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FABRICATION OF MULTIPLE FILL TUBE TARGETS FOR SANDIA NATIONAL LABORATORY

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Target design for the National Ignition Facility requires either a glass or polyimide (PI) fill tube. To study the hydrodynamic effects that are introduced by a fill tube during capsule implosion, fill tube targets were fabricated for experiments at the Z-Pinch facility. Three and four fill tube targets were designed and fabricated to maximize data during each experiment. Targets were made with PI and glass fill tubes on the same capsule to study the shadowing differences between glass and plastic fill tubes. Four tube targets were fabricated with diameters ranging from 10–45 µm to study the effect diameter has on implosion characteristics. Capsules were coated with a germanium-doped layer of glow discharge polymer. Blind holes were drilled in the capsules using an excimer laser. Fill tubes were fabricated using modified capillary pullers and assembly was done on a specially designed assembly station designed for fill tube fabrication. Targets were characterized by optical microscopy and by micron resolution x-ray tomography.

I. INTRODUCTION

The National Ignition Facility (NIF)[1] capsule design will use fill tubes to allow for DT filling. The baseline specifications for fill tubes and holes in NIF capsules are:[2]

- Fill hole: 5 µm diameter
- Fill tube: 10 µm diameter glass tube
- Glue Mass: 2.5 ng

Fill tubes introduce hydrodynamic perturbations on capsule implosion and have been modeled[3] with computer simulations. The results found that the origin of the perturbation was from a shielding of the ablator in the area of the fill tube and that it varied linearly with the diameter of the fill tube. The simulations also implied that the size of the perturbation depends on the composition of the tube. Recent experiments were designed to compare computer simulations of fill tube perturbations to data.

Fill tube perturbation experiments were designed for the Z-Pinch facility at Sandia National Laboratory to utilize its 20 µm resolution radiography system to study capsule implosion. The design called for a 2 mm 80 µm thick CH capsule. The outer 40 µm layer was to be doped with 1 at. % germanium to increase contrast during experiments. Targets with three and four fill tubes on the equatorial plane of the capsule 90° apart on one target were designed to maximize data per shot and allow for the best comparison of data. The fill tubes were surrogates to study the radiation shadowing effects caused by varying diameter and composition of fill tubes. The fill tube diameters ranged from 10–45 µm and were made from polyimide (PI) and glass. All fill tubes were inserted into the capsules with 40 µm deep blind holes that were drilled. Optical and x-ray characterization was performed on the fill tube targets. All targets were mounted to 200 µm diameter tungsten stalks for laser drilling, assembly, characterization, handling, and transportation purposes using a water soluble UV glue which would later be removed before capsule implosion.

II. FABRICATION

II.A. Capsules

Two millimeter poly(α-methylstyrene) (PAMS) mandrels were fabricated using a triple orifice generator.[4] The capsules were then coated using a glow discharge polymer[5] (GDP) and germanium doped GDP.[6]

II.B. Capsule Holes

Holes were laser drilled in the capsules using a 248 nm excimer laser with five-axis stage control. The stalks with capsules were mounted into a pin vise, which was mounted into a micro lathe for laser drilling. Once mounted into the micro lathe the shells could then be rotated 90° in between hole boring. Different sized chrome on quartz masks were used with 15× demagnification to get appropriate sized holes. A consistent depth of the holes was achieved by experimental determination of an ablation rate of the GDP. Table I is a summary of the different hole dimensions drilled in the capsules. Due to a lack of different mask sizes, hole diameter and fill tube diameter sizes varied are in some instances. Figure 1 contains a scanning electron micrograph (SEM) of a laser-drilled hole. The entrance hole of the shell is smooth and has little visible debris. Figure 2 depicts x-ray images of the different size holes used in the experiments. The holes appear to be "trumpet" shaped with a larger absorption of laser energy on the shell surface, which then tapers to a constant diameter.

Table I. Laser Hole Dimensions and Range of Fill Tube Sizes Attached to Corresponding Hole

Hole	Entrance Diameter (μm)	Bottom Diameter (μm)	Depth (μm)	Fill Tube Diameter Range (μm)
1	25	17	40	10–16
2	38	31	40	19–27
3	56	48	40	31–48

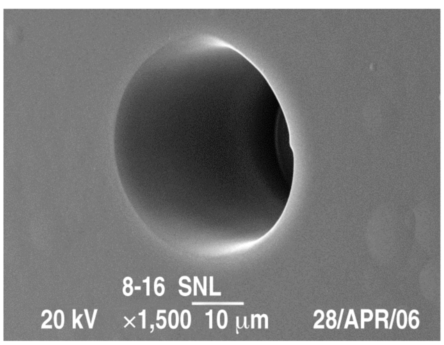

Figure 1. SEM images of a 50 μm laser drilled hole. Very little debris is present and hole is very circular and smooth at entrance of shell.

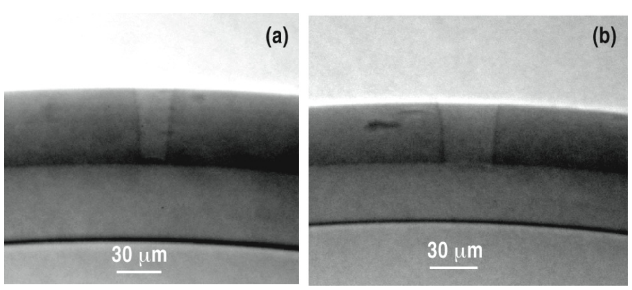

Figure 2. X-ray images of "blind" holes before fill tube insertion.

II.C. Fill Tubes

PI and glass fill tubes with appropriate dimensions were fabricated for experiments. The glass fill tubes were made using a commercial capillary puller and 20 μℓ pipettes. The PI fill tubes were fabricated with a modified glass capillary puller using Aurum thermoplastic tubing.[7] The temperature of the thermoplastic tubing had to be kept just above the melting point (388°C) in order for the tubing to be drawn out and not break. Once the PI fill tubes were pulled they were then cut with the excimer laser to the desired diameter. Table II contains a summary of the different fill tube diameters and their corresponding wall thickness used in the fabrication of these targets.

Table II. Lists Different Fill Tube Sizes Made for These Experiments and the Corresponding Holes the Fill Tube Were Attached To

Type	Diameter Range (μm)	Wall Thickness Range (μm)	Hole Attached To
Glass	11–15	3–5	1
Glass	18–26	5–8	2
Glass	31–39	8–12	3
Glass	39–48	12–14	3
PI	25–47	3–5	3

III. ASSEMBLY

A specially designed fill tube assembly station was used to attach the fill tubes to the capsules. Figure 3 is a schematic and picture of the assembly station. Two X Y Z micromanipulators with a few μm resolutions were mounted 90° apart. Two microscopes with CCD cameras mounted 90° apart with a tilt range from 15°-30° allowed for optical alignment of fill tube and hole to within a few μm. Centered within the micro manipulators and microscopes is a precision X Y Z stage with a few μm resolution.

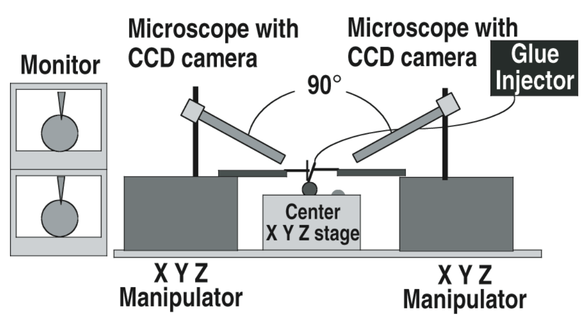

Figure 3. A schematic of assembly station set up used to attach the fill tubes to the shells.

To closely match experimental simulations the fill tubes should not have any glue inside the tube extending past the surface of the shell. To remove extra space they were pre-plugged with glue to a controlled height to avoid any additional wicking of the glue inside the tube during attachment. This way there was no concern of trying to keep the tip of the fill tube glue free during attachment. This was done by careful selection of glue viscosity and a controlled exposure time of the fill tube tip in a glue reservoir using the assembly station. After glue had wicked to an appropriate height <40 μm the glue was then cured with UV light.

To fabricate these targets a pin vise holding the mounting stalk with shell was held with one X Y Z manipulator and a fill tube in the other X Y Z manipulator. Using the viewing system for guidance the shell was positioned so the hole was located on the apex of the shell. Glass fill tubes were pre-broken to a length about 1 mm and then attached to the capsule, while PI tubes were first attached to the capsule as ~2 cm long tubes and then laser cut to the desired length. Glue was applied to the fill tube tip prior to attachment. The amount of glue that wicked onto the tip of the fill tube was controlled to a <1 ng by the viscosity of the glue and the length of time it was exposed to a glue reservoir. Knowledge of the hole shape and fill tube diameter along with scanning electron microscope (SEM) measurements allowed for glue volume calculations. The fill tube was then positioned normal to the shell surface and inserted into the hole. Glue would then wick from the fill tube tip into the void of the hole not occupied by the fill tube and onto the shell surface forming a fillet. A glue fillet would form if there was a volume of glue in excess of the hole void volume on the tip. Once inserted into the hole the fill tube would be manipulated so that it was normal to the surface of the shell and then cured with UV light. Figure 4 is a SEM of an early fill tube trial. As visible in the SEM, this technique can create attachments with no glue fillet and glue amounts less than the NIF spec of 2.2 ng. This led to questions concerning the glue not fully filling the hole void volume, however, so an excess of glue was used to try and completely fill the hole void to match simulations. As each fill tube was attached the pin vice was rotated in

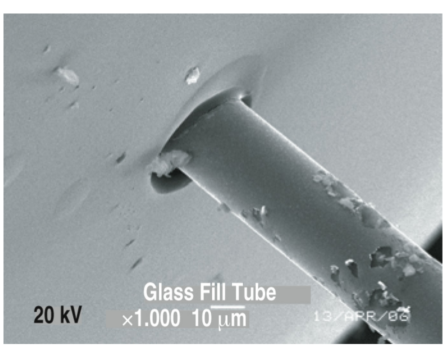

Figure 4. High magnification SEM image shows glue does not fill hole completely to surface. Debris seen is gold coating for SEM that has flaked off.

the holder and the next hole was positioned on the pole of the shell. For the four glass tube targets of varying diameter the attachments always progressed from smallest to largest diameter because the smallest tubes had the highest attrition rate. In Fig. 5 optical pictures of a fully assembled three tube varying composition and a four tube varying glass diameter target are shown.

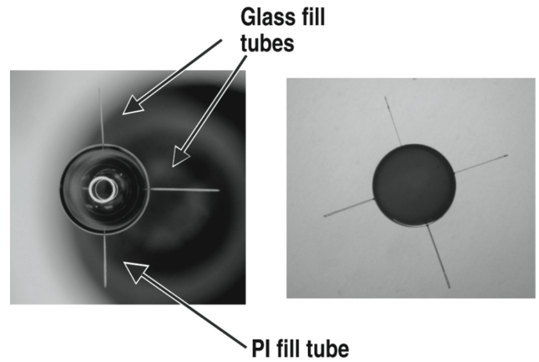

Figure 5. (a) A three-tube target with constant diameter PI and glass fill tubes attached, ring on top surface of shell is light reflection. (b) A four tube all glass target with varying diameters.

IV. CHARACTERIZATION

Fully assembled targets were characterized using optical microscopy and x-ray analysis. Optical microscopy allowed for fill tube length, diameter, glue fillet height and diameter to be metrologized. x-ray characterization was able to show internal details of the targets such as fill tube insertion depth and fill tube wall thickness as well as the dimensions obtained optically. Only a few targets were optically characterized as a comparison to x-ray analysis due to handling issues of the targets and x-ray analysis provided the same information as optical characterization. Table III is a comparison between x-ray and optical measurements.

The amounts of glue used for each attachment were calculated based on the diagram in Fig. 6. It is clear that:

$$V_{\text{glue out}} = \frac{\pi f_{\text{d}}^2 f_{\text{h}}}{12} - \frac{\pi h d^2}{4} \quad , \tag{1}$$

$$V_{\text{glue in}} = V_{\text{hole}} - V_{\text{tube in hople}} \quad , \tag{2}$$

height and diameter to be metrologized. x-ray characterization was able to show internal details of the targets such as fill tube insertion depth and fill tube wall thickness as well as the dimensions obtained optically. Only a few targets were optically characterized as a comparison to x-ray analysis due to handling issues of the

Table III. A Comparison Between Optical Measurements and X-ray Measurements, Good Agreement Between Measurements was Observed

	Optical Length (μm)	X-ray Length (μm)	Optical Diameter (μm)	X-ray Diameter (μm)	Optical Fillet Height (μm)	X-ray Fillet Height (μm)	Optical Fillet Diameter (μm)	X-ray Fillet Diameter (μm)
Tube 1	841	850	26	27	28	25	65	71
Tube 2	1430	1444	26	25	None observed	None observed	None observed	None observed
Tube 3	1111	1120	31	29	14	12	13	16

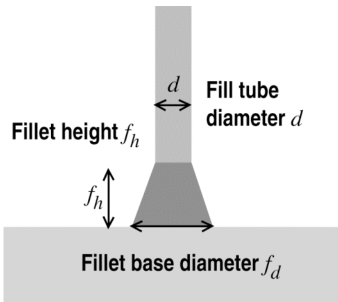

Figure 6. Diagram of key parameters for glue volume.

targets and x-ray analysis provided the same information as optical characterization. Table III is a comparison between x-ray and optical measurements.

The range of glue used for attachments was between 2.3–86 ng. Figure 7 shows a high magnification x-ray image with the glue fillet visible as well as the fill tube depth.

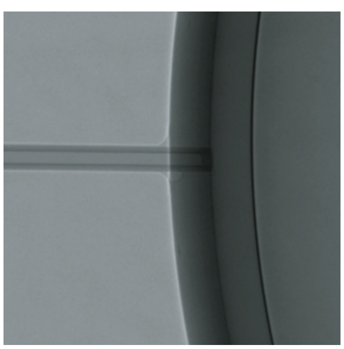

Figure 7. (a) A high magnification x-ray image of a glass fill tube attachment. Fill tube insertion depth, wall thickness, and a small with hole cavity are observed in the x-ray image.

V. CONCLUSION

Fourteen different multiple fill tube targets were fabricated for experiments at Sandia National Laboratory. Four glass fill tube with diameters ranging from three and four tube targets with constant diameter but varying composition of PI and glass were fabricated. Characterization data provided important input for computer simulations. Experimental results have provided important data for comparison to simulations and their implication on NIF capsules with fill tubes.

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