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Development of a multi-configuration support for the comparison of X-ray computed tomography and optical profilometry surface texture measurements

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Abstract

The comparison of measurements from different instruments is an increasingly common task in advanced metrology. One case in point is the calibration of measuring machines using task-specific calibration artefacts. Another example is when two different measurement technologies are combined, e.g., to emphasise their strengths and mitigate their weaknesses. The study presents a practical case where design for metrology principles were applied to create a versatile additively manufactured support for test specimens. This support, compatible with both X-ray computed tomography and optical profilometry, not only serves the purpose of holding the specimen in place but it is also designed to include specific common features to assist in the subsequent data alignment operations, that would be otherwise challenging due to the high complexity of AM surface topography.

Design for Metrology, Surface Texture, X-ray Computed Tomography, Optical Profilometry, Additive Manufacturing

1. Introduction

When deciding which measurement strategy and instrument to adopt to perform a specific metrology task, several factors must be considered. These include the metrological characteristics of the measuring instrument and the geometrical complexity of the measurement to be performed [1]. In addition, the type of features and/or materials to be measured must also be taken into account. There is no such thing as an omnivalent measuring instrument, and very often, one has to compromise between the advantages and drawbacks of different techniques. Sometimes, the choice is relatively straightforward, while for other measuring tasks, an obvious solution seems to be lacking due to the limitations of the available measuring systems. In such cases, the solution frequently lies in merging the results of measurements from different measuring instruments to enhance their strengths and compensate for their weaknesses.

To this aim, appropriately referencing of measurements originating from different instruments is an important step. When dealing with surface texture measurements, previous works in the literature show the challenges linked to the comparison of results obtained using different measuring systems [2-3]. Among the most difficult surfaces to be evaluated, additively manufactured (AM) as-built surfaces are peculiar due to their inherent complex texture showing high roughness values [4], which also manifest significant variability depending on both process conditions and fabricated features [5]. Furthermore, the presence of re-entrant features makes effective measuring tasks challenging, thus motivating the use of X-ray Computed Tomography (XCT) to overcome the inherent limits of line-of-sight measuring instruments. On the other hand, instruments such as those based on Optical Profilometry (OP), are ideal for performing surface texture measurements with more than adequate resolution, but struggle with the identification of steep slopes and undercuts.

This work aims to exploit design for metrology principles to devise a measurement setup enabling the comparison of surface texture measurements in additively manufactured test specimens (e.g., for tensile testing), carried out using XCT and OP. The proposed approach can potentially be leveraged to provide more accurate and reliable surface texture measurements resulting from a fusion of data obtained with different instruments.

2. Specimen holder design methodology

Establishing functional requirements or limitations is paramount before proceeding with the design of any support equipment. This paper selected a specific sample with rotationally symmetric geometry. The first requirement relies on the need to collect information across the entire surface of the central portion of the test specimen shown in *Fig. 1*, where its main dimensions are reported.

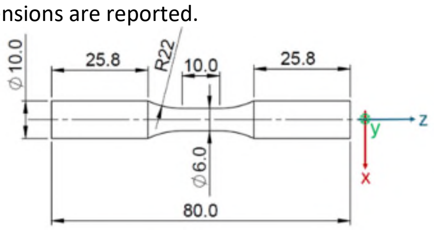

Figure 1. Test specimen geometry (dimensions are in mm).

Furthermore, the specimen holder should enable the comparison between surface texture measurements obtained using XCT and OP. Measurements should be repeatable also after the specimens are tested and the references must be preserved. To measure with OP, the specimen should be housed horizontally. The support should allow the user to place the specimens repeatedly in the same position. To do so, the holder should be able to lock the three linear translations ($\vec{x}$, $\vec{y}$, $\vec{z}$) and two of the three rotations ($\vec{r_x}$, $\vec{r_y}$), allowing the specimen to rotate only around the generative axis ($\vec{r_z}$). In addition, to capture the whole surface and label each patch, the rotation axis should have a reference system with its zero and some discrete controlled positions. Regarding XCT scans, the specimen should be oriented vertically, and only the zero reference for the $\overrightarrow{r_z}$ rotation should be collected, since the entire specimen volume of interest is acquired. Therefore, as opposed to OP, the need for labelling each patch does not apply to XCT measurements. However, depending on the system's properties and on the desired magnification, the volume acquired during a circular scan has fixed dimensions. Hence, the zero mark should also be comprised in the scanned volume to be acquired with the specimen. *Tab. 1* summarises the functional requirements and limitations considered within the design for metrology workflow.

Table 1 Functional requirements and limitations for the specimen holder

	OP	XCT
1	Reproducibility	
2	Horizontal support to lock ($\vec{x}$, $\vec{y}$, $\vec{z}$) translations and ($\overrightarrow{r_x}$, $\overrightarrow{r_y}$) rotations	Vertical support to hold up the specimen
3	Zero reference system on axial rotation $\overrightarrow{r_z}$	Zero reference system for the specimen axial rotation $\overrightarrow{r_z}$ comprised in the XCT scanning volume
4	Stepped control on axial rotation $\overrightarrow{r_z}$	

Considering the specifications listed above, a design solution for multi-purpose support has been developed. The proposed specimen holder designs are shown in *Fig. 2,* for the XCT and OP configurations, respectively.

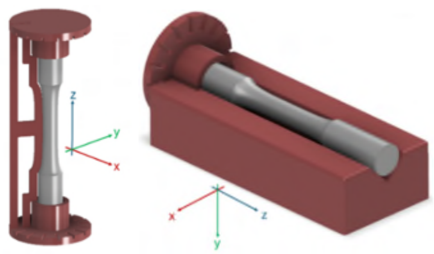

Figure 2. Specimen holder in XCT configuration (left) and OP configuration (right).

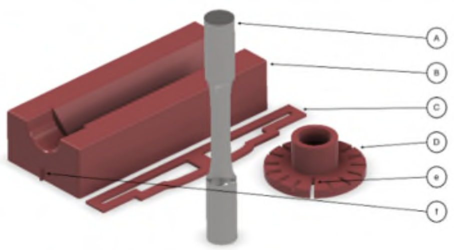

Figure 3. Proposed solution: (A) specimen, (B) V-shape support, (C) zero flap, (D) base disc, (e) zero notch, (f) coupling protrusion.

The two configurations share the base disc (*Fig. 3.D*) as a common component. This base disc, unequivocally interlocked with the specimen (*Fig. 3.A*), has *n* notches to mark different angular positions. The zero notch (*Fig. 3.e*) is the only one passing through the whole disc thickness, therefore easily recognisable. For the OP configuration, the specimen is placed on top of a V base support (*Fig. 3.B*) that locks two rotations ($\overrightarrow{r_x}$, $\overrightarrow{r_y}$) and two linear translations ($\vec{x}$, $\vec{y}$). To stop the last translation ($\vec{z}$), the base plate is brought up against a wall of the V-shaped base where, thanks to the coupling of a protrusion (*Fig. 3.f*) with the notches, the rotation can be controlled.
For the XCT configuration, a second disc is mounted on the other specimen gripping section, which presents a pass-through zero notch as well. Thus, a lightened flap (*Fig. 3.C*) is vertically mounted using the zero notches on each disc and it will appear inside the scanned volume to serve as the zero reference. Therefore, thanks to the notches the OP acquired patches will have consistent overlapping regions, thus facilitating the stitching. The zero flap, on the other end, will provide a common reference system between the two scanned surfaces.

3. Realisation and future works

The support has been fabricated in Polylactic Acid (PLA) using a Raise3D Pro3 (Raise3D, CA) system, applying a material extrusion (MEX) layer-wise manufacturing approach. The specimen holder has been tested in both the proposed configurations and it has proven to be successful in facilitating the comparison of data of corresponding regions between OP and XCT. *Fig. 4* shows the prototype used for OP (a) and for XCT scans (b).
Future works will focus on developing smart algorithms to stitch the *n* surface patches obtained using OP into a single surface that can then be compared and fused with the data coming from XCT. This approach has the potential to allow for more comprehensive surface texture data enhancing the knowledge on the AM surfaces and mechanical properties.

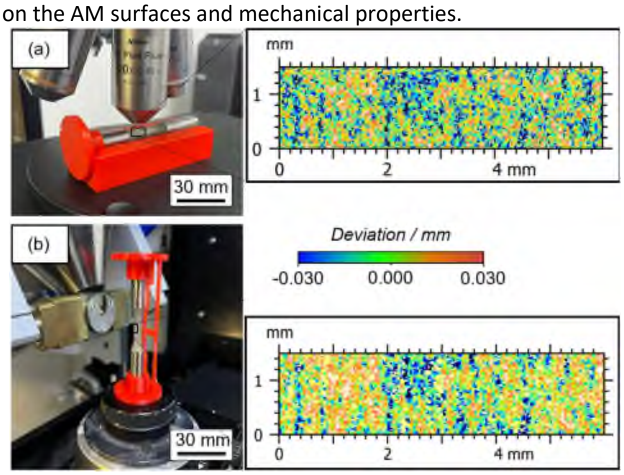

Figure 4. Specimen holder prototype used to measure an AM specimen using OP (a), and XCT (b). Insets show the corresponding respective measured surface topographies.

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