Micro-computed tomography for characterisation of high-power laser targets

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1. Introduction

Precise characterisation of targets is a necessity in the field of high power laser (HPL) experiments, to allow accurate analysis of experimental data, as well as to confirm that the targets produced conform to the agreed specifications.

For targets where features are embedded within other solid regions, standard imaging techniques (e.g. SEM, AFM) are inadequate. Micro-computed X-ray tomography (µCT) provides a means of imaging the interior of solid targets, thus overcoming this limitation. Using µCT it is possible to detect regions with different densities to the surrounding material within objects.

This report presents two case-studies in the use of µCT for imaging foam targets with embedded components, and the method of characterisation for these samples.

2. µCT theory

Micro-computed X-ray tomography can be described as a four step process.

Firstly, X-rays are generated from an X-ray source and fired at the object. The choice of X-ray power is important here: higher power X-rays are required to image denser materials, but too high a power will result in them passing through the object without any interaction. Further to this, at higher powers it is necessary to employ a filter for the X-rays (often Al or Cu): this blocks lower energy radiation, giving the beam a higher average energy, and therefore delivers better imaging of high density materials.

Secondly, after passing through the object, the X-ray transmission is measured by a detector array behind the sample (**Figure 1**). A single image from this will give a result similar to that found from conventional X-ray imaging used in the medical field (i.e. a 2D image).

To gain a complete 3D image, the third step involves rotating the sample in uniform steps, with a new image taken at each step, until tehe object has been rotated through at least 180 degrees.

In the final step, the image is reconstructed from these 2D images; specifically, cross-sectional images produced at different Z heights are then 'stacked' together to render a 3D image.

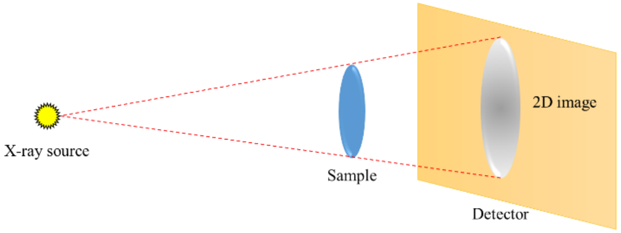

Figure 1 - Schematic of the µCT imaging process; X-rays pass through the object, and are rendered on the detector, with denser regions producing darker images

3. Target manufacture

Two foam targets with embedded materials are presented here.

3.1. Embedded bead targets

The proposed target design shown in **Figure 2** involves a polystyrene (PS) bead suspended in a UV-curable polymer foam, in a 1 mm diameter polyimide (PI) tube.

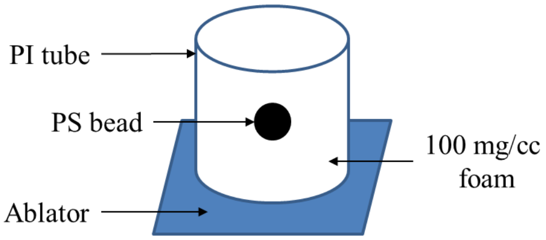

Figure 2 - Schematic of proposed target design

Manufacture was achieved by partially filling the PI tube with a pre-polymer solution, and then curing it. After this, a 200 µm diameter PS bead was placed in the centre of the cured gel, and the rest of the tube then filled and cured, before critical point drying was employed to generate a low density foam.

For precise filling, the pre-polymer solution was dispensed using a 10 µm bore glass capillary attached to a.

3.2. Multilayer embedded particle targets

For these targets, a series of well-defined foam layers were produced, each loaded with particles of different diameters: a 100 mg/cc foam layer, followed by a foam layer doped with 9 µm particles, and finally a foam layer doped with 80 µm particles.

The manufacture of these targets (**Figure 3**) involved first dispersing the particles in a liquid pre-polymer solution. These solutions were sequentially deposited and cured in layers on top of the previous layer, to build the multi-layered structure. A PI tube was then depressed into the cured gel, which could then be removed with the gel layers still intact after critical point drying.

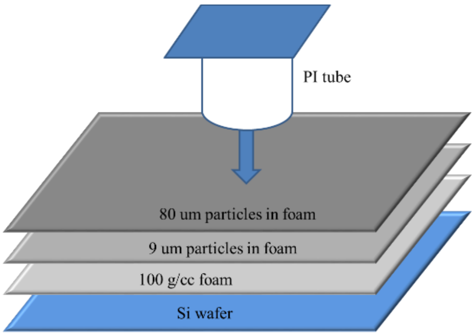

Figure 3 - Schematic for production of multilayer embedded particle foam targets, where a PI tube is inserted into cured polymer before critical point drying

4. µCT characterisation of targets

4.1. CT images of embedded bead foam targets

Imaging the foam targets presented difficulties due to their low density. Not only was the bulk density low, but the density of the polymer itself was only 1 g/cc (low compared to metals and other inorganics). It was, therefore, necessary to use a low X-ray power of 20 kV with no filter, which is the lowest setting. A rotation step of 0.1 degrees was also used, in an effort to maximise the resolution; smaller rotation steps meant a greater amount of 2D images, and therefore increased image quality, although the acquisition time was much longer. For these targets, the most important parameters were that the height and central placement of the bead were within the specifications.

The full µCT scan (**Figure 4**) presented a clear image of the bead embedded in the foam. There is high contrast between the bead and the foam, which was expected as there a roughly an order of magnitude difference in the bulk densities. The image highlights the main advantage of µCT, in that it is possible to crop the image to view a cross-section from inside the object, from which it is possible to measure the dimensions of the target, including bead height, diameter and centring.

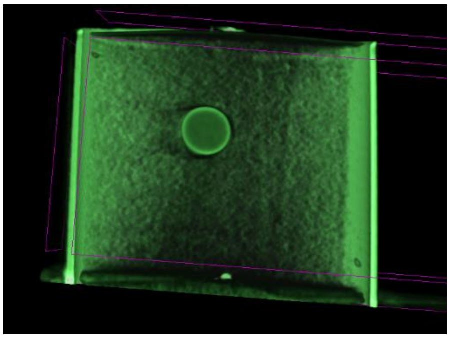

Figure 4 - µCT scan of PS bead embedded in a foam target

While this type of scan gives a thorough analysis of the internal morphology of the target, it is prohibitively time consuming, taking between 6 and 10 hours to complete. For a full run of targets (30+), such scans would require an impractical amount of time, and therefore a quicker process is used for the majority of characterisations.

During the parameter optimisation stage before scanning, there is a constant 2D image rendered by the X-ray source. This image (**Figure 5**) allows for measurement of the bead placement; one image is enough to determine the height of the bead, while a second image at right angles to the first allows full characterisation of the bead's orientation on the X and Y axes. Thus from two 2D images, which can be rendered in less than 15 minutes, it was possible to fully characterise the bead position. The image processing program *ImageJ* was used for the measurements, using the cylinder width as a scale marker.

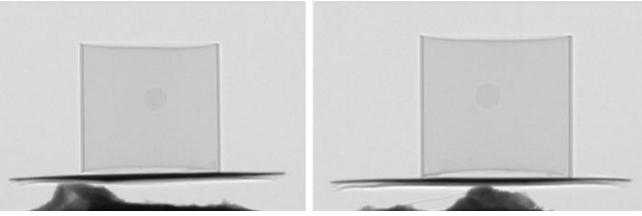

Figure 5 – 2D images of embedded bead foam targets taken with only the background X-rays, with 0º (left) and 90º (right) rotation in the X-Y plane

4.2. CT images of multilayer particle-doped foam targets

From the background X-ray 2D image (**Figure 6**) for the multilayer targets, it was clear that there was a difference in the average densities of the layers (shown by changes in tone). The larger particles in the top layer were also visible, and could be seen to have sunk to the bottom of the layer.

This image was, however, not adequate to fully assess the target, as individual particles in the middle layer were not detectable, and could only be inferred from the density change.

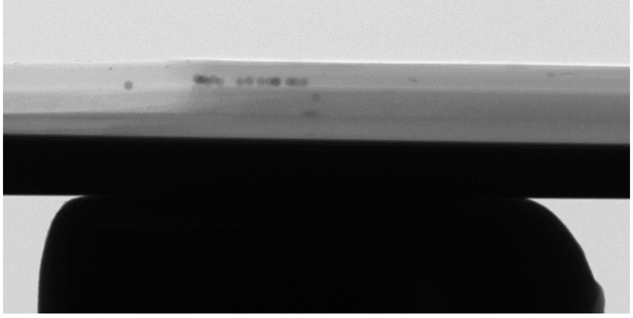

Figure 6 – 2D CT image of multilayer target – although different densities are visible, not enough data are shown to fully characterise particle distribution in the layers

The full CT scan (**Figure 7**) confirmed the distinction between layers, and allowed for accurate measurement of the layer thicknesses with *ImageJ*. In this case, the use of µCT scanning was particularly relevant for target development, as it would have been difficult to measure layer thicknesses by other methods, but due to the sensitivity of µCT to density, a direct relationship between synthetic methods and target morphology could be established.

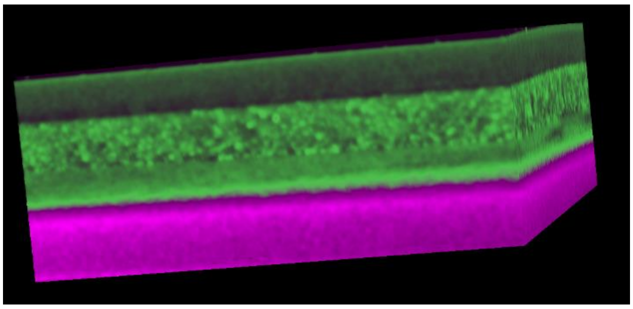

Figure 7 – CT scan of a multilayer target showing four distinctive layers: from bottom to top - Si wafer; 100 mg/cc foam; foam doped with 9 µm particles; foam doped with 80 µm particles

5. Conclusions

The use of µCT has been effective in both the characterisation of fabricated targets before an experiment, and in the development of new targets.

Full 3D image rendering by CT scanning, and 2D X-ray images have been used to build a complete picture of the targets.

6. Future work

The future of µCT in target fabrication lies not only in establishing more characterisation protocols for different targets, but also in investigating novel target architectures which would previously have been impractical due to an inability to fully characterise their internal morphologies.