APPLICATION OF CHARACTERIZATION BY MICRO X-RAY COMPUTED TOMOGRAPHY AND ADDITIVE MANUFACTURING FOR LASER TARGET FABRICATION

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Abstract

To perform experiments on the Laser Megajoule (LMJ) [1, 2], targets are build up and developed with dimensional specifications ranging from nanometric to millimetric scale.
Additive manufacturing becomes an important process to realize target element or target assembly tools.
To match stringent specifications, accurate systems of characterization are used to characterize targets and manufactured micro-tools.
Micro X-Ray computed tomography is a powerful instrument of control and information acquisition for manufactured products. This technology can be useful in the validation of geometric parameters which are difficult to obtain with other metrology systems. It allows characterizing internal defects volume and geometry. The obtained tomographic volume is analyzed with a post processing visualization tool.
This work highlights improvements of the characterization of 3D printed target element, with complex shapes, by computed tomography. Results are presented and detailed.

1. Introduction

In order to produce targets for laser plasma experiments [1, 2] the CEA target department develops manufacturing and characterization methods able to be consistent with the target requirements in terms of quality, delay and cost.
X-ray computed tomography (XCT) is a non-destructive characterization method; it allows getting new information about measurements, especially of inner features as well as non-destructive porosity verification, with a micrometric and even sub-micrometric resolution.
Additive Manufacturing (AM) provides freedom of design that is generally infeasible by other manufacturing methods, particularly regarding the creation of complex internal features that are unrealizable to well-established measurements tools.
In this work 3D printed target parts and tools are realized and characterized by XCT. As mentioned in [3], the complementarity between XCT and AM is in full expansion and is commonly present in medical application. Nowadays it is expanding to industry.
To qualify XCT as a characterization process, XCT measurements are compared with those obtained with an optical measurement method.
A morphological deviation and defect analyses in comparison to the nominal CAD target element design is performed as well and results are presented in this paper.
2. Adaptative Manufacturing: principle, fabrication of target elements (example of sample)

2.1 Principle

The AM process used for this study is based on a selective layer by layer photopolymerization of a vat of liquid photopolymer resin (SLA). Once the tool machining is done, a post-treatment built-in UV polymerization is performed. The device is a 3D printer Micro-SLA ProJet 1200 and the resin used is “VisiJet FTX Green”. The resolution of the printed sample is 100 µm.

2.2 Manufacture of target elements

The development for 3D printing technologies allowed realizing complex shapes impossible (or with difficulty) to obtain with other means (machining, coating …), and in a short delivery time. Main difficulties for target application are the millimetric scale combined with the micrometric wall thickness, as well as the narrow tolerances required for the experiments [4]. Not only AM has proved its usefulness during laser target assembly process with AM-made holders, but in some cases it is also used to manufacture target elements themselves. In this study, as an example, a target element is 3D printed. This sample is not the same as the original machined target element (see figure 3). Indeed, AM has its limitations, the millimetric scale and the geometry constraint do not allow having the original target element design. So a template is added to the target element. A comparison between machined and 3D printed target is presented in figure 1.

3. Computed Tomography:

3.1 Principle

X-ray computed tomography is a nondestructive imaging technique allowing the 3D reconstruction of a sample. XCT characterization is divided in two successive steps: 2D x-ray images acquisition and acquired data processing (tomography reconstruction and metrology analyze). Two workstations are in place to process these steps:
- Acquisition station: axis moving, data acquisition.
Data processing station: CT slices reconstruction and 3D analysis (Measurement, Material Integrity).

The first step is to realize 2D x-ray images of an object in a 360-degree rotation, placed between an x-ray source and a detector. The second step is a digital reconstruction (slices) in gray levels from 2D x-ray images. The gray levels in a CT slice image correspond to x-ray linear attenuation of the x-ray source. At last, after analyzing the whole volume, it is possible to localize heterogeneities, porosities and inclusions in the sample.

3.1.1 Device and Sample
The target element previously presented is characterized with micro X-ray computed tomography system [8]. The experimental settings of this device are presented in table 1.

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>160 kV</td>
<td>50 µA</td>
<td>Tungsten</td>
<td>Automatic</td>
<td>Be</td>
<td>800 mm</td>
<td>Gadox</td>
<td>4008 x 2672</td>
<td>9 µm</td>
</tr>
</tbody>
</table>

3.1.2 Sample
The target element is realized based on the CAD plan as presented in figure 2.

Figure 2. Target element CAD plan.

3.3 Acquisition
The X-ray acquisition parameters for the target element scan are presented in table 2.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
<th>Target material</th>
<th>Tube Window</th>
<th>Voxel size</th>
<th>Sensor material</th>
<th>Number of projections</th>
<th>Frame rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 kV</td>
<td>30 µA</td>
<td>Tungsten</td>
<td>Be</td>
<td>5 µm</td>
<td>Gadox</td>
<td>4320</td>
<td>1 images/s</td>
</tr>
</tbody>
</table>
The reconstruction of the projections into the voxel volume is performed using the data reconstruction software named “X-Act” [8].

3.4 Results

3.4.1 Comparison with optical measurement

The CT datasets are analyzed using the data processing software VGStudio Max 3.0 [9]. To qualify XCT as an effective characterization method for 3D-printed target element, it is also measured with another device that is the current reference equipment. This equipment [10] is a profile projector. Its principle is based on shadowgraphy and edge detection. Measurements are given with 3 μm uncertainty. All features on the AM element target are measured and compared to optical measurement. Deviation is also evaluated.

The results show a maximum measurement deviation of 0.106 mm. Deviation can be explained by target element defects (see figure 3), due to the AM resolution, which is 100 μm, and by geometry complexity. It can also be caused by the optical measurement principle as the lighting choice (angle, light diffusion…).

For example, windows in figure 3a and 3b present a strong defect that cannot be fully characterized by optical measurement while XCT allows it.

These defects can be characterized by XCT and new ones can be discovered as defect circularity, defect concentricity of the entrance hole (see figure 4), porosity, with the help of complementary VGStudio Max modules [9]. During AM process, windows circular geometry does not meet expectations. Indeed, an extra thickness is created. Optical measurement method (see figure 3) only allows extremum measures of the extra thickness. So XCT can fit the defect perfectly with precision and visualize the defect on its whole.

![Figure 3. Windows defects of the target element and circular defect, taken with the profile projector.](image)
Figure 4. Defects representation of the target element, taken with XCT.

So XCT resolution and specifications are sufficient for AM resolution. AM process is in constant development [3]. CT’s resolution allows the characterization of future laser target that will be 3D-printed with a higher resolution.

3.4.2 Porosity
Porosity can be displayed by CT slices of the target element (figure 5). It can be measured with VGStudio Max 3.0 defect detection module, with the defect detection analysis. The analysis area is based on the determined surface, with “VGDefX” algorithm.

Figure 5. Visualisation of pores and its distribution seen in XCT volume and slices.

Pores spatial distribution is seen as well (Figure 5). Pores are spread along the 3D printed target element build direction (Figure 5). Average pore size (equivalent spherical diameter) is about 80 μm, the minimum size is 25 μm and the maximum size is 300 μm. The proportion of voids in the whole volume represents less than 0,1%. It is negligible and does not compromise the target element integrity. So AM process is qualified for the laser target fabrication process.

3.4.2 CAD
Additional information is obtained with a morphological deviation and defect analyses in comparison to the nominal CAD target element design. It is performed using the “comparison theory/original” module.
Most of the morphological deviation and the deviation caused by defects observed between XCT and AM are detected and localized in the thin wall structure area. It is reminded that AM resolution is 100 μm. The histogram illustrates this deviation and shows its distribution (figure 6). The maximum deviation is 200 μm and the average deviation measures 20 μm. AM limited resolution and fabrication issues explain these results.

4. Conclusion:

This study demonstrates the complementarity of Additive Manufacturing and X-ray Computed Tomography for laser target fabrication. AM contributes to assembly and laser target element fabrication process. It shows its limitations like the resolution and the wall thickness layer but with future development it is a promising answer for a wider laser target range application. XCT characterization made a contribution to element target knowledge in comparison with the current reference method. It allows working with a better resolution (micrometric and sub-micrometric) and provides new information like porosity and measurement, impossible to obtain before. Indeed, this information is obtained without degrading target elements by the NDT device that is X-ray micro tomography. Thus the laser target fabrication process is improved. In addition, XCT can realize comparison between the whole volume and nominal CAD target element design.

References and footnotes

10. OGP, “CNC 250”, device.