Experimental Studies of ICF Indirect-Drive Be and High Density C Candidate Ablators*

O L Landen, D K Bradley, D G Braun, V A Smalyuk1, D G Hicks, P M Celliers, S Prishbey, R Page, T R Boehly1, S W Haan, D H Munro, R G Wallace, A Nikroo2, A Hamza, J Biener, C Wild3, E Woerner3, R E Olson4, G A Rochau4, M Knudson1, D C Wilson4, H F Robey, G W Collins, D Ho, J Edwards, M M Marinak, B A Hammel, D D Meyerhofer1 and B J MacGowan

Lawrence Livermore National Laboratory, Livermore, CA, USA
1 Laboratory for Laser Energetics, Rochester, NY, USA
2 General Atomics, San Diego, CA, USA
3 Fraunhofer Institute for Applied Solid State Physics, Freiburg, Germany
4 Sandia National Laboratory, Albuquerque, NM, USA
5 Los Alamos National Laboratory, Los Alamos, NM, USA

E-mail: landen1@llnl.gov

Abstract. To validate our modeling of the macroscopic and microscopic hydrodynamic and equation of state response of these candidate ablators to NIC-relevant x-ray drive, a multi-lab experimental program has been verifying the behavior of these new ablators. First, the pressures for onset and termination of melt for both Be and HDC under single or double shock drive has been measured at the Z and OMEGA facilities. Second, the level and effect of hard x-ray preheat has been quantified in scaled experiments at the Omega facility. Third, a long planar x-ray drive has been developed to check 2D and 3D perturbation growth at the ablation front upon acceleration. The concept has been extended to study growth at and near the ablator-ice interface upon deceleration. In addition, experimental designs for validating the expected low level of perturbation seeding due to possible residual microstructure after melt during first and second shock transit in Be and HDC have been completed. Results so far suggest both Be and HDC can remain ablator choices and have guided pulse shaping designs.

1. Introduction

The indirect-drive Inertial Confinement Fusion (ICF) capsule point design for the National Ignition Campaign (NIC) on NIF uses a Cu-doped Be ablator [1] (see Figure 1a) to decrease sensitivity to hydrodynamic instabilities seeded at surfaces and increase coupling efficiency relative to mid-Z doped CH capsules that have been extensively tested [2] in the past. In addition, a recent alternate ablator candidate, high density carbon (HDC) (see Figure 1b), is predicted to provide a further increase in coupling and yield by virtue of its 2x larger density and hence larger inner diameter and DT fuel capacity for fixed initial outer diameter. However, unlike CH, both Be and HDC are polycrystalline in the solid phase, are predicted to melt at considerably higher temperatures and pressures, and could provide either additional or reduced seeding of instabilities before fully melted depending on the level of material strength remaining.
2. Melt Pressures

Since shock propagation through solid polycrystalline Be is predicted to lead to unacceptable distortions of the shock front and hence perturbation seeding due to crystal sound speed anisotropies, the first shock pressure for the ignition pulse fully melts the Be by computational design [1]. The single shock pressures for onset and completion of melt in Be have been determined at the Z facility [3] to be 2 and 2.6 Mbar, respectively. Similar measurements suggest HDC begins and fully melts at single shock pressures of 6 and 11 Mbar, respectively. However, the shock distortions in nanocrystalline HDC are predicted to be smaller principally due to the smaller grain size (< 50 nm) as long as the HDC is not left in large co-existing domains of melted and solid material. The strategy for HDC is hence to leave it in a low adiabat, solid state after first shock passage (by operating at ≈ 4 Mbar) and fully melt during the second shock passage. Experiments to determine this second shock melt pressure were carried out at the Omega facility in a 2-shock direct-drive planar configuration on µcrystalline HDC samples. The experiments inferred the temperature of an overtaking second shock from the strength of its optical emission (Figure 2) as a function of the strength of the second shock for either a 3 or (4) Mbar first shock. The results show a sudden rise in the second shock temperature at a pressure of about 18 (21) Mbar, indicating the completion of melt. This information has led to a revised HDC drive pulse-shape with a second shock pressure of 23 Mbar.

3. X-Ray Preheat and Shock Heating

Having determined the minimum shock pressure for Be melt, the next question was whether we could predict the hohlraum conditions required to melt Be while not putting it on too high an adiabat. For this purpose, a scaled hohlraum experiment was completed at Omega that emulated the Tr ≈ 100 eV NIF ignition foot conditions in terms of laser power, intensity and fraction of wall covered with laser beams. The observable was the rear-surface expansion of planar Be steps as measured by VISAR fringe shifts (Figures 3a and b). The results showed the expected gradually increasing Be expansion...
due to > 1 keV x-ray preheat followed by the sudden loss of reflectivity upon shock break-out. Figure 3c shows the calculated rear-surface temperature relative to the expected melt temperature for a variety of Be foil thicknesses. These results validated that for the NIF foot drive pulse, the first 20-25 µm of Be will be melted by x-ray preheat and the remainder by the first shock.

![Figure 3](image)

**Figure 3.** a) Experimental set-up b) Representative VISAR data. c) Calculated rear-surface temperature vs time for various thickness samples.

4. Hydroinstabilities

Simulations predict that residual microstructure and velocity fields in melted Be could still seed some hydrodynamic instabilities upon shock break-out, but at a level below that expected and acceptable from growth of allowable and measurable initial surface imperfections. To validate these expectations, we have designed Omega experiments to either look directly (see Figure 5b) for the velocity perturbations Δv/ν on shock fronts that would still be acceptable (Δv/ν < 2x10⁻⁴) or amplify their perturbation seeding using high growth factor (GF ~ exp(γτ)) Rayleigh-Taylor instability experiments (see Figures 4a and 5a).

![Figure 4](image)

**Figure 4.** a) Experimental set-up for ablation front Rayleigh-Taylor growth measurement. b) Measured vs calculated x-ray drive Tr. c) 4.3 keV radiograph of growth of NIC-surface roughness on Be(Cu) foil at 8.2 ns.

To achieve the latter, a τ = 8-10 ns long drive has been developed [4] (see Figure 4b), which for a given achievable radiographic accuracy ΔGF/GF = τΔγ, leads to an improved growth rate accuracy Δγ ~ 1/τ over previous shorter drive experiments [5]. This drive also provides sufficient sensitivity (2D GF ~ 200 at 50 µm wavelength [4]) to directly measure through x-ray radiography the 3D growth from BeCu planar foils (see Figure 4c) with an initial level of surface roughness equal to the NIF.
ignition design surface roughness tolerance of 25 nm rms over wavelengths 20 – 100 µm. Lineouts of the radiographs show 10% transmission variations along ridges reaching 30% at nodes, consistent with GF’s ≈ 150-400 and with simulations only considering growth from surface perturbations. Hence, the results suggest that at least for ablation front instability growth, microstructure is not important. Ongoing Omega experiments shown schematically in Figure 5 are testing for microstructure seeding and growth at a more susceptible location, the ablator-fuel interface where there is no ablative stabilization [6]. We expect the use of a 2 pulse 2D VISAR imaging system (Figure 5b) to provide shock velocity perturbation measurements down to Δv/v = 10^-5 on relevant spatial scales (few microns), for both planar and sections of real capsule ablator shells.

5. Summary
We have experimentally validated many of the residual physics parameters specific to dense, polycrystalline ablators. Experiments measured or confirmed shock pressures for onset and termination of melt, the level of hohlraum X-ray preheating and shock heating and the expected ablation front Rayleigh-Taylor growth. Results so far suggest both Be and HDC can remain ablator choices and have guided pulse shaping designs. Ablator-fuel interface hydroinstability and material strength experiments have also been designed and/or are in progress to further test models and physics.

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