VISAR WAVE PROFILE MEASUREMENTS IN SUPRA-COMPRESSED HE

D.J. ERSKINE, L. GREEN and C. TARVER

Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94550*

Using a VISAR velocimeter with nanosecond time resolution, wave profiles of the reaction zone were measured in planar TNT and 92.5/7.5 TATB/KEL-F samples impacted by flyer plates from a two-stage gas gun, at shock pressures exceeding the detonation pressure. The results indicate that for increasing piston-supported pressures the difference between inert and reaction product Hugoniots becomes very small. For TNT, the reaction zone is fairly well defined and does not extend beyond 150 ns.

1. Introduction

In recent years, it has become possible to supracompress (overdrive) detonating solid explosives to pressures exceeding their self-sustaining Chapman-Jouguet (C-J) pressures by impacting them with gas-gun accelerated flyer plates at velocities of several kilometers per second. Previous studies of this type¹ had indicated that it is difficult to fit, with the same JWL equation of state and standard assumptions, both the supracompressed and C-J states. It was suggested² that this may be due to the presence of a relatively slow reaction (possibly carbon condensation) following a fast reaction that prevents the conventionally accepted C-J state to be in true equilibrium. One of the goals of the present work was to measure the reaction zone of various reacting explosives near to the C-J pressure in piston-supported experiments with sufficient resolution to determine if such a slow reaction was present. In addition, extending the measurements to pressures significantly above the C-J state provides new information on the inert and reaction product Hugoniots.

2. Experimental

Plane shock waves were sent through thin planar TNT and LX-17 (92.5/7.5 TATB/KEL-F) samples using the twostage light gas gun facility at LLNL and the velocity profiles of the emerging wave at a LiF reference window were measured by a VISAR velocitometer. The HE samples were



FIGURE 1

Target Schematic. A gold layer between the LiF window an HE layer provides specular reflection for the recording instruments.

approximately 25 mm in diameter and 2 or 3 mm thick. They were struck by a 3 mm thick 1100 Aluminum flyer plate. As shown in Fig. 1, a LiF window 5 mm thick was attached to the rear of the HE sample. A thin (4000Å) gold layer evaporated onto the LiF window at the HE/LiF interface provided a specularly reflective surface for the VISAR. In some experiments, a 0.5 mm buffer of Magnesium alloy was placed between the HE and the LiF to help protect the reflective interface from 3-dimensional irregularities in the shock front. Two shorting pins flush to the impact surface of the HE across the target diameter provided a trigger pulse for the diagnostic

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

equipment. A 50 mm f1.8 lens mounted at the rear of the target assembly focussed light from the VISAR system onto the reflective surface at the LiF/HE or LiF/Mg interface and collected the returning light.

The velocity of the LiF/HE interface was measured using a VISAR interferometer system of a "push-pull" design by Hemsing³ and an Argon ion laser for illumination. The VISAR system, including the photomultipliers and recording instrumentation, had a 1.5 ns net rise time and a 3 m/s velocity resolution limit. The VISAR interferometer was mounted on an optical table housed in a room separate from the gas gun room. Fiber optical cables linked the interferometer to another set of optics (the gunroom optics) immediately adjacent to the gun tank which illuminated and collected light from the target. Separate fibers were used for the illuminating and reflected light. To reduce signal degradation due to dispersion in electronic cables, the VISAR photomultipliers were mounted adjacent to the electronic recording instrumentation in the gun control room and linked to the interferometer via optical fiber.

The gunroom optics shown in Fig. 2 were designed to illuminate the target with light from one fiber, while coupling co-axially reflected light into the return fiber to the interferometer. A 3" diameter mirror (M1) with a central 1/8" hole picks off returning light from the beam path of the illuminating beam. The target lens (L1) was focussed such that the reflected beam diameter at M1 was larger than this hole for all anticipated sample movement during the shot. The coarse focusing of lens MO2 was such that the aperture of L1 was imaged to the aperture of MO3, which coupled the light into the return-beam fiber. The fine adjustment of the lenses was such to both maximize the amount of returning light, and to maximize the depth of field.

Apart from the use of fiber optics, the design of the interferometer followed that of Hemsing and others and the reader is referred to Reference 2 for details of the optical arrangement of the interferometer and data analysis scheme⁴ for a "push-pull" VISAR. The gist of the technique is that due to a Doppler shift, a shift in fringes (sinusoidal variation of light output from the interferometer) is observed proportional to the change in target velocity, with the proportionality constant dependent on the length of an etalon inside the interferometer. (For our experiment,the constant



FIGURE 2

Schematic of gunroom optics, which couples light between fibers and target. MO=10x microscope objective. L2 and L1 are 50mm 1.8 camera lenses.

was 231.4 m/s per fringe for a free surface target. For a target windowed with LiF a correction must be supplied due to the shock induced index of refraction change. This has been calibrated by other laboratories⁵, and in our experiment implied a 181 m/s fringe constant.

3. Results

Figures 3 and 4 show the measured velocity profiles for TNT and for LX-17 respectively. The indicated pressures are the calculated piston supported pressures based on the measured flyer velocity and estimated equation of states (EOS) of the two explosives. Due to the finite response time of the VISAR photomultipliers, the instrumentation could not record the nearly instantaneous passage of fringes at the moment of shock when the velocity jumps discontinuously. We allowed 3 ns for the photomultipliers to settle (twice the response time). As a consequence, we must consider an unknown, but integer number of fringes to have skipped past unrecorded at the moment of shock. By comparing the data with the expected velocity, we determine the integer number of fringes to add as an offset to the record, and after multiplying by 181 m/s per fringe we obtain the velocity records shown in the Figure. Since the difference between measured and calculated velocities behind the reaction zone (t>70ns) are significantly less than 181 m/s we have correctly identified the integer number of fringes skipped.

The calculated curves for TNT were made by an ignition and growth reactive flow hydrodynamic calculation assuming a JWL EOS with the parameters: P_{CJ} =190 kB, ρ_0 =1.645, V_{DET} =0.693 cm/µs, E₀=0.07, R₁=5.8, R₂=2.1, ω =0.3, A=8.797808, B=0.322774, C=0.01914. This JWL EOS was obtained by fitting cylinder test expansion data and





VISAR measured velocity profiles of LiF/HE interface for TNT at three different (calculated) piston supported pressures. Note the different time scale of the top plot. The dashed curves are calculated results using a JWL equation of state.

Kineke and West⁶ supra-compressive data on TNT. A more detailed description of this calculation is in Reference 7.

4. Discussion 4.1 TNT

The 20.2 GPa shot is close to the C-J state and shows a reaction zone which ends at about t=100 ns, but seems to tail–out possibly to 200 ns. There is no apparent long time constant component of the decay since the data is fairly level from t=200 to t=600 (only the first 350 ns are shown), when the release wave from the rear of the flyer arrives. For the 30.9 GPa shot, the change in velocity (Δv) across the reaction zone has decreased from about 0.4 km/s to 0.1 km/s



FIGURE 4

Measured velocity profiles of LiF/HE interface for LX-17 at two different (calculated) piston supported pressures. The expected velocities after the reaction zone for the top and bottom records are 3.1 and 1.8 km/s, respectively. In the top record, the feature at t=270 ns is related to the arrival of a second shock from the aluminum/LX-17 interface. The fluctuations at t=25 ns in the bottom record are spurious, not related to a velocity feature, judging from the radii of the fringe signal⁴. (This may be due to 3-dimensionality of the shock front.)

and has narrowed to 60 or 70 ns.

At the highest pressure, Δv has reduced even further. But the most significant feature of this record is that for 3 < t < 15 ns the velocity increases, whereas for the other records the velocity monotonically decreased from t>3 ns. We are confident the initial rise is not an artifact of the risetime (1.5 ns) of the photomultipliers since it is too slow, and since the horizontal and vertical fringe signals of the quadrature coding scheme of the push-pull VISAR are consistent with each other⁴ from t>3 ns.

An additional TNT shot at 36.5 GPa (not shown) had a Δv of zero; the velocity record was flat (± 5 m/s) from t>3 ns. We interpret the decreasing magnitude of Δv versus piston pressure to suggest that the product and reactant Hugoniots may cross at elevated pressures.

4.2 LX-17

The LX-17 data shows a similar decrease of Δv in the reaction zone versus piston pressure, except that it occurs at a higher pressure than the TNT. For the 31 GPa case, which is close to the C-J pressure, the knee of the reaction zone is more rounded than in the corresponding TNT record, and there may be a very slight long time constant component to the decay. Otherwise the reaction zone is similar to that in TNT.

The LX-17 records show more fluctuations than the TNT records. This may be due to a 3-dimensionality of the shock front since a shot (not shown) identical to the bottom shot of Fig. 4 except using a Mg buffer layer in between the LiF and the HE showed significantly less fluctuations.

Acknowledgements

Thanks to Gary Otani for his assistance in the operation of the VISAR and to Leona Meegan for target preparation.

References

- L. Green, E. Lee, A. Mitchell and C. Tarver, 8th Symp. (Internatnl.) on Detonation, Naval Surface Weapon Center MP86-194 (1985) 587; L. Green, N. Holmes and J. Kury, Proceedings of Intrnatl. Symp. on Pyrotechnics and Expl., Beijing (1987) 518 (LLNL Rprt. #95461).
- C. Tarver, "On the Difference Between Self-sustaining Converging Detonation Waves and Piston-Supported Overdriven Detonation Waves", Lawr. Livrm. Nat. Lab.Rprt. 90714 (1984).
- 3. W. F. Hemsing, Rev. Sci. Instr. 50 (1979) 73.
- 4. The push-pull VISAR consists of two independent interferometers, out of phase by 90° so that the direction of the fringe movement can be determined by noting which way the loci rotates about the origin when the fringes are plotted in X-Y fashion. The angular movement of the loci is proportional to the change in target velocity. The radii of the locus gives the intensity of light returning from the target and typically varies slowly as the loci revolves. During the shock jump (0<t<3 ns) the average loci moves into the origin until the photomultipliers recover. A relatively steady radii therefore indicates the data is real and not an artifact of the photomultiplier response time or a noise fluctuation.</p>
- J. Wise and L. Chhabildas, Laser interferometer measurements of refractive index in shock-compressed materials, in: Shock Waves in Condensed Matter, ed. Y.M. Gupta (Plenum Press, NY 1986) p. 441.
- J. Kineke and C. West, 5th Symp. (Internatnl.) on Detonation, U.S. Naval Ord. Lab., Pasadena (1970) ACR-184, ONR 0852-0057 and private communication.
- L. Green, C. Tarver, and D. Erskine, "Reaction Zone Structure in Supracompressed Detonating Explosive", to be published in proceedings of 9th Detonation Symposium to be held in Portland, Ore. Aug. 1989.

720