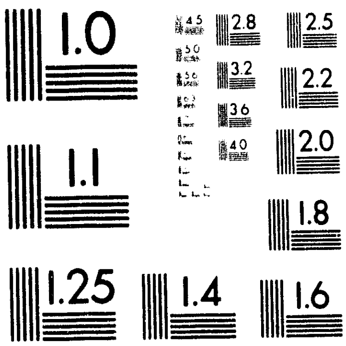
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CONF-930676--10

Dynamical Behavior of Tantalum*

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We have performed four dynamic impact tests on tantalum to determine its high-pressure yield and viscoelastic properties. Our experiments used compressed gas gun techniques to produce a combination of shocks, reshocks and releases over the pressure range 0-12 GPa in samples5.0 amd 7.3 mm thick Profiles were recorded using VISAR (velocity interferometry) techniques. Elastic precursors suggest a yield strength of 0.95 GPa, which is somewhat above literature values. As with other metals, release waves do not show a perfect elastic-plastic behavior, indicating a slight Baushinger effect. Lagrangian sound velocities for singly shocked states are consistent with earlier results (about 4.5 km/sec).

INTRODUCTION

As part of an effort to characterize the viscoplastic behavior of a variety of refractory metals we have undertaken a study of the dynamical properties of molybdenum, tantalum, vanadium and tungsten (all body-centered cubic materials), using time resolved velocity interferometry techniques. The detailed results obtained to date for tungsten, vanadium, molybdenum and tantalum (higher stress regimes) are summarized elsewhere[1,2,3,4] In this paper, the most recent results on tantalum are summarized. The experiments were conducted over a pressure range of 3.5 to 12 GPa. Most of the physical phenomena of interest contribute significantly to the observed wave behavior for loading and unloading in this pressure range. The viscoelastic behavior of tantalum can be deduced from the rise time (and release time) measurements of stress or particle velocity profiles. Specific viscoelastic properties of interest include the Hugoniot Elastic Limit (HEL), its dependence on run distance and final stress amplitude, the strain rate in the plastic loading wave, properties of release, reshock and release/reshock cycles, and yield strength in the shocked state; metallurgical properties of virgin and recovered material are also of interest. These measurements are the first of this nature for fully dense tantalum.

The objective of the present paper is to present the data obtained from the impact experiments conducted with tantalum and interpretations of the loading/unloading properties from the observed wave profiles.

*Sponsored by the U.S. Department of Energy and conducted under the auspices of the U. S. Department of Energy under Contract DE-AC04-76DP00789.

IMPACT EXPERIMENTS

Method and Matrix

A suite of four impact tests was designed to allow the observation of strength effects, the Hugoniot, and release properties. The configurations used are shown schematically in Fig. 1, with relevant dimensions given in Table 1.

Sapphire impactors and windows were chosen because sapphire is an extremely high-impedance, elastic material with well-studied optical and mechanical properties in the stress regime of interest (stresses up to about 9 GPa are achieved in the windows in the present study).

Results and Discussion

The first two experiments conducted (Ta 1 and Ta 2) utilized samples of similar thickness and impact velocity, but differed in that Ta 2 provided a reshock of the sample followed by a release, while

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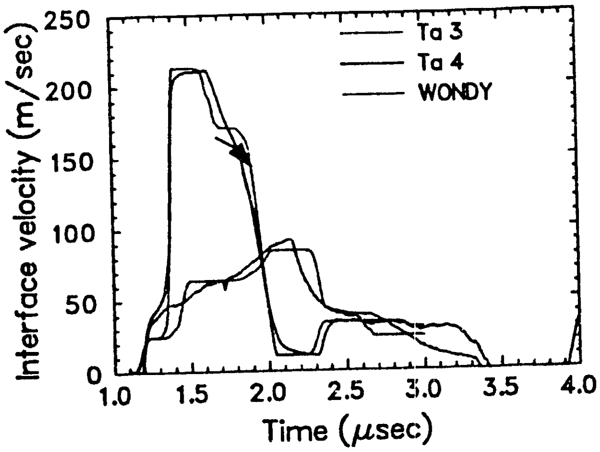

Figure 3. Wave profiles for Ta 3 and Ta 4.

Test #	Particle Vel. km/s	Stress GPa	Density gm/cm^3	Shock Vel. km/s
Hugoniot states (Lagrangian analysis)				
Ta 1	0.125	7.94	17.04	3.64
Ta 2	0.130	7.86	17.20	3.61
Ta 3	0.183	11.41	17.47	3.63
Ta 4	0.054	3.46	16.88	3.30
Hugoniot states (Impedance match analysis)				
Ta 1	0.129	8.02	17.25	3.65
Ta 2	0.130	7.99	17.26	3.60
Ta 3	0.189	11.61	17.56	3.63
Ta 4	0.056	3.46	16.91	3.22
Elastic precursor states				
Ta 1	0.026	1.83	16.756	4.175
Ta 2	0.027	1.89	16.759	4.175
Ta 3	0.025	1.72	16.749	4.177
Ta 4	0.030	2.06	16.769	4.175

Table 2. Hugoniot states for tantalum. (Note that arrival of Ta 4 second wave is poorly defined)

time to be consistent with a precursor velocity of 4.175 km/sec.

Precursor states were computed by impedance match methods; i.e.. from shock velocity and plateau level in the wave profiles and from the known elastic properties of the Z-cut sapphire windows; these are summarized in Table 2.

Hugoniot conditions were calculated by two methods: impedance match (referenced to the post-precursor state) and finite-velocity-increment Lagrangian analysis. Results for the two methods differ slightly, and are presented in Table 2 and plotted in Figure 4. Some difference is expected because the waveforms are not sharp steps in this material (Fig. 5).. Advancing the arrival times to the sample positions shown in Fig. 5. brings the calculations into agreement. Shock velocities are presented in Lagrangian form, i.e. as original specimen thickness divided by transit time.

The Lagrangian analysis yielded tabular relations between wave speed, stress, strain, strain rate,

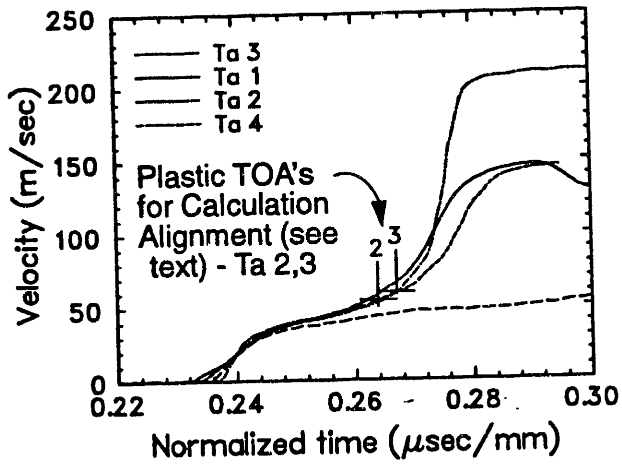

Figure 5. Details of loading profiles to Hugoniot.

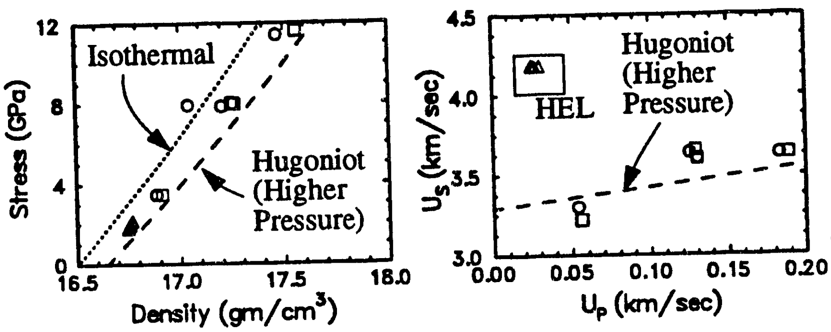

Figure 4. Hugoniot of Tantalum. Isothermal curve is from Birch-Murnighan fit to static data with $K_0 = 194$ GPa and $K' = 3.98$[6]. Hugoniot shown is ρ_0=16.65 gm/cm^3, $C_0 = 3.293$ km/s, $S = 1.307$

□ ○ Present Data (Impedance match, Lagrangian analysis, respectively.)

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