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TITLE: HUGONIOT AND INITIATION MEASUREMENTS ON TNAX EXPLOSIVE

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DISCLAIMER

HUGONIOT AND INITIATION MEASUREMENTS ON TNAZ EXPLOSIVE[†]

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Particle velocity measurements have been made on samples of TNAZ (1,3,3-trinitroazetidine) explosive pressed to 98 - 99% of theoretical maximum density. Measurements were made with magnetic particle velocity gauges and a VISAR interferometer. Stirrup shaped magnetic particle velocity gauges were mounted on the front and back of the TNAZ pressing. The back gauge was located at the interface of the TNAZ and a PMMA window and was also used as the diffuse reflector for the VISAR measurement. This allowed the simultaneous measurement of particle velocity by both a magnetic gauge and a VISAR. Well defined inputs to the TNAZ, ranging from 0.6 to 2.4 GPa, were produced by gas gun projectile impact. Unreacted Hugoniot data were obtained from the front gauge measurement and shock transit times through the TNAZ. A linear shock velocity vs. particle velocity fit of $U_s = 2.39 + 2.31u_p$ mm/µs was obtained for the unreacted Hugoniot. An elastic-plastic transmitted wave, similar to that which has been seen in other explosive materials, was observed in the 0.6 GPa input experiment. Considerable amounts of reaction were observed in experiments with inputs of 1.6 and 2.4 GPa.

INTRODUCTION

TNAZ (1,3,3-trinitroazetidine, see Fig. 1) is a relatively new explosive that has an output similar to that of HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) based plastic bonded explosives, such as PBX9404, but has a relatively low melting point near 100 °C. Experiments have been done on TNAZ at both Los Alamos and LLNL to characterize the initiation behavior and the unreacted Hugoniot. Wedge experiments were completed by Hill et al. (1) of Los Alamos and Manganin pressure gauge measurements were made at LLNL (2). These studies indicate that TNAZ is slightly more sensitive to sustained shock initiation than PBX 9404.

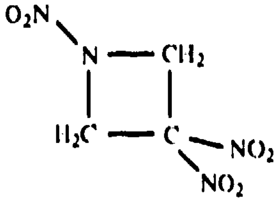

FIGURE 1. Chemical structure of TNAZ, $C_3H_4N_4O_6$.

Because there were large differences in the unreacted Hugoniots measured in Refs. (1) and (2), we made measurements to characterize the shock and initiation properties of this material up to 2.4 GPa. Particle velocity waveforms were recorded as a function of time at both the input and output faces of the TNAZ. This allowed us to obtain initiation profiles on the higher pressure shots at the same time we were measuring Hugoniot points.

EXPERIMENTAL DETAILS

TNAZ samples used in these experiments had densities of 1.81 - 1.82 g/cm^3, or 98 - 99% of the 1.84 g/cm^3 theoretical maximum density (TMD). Density measurements were made on each sample.

Impact experiments were performed using a gas gun to provide well controlled inputs to the TNAZ. A cross-section view of the experimental setup is shown in Fig. 2. A Lexan projectile, faced with a single-crystal z-cut sapphire impactor, strikes a target comprised of the TNAZ sample (25.4 mm diam. by 7.8 mm thick), a Kel-F confinement ring, and a PMMA back window. Stirrup shaped

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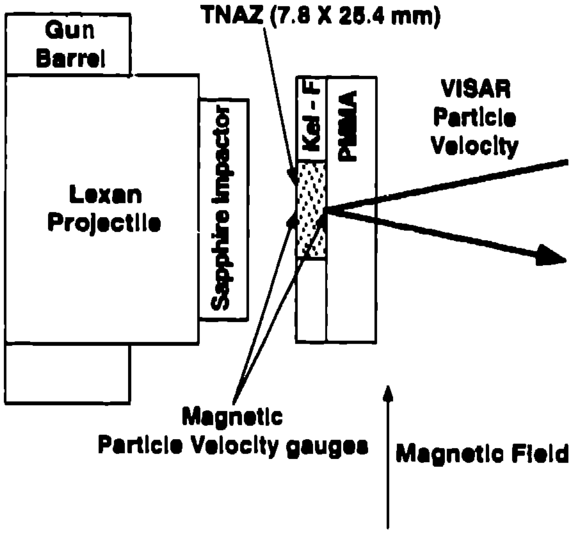

Figure 2. Experimental setup for magnetic gauge and VISAR particle velocity measurements in TNAZ.

magnetic particle velocity gauges. fabricated from 5 µm thick aluminum foil, were located on the impact surface and at the interface of the TNAZ and PMMA window. The front gauge was insulated on both sides with 12 µm of Kapton film. The back gauge was insulated on the side next to the TNAZ with 12 µm of FEP Teflon. The active element of these gauges is 10 mm long. The center of the back gauge was used as a diffuse mirror for VISAR measurements (3).

Because of the aspect ratio of the TNAZ samples, we were concerned about the length of time the 10 mm long back stirrup gauge would remain in one dimensional strain. (The Kel-F confinement ring was one method we used to help maintain 1-D strain.) The small VISAR measurement area (≈ 100 µm diam.) on the axis of the target should be in 1-D strain for ≈ 1 µs longer than the edges of the stirrup gauge. Differences in the stirrup gauge and VISAR measurements indicate that the back stirrup gauge is no longer in a state of 1-D strain.

Because the PMMA window has a lower shock impedance than TNAZ, a small rarefaction is sent back into the TNAZ when the shock wave reaches this interface. The transmitted wave profile is thus perturbed by a small amount, but is still representative of the transmitted wave.

RESULTS AND DISCUSSION

Four experiments, covering an input stress range of 0.6 to 2.4 GPa, were completed. Shot data, including unreacted Hugoniot points, are summarized in Table 1. All the waveforms from the magnetic gauges and the VISAR were successfully obtained in each experiment.

Particle velocities for the Hugoniot measurements were obtained from the front gauge record. Shock velocities were obtained by dividing the TNAZ thickness by the shock transit time. Unreacted Hugoniot data for each experiment are presented in Table 1 and are plotted in Fig 3.

In Shot 1030. with an input of 2.4 GPa, there was considerable reaction in the wave as it traveled through the TNAZ. Analysis of the back gauge record indicates that most of the reactive growth is behind the shock front. The reactive wave had not quite caught up to the shock front at the time it reached the gauge plane. This means the shock velocity should be reasonably accurate despite the reactivity. However, since the shock front has grown a little bit. a slight error in shock velocity (on the high side) would be expected.

The unreacted Hugoniot data from this study are plotted in the shock-velocity vs. particle-velocity plane in Fig. 3. The data fit a linear relationship with $U_s = 2.387 + 2.319u_p$ where U_s is the shock velocity and u_p is the particle velocity. Also shown

TABLE 1. Gas Gun Shot and Unreacted Hugoniot Data for TNAZ

Shot No.	Impactor Material	Impact Velocity (mm/µs)	Initial TNAZ Density (g/cm^3)	Particle Velocity (mm/µs)	Shock Velocity (mm/µs)	Shock Pressure (GPa)	Relative Volume (V/V_0)
1028	Sapphire	0.134	1.82	0.121	2.716†	0.60	0.9555
	(Elastic wave data)‡			0.058	2.774	0.29	0.9791
1027	Sapphire	0.247	1.81	0.221	2.86	1.14	0.9227
1029	Sapphire	0.336	1.81	0.300	3.016	1.63	0.9007
1030	Sapphire	0.454	1.81	0.397	3.363	2.41	0.8820

† Shock velocity obtained by using the time to 1/2 maximum particle velocity on back gauge waveform

‡ Elastic wave data obtained by using the first part of the back gauge waveform to determine both U_s and u_p

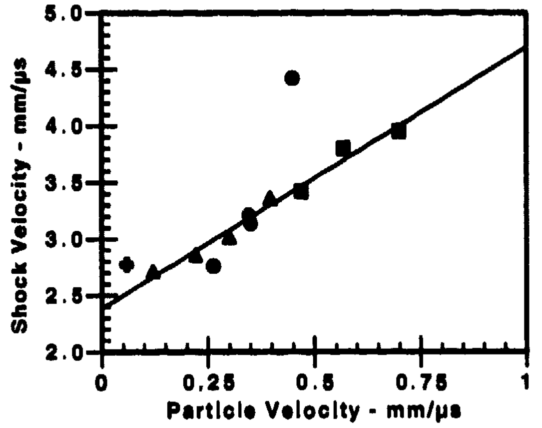

FIGURE 3. Unreacted TNAZ Hugoniot plot. Data from this study are the triangles. Hill et al's. wedge test data (1) are the squares, and data from the LLNL Manganin gauge experiments (2) are the circles. The cross is the point for the elastic wave.

are the earlier data from Los Alamos (1) and LLNL (2). Our data agree well with the Los Alamos wedge test data and with two of the points from LLNL. However, the highest and lowest pressure LLNL points are in question. The Manganin gauge waveforms for the high pressure shot show a great deal of reaction. This is likely the reason this point is high in shock velocity. The waveforms for the low pressure experiment are of poor resolution so this point has large error bars. For these reasons these two LLNL points have been left out of the overall fit. If all the other data are included, the fit is $U_s = 2.386 + 2.307u_p$. This should be considered the best unreacted Hugoniot for TNAZ of density 1.81 - 1.82 g/cm^3.

Particle velocity waveforms for two of the experiments are shown in Fig. 4a and 4b, and cover the regime from very little reaction to a great deal of reaction. Front and back particle velocity waveforms for Shot 1027, which had an input of 1.14 GPa, are shown in Fig. 4a. The front gauge shows no evidence of reaction in this shot. (The rarefaction which appears at ≈ 2 µs comes from the back of the 10-mm-thick sapphire impactor.)

The back gauge waveforms obtained from the VISAR (light line) and the magnetic gauge are essentially identical up to ≈ 4 µs, at which time the magnetic gauge record gets increasingly lower than the VISAR record. This indicates that the stirrup gauge is experiencing 2-D strain. The drop in particle velocity which occurs at a time of ≈ 3.5 µs is due to the rarefaction from the back of the sapphire impactor. The particle velocity measured by the VISAR and the back magnetic gauge were very close at early times in all four experiments. This agreement gives us confidence in the accuracy of both measurements.

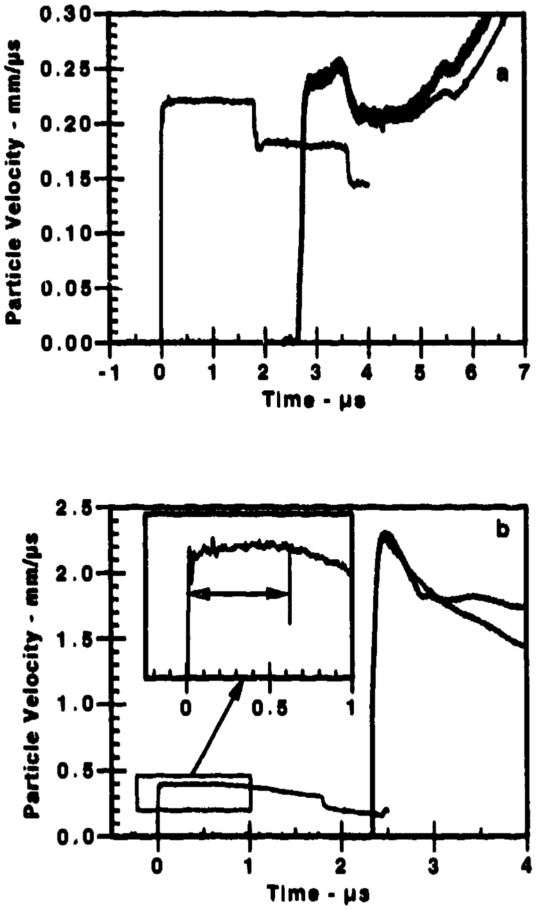

FIGURE 4. Particle velocity waveforms obtained from Shot 1027 with a 1.14 GPa input are shown in (a). Those from Shot 1030, with a 2.41 GPa input, are shown in (b). The dark line is the magnetic gauge measurement and the light line is the VISAR measurement.

No reaction was observed in the front gauge records for the shots with inputs of 0.6, 1.14, and 1.63 GPa. Shot 1030, with an input of 2.41 GPa (shown in Fig. 4b) showed evidence of reaction at the front gauge after an induction time of about 0.6 µs. This is shown by the particle velocity decrease starting at ≈ 0.6 µs and is clearly seen in the inset in Fig. 4b. The particle velocity decreases because the TNAZ is reacting, causing the pressure to increase and the impact interface (gauge plane) to decelerate. If other shots were done at input pressures above and slightly below 2.4 GPa, an induction time vs. input pressure relationship could be determined.

After reaction starts near the front gauge plane, it is not extinguished by the rarefaction from the back of the sapphire impactor. Evidence for this comes from the particle velocity/time slope being about the same before and after arrival of the rarefaction. An estimate of the pressure decrease due to the rarefaction is ≈ 0.6 GPa or 25% of the initial pressure. With a reaction rate that is sensitive to pressure one might expect the rate to change dramatically due to this decrease in pressure.

As mentioned earlier, for this experiment there is a shock front followed by a large reactive wave (with a particle velocity of about 2.3 mm/μs) that is just about to overtake the shock front at the time it interacts with the back gauge/PMMA interface. The shock front has grown from 0.4 to 0.9 mm/μs. That this much of an increase has occurred may indicate that the reactive wave has already started to overtake the front. The large reactive wave is not a shock but has a steep front with a risetime of 60 - 70 ns. We estimate that the wave would evolve into a detonation in 2 or 3 mm more of travel, i.e., the run distance would be about 10 to 11 mm. This estimate compares favorably with the wedge data Pop-plot (1) which gives a run distance of 12.4 mm for a 2.41 GPa input.

From this single experiment it is not possible to determine if the initiation is more homogeneous than heterogeneous in character. Because the reactive wave is very large behind the shock front, and the shock front amplitude has increased very little, we think the initiation is behaving more homogeneously than heterogeneously. Multiple embedded gauge experiments would be needed to verify this.

Shot 1029 with an input of 1.63 GPa showed no reaction at the front gauge or in the shock front as it moved through the sample. Reaction did begin after the shock interacted with the PMMA window. This is puzzling because the PMMA has a lower impedance than the TNAZ and interaction of the wave with this interface reduces the pressure. An estimate of the reaction rate at the back gauge is ≈ 0.4 μs^{-1}.

An interesting material response was observed in Shot 1028, the lowest input experiment at 0.6 GPa. Figure 5 shows the transmitted wave profile. The wave is composed of a shock with a sharp jump up to 0.04 mm/μs followed by a disperse wave spread out over ≈ 0.5 μs. We think this is elastic-plastic behavior, similar to that which has been seen in other explosives by Lemar et al. (4), Dick et al. (5), and Wasley and Walker (6). Using the initial jump, the elastic wave in TNAZ has an amplitude of about 0.29 GPa. This can be compared to the estimate of 0.14 GPa for Comp B-3 (4). The elastic wave would be overdriven by a wave with a particle velocity greater than 0.2 mm/μs.

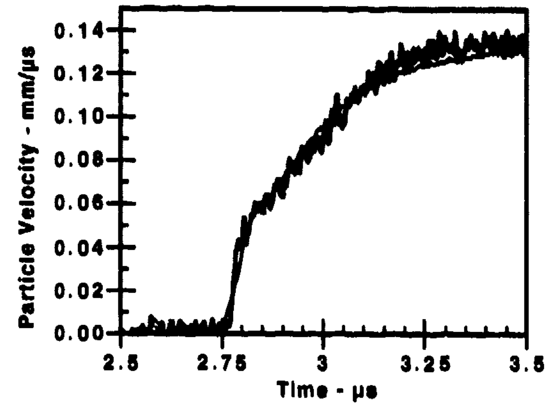

FIGURE 5. Transmitted wave profile for Shot 1028 showing elastic-plastic behavior. The dark line is the magnetic gauge measurement and the light line is the VISAR measurement.

ACKNOWLEDGMENT

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