SAND2001-2989C

HIGH INTENSITY X-RAY COUPLING TO METEORITE TARGETS

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Abstract. Experimental results of shock wave effects from high intensity (70 -215 GW) soft X-ray irradiation on several meteorite targets are presented. From inhomogeneous materials, useful data on particle velocity and in-situ velocity were obtained and permitted the computation of the yield stress, shock wave velocity, compression, as well as the momentum and energy coupling coefficients.

INTRODUCTION

High intensity ($\geq$ 200 GW/cm^2) X-ray pulses generated from an exploding wire/hohlraum configuration at the Sandia Z-machine have been used to generate shock wave driven high pressures (multi megabar range) on various test samples and structures in order to determine the equation of state (EOS) and constitutive properties of materials at these high pressures[1]. Following this lead, we report on the utilization of the Sandia Z-machine to irradiate several meteorite specimens with soft X-rays (Plankian and line emission) in order to study the meteorite targets' response to high rates of dynamic loading provided by the ablation driven shock waves and the ensuing high pressure generation throughout the target sample. Previous work on these same meteorite targets used pulsed lasers to generate pressures from 0.7 to 11 GPa[2], the results of which provided significant insights into the response of different meteorite material categories[3] to high strain rate dynamic loading.

The rationale for these Z-pinch experiments is an outgrowth of a suggestion in 1995[4] that soft X-ray hohlraums be used to provide experimental approaches to understanding how the microstructures of near-earth objects (NEOs) respond to high pressure and loading conditions, using meteorites as asteroid analogs. This current series of experiments is anticipated to lead to an empirical understanding of the high pressure thermodynamics and material properties, such as material strength and isentropic compression and decompression of several different meteorite materials.

Of particular importance for this research is the determination of the momentum coupling coefficient, C_M, for the NEO material categories when subjected to intense (soft) X-ray irradiation. Knowledge of C_M is absolutely necessary to calculate orbital adjustments of potentially hazardous NEOs. Another objective is to gain an understanding of the EOS and constitutive properties of the different meteorite categories, which will help in modeling the dynamic response of asteroids to a high energy density interaction. These objectives will be somewhat difficult to achieve due to the inhomogeneous and irregular nature of these naturally occurring materials. Nonetheless, the results of the initial experiments appear to be encouraging. It is noted that this experimental approach provides significant advances towards understanding high energy density X-ray coupling to heterogeneous materials in general as well as for momentum transfer, heating, phase changes, and radiative scattering interactions with materials encountered in space.

Other applications include the interpretation of momentum coupling and related interactions from strong X-radiation with primordial solar nebula material and the interstellar medium.

DESCRIPTION OF THE SANDIA Z-PINCH EXPERIMENT

The experimental objective is to demonstrate the feasibility of obtaining reliable measurements of shock Hugoniots for meteorite materials experiencing ablative loading in order to determine their EOS and momentum coupling coefficients. The Sandia Z- machine is a 4.5 MV accelerator using Marx generators to store capacitive energies of about 11MJ which can produce currents of about 20 MA within the thin conductive wires between the anode and cathode (see Fig. 1) over a time scale of about 100 ns. Usually, a few hundred wires are used to generate the Z pinch source within the primary hohlraum whose typical diameters are 2 - 5 cm with 1- 2 cm heights and contains the radiation produced by the imploded pinch. After implosion of a (tungsten) wire array, a Z pinch Planckian-like radiation source with a 2 mm diameter is formed on axis within the primary hohlraum with temperatures of about 150 eV.

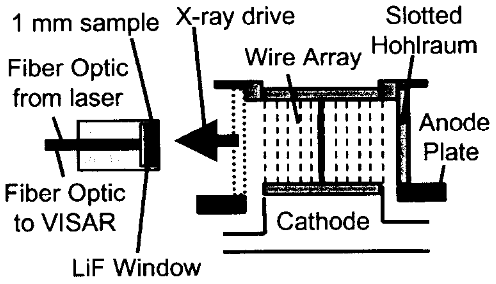

FIGURE 1. Configuration of Z-pinch experiment. Components on the right side of the figure are cylindrically symmetric about the heavy line at the center of the array (location of the pinch).

X-ray radiation is delivered to the sample through slots in the primary hohlraum. For the present experiments, no radiation filtration was performed. Instrumentation used to diagnose the sample response was comprised of a VISAR interferometer measuring the velocity of a spot at the back of the sample. For details of Z pinch instrumentation available, one is referred to many sources such as Konrad[5].

EXPERIMENT RESULTS

Velocity Measurements

Observed velocity profiles are shown in Figure 2, and appear to correspond to attenuating waves. In most cases dual-delay VISAR (velocity interferometry) instrumentation was used to measure velocity histories.

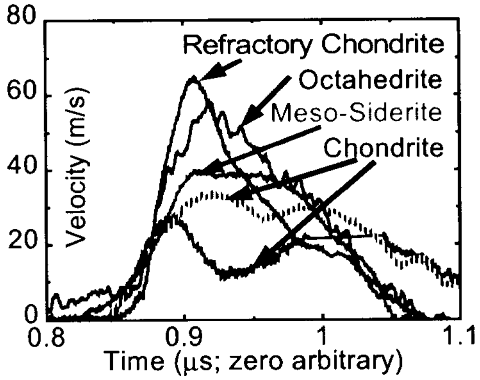

FIGURE 2. Observed velocity histories.

Shocked States

Basic experimental results for high intensity soft X-ray coupling to meteorites targets are summarized in Table 1, which lists estimated stress, P, in gigapascals (GPa), the observed (VISAR) particle velocity, V_p, and the inferred (in situ) velocity, V.

TABLE 1. Shocked states achieved in present tests.

Sample	CV3 Allende		Refr. Chond (LL6) Tuxtuac	Meso siderite Vacamuerta	FeNi (Og) Odessa
Test #	Z675	Z676	Z676	Z675	Z636
Sample	1/2	1/1	2/1	3/1	8/1
P GPa	0.5	0.5	1.0	0.53	1.20
V_P *m/s*	33	33	64	39	55
V m/s	30	30	58	39	40
D km/s	5.73	5.73	5.71	3.78	4.16
ρ_0 g/cm^3	2.91	2.91	3.02	3.60	7.21
ρ/ρ_0	1.006	1.006	1.012	1.013	1.013

The shock wave velocity D may be obtained from the momentum conservation relation:

$$P = \rho_0 D\,V, \qquad (1)$$

where ρ_0 is the pre-shock density. The post shock density, ρ, can be obtained from the mass conservation equation:

$$\rho = \rho_0 D/(D - V) \qquad (2)$$

All of the particle velocities listed in Table 1 appear to be attenuating (transient) waves, with the overtaking release wave corresponding to the decay of the Z -pinch emission. These particle velocities are corrected for the mechanical effect of the windows (which reduces the particle velocity at the interface observed by VISAR by 30 – 50%. The windows were necessary to preserve the reflecting surface, allowing the velocity measurements.

The inferred in-situ velocity can be interpreted as representing a lower bound for the ultimate velocity a thin slice of sample material would have reached under an extended X-ray pulse. Although peak stress is relatively low for natural (meteorite) materials, as compared to pure materials, they nonetheless possess high shock velocities because their particle velocity is very low as compared to pure materials.

Momentum and Energy Coupling Coefficients

Momentum and energy coupling coefficients may be calculated by two methods. The first (SS) treats the x-ray drive as a steady input stress; the second (I), as an impulse. The best value for application to problems is probably intermediate between the values thereby computed. Inputs and results from both methods are shown in Table 2.

In the steady input stress method, the input intensity I is taken as a constant. The momentum coupling coefficient, representing the momentum uptake of the target, is the ratio of the pressure P to the radiation intensity I:

$$C_{M,SS} = P/I = \rho_0 D\,V/I = P/I \qquad (3)$$

Here, D, V, I and P are (respectively) the in-situ material velocity, the shock velocity, the radiation intensity, and the resultant pressure.

The energy coupling coefficient, C_E, is the fraction of original input energy coupled to the target such that,

$$C_E = E_{Sam}/E_{In} = \tfrac{1}{2}\,\rho_0\,(d)\,V^2/E_{In}, \qquad (4)$$

where E_{In} is the (X-ray) energy incident on the target, E_{Sam} is the kinetic energy imparted to the target sample, and d is the sample thickness.

The Z-pinch is not a point source at these ranges R from the pinch, but is intermediate between point and cylindri-cal, so the intensity varies approximately as $R^{-3/2}$.

In the impulse method of calculating coupling coefficients, the x-ray pulse is taken as providing a brief impulse which accelerates the plate to a limiting velocity taken as the in-situ material velocity just below the monitored surface. Thus,

$$C_{M,I} = \rho_0\,(d)D\,V/F, \qquad (5)$$

where F is the fluence of radiation incident on the sample.

TABLE 2. Computation of the momentum, C_M, and energy, C_E, coupling coefficients

Sample	CV3 Allende		Refr. Chond (LL6) Tuxtuac	Meso siderite Vaca-muerta	FeNi (Og) Odessa
Test #	Z675	Z676	Z676	Z675	Z636
Sample	1/2	1/1	2/1	3/1	8/1
*d mm**	1.012	1.014	1.01	1.013	1.508
4πE kJ	867	1116	1116	867	1187
R cm	14	14	14	14	10
Fluence J/cm²	352	453	453	352	945
τ *(ns)*	5.03	5.03	5.03	5.03	4.40
I GW/cm²	70	90	90	70	215
$C_{M,SS}$ $s/m\times10^{-5}$	0.050	0.31	0.078	0.080	0.054
$C_{M,I}$ $s/m\times10^{-5}$	2.51	1.56	3.91	4.0	4.6
C_E $\times10^{-5}$	0.38	0.19	1.13	0.79	0.92

*Radii of all targets was about 3mm, yielding an area of about 0.283 cm^2. The volume of each target was 0.029 cm^3 except for sample 8 which was 0.038 cm^3