Dynamical Materials Experiments on Sandia's Z Machine: Obtaining Data with High Precision at HED Conditions

Thomas R. Mattsson and Seth Root

Sandia National Laboratories, Albuquerque, NM USA

Summary: The Z machine at Sandia National Laboratories has successfully been used to study a wide range of materials under extreme conditions. In this paper, we will discuss the methodology resulting in high-pressure measurements at multi-Mbar pressures as well as present experimental data for shock compression of poly methyl-pentene, a hydrocarbon plastic.

Introduction

During the last few years, there has been a notable increase in the interest of high-pressure science. The increase in interest has been driven by the remarkable capabilities of new and improved platforms like diamond anvil cells (DACs), pulsed power (Sandia's Z machine [1]), and high-powered lasers (Omega, NIF, Gekko, Luli, Orion, etc.) as well as by the renewed interest in planetary science. The growing list of exo-planets challenges our understanding of planetary formation and development. Accurately modeling these systems requires knowing the behavior of materials under even more extreme conditions than is found within the solar system. Comprehensive advances have been made for many elements and simple compounds, for example deuterium [2], carbon [3], quartz [4], and xenon [5]. In this paper, we will discuss the overall approach used to achieve results with high precision, in particular the need for accurate shock standards, and present results for shock compression of the hydrocarbon plastic (TPX®) poly methyl-pentene (PMP) as an example of a more complex material [6].

Method

The Z-machine at Sandia National Laboratories is the most powerful pulsed-power machine, capable of delivering more than 25 MA current to a load during a time of less than 100 ns [1]. Dynamical materials experiments are conducted by harnessing the magnetic field generated in a short-circuited load. By tailoring the shape of the drive current, it is possible to accelerate the anode plates as flyers. The plates free fly for a distance of a few mm, at which point they impact a sample. The sample can be solid or a contained liquid or gas. By measuring the velocity of the impacting flyer plate using laser interferometry (VISAR) and the generated shock velocity in the sample, the Hugoniot state in the sample can be determined through impedance matching. The sample shock velocity is either measured directly, for samples with reflecting shock fronts, or indirectly using transit-time techniques, for samples that are opaque. The experimental setup thus directly mimics a traditional shock-impact experiment and can take full advantage of the thermodynamic constraints of a shock wave, the Rankine-Hugoniot relations. This reliance on fundamental conservations laws makes for definite experimental interpretations.

Figure 1 shows the result from shock experiments on the transparent hydrocarbon plastic poly-methyl pentene. The sample material is initially transparent, which allows for a direct measurement of the approaching flyer plate followed by a measurement of the shock velocity in the sample – since PMP/TPX® has a reflective/metallic shock front. The shock velocity is measured directly with VISAR, with very high precision, directly translating into high accuracy in the resulting shock pressure data.

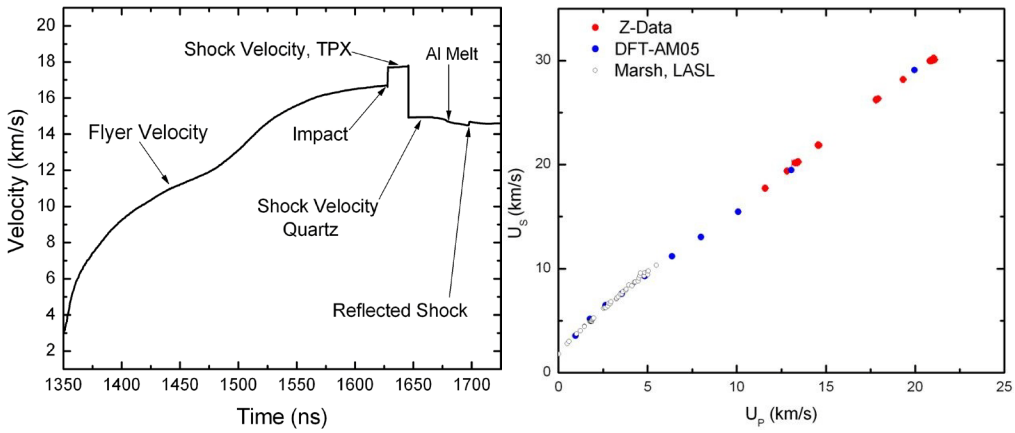

Figure 1. Shock compression of PMP plastics: experimental VISAR record from an experiment showing the sequence of velocities taken during the experiment (left); shock velocity versus particle velocity for PMP (TPX): LASL shock handbook (black circles) [7], DFT/QMD simulations (blue circles) [6], and data from Z (red circles).

Summary

High-precision measurements at Mbar pressures are reliably performed on Sandia's Z machine for many types of solids and liquids. The new data from Z has for many materials, for example cryogenic noble gases and PMP hydrocarbon plastic, extended the pressure ranges where the properties under shock compression are known with high precision by an order of magnitude.

References

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Acknowledgments

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