Characterization of microshells experimented on Laser Megajoule using X-Ray tomography

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Abstract
Some targets experimented on the Laser Megajoule (LMJ) facility are composed of amorphous hydrogenated carbon microshells. Some of them present rippled surface features like sinusoidal functions. The main difficulty when analyzing these microshells is to characterize the feature’s orientation and engraving depth. An X-Ray tomography is used to measure them. This work details the methodology and gives results obtained.

Keywords: LMJ targets, dimensional characterization, X-ray tomography

1 Introduction
As part of the Laser-Megajoule (LMJ) [1, 2] program, the French CEA (Commissariat à l’Energie Atomique et aux Energies Alternatives) designs, develops and fabricates targets or components of target with drastic specifications in order to study astrophysic hydrodynamics for instance. To match and to control these specifications, process and characterization devices have to be continuously improved.

Some targets or components are amorphous hydrogenated carbon microshells. Their outer diameters vary between 500 µm to 2000 µm with a thickness belonging to 10 µm to 200 µm. Some of these microshells present rippled surface features like sinusoidal functions.

A non-destructive characterization process was performed using an X-ray microtomography to obtain precisely the microshell’s feature orientation and engraving depth.

This paper presents the method and results obtained on the microshell’s features characterization. First, the key factors influencing the measurement are overviewed. This allows improving the quality of the data acquisitions and the definition of the processing parameters. All optimized factors then lead to the characterization of the feature’s orientation and engraving depth.

2 Metrology’s key factors
As dimensional metrology is a recent field of (CT) computed tomography applications, many studies [3] were focused on improving it by determining key factors. Some of these key factors can have no effects on CT work pieces as the beam hardening when characterizing plastic microshells. Among these key factors, the voxel size, the number of projections and the data filtering are those that only influence the measurement of the low X-ray absorption material.
2.1 The voxel size and the number of projections

**Voxel size:**
The voxel size is a major contributor to the dimensional resolution of the CT reconstructed sample. It is often used as a measure of the smallest defect or object contained in the sample. In other words, the smaller is the voxel size, the best is the dimensional resolution.

**Number of projections:**
The reconstructed sample resolution for the computed tomography systems also depends on the number of projections. The reconstruction is improved by increasing the number of projections.

2.2 Data filtering

Data filtering means the removal of unwanted information (noise) added to the signal of interest. Data filtering used on CT system for noise removal can be applied at many stages of the CT dimensional characterization, e.g. on the projections or during the reconstruction.

The main perturbations for the reconstruction of low absorption sample are the ring artifact and the phase contrast imaging. Ring artifacts are CT phenomena which occur when there is a miscalibration or a failure of one or more detector elements in a CT system. They are usually observable close to the scan isocentre and at the same location on each slice. They represent a common problem in the low absorption sample tomography acquisition. Phase contrast imaging is based on phase effects and occurs due to light element being in the sample. It occurs close to the internal and external surfaces.

3 X-ray microtomography and methods

3.1 X-ray microtomography system

The X-ray tomography system is implemented in a clean room. The room temperature is (21 ± 1) °C. The hardware characteristics of the X-ray tomography system are presented in Table 1.

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<tr>
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</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>

3.2 Data processing software

All the tomography data processing operations required to obtain the final reconstructed volume (e.g. beam hardening correction, phase contrast correction, ring artefact, reconstruction…) are performed with the tomography operating software (see Ref. [4]). Each sub-volume of interest defined by its external surface is localized by using geometrical predefined surfaces implemented in the tomography data processing software quoted in the reference [5].

4 Microshell’s characterization

4.1 Microshell

The microshell is an amorphous hydrogenated carbon sphere (654 µm diameter; 47 µm thick). The feature [6] is machined as a sinusoidal shape with a 4 µm peak-to-peak amplitude and a 100 µm modulation period.

4.2 Measurements

The X-ray acquisition parameters for the microshell CT scan are presented in Table 2. Measurements were taken on the previously described microshell with a 0.6 µm voxel side size.
Table 2: Microshell CT acquisition parameters

<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>10 µA</td>
<td>Tungsten</td>
<td>Be</td>
<td>0.6 µm</td>
<td>Gadox</td>
<td>1568</td>
<td>5 images/s</td>
</tr>
</tbody>
</table>

The final reconstruction allows observing the sinusoidal shape on the outer surface of the microshell (See Fig. 2).

![Figure 2: CT reconstruction of a microshell with a sinusoidal shape.](image2)

With the data processing software, the thickness of the microshell at each point can be characterized. A global representation illustrates the thickness variation (see figure 3).

![Figure 3: Microshell thickness variation.](image3)

The data processing software does not allow characterizing a sinusoidal shape. As an approach to estimate the characteristics of a sinusoidal function, points are picked on the outer surface of the microshell (see figure 4), such that they define peaks and valleys on the sinusoidal shape.

![Figure 4: Points picked on the outer surface of the microshell.](image4)
Since the microshell is machined along 210° around one microshell revolution axis, 16 cross sections are extracted. That means a cross section is chosen every 15°.

Figure 5: Example of a cross section from the reconstructed microshell.

On each cross section containing the microshell revolution axis, points are placed on the peaks and on the valleys of the sinusoidal shape. Experimental profiles, such as each profile corresponds to one microshell’s longitude, are then extracted from the reconstructed microshell (see figure 6).

Figure 6: Examples of extracted profiles.

Since the feature machining is not perfect, there is depth deviation. To model the sinusoidal shape, the depth has to be taken into account. The model $P(\theta)$ that was empirically determined is:

$$P(\theta) = d + a.\theta^2 + b. \sin(c. \theta)$$

With $\theta$ the angular position (deg) along a microshell longitude, $b$ the amplitude (µm) of the sinusoidal shape, $c$ the pulse of the sinusoidal shape, $d$ (µm) and $a$ (µm.deg$^{-2}$) parameters of the depth deviation function.

For each extracted profile, each parameter is estimated (see figure 7) by respecting the following criteria $R_p < 0.5$. The coefficient $R_p$ is defined by the formula:

$$R_p = \sqrt{\frac{\sum_{i=1}^{n}(t_i - P(\theta_i))^2}{n}}$$
With \( n \) the number of points placed on the peaks and on the valleys of the sinusoidal shape, \( t_i \) the microshell thickness at the angular position \( \theta_i \), \( P(\theta_i) \) the evaluated model at the angular position \( \theta_i \).

![Extracted profile vs modelled profile for the 407° longitude](image)

**Figure 7:** Example of extracted profile versus modelled profile.

After analyzing the whole set of profiles, each parameter mean is computed. Thus the pulse \( c \) of the sinusoidal signal is equal to 20.1 and the amplitude \( b \) is equal to 2.5 µm. The standard deviation is computed for the amplitude and the pulse. The other parameters \( a \) and \( d \) are not constant. They are parameters only to estimate locally the sinusoidal shape machined on the microshell.

The determined model \( P(\theta) \) for this microshell is: \( P(\theta) = d + a \cdot \theta^2 + 2.5 \cdot \sin(20.1 \cdot \theta) \).

The modulation period of this sinusoidal shape is determined using the formula given in [6]:

\[
c = \frac{2\pi R_{\text{rms}}}{T},
\]

with \( R_{\text{rms}} \) the outer microshell radius (µm), \( T \) the modulation period (µm) and \( c \) is the pulse of the sinusoidal signal.

<table>
<thead>
<tr>
<th>Table 3: Sinusoidal shape characterization</th>
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<td></td>
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<tr>
<td>Amplitude</td>
</tr>
<tr>
<td>Pulse</td>
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<td>Modulation period</td>
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</table>

5 Conclusion

An amorphous hydrogenated carbon microshell with its machined orientated feature is characterized using an X-ray microtomography with a resolution of 0.6 µm per voxel and a methodology based on a peak to valley depth evaluation.

In metrology, the result of a measurement \( Y \) can be denoted by \( Y = y \pm U \), with \( y \) the best estimate of the value \( Y \), \( U \) the expanded uncertainty of measurement. There are a lot of ways to get the measurement uncertainty [7] as Monte Carlo simulation, measurement repeatability, ray-tracing simulation, and so on... As CT metrology is a new way to characterize the microshells experimented on the Laser Megajoule, the determination of this associated measurement uncertainty stills a work in progress.
References


