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TIME-RESOLVED WAVE-PROFILE MEASUREMENTS AT IMPACT VELOCITIES OF 10 KM/S

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Abstract

Development of well-controlled hypervelocity launch capabilities is the first step to understand material behavior at extreme pressures and temperatures not available using conventional gun technology. In this paper, techniques used to extend both the launch capabilities of a two-stage light-gas gun to 10 km/s and their use to determine material properties at pressures and temperature states higher than those ever obtained in the laboratory are summarized. Time-resolved interferometric techniques have been used to determine shock loading and release characteristics of materials impacted by titanium and aluminum fliers launched by the only developed three-stage light-gas gun at 10 km/s. In particular, the Sandia three stage light gas gun [1-3], also referred to as the hypervelocity launcher, HVL, which is capable of launching 0.5 mm to 1.0 mm thick by 6 mm to 19 mm diameter plates to velocities approaching 16 km/s has been used to obtain the necessary impact velocities. The VISAR, interferometric particle-velocity techniques [4] has been used to determine shock loading and release profiles in aluminum and titanium at impact velocities of 10 km/s.

Three-StageLight-GasGun: The principle of operation of the Sandia's three-stage light gas gun is briefly described here. Very high driving pressures (tens or hundreds of GPa), are required to accelerate flier plates to hypervelocities. This loading pressure pulse on the flier plates is time-dependent to prevent the plate from melting or vaporizing. This is accomplished by using graded-density impactors [1-3]. When this graded-density material is used to impact a flier-plate in a modified two-stage light gas gun, as indicated in Figure 1(a), nearly shockless, megabar pressures are introduced into the flier plate. The pressure pulse is also tailored to prevent spallation of the flier-plate. This technique has been used to launch nominally 1-mm-thick aluminum, magnesium, titanium (gram-size) and tantalum [5] intact plates to 12.2 km/s. The technique has been enhanced by using the experimental configuration shown in figure 1(b) to allow the launching of titanium and aluminum plates to velocities approaching 16 km/s [3]. This is the highest mass-velocity

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capability attained with laboratory launchers to date, and therefore should open up investigations into new regimes of impact physics using various diagnostic tools [4,5].

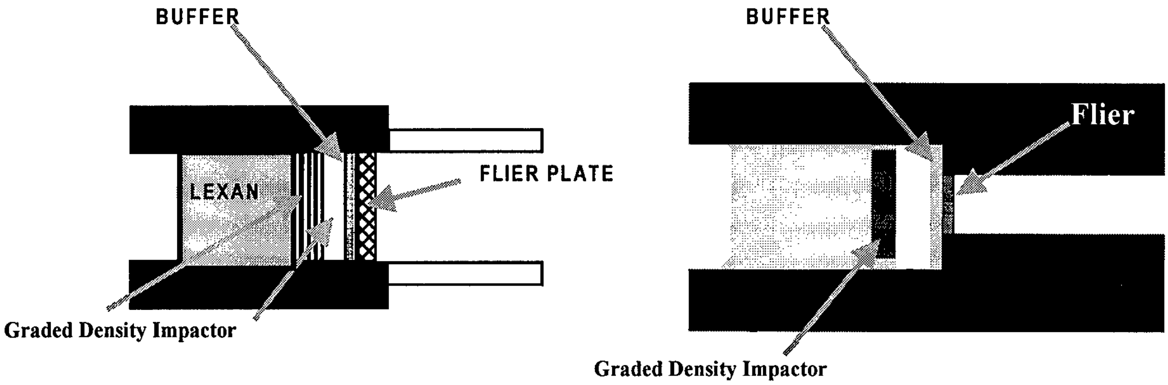
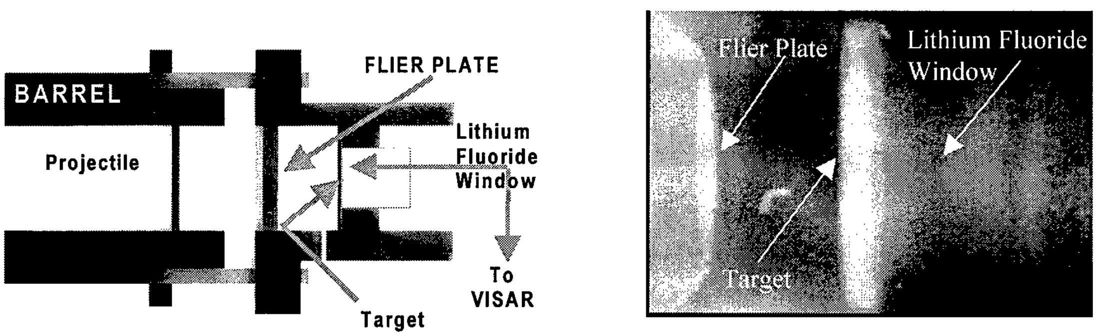


Figure (1a). The third stage configuration used to launch flier plates to hypervelocities. The Enhanced Hypervelocity Launcher, configuration, fig (1b), is used to launch confined flier plates in a tungsten barrel to velocities approaching 16km/s.

We have used the three-stage light gas gun to perform one-dimensional plate-impact experiments. To achieve one-dimensional conditions, the target plate is stationed ~ 20 mm from the flier-plate. This ensures that the flier plate achieves peak particle velocity prior to impact, and remains relatively flat prior to impact. The experimental configuration used to perform shock loading and release measurements is shown in Figure 3(a).



(a) (b)

Figure(3a). Radiograph of a Titanium flier-plate (prior to impacting a titanium target). The flier-plate is traversing at 9.60 km/s. The third stage configuration used for shock-loading and release experiments (b). Resultant loading and release is measured as particle-velocity history at the target lithium-fluoride window interface.

Symmetric plate-impact experiments have been performed using aluminum, titanium, and tantalum at impact velocities of ~ 10 km/s. Figure 3b shows the radiograph of an experiment in which a 0.56 mm titanium alloy (Ti-6Al-4V) flier-plate is launched at 9.6 km/s prior to impacting a 2.0 mm thick titanium alloy target. The lithium-fluoride window is seen

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in the radiograph in Figure 3b. The flat portion of the flier-plate prior to impact as observed in the radiograph is 19 mm. Note that for the full duration of the experiments there is a free rear surface behind the flier-plate; this allows measurements of a complete release from the shocked state. As indicated in Figure 4, a velocity interferometer VISAR [4], records the particle-velocity history at the sample/lithium-fluoride window interface. The time-resolved particle velocity history measurements at the target/lithium-fluoride window interface are shown in Figure 4(a) and 4(b) for aluminum and titanium, respectively. Since no fiducial was established in these experiments, the shock arrival time at the target/window-interface is arbitrarily set to zero.

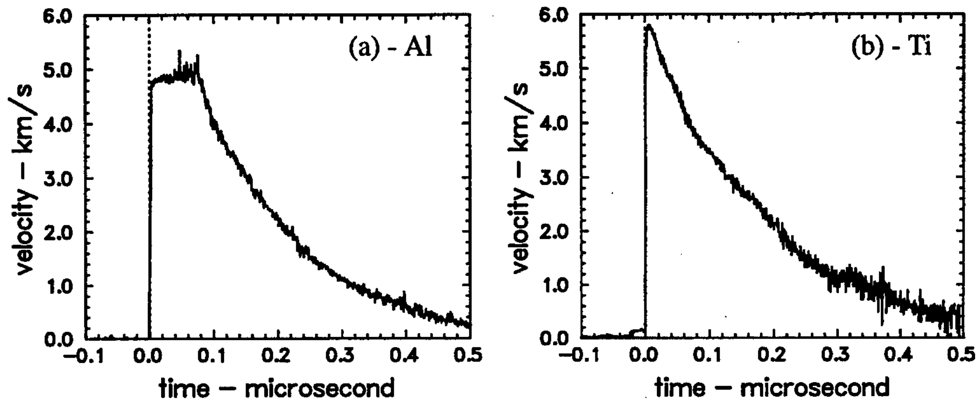

Figure (4). Measured interface particle velocity history for shock-loading and release experiments in (a) 6061-T6 aluminum at an impact velocity of 9.95 km/s, and (b) Ti-6Al-4V alloy at an impact velocity of 9.6 km/s. Symmetric impact configuration was used in both experiments.

Aluminum Experiment: Figure 4(a) depicts the shock loading and release profile in aluminum shocked to over 1.62 Mbar at an impact velocity of 9.95 km/s. In this experiment, a 0.98 mm thick aluminum flier-plate impacts a 1.98 mm thick aluminum target. Notice that a sustained shock of approximately 80 ns is observed in the figure prior to release. The titanium alloy is shocked to 2.3 Mbar at an impact velocity of 9.6 km/s, and a complete release profile as indicated in Figure 4(b) is measured. A profile resembling wave attenuation is measured in the titanium experiment because a thin flier plate (0.56-mm) impacts a thick (2.0 mm) target. Both experiments indicate a lack of elastic-plastic release structures which is a clear indication of complete melt in the shocked state. Most significantly, the results demonstrate the successful use of time-resolved velocity interferometric techniques for EOS investigations using the three-stage light-gas gun. These release profile structures will yield the off-Hugoniot states of materials shocked to extremely high-pressure.

The lack of elastic-plastic release clearly indicates complete melt in the shocked state at 1.62 Mbar. This is indicated as zero shear stress in Figure 5(a), and is consisitent with previous measurements by Asay and Chhabildas [6,7]. The Hugoniot state is based on measurements of the impact velocity and the existing equation of state for aluminum [8]

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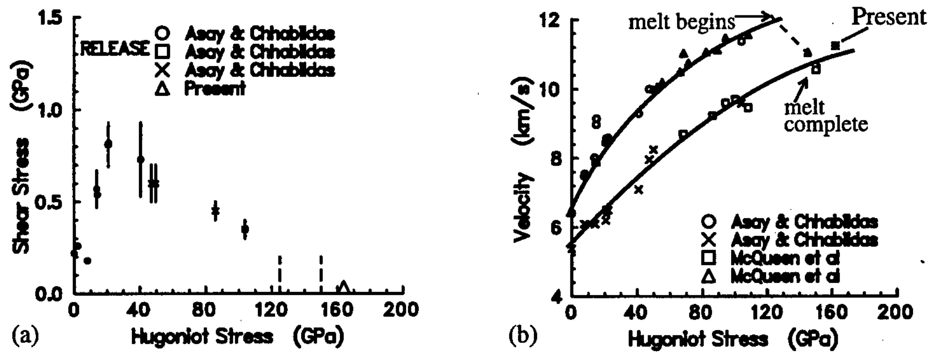
given by the shock velocity (U_s)-particle velocity (U_p) relation as (U_s (km/s) = 5.386 + 1.339 u_p). The leading edge of the release wave velocity, or the sound speed in the shocked state at 1.62 Mbar can be calculated knowing the sample and impactor dimensions, the dwell time of the shock at the sample/window interface, and the impact velocity. The calculated value of 11.24 km/s agrees quite well with extrapolation of previous sound speed measurements by Asay and Chhabildas [6,7] and McQueen *et al* [9] and is shown in Figure 5.



Figure(5). Measurements of (a) shear stress and (b) sound speed at 162 GPa in aluminum as determined from the release wave profile indicated in figure 4(a). Comparison with previous studies is also indicated.

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