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# PARTICLE VELOCITY AND STRESS MEASUREMENTS IN LOW DENSITY HMX*

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Magnetic particle velocity gauges and PVDF stress rate gauges have been used to measure the shock response of low density HMX explosive (1.24 g/cm$^3$). In experiments done at LANL, magnetic particle velocity gauges were located on both sides of the explosive. In nearly identical experiments done at SNL, PVDF stress rate gauges were located at the same positions. Using these techniques both particle velocity and stress histories were obtained for a particular experimental condition. Loading and reaction paths were established in the stress-particle velocity plane for each input condition. This information was used to determine that compacted HMX has an impedance close to that of Kel-F and also that a global reaction rate of ≈ 0.13 μs$^{-1}$ was observed in HMX shocked to about 0.8 GPa. At low input stresses the transmitted wave profiles had long rise times (up to 1 μs) due to the compaction processes.

## INTRODUCTION

Porous octotetramethylene tetranitramine (HMX) at a density of 1.24 g/cm$^3$ has been shown to reproducibly undergo a deflagration-to-detonation transition (DDT) when suitably confined.[1] Small input energies, in the form of a flame or a slowly moving piston, precipitate the DDT process, illustrating that insensitive explosives can be made to detonate with small inputs under the right conditions. This gives rise to safety concerns which is the principal reason for studying porous HMX under low shock input conditions.

Two studies with direct application to this work have been done on low density HMX. Dick performed several explosively driven cutback tests in which he measured the average transit time through HMX compacts of different thicknesses (at a density of 1.24 g/cm$^3$) for inputs of 0.8 and 2.0 GPa.[2] By plotting transit time vs. compact thickness, he was able obtain some Hugoniot and initiation information. Elban and Chiarito subjected two different HMX powders to slow compaction conditions up to 0.2 GPa.[3] They found that the breakage of HMX crystals starts at stresses below 1 MPa and that widespread crystal fracture takes place between 62 and 75% of theoretical maximum density (TMD). At a stress of 0.2 GPa, 96% of TMD was obtained. The data from these studies are not sufficient to construct a reliable EOS so we embarked upon a study to make time-resolved measurements as an extension of Dick's work with manganin gauges.[4]

Magnetic particle velocity measurements were made at Los Alamos National Lab. (LANL) and polyvinylidene difluoride (PVDF) stress rate measurements[5,6] were done at Sandia National Labs. (SNL) in experiments that were nearly identical. Time-resolved measurements of these two properties allows tracking of any process occurring (e.g. compaction or reaction) in the stress vs. particle velocity plane. This paper discusses some of the experiments completed and their interpretation.

## EXPERIMENTAL DETAILS

Experiments at both labs utilized gas gun driven projectiles to obtain sustained-shock input conditions. Projectile velocities were nearly the same at both labs for a given experimental setup so that in separate, similar experiments, both stress and particle-velocity histories were measured.

HMX powder was confined in sample cells which had a polychlorotrifluoroethylene (Kel-F) front face (on which the projectile impacted) and a poly 4-methyl-1-pentene (TPX) cylindrical plug back. (TPX is a low impedance material and therefore a reasonable impedance match to the pressed HMX.) Gauges were epoxied on the HMX side of both pieces. The front face was

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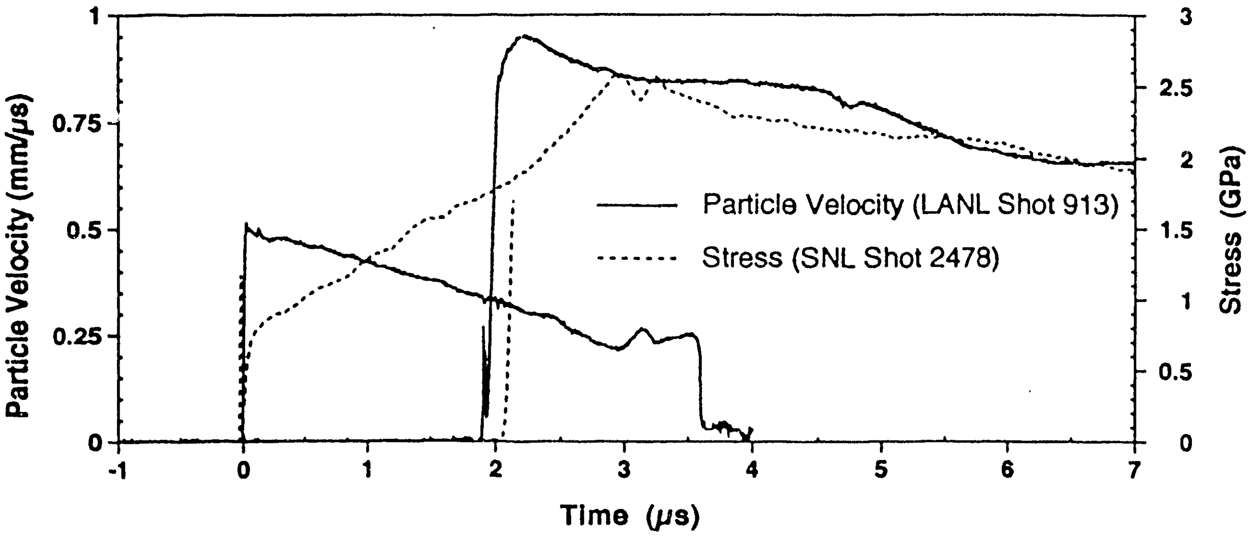


Figure 2 Particle velocity waveforms (LANL Shot 913, proj. vel. 0.696 km/s) and stress waveforms (SNL Shot 2478, proj. vel. 0.669 km/s) for two similar experiments involving a Kel-F faced projectile impacting the Kel-F sample cell front. The SNL projectile velocity was slightly lower so the arrival times at the back gauges do not coincide exactly.

the front and back gauge measurements. Reaction in the front gauge is manifested by a decrease in particle velocity (the reacting HMX is slowing down the cell front) and a corresponding increase in stress. The wave grows as it traverses the HMX sample because of reaction in the shock front so rather than the 0.5 km/s expected when a nonreactive wave interacts with the TPX back, a particle velocity of 0.95 km/s is measured. (The back PVDF gauge measurement was lost.) The risetime in the back particle velocity gauge was also considerably faster than in the lower input experiments (without reaction). However, it is still ≈ 50 ns, longer than expected for a sharp shock. There is apparently competition between the reaction (trying to sharpen up the wave) and the compaction (trying to smear it out).

The Hugoniot data obtained from the experiments, along with an equation of state development is discussed in a paper to be given later.[7]

## DISCUSSION

Using the particle velocity and stress data from the experiments shown in Fig. 1, these two properties can be plotted against each other at the appropriate times in the stress vs. particle velocity plane. This plot can be superimposed on a Hugoniot cross plot to give some understanding of the processes that are occurring in the experiment. This plot is shown in Fig. 3 from the data of Fig. 1.

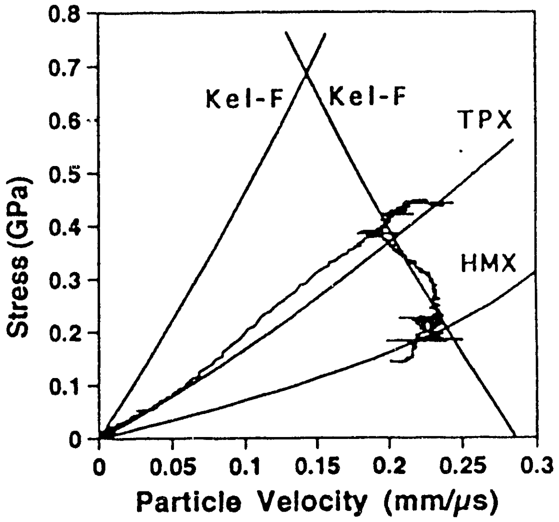


Figure 3 Stress vs. particle velocity plot obtained from the data of Figure 1. Plots are shown for both the front and back gauges; they are the wiggly curves. Appropriate Hugoniots are also shown.

The curve for the front gauge data starts somewhat low (due the viscoelastic wave shaping in the Kel-F) and moves up to and hovers near the HMX/Kel-F Hugoniot crossing, where it would be expected to be. It stays near this point until the wave reflected from the back face of the cell returns to the front gauges, at which time it moves up the backward facing Kel-F Hugoniot to the point where the TPX Hugoniot intersects it. This indicates that the compacted HMX Hugoniot is similar to that of Kel-F. If one looks at the fully dense HMX and the Kel-F Hugoniots, they are similar with the Kel-F being slightly softer.

In the same figure, the back gauge data starts out near the zero state and moves up along the TPX Hugoniot for a ways and then plots above it. It eventually gets near the TPX/Kel-F crossing, which is separate supporting evidence that the compacted HMX Hugoniot is close to that of Kel-F. This loading path is for the disperse wave which results from the compaction processes. It plots above the TPX Hugoniot where it would be expected to be if a ramp wave were loading the TPX. In this experiment there was no evidence of reaction in any of the waveforms.

The data shown in Fig. 2 are definitely in the regime where reaction is taking place. Using the front gauge data and plotting the stress vs. particle velocity results in the wiggly curve shown in Fig. 4. Again, it starts somewhat low in stress due to the viscoelastic effects in the Kel-F but then moves along the backward facing Kel-F Hugoniot clear off the figure. In other words, the state at the front gauge as the reaction occurs moves up along the Kel-F Hugoniot because this is what it is in contact with. In this experiment the maximum stress at the front gauge was about 2.5 GPa. Ritchie[8] has calculated the BKW reaction product equation of state for 1.24 g/cm$^3$ HMX and it can be shown that about 40% reaction has taken place by the end of the 3 μs record, leading to an estimated global reaction rate of ≈ 0.13 μs$^{-1}$.

The back magnetic gauge had a maximum particle velocity of 0.95 km/s, which corresponds to a stress of 2.8 GPa on the unreacted HMX Hugoniot and a shock velocity of 2.4 km/s. The average shock velocity through the sample was 1.96 km/s, considerably above the 1.36 km/s expected if there were no reaction. Considerable reaction is occurring in the shock front (as is normally the case for heterogeneous explosives) to strengthen the shock to this level. If the porous HMX were detonating, the detonation velocity would be 6.7 km/s.

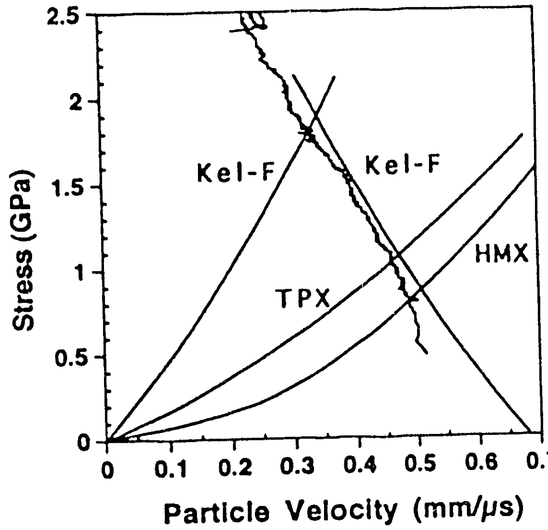


Figure 4 Stress vs. particle velocity plot obtained by plotting the stress and particle velocity against each other for the front gauge data shown in Fig. 2.

This set of experiments demonstrates the usefulness of making both stress and particle velocity measurements in near identical experiments. It is clear that to really understand the compaction and reaction processes in detail, computer modeling with accurate material, compaction, micromechanical, and reaction models will be required.

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