Evaluation of solid spherical fuel compression by comparison with simulation

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Fast ignition (FI) is a potentially highly efficient method of inertial confinement fusion (ICF). It is expected to achieve the gain of 100 necessary for realizing inertial fusion energy (IFE). The compression and heating processes are separated, eliminating the need to form a hot spot during fuel compression in FI. As a result, it becomes possible to employ a low-adiabat, slow implosion for forming a high-density fuel plasma. In low-adiabat implosion, controlling and optimizing the implosion velocity is crucial for achieving high-density compression. However, there are limits to optimizing the experimental conditions, particularly the optimization of the laser waveforms, through simulations because of the incompleteness of the equation-of-state tables. Consequently, it is necessary to optimize the experimental conditions while experimentally evaluating the implosion. On the other hand, the absence of a hot spot means that neutrons, which are most commonly used to evaluate implosion performance, are not generated. This makes it difficult to assess the implosion performance.

Here, we introduce the evaluation method for the implosion performance of a solid sphere by measuring the outer shape of the compressed plasma through X-ray shadowgraphs. This evaluation improved the achievable density. In particular, we visualized the negative impact of implosion not incorporated into the simulation. This approach was made possible by previous research [1] that enhanced the one-dimensionality of the compression.

In this experiment, a 200-µm-diameter deuterated polystyrene (C_8D_8) solid sphere, suspended by a microfiber, was used as a mock fuel. The experiment was conducted on the GXII–LFEX laser system at the Institute of Laser Engineering, The University of Osaka. The GXII laser has twelve beams arranged on the faces of a regular dodecahedron, with an F# of 3. Each beam had an energy of 120 J, a wavelength of 0.526 µm, a pulse width of 6.0 ns, and employed a three-step waveform structure (Fig. 1), which was slightly changed for each shot. The laser spatial profile was set as r_L/r_{s0} = 1.9 [1], where r_L is the $1/e^2$ radius of the laser beam, and r_{s0} is the initial radius of the target. We used a Random Phase Plate with a segment size of 2 mm × 2 mm for achieving r_L/r_{s0} = 1.9 and reducing spatial disturbance. A flash

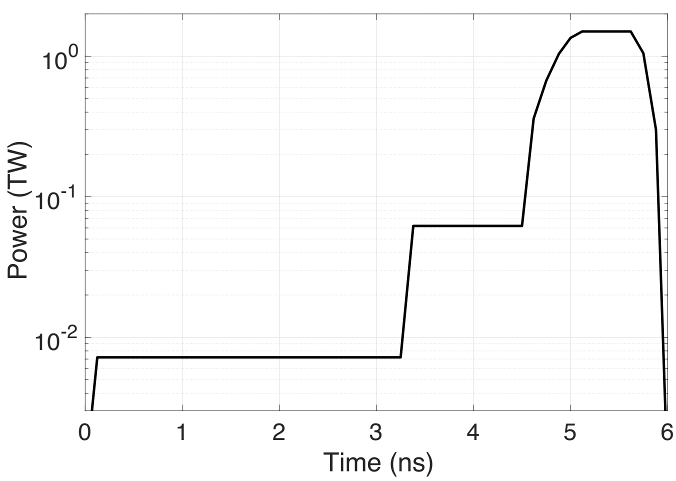

Fig.1 Laser waveform used in experiment which was optimized by 1-D radiation hydrodynamics simulation code to maximize the areal density.

X-ray shadowgraph was measured with a spherical crystal imager, providing a spatial resolution of 13 ± 5 μm and an energy bandwidth of 5 eV. The X-ray source consisted of Ti-Kα radiation (4.5 keV), generated by irradiating titanium foils with two LFEX laser beams. The LFEX laser system has four beams, each with an energy of 250 J, a wavelength of 1.053 μm, a pulse width of 1.3 ps, and an F# of 10. Two X-ray sources, separated by 240 ps, were used to obtain two images in one shot.

Figure 2 shows the comparison of the outer plasma radius between experimental data and simulation results. The outer radius is defined as the FWHM of the plasma transmittance profile. Here, we present a good prediction of the experimental radius by artificially adjusting the simulation parameters in Fig. 2b. It is crucial to eliminate any detrimental effects on the implosion that are not incorporated into the simulation in order to create experimental conditions as closely as possible to those under the simulated scenario. One example shows the effects of the glue used to hold the target in place. The data points circled in red in the figure represent the case where the glue was larger, exhibiting a trend different from the other cases. When the glue is large, the plasma's outer shape becomes larger, indicating insufficient compression due to the glue's influence. Because these effects are not incorporated into the simulations, it is necessary to evaluate them based on the trends observed in the data. Furthermore, we conducted experiments under the optimal conditions predicted by the simulation, successfully achieving a significant increase in the attained density.

This talk will report on the experimental results of spherical solid ball compression and more details about comparing experimental results and simulation results.

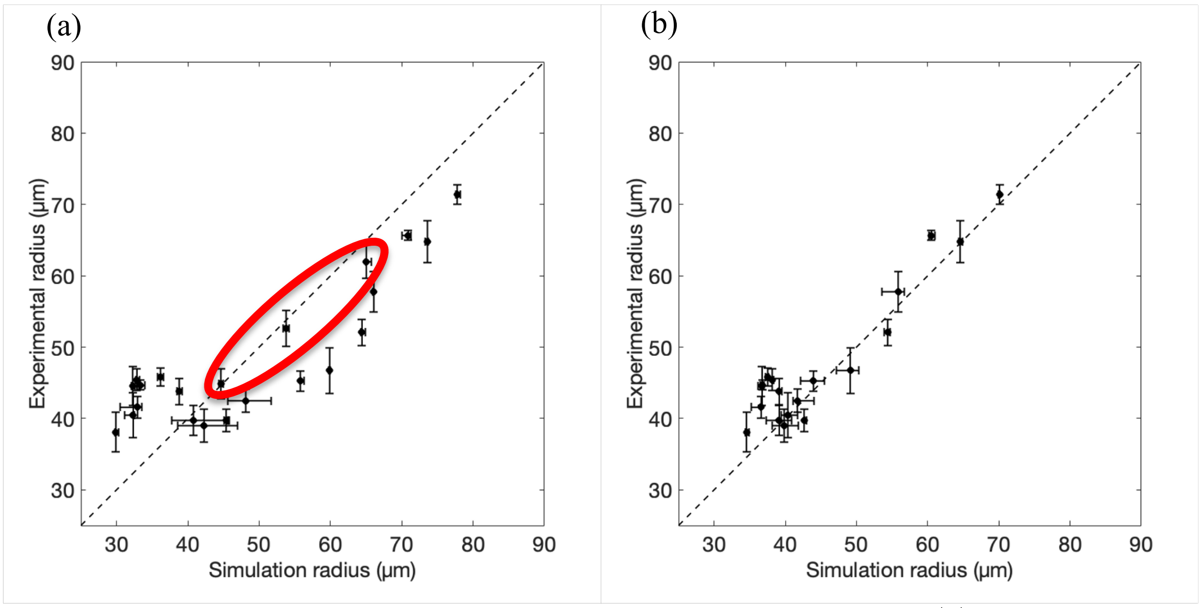

Fig.2 Comparison of the experimental and simulation results (a). The comparison trends differ between the cases with little glue (b) Input parameters on the simulation is artificially adjusted.

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