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DETERMINISTIC FABRICATION AND CHARACTERIZATION OF FILL TUBE SURROGATE TARGETS FOR OMEGA EXPERIMENTS USING A POLYMER STALK

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Equipment and techniques have been developed for the fabrication of fill tube surrogate targets for OMEGA experiments. The fill tube is attached manually by heating 4000 MW poly-α-methylstyrene in a fixed reservoir, which can be touched onto the capsule surface and pulled into the shape of a fill tube. The joint is uniform and robust with diameters no less than 20 μm. A series of surrogate fill tubes can be achieved by modifying temperature and technique with a diameter reproducibility within 5 μm. After attachment, the capsules are mounted onto a calibrated stage to trim the length of the surrogate to specifications. Characterizing the surrogates involved positioning the polymer stalk to measure the fillet diameter, stalk diameter, and length at orthogonal orientations. Details of the heating and pulling techniques will be discussed as well as a description of the polymer reservoir.

I. INTRODUCTION

Cryogenic experiments at the National Ignition Facility (NIF) call for ignition shells with a fill tube; therefore, the experiments conducted at OMEGA required a series of surrogate fill tubes, or stalks, to investigate how the size of a fill tube perturbation affects implosion symmetry. The stalks were composed of a low-Z plastic with hydrodynamic properties similar to a fill tube. Initially, the "stalk pulling" method of John Burmann[1] with poly-α-methylstyrene (PαMS) was used to fabricate these surrogate fill tubes, however, it was found to be insufficient to make a series of stalks within specifications. A heated reservoir was designed to contain the PαMS, which allowed for the control of process parameters and polymer pulling technique. Ultimately, this deterministic fabrication was possible and a series of polymer stalks were fabricated with yields greater than 75% as compared to 20% for the initially implemented technique.

The stalks were attached to capsules with diameters of ~500 μm; less than ignition designs for NIF to accommodate requirements for the OMEGA laser facility. The capsules consisted of a Ti-doped layer for the purpose of imaging the x-rays expected from the hydrodynamic jet produced by the stalk.[2,3] These stalks would provide the first set of experiments on the hydrodynamic effects of a fill tube. The fill tube experiments were designed for comparison to simulations in order to optimize NIF fill tube specifications. Simulations suggest that a fill tube with a 10 μm diameter would not produce a significant jet[6] in the NIF design described by Haan.[3] Challenging specifications were required for the surrogate fill tubes; stalk diameters needed were 10 μm, 17 μm, 25 μm, and 30 μm with corresponding fillet diameters and lengths indicated in Table I. In order to achieve these requirements, a deterministic fabrication technique was developed to control the process parameters and produce stalks within specifications, and characterize them to within ±1 μm.

Table I. Challenging Specifications Required for Series of Surrogate Fill Tube Targets

Fillet Diameter	Stalk Diameter	Length
25±5 μm	10±3 μm	100±20 μm
37±7 μm	17±3 μm	100±20 μm
50±5 μm	25±3 μm	100±20 μm
60±5 μm	30±3 μm	100±20 μm
Offset angle of stalk: Surface normal ±3°		

II. EXPERIMENTAL

II.A. Initial Method

In the initial attempts to make stalks within specifications, the technique presented by John Burmann for "plasma polymer shells with integral fill tubes" was implemented. In brief, stalk pulling involved melting PαMS crystals onto a heated gold-coated glass slide, touching a capsule held by a vacuum chuck and micromanipulator to draw a fiber that solidified upon cooling.[1] It was found to suffer from poor reproducibility with a low yield of the desired dimensions, less than 20%

as shown in Fig. 1 for a 25 μm fillet diameter. These problems arose from an inconsistent molten PαMS source that varied with the crystal size and shape, and a technique, which required constant polymer replenishment and realignment of capsule and molten PαMS. A non-uniform fillet and stalk diameter would result from the inconsistent PαMS melt, therefore, a deterministic stalk pulling technique was developed with a new polymer reservoir design.

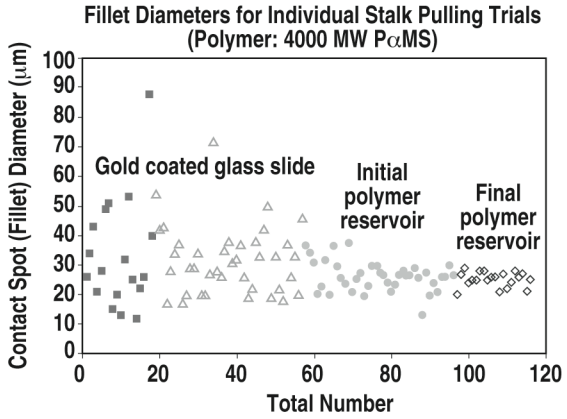

Figure 1. The graph indicates the increased yield and reproducibility using the polymer reservoir as compared to previous methods. The data points represent individual trials with fillet diameters indicated on the y-axis.

II.B. PαMS Reservoir

A heated reservoir was designed to address the reproducibility problem and produce a controlled polymer supply. Figure 2 shows a cross sectional view of the reservoir. Stainless steel tubing of different inner and outer diameters, as indicated, was inserted and soldered into the hollowed V-shaped joint of a solid aluminum cylinder in contact with a solid heated aluminum block mounted on a micrometer controlled stage. The V-shaped joint accommodated larger capsules up to 3 mm. PαMS crystals were inserted into the system through the larger tubing and displaced with a plunger. Once the PαMS melt rose and formed a constant molten polymer bead at the opening of the smaller tubing the plunger was removed and reused when needed. This replaced the molten PαMS puddle on the gold-coated glass slide and proved to be constant and easy to align with respect to the capsule.

II.C. PαMS Selection

The selection of the PαMS was an important factor in fabricating stalks governed by viscosity, which affects taper control and uniform spreading of the fillet. The extreme conditions are when the polymer is too viscous or too fluid. Stalk fabrication is best controlled when the viscosity lies between these extremes. When the melt is too fluid, the polymer suffers from excessive tapering and does not solidify completely as it tapers so that it curls when pulled away from the PαMS bead. When the melt is too viscous, the PαMS bead cannot be drawn into a fiber and the capsule risks getting stuck to the melt and damaged. There are different molecular weight PαMS that melt at different temperatures and have different strengths. Accordingly, higher molecular weights require higher temperatures to achieve the same viscosity as a lower molecular weight PαMS, and form stronger fibers, respectively. Ultimately, the 4000 MW PαMS from Aldrich®, with a polydispersity index of 2.0, was found to be most suitable at 155°C. Stalks made with <4000 MW were brittle and difficult to handle, whereas stalks made with >4000 MW required melt temperatures ≥200°C that would deform the capsule.

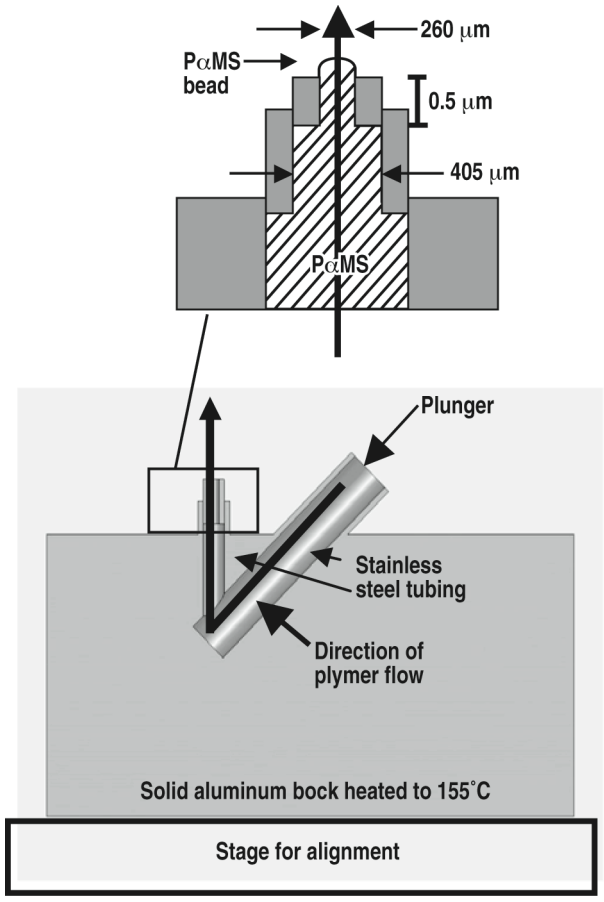

Figure 2. A cross sectional view of the polymer reservoir is illustrated. The block was heated to 155ºC to achieve the desired viscosity for the 4000 MW PαMS and produce a bead from the reservoir.

II.D. Deterministic Fabrication

In order to select for the specified stalk dimensions and fabricate them with the polymer reservoir and PαMS bead, a precision assembly station was needed with a high resolution viewing system. A schematic of the viewing system in Fig. 3 illustrates an overlaid grid on the monitor with 5 μm increments that define the resolution when the capsule and bead are viewed at highest magnification on the viewing microscope. The monitor is also used to orient the capsule secured with a vacuum chuck normal to the PαMS bead. The stage was manipulated in the x-y direction with micrometers having a ±1 μm accuracy and the capsule was positioned using sensitive micro-manipulators in the x-y-z direction. Another microscope directly above the capsule and reservoir confirmed the centering of the capsule over the bead. Once aligned, the z-axis control for the capsule was used to draw the polymer stalk. The depth of the capsule into the PαMS bead determined fillet diameters, whereas taper and stalk diameters were controlled by the pulling rate with reproducible results. Figure 4 shows a typical stalk pulling at lower magnification.

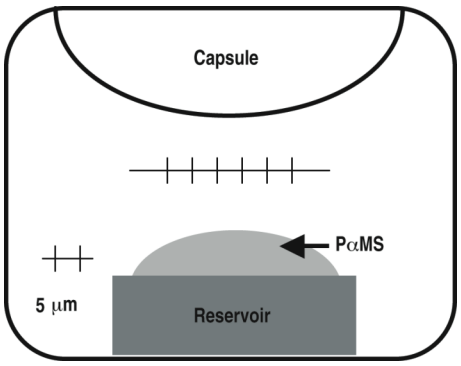

Figure 3. Schematic of stalk pulling viewing system is shown here, where the capsule is held with an appropriate vacuum tip and positioned over the reservoir and aligned with the polymer bead. The fillet diameter and stalk diameter are determined using the overlaid grid.

II.E. Stalk Length

Stalk lengths produced by pulling the polymer were greater than the 100±20 μm specification to compensate for the inevitable taper as the fiber was pulled away from the reservoir. An aluminum scanning electron microscope mount was machined to hold the ~500 μm diameter capsules securely in preparation for cutting. A hemisphere with a 522 μm diameter was milled into the center of the mount to form a well for the capsule. To transfer the capsule from the plastic dish into the well, a hole was

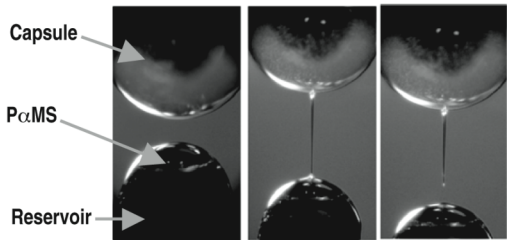

Figure 4. The photos were taken during the three stages of stalk pulling, which are alignment, touching the capsule onto the melt for the fillet diameter, and pulling the polymer into a stalk of a desired diameter.

drilled at the base of the well through the stem of the mount, through which a vacuum could be drawn. The mount was fitted into a brass holder, which was connected to vacuum. As the capsule was brought to the mount with a vacuum chuck and released over the well, the vacuum kept it snug in the well. Great care was required during transfer to avoid damaging the stalk. The capsule was picked up from the plastic dish so that the stalk was facing upwards away from the vacuum chuck. This orientation ensured that when the capsule was placed over the well and released from the vacuum chuck to the vacuum well, the stalk would not hit the edge of the well and break, rather, it would be facing upwards or rest on the flat surface of the mount. Afterwards the mount was transferred from the vacuum brass holder to a second brass holder not connected to a vacuum. The second brass holder was attached onto the same x-y-z axis stage that held the heated polymer reservoir. A 22.5° incision scalpel from OASIS Medical, Inc. was substituted into the micromanipulator that held the capsule during polymer pulling. Using the viewing system, the scalpel was positioned parallel to the surface of the mount and the stalk was brought into view. If the stalk did not lie flat on the mount, the scalpel was touched lightly onto the stalk to push it down flat without fracturing the polymer fiber. Simultaneously, the stage was manipulated to assist in the reorientation of the stalk. The scalpel was positioned directly over the fillet and the micrometer zeroed. The stalk was translated 100 μm with the digital micrometer stage and cut with the scalpel with an accuracy of ±10 μm.

II.F. Stalk Characterization

After trimming the stalk, the capsule was mounted onto a WF Gel Film from Gel-Pak® and positioned with a vacuum chuck so that the whole stalk profile was viewable by the measuring microscope and normal to the capsule surface. The microscope resolution and measuring tool allowed for accurate measurements of ±1 μm for the fillet diameter, stalk diameter, stalk length, and stalk angle. To confirm the uniformity of the fillet and stalk,

and to measure any angle in the stalk tip resulting from cutting, the capsule was rotated 90° for additional measurements and 45° upwards for imaging.

III. RESULTS AND DISCUSSION

The polymer reservoir and pulling technique increased the yield of surrogate fill tube targets within specification from 20% to greater than 75%. Improvements of trial runs relative to systematic modifications to the PαMS reservoir can be seen in Fig. 1, where each data point represents one pulled stalk aiming for a 25 μm fillet diameter. X-ray images of the hydrodynamic jets produced by stalk diameters ranging from 9–37 μm gave the first experimental data for comparison to fill tube simulations, and indicate that a stalk diameter less than 10 μm did not have an affect on implosion[6].

The heated reservoir and polymer pulling techniques were also employed for the monolithic fill tube targets discussed by Alfonso.[5] These polymer stalks were initially trimmed using the feather blade and SEM mount, however, capabilities now allow for an accuracy of ±3 μm using Excimer laser cutting.

IV. CONCLUSION

A deterministic technique to fabricate polymer stalks was developed and used to successfully produce a series of surrogate fill tube targets for hydrodynamic studies at OMEGA. This effort has also been applied to the fabrication of polymer mandrels for monolithic fill tube targets.

ACKNOWLEDGMENT

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