Automated Production of High Rep Rate Foam Targets

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Abstract.

Manufacturing low density targets in the numbers needed for high rep rate experiments is highly challenging. This report summarises advances from manual production to semi-automated and the improvements that follow both in terms of production time and target uniformity. The production process is described and shown to be improved by the integration of an xyz robot with dispensing capabilities. Results are obtained from manual and semi-automated production runs and compared. The variance in the foam thickness is reduced significantly which should decrease experimental variation due to target parameters and could allow for whole batches to be characterised by the measurement of a few samples. The work applies to both foil backed and free standing foam targets.

1. Introduction

With the recent developments in laser technology there are an increasing number of high repetition rate systems that are available for utilisation by the plasma physics community for experiments investigating topics such as ion acceleration. One of the most interesting types of targets in this field is a low density target that can be used to investigate hole boring[1]. One such type is low density polymeric foam that is on the order of 10-100 microns in thickness. It is however difficult to manufacture thin foams in the numbers that are required to carry out these experiments. Current manufacturing techniques rely on a manual fill of target geometries under a microscope with a syringe and subsequent processing using a critical point dryer. We report on a production method that is using a semi-automated dispensing and curing system and developments to maximise the output of the drying process to produce targets that are technically challenging and previously not possible to fabricate.

Typical target geometries that have been requested to date have been foam densities in the range 3 to 300mg/cc and thicknesses in the range from 50 to 500 microns. For low repetition rate experiments on facilities such as the Vulcan laser at the Rutherford Appleton Laboratory (RAL), there may be a need for 10's of targets but for medium repetition rate experiments, such as those on the Astra Gemini laser at RAL there may be the need for several 100's of targets. There is a trend within the community to require the more demanding thin and lowest density targets and these specifications are especially

challenging to achieve for free-standing foams and may well be beyond the realms of existing technology and beyond the budgets of experimental campaigns.

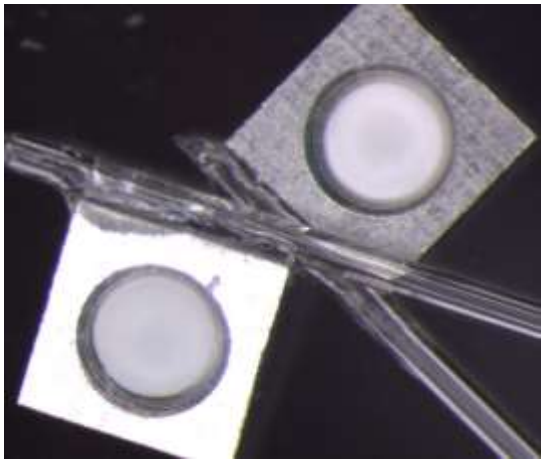

Figure 1a. Individual foam targets with washer supports for low rep rate experiments. Shot on the Vulcan laser at RAL, UK (May 2013).

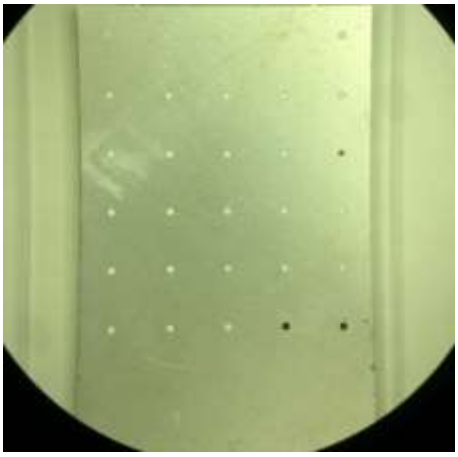

Figure 1b. Array based foam targets for med rep rate experiments. Shot on the Astra Gemini Laser (May 2013).

The composition of different foam types makes them more or less suitable for different experiments. This can be quantified in terms of the chemical makeup, the physical structure (with pore size being a key factor), density regime, machinability and finally quality. This last attribute, quality, can include uniformity, defects both in terms of high density inclusions or holes, and the presence of a higher density skin.

TMPTA or Trimethylolpropane triacrylate has a chemical composition of Carbon, Hydrogen and Oxygen. For some experiments the presence of oxygen prevents this type of foam from being used. However, the foam benefits from having no predefined pore size meaning that the density can be reduced without introducing complicating large voids. If pure chemicals are used and clean conditions are employed then inclusions of high density defects and skin effects can be minimised. The foam is not particularly easy to machine so a support or mount is used to define the shape and size of the foam.

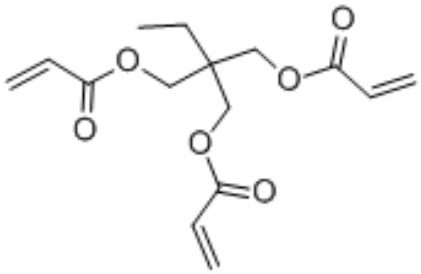

Figure 2. The chemical structure of Trimethylolpropane triacrylate (TMPTA) showing the three functional acrylic groups available for polymerisation.

2. Manual production

Foam production has an established process [2] that starts by producing a foam solution. The solution is made up of three parts. The ratio of TMPTA and a solvent defines the final density of the foam. A very small quantity of UV sensitive photo initiator is added which allows the foam to polymerise. The solvent and photo initiator are carefully chosen to only contain the same elements as the TMPTA to avoid any chance of cross contamination. Some initiators as an example might contain high Z

elements such as chrome (Cr) or Iron (Fe). The foam solution is dispensed into cavities which could be individual mounts for single shot experiments or arrays for medium rep rate. This is typically done under a microscope due to the small size of the cavities and this would typically take 10 seconds per cavity. For several hundred targets this stage could take a number of hours.

A mercury arc lamp or LED UV source is used to cure the foam. Over a time frame of a few seconds, depending on the power of the UV source, the clear solution will turn white. This is because the polymer network now scatters the light that passes through and this tells us that the curing stage is complete. Again this will take several hours for several hundred targets. The last stage in the process involves removing the solvent. Drying of the foam by evaporation of the solvent would collapse the delicate foam structure. For this reason a Critical Point Drier (CPD) is used. It is a commonly used tool within industry for drying delicate samples and includes putting the targets into a high pressure vessel. Liquid carbon dioxide is used to fill the chamber at a high pressure (above 75 Bar) and the temperature is controlled from around 20°C up to 40°C. At the higher temperature the carbon dioxide behaves as a supercritical fluid displaying the properties of both a gas and liquid simultaneously. Once in this state, the carbon dioxide can be vented off without any sudden change in density and without any surface tension effects. When this process is complete, the foam is dry and ready to be used as a target. The last stage takes approximately two hours.

2.1. Polymerisation process

When UV light of an appropriate wavelength is incident on the dissolved photo initiator molecules they split into two or more free radical parts. The free radicals can either recombine but will split again under the UV or they can react with the TMPTA monomer molecules but not the carefully chosen solvent. TMPTA has three functional groups containing a carbon double bond which are possible sites for a free radical to bond with. When a free radical reacts with a TMPTA molecule it opens up the double bond and forms a small chain at this point but leaves the other half of the double bond as a free radical. It is this property that allows the chain to react with further TMPTA molecules creating longer and longer chains. Since TMPTA has three functional groups it is possible to have cross-linking between adjacent chains and this gives the overall polymer network rigidity.

High purity chemicals are key to the success of the polymerisation process because the free radical photo initiator parts or polymer chains will react with any impurity stopping the formation or growth of the polymer network. Having clean cavities is also key to the foam network bonding with the walls and therefore remaining in place once the drying process is complete.

3. Semi-Automated Production

The most time consuming stages of the foam production process are the filling and curing steps. Given the regular spacing and grid-like nature of arrays, it was thought that a robot might be able to complete both of these steps simultaneously allowing fabricators to be freed up for other tasks. The shot-to-shot variation in the foams should also be reduced by using pre-set dispensing values.

A three axis (x, y, z) robot with dispensing capability (figure 3) was used to prove the principle of automated production. The robot can be controlled via a laptop and custom written software which would allow the integration of the UV curing stage using a digital signal to trigger a LED source.

Figure 3. Dispensing robot with three axis stage. Four mounting screws are available for custom made plates.

There were a number of challenges that needed to be addressed to commission the system to be suitable to make foam targets. An array mount holder, shown in figure 4, was designed to hold multiple arrays with an x, y positional accuracy of better than 200um. When thin (<150um thick) arrays were placed into this holder, it was found that they could bow with a change in height of several hundred microns. In addition to this, different thickness array mounts could in practice be used and so it was decided that it was necessary to incorporate a feedback loop between the metal dispensing tip and the metal arrays. This would trigger only when the tip touched the array and this position in z would be considered zero. From here, the tip could then rise by a predefined amount before performing a dispense routine. This feedback loop allows the system to cope with multiple target designs and builds flexibility into the production process.

Figure 4. Holder plate with space for 20 array mounts. Positional accuracy was specified to be better than 200um in x & y.

It was discovered that when dispensing different liquids through a standard tip the physical characteristics of the liquid can yield surprisingly different results as shown in figure 5. For water, the droplet would form below the end of the tip. For the foam solution, the liquid would climb up the outside of the tip. When dispensing into a shallow container there are obvious limitations if the liquid does not present itself at the end of the needle, especially if the foam solution is to be dispensed onto a very thin backing foil of a few 10's of nanometers thick, where any contact between the needle and the foil will destroy it. It was decided to bend the end of the tip by 90° and use the wicking property of the foam solution to help with the filling procedure. With the foam solution exposed proud of the needle it could be dispensed on one side of an array hole and the meniscus dragged over to the opposite side without the needle touching the fragile foils. To ensure this is the case a gap is required between the tip and the array of the order of 50 – 100 microns which was possible to program using the contact feedback loop.

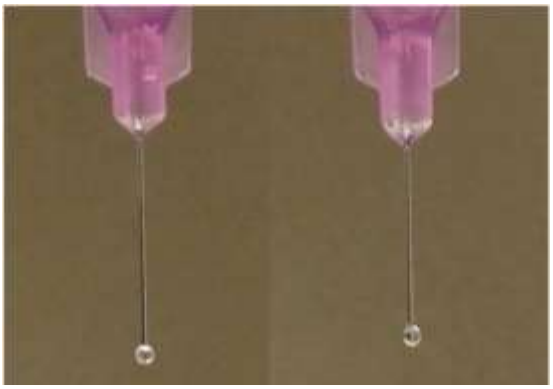

Figure 5. Left: A water droplet hangs below the end of the dispensing tip. Right: A foam solution droplet climbs up the dispensing tip.

4. Results

The height of the foam was measured relative to the flat surface of the array mount and this was done for a previously produced 36 shot array of foams made by hand and compared with a set produced using the robot. Measurements were taken using a white light interferometer which produced a 2D height map as shown in figure 6. This height map was levelled and a lineout taken through the centre of a foam to obtain a measurement.

The robot dispensing system has the ability to vary the amount of foam solution that it dispenses and therefore can vary the height of the foams above the mount that it produces, however for this investigation it was kept a constant to investigate variation over the range of positions using a common setting.

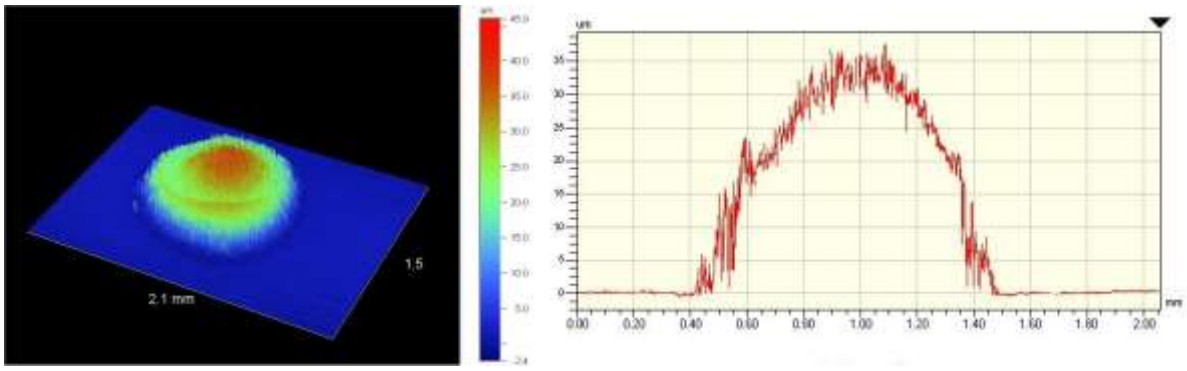

Figure 6. Left: 3D reconstruction of a scan using a white light interferometer of a foam. Right: A lineout taken through the centre of the foam to give a height profile above the level of the array mount.

The results in figure 7 show a standard deviation of 10.8um from the foams produced by hand and 6.7um from the machine made foams. Qualitatively the shape of the machine made foams (figure 8) is slightly egg shaped but consistent across the array. The shape could be modified by using a different fill routine.

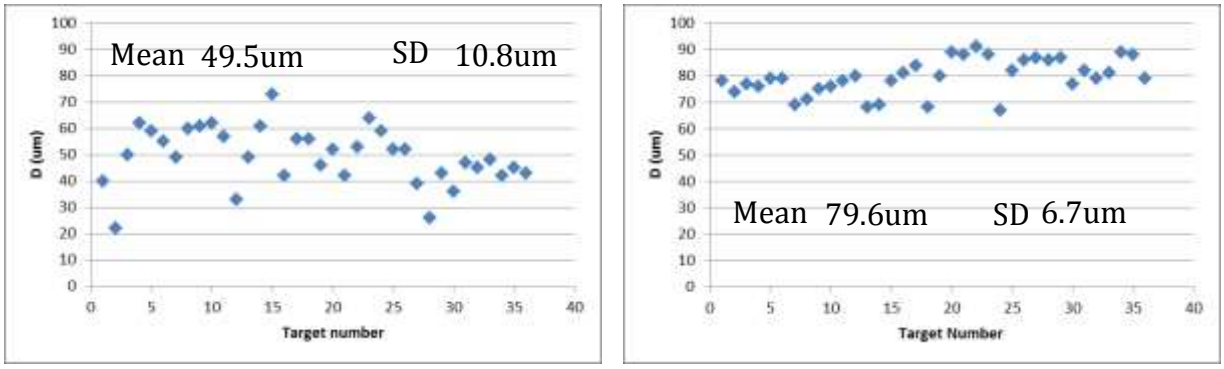

Figure 7. Results of the height of the foam solution measured relative to the array mount for human fill (left) and machine fill (right).

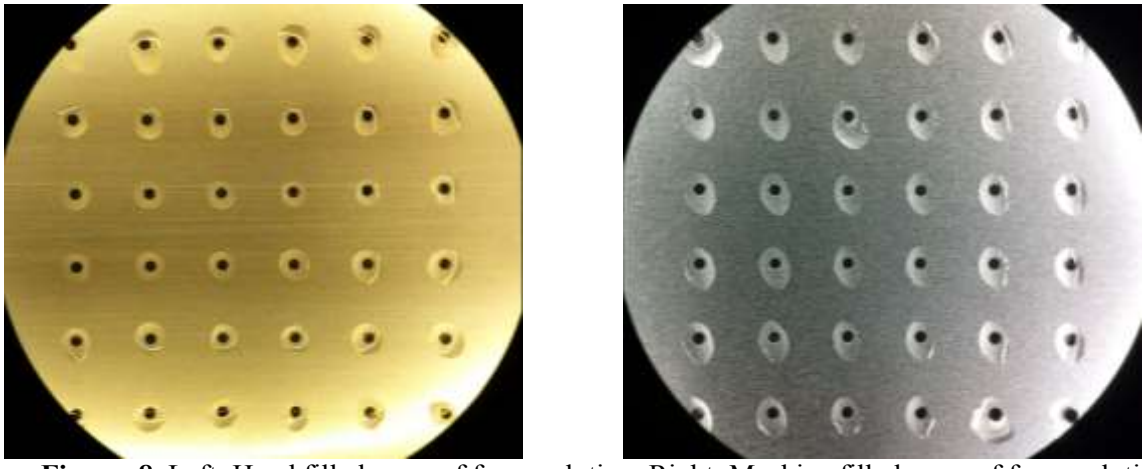

Figure 8. Left: Hand filled array of foam solution. Right: Machine filled array of foam solution.

5. Conclusions

The robot has shown good results in improving the quality of the foams by reducing the target-to-target variation and with careful programming it is hoped that this variation can be further reduced. The aim is to obtain a variance low enough that a whole batch of foams can be characterised by the measurement of only a few samples. The time taken to produce the foams has been significantly reduced. As more laser systems utilise the high repetition capabilities that are being developed a large number of arrays will be required. This time saving will be essential in ensuring that the laser systems are not target limited. Over the next few years we will develop further target geometries in collaboration with user groups in an effort to enhance the experiments undertaken.

References

[1] Robinson A P L et al, *PPCF*, **51**, 024004, (2009)
[2] Nazarov W, *Fusion Sci. & Technology* **41**, 193, (2002)