Embedding of Ruby Microspheres in Low Density Foam Targets

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Introduction

Shock tube experiments can demonstrate flows and phenomena that are similar to those encountered in astrophysical jets [1] and the targets that are used to carry out these experiments are often very complicated to manufacture. They are often include a pusher that produces a plasma which then propagates through a lower density medium before impinging onto a denser obstacle. The CLF Target Fabrication group has in the past produced targets that required dust particles to be dispersed within a low-density foam [2] and the target described in this article was of similar design but required a solid density microsphere to be positioned within the foam to high accuracy.

Using a foam for the lower density medium is advantageous as the foam provides a structure capable of fixing the particles in place, while simultaneously having reduced interaction with the propagating force, as it uses up to 95% less material than its solid form.

This report focuses on a process to embed ruby microspheres into trimethylolpropane triacrylate (TMPTA) foam. The spheres were chosen due to their density and average Z.

Target Specification

The target consisted of a 20um thick plastic ablator with a 200nm aluminium flash coating (to stop laser propagation through the foil). The foam target was 250mg/cc density formed in a 50um wall thickness polyimide tube that was 1.5mm diameter and 1.5mm long. The sphere centres were to be placed 300um from the ablator and centered from a top-down view.

The dense obstacle was formed using a 160 micron diameter ruby sphere and the alignment of this posed challenges for placement and repeatability, with a tolerance of 10% in each direction acceptable.

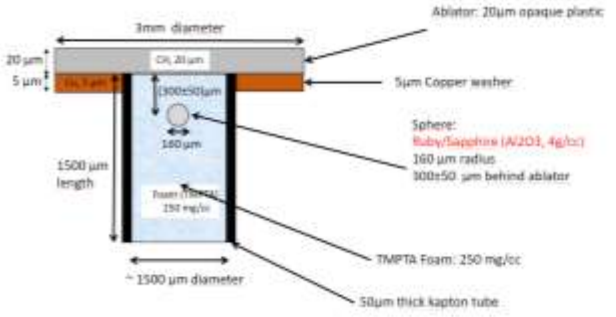

Figure 1. Target Design for the Experiment

Manufacture Methods

Foam precursor solution was prepared by mixing TPMTA with Brij L4 polymeric solvent. Benzil was added as a photo initiator. Foams are produced by reacting a trifunctional acrylic monomer in a non-volatile solvent, in this case a polymeric solvent is used as it has zero vapour pressure. After curing a gel is formed, the liquid phase is then exchanged with a CO2 soluble solvent, in this case methanol. The gel-methanol mixture is transferred to a high-pressure vessel; after exchange with CO2 the liquid phase is released and the foam remains intact as there are no surface tension effects from the media. This method was used to manufacture both the empty foam targets and the targets that had the embedded ruby spheres.

Ruby spheres of 160um diameter were purchased from Goodfellow. Because the spheres are challenging to manipulate, a 10um diameter glass filament was dipped in Brij L4 solvent. The end of the filament can then adsorb a sphere for fine placement. The polyimide tube was filled to a depth of roughly 380 microns with the foam precursor solution; control of the fill height was achieved by placing a piece of silicon of the desired height next to the tube and using the focal distance on an optical microscope to finetune the fill.

The precursor solution was partially cured by 3 seconds of UV irradiation. It was important to not under cure, as the much denser ruby will sink, and to not overcure as this leaves an unacceptable interface in the foam when the second filing and curing is completed. The ruby was positioned manually in the x and y directions using a graduated reticule on the microscope for alignment. When in position the solution was flash cured again for less than 3 seconds to fix the sphere in place with the polymer network. The tube was then filled fully and cured with UV.

The cured gels were placed in methanol for 1 hour until the methanol had fully exchanged with the polymeric solvent. To this vessel 5 molecular sieves of 3 Angstroms pore size were added to ensure no ingress of atmospheric water. The vessel was then placed in a critical point drier and the methanol was exchanged with liquid CO2 until the effluent was free from methanol. The temperature was raised to 38C, which also raised the pressure to roughly 1200 PSI, thus taking the medium to its supercritical state. The vessel was vented slowly leaving low density CH foams with the ruby microsphere embedded within.

Characterisation

The target design required that the microsphere was centered and at a specified distance (300um) from the ablator. It was not possible to measure the distance optically because the resulting foams were opaque. Characterisation was conducted primarily by radiography. The washer that held the assembly was manufactured to include two spikes at 90 degrees to each other – this enabled verification of the orientation of the target when measured on the characterisation equipment compared with when mounted in the target chamber (fig 2). Characterisation was carried out with the tubes orientated horizontally in the chamber.

In this geometry it is possible to determine the distance of the sphere from the ablator. By taking radiographs at 90-degree rotation intervals it is possible to fully describe the sphere's 3D position laterally in the tube (fig 3 and 4).

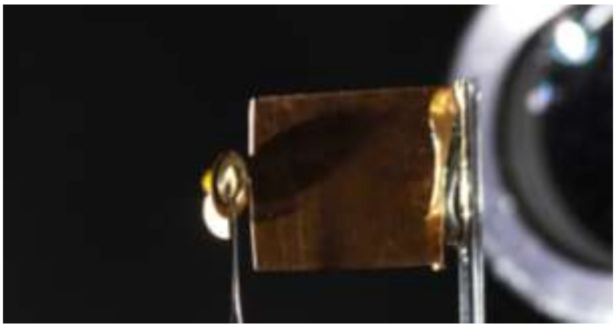

Figure 2. The target in the chamber (left) with additional shielding (right).

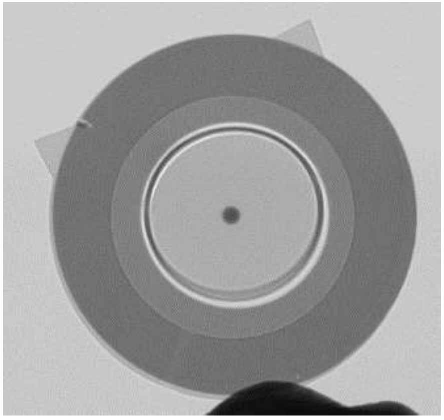

Figure 3. 'Top down' CT radiograph of ruby sphere in 100 mg/cc TMPTA foam, centered.

Initial results showed the importance of fixing the sphere in place with a flash cure after placement because the spheres were sinking in the gel. It was also observed that excessive time for the first cure created a distinct membrane in the foam which was undesirable. The effect can be seen in figure 4 with a much less defined membrane seen in figure 5. The presented images show that in the final targets produced by the process the spheres were well centered and stable in their positions with no detrimental effects on the foam structure observed.

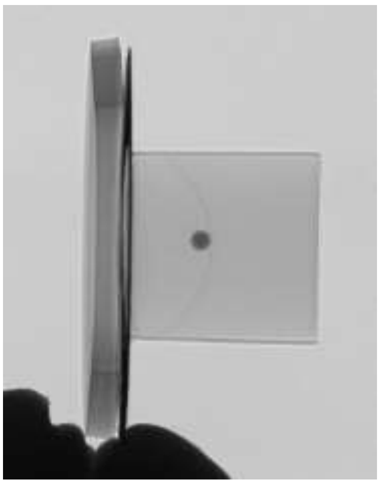

Figure 4. Side on radiograph of ruby embedded in TMPTA foam showing a slight interfacial membrane.

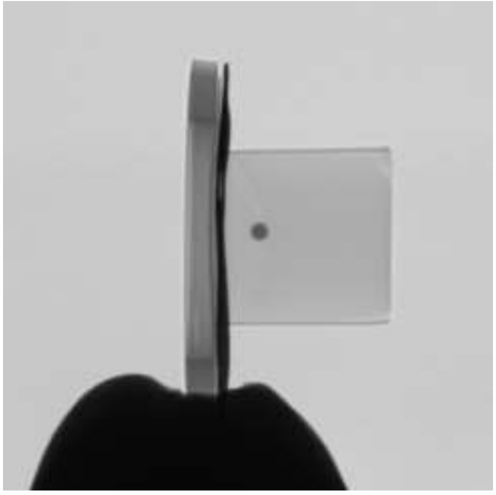

Figure 5. Side on radiograph with a much-reduced interfacial membrane.

Conclusions

Ruby microspheres were embedded in low density CH foams with high accuracy (better than 10% positional accuracy to a 300um specification) in the x. y and z dimensions. X-ray micro-CT analysis was used as the primary tool for characterizing the targets and confirming sphere placement.

It was found that controlling the cure of the gel was important for maintaining positional uniformity in the targets. Using radiographic imaging allowed for a high throughput of target characterization.

The targets were successfully shot on the PHELIX laser in GSI and full analysis of the data is ongoing. A representative image is shown in figure 6.

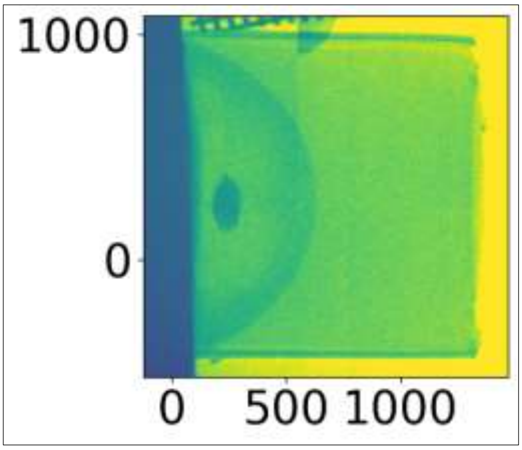

Figure 6. An image of the experimental use of the target showing the shock propagating through the foam target. X and y scales are in um; the colour scale trends from yellow, to green to blue, in order of decreasing density.

References

[1] P. Hartigan et al. Laboratory experiments, numerical simulations, and astronomical observations of Deflected supersonic jets: application to hh 110. The Astrophysical Journal, 705:1073–1094, 2009

[2] S. Irving. Particle Functionalization for Dispersion of inorganic 'dust' within low density polymeric targets. CLF Annual Report 2021-2022