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SIMULTANEOUS PVDF/VISAR MEASUREMENT TECHNIQUE FOR ISENTROPIC LOADING WITH GRADED DENSITY IMPACTORS

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A simultaneous PVDF/VISAR measurement technique was used for isentropic-loading experiments with a polymethyl methacrylate (PMMA) specimen. The experiments used a graded density impactor accelerated onto a tantalum driver backed with PMMA and then lithium fluoride windows for each experiment. Simultaneous measurements made at each window interface provided precise transit time and particle velocity measurements which can be used to determine the stress-vs-strain loading path using Lagrangian analysis techniques. The experimental technique provides access to 40 GPa stress levels in PMMA under isentropic-loading conditions.

INTRODUCTION

Shock loading techniques allow the capability for characterization of material properties at high pressures and strain rates¹. During shock loading, a substantial temperature increase can accompany the pressure increase. The use of finite-rise-time loading produces quasi-isentropic compression of materials by introducing a series of small shocks that provide access to high pressure equilibrium states with lower temperatures than those obtained at Hugoniot shock states (quasi-isentropic loading will be referred to as isentropic loading in this paper for brevity, although isentropic loading is achieved only in the limit as the amplitude of each shock jump approaches zero).

A variety of isentropic-loading techniques have been developed that make use of the unique material properties of fused silica and glass ceramics to transform a shock input wave into an acceleration wave when used as buffer materials.

(2,3,4) The stress limitations are approximately 3 and 20 GPa, respectively, due to their stress-strain behavior. (5) Graded density impactors have also been used for isentropic loading using both powder sedimentation techniques (6) and multiple layer impactors. (7,8)

The present technique development is intended to extend the level of stress achievable under isentropic loading by use of a multiply-layered, graded-density impactor accelerated onto a high impedance buffer material backed by the specimen and optical window. The material impedances and thicknesses in this technique were optimized with numerical simulations. There are two primary motivations for this technique development: material characterization under isentropic loading, and exploration of the response of the piezoelectric polymer PVDF under isentropic-loading conditions beyond the present limit of 10 GPa. (9) The present report describes the details of this isentropic-loading technique, and presents

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preliminary results that are encouraging in regard to the optical use of PMMA at high stress levels.

EXPERIMENTAL TECHNIQUE

Isentropic loading over the velocity range of 0.6 to 2.2 km/sec was achieved by impacting a graded density impactor onto the tantalum driver-

Figure 1. Isentropic-loading technique with multiple-layer laminated impactor accelerated onto tantalum driver in target. PMMA specimen is backed with lithium fluoride to allow optical access to front and rear surfaces of PMMA. Impactor layers increase in density and decrease in thickness from the TPX impact layer to the tantalum rear surface.

The simultaneous PVDF/VISAR measurement technique used in these measurements is based on the technique of Setchell (10) and prior material response characterization of the high explosive HMX (11), employing both laser interferometer (VISAR) (12) and piezoelectric polymer (PVDF) (9) diagnostics in simultaneous measurements at two independent locations. The two independent VISAR measurements, when used in conjunction with the precise measurement of shock propagation time through the sample from the PVDF sensors, allow determination of the stress-vs-strain loading path of the specimen from the Lagrangian wave analysis method of Fowles and Williams. (13) This isentropic loading technique will also provide a method for examination of the loading-path effects on PVDF response at stress levels up to 40 GPa.

An 88-mm diameter, powder-driven, single-stage gun was used for these experiments. Projectile

plate/specimen/window assembly to provide an isentropic loading to the specimen as seen in Fig. 1. The lithium fluoride window provides optical access to the specimen. The present study uses a polymethyl methacrylate (PMMA) specimen which provides optical access to the driver/specimen interface. PVDF sensors are mounted at each VISAR reflecting surface.

velocity was measured at impact with $\pm 0.5\%$ accuracy. Measured tilt angle at impact is typically 1 milliradian or less. The graded density impactor was made from multiple layers laminated together, each layer having an increasing density and decreasing thickness from front to back. The aluminum backer is an integral part of the phenolic projectile. The experimental details of the impactor and target materials are listed in Table 1.

The mechanical shock impedance (Z) of each material is defined as the product of the unshocked density (ρ_0) and the Y intercept from each material's tabulated U_s -vs- u_p fit at $u_p=0$. The impedance of the impactor varies from $0.1326 \text{ gm/cm}^2 \mu\text{sec}$ for TPX to $5.713 \text{ gm/cm}^2 \mu\text{sec}$ for tantalum.

The tantalum driver thickness was chosen from numerical simulations to allow smoothing of the individual shock reflections at each interface layer within the graded density impactor. The thickness

TABLE 1. Experimental configuration and dimensions for isentropic-loading technique.

Exp #	Impact vel. (mm/usec)	Impactor material	Impactor thickness (mm)	Target material	Target thickness (mm)
51105	0.606	Ta/Cu/Ti/Al/Mg/TPX	4.579/.388/.314/.530/.589/1.056	Ta/PMMA/LiF	5.999/.988/25.451
51123	0.911	Ta/Cu/Ti/Al/Mg/TPX	4.506/.391/.312/.528/.587/1.064	Ta/PMMA/LiF	6.337/.967/25.350
51125	1.77	Ta/Cu/Ti/Al/Mg/TPX	4.443/.380/.319/.526/.591/1.019	Ta/PMMA/LiF	3.177/.996/25.277
51124	2.12	Ta/Cu/Ti/Al/Mg/TPX	4.443/.379/.317/.518/.597/1.022	Ta/PMMA/LiF	1.983/.997/25.209
51106	2.21	Ta/Cu/Ti/Al/Mg/TPX	4.516/.394/.315/.536/.592/1.067	Ta/PMMA/LiF	1.996/.971/25.458

was constrained to prevent the high velocity tantalum reflected shock from the rear of the impactor to overtake the low velocity TPX shock, thus creating a shock jump input condition to the specimen. The tantalum thickness at the rear of the impactor was chosen to delay the shock release from the rear surface from overtaking the loading wave into the target.

VISAR measurements were made at the driver/specimen interface and the specimen/backer interface by depositing 2000Å-thick reflecting surfaces over opposite halves of the two interfaces.

PVDF measurements were made in current-mode operation (14) with the recording instrumentation arranged to provide a common time-base between the two sensor locations.. The amplitude of piezoelectric current generated by PVDF in current-mode operation is proportional to the stress difference between the front and rear surfaces of the 25 µm thick film. Shock arrival at the front surface of

PVDF generates a current pulse with a few nanosecond rise time to peak current, thus allowing a precise measurement of loading wave arrival times. Typical accuracy in transit time measurement is ± 2 nanoseconds based on typical recording intervals of 1 nanosecond. The specimen transit time is calculated by subtracting shock transit times through the PVDF and insulation layers using shock properties for each film.

RESULTS

The measured particle velocity profile at the front surface of the PMMA specimen shows initial shock jumps to 11% of the peak amplitude, followed by an acceleration loading that approaches isentropic compression of the specimen as seen in Fig. 2. The measured front-surface particle velocity reaches a maximum of 1.94 mm/µsec, corresponding to 40

FIGURE 2. Particle velocity profiles from front and rear surfaces of PMMA specimen under isentropic loading. Mechanical equilibrium is achieved within specimen before release arrives. 22 GPa transparency limit for shock loading is shown.

GPa, well beyond the 22 GPa limit for transparency under shock-loading. (15)

The overlaid measurement profiles from front and rear specimen surfaces show that equilibrium is achieved within the specimen before release arrives.

The desired result from these isentropic-loading experiments is stress-vs-strain loading paths for PMMA up to 40 GPa. The Lagrangian analysis used to calculate stress-vs-strain paths (12) makes the assumption that the wave velocity for any given level of particle velocity is constant. Multiple thicknesses of specimens need to be studied at the same input conditions in order to satisfy this assumption. Analysis of the present data is in progress.

The PVDF measurements are not shown due to an unanticipated complication. The PVDF response was obscured at high stress levels by the shock-induced polarization of the uninsulated PMMA specimen. The onset of shock-induced polarization from the PMMA specimen was observed at 1.0 GPa superposed onto the piezoelectric current generated from the PVDF sensor, thereby preventing the observation of quantitative stress histories. Accurate arrival times were measured at low stresses only. This observation demonstrates the need for electrical insulation and shielding of the PMMA specimen. Teflon insulation is typically used due to the low level of piezoelectric activity (10^{-7} C/m²), in contrast to PMMA (10^{-4} C/m²) which is larger by 3 orders of magnitude. (16)

CONCLUSIONS

This simultaneous PVDF/VISAR measurement technique combined with the isentropic-loading technique provides the capability for exploring the isentropic response of materials to higher stresses. PMMA appears to remain transparent during isentropic-loading to 40 GPa. Care must be taken to properly insulate the PVDF gauges when using samples that may show high-stress piezoelectric behavior.

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