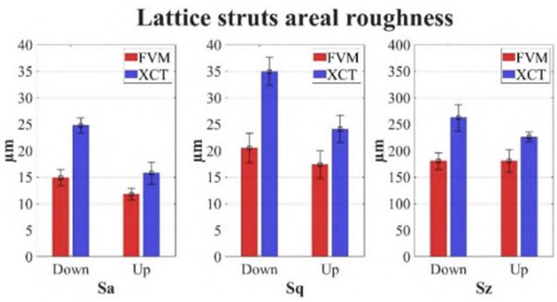

Figure 3. Areal roughness mean values and standard deviations.

Graphs show higher values in all areal roughnes parameters evaluated in surfaces obtained by XCT, with similar standard deviations in the results. It is significantly more evident in downward surfaces, where texture is rougher due to the manufacturing process itself; however, differences upward-downward are better characterized by XCT. It follows the same tendency identified in previous studies [5]. Surfaces obtained by XCT has no void areas due to blind spots (as it occurs in FVM), and even though the resolution is worse, it is more suitable for the characterization of micrometric details such as surface texture and roughness.

4. Conclusions and future work

In this paper, an estimation of the accuracy of XCT on the evaluation of surface roughness in polymeric strut-based lattice structures is presented. An experimental framework is settled by comparing XCT results with measurements obtained by a FVM, a reference device typically used for surface texture inspection. Results show higher values in the evaluation of areal roughness parameters (Sa, Sq and Sz) by XCT than FVM, identifying more clearly the texture difference between upward and downward surfaces in the struts. This confirms the suitability of XCT when measuring complex geometries such as lattice structures. It has the initial advantage of being less time-consuming, but most important is that it is able to better characterize micrometric features even considering XCT limitations on this field (artifacts, noise and worse resolution than other devices specifically designed for surface texture characterization).

The adequated accuracy of XCT 3D volumes led to their usage in realistic mechanical simulations which consider the real geometry of the lattice and, therefore, could be able to predict the mechanical behaviour of the part. However, this should be taken with caution, as this study is limited to polymers. Further studies should be performed on materials with higher attenuation, such as metals, where noise could difficult the inspection of these micro geometries.

5. Acknowledgements

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